Bioretention (BRC)

Bioretention in Railroad Park; Birmingham, AL

Site Selection

Quantity Control	possible
Drainage Area	small-med
Space Required	med

Works with:

Steep Slopes	---
Shallow Water Table	---
Poorly Drained Soils	---

General Significance

Construction Cost	med/high
Maintenance	med/high
Community Acceptance	med/high
Habitat	med
Sun / Shade	sun to p.shade

Synonyms: Bioretention basin

Bioretention cells (BRCs) remove pollutants in stormwater runoff through adsorption, filtration, sedimentation, volatilization, ion exchange, and biological decomposition. A BRC is a depression in the landscape that captures and stores runoff for a short time, while providing habitat for native vegetation that is both flood and drought tolerant. BRCs are stormwater control measures (SCMs) that are similar to the homeowner practice, rain gardens, with the exception that BRCs have an underlying specialized soil media and are designed to meet a desired stormwater quantity treatment storage volume. Peak runoff rates and runoff volumes can be reduced and groundwater can be recharged when bioretention is located in an area with the appropriate soil conditions to provide infiltration. Bioretention is normally designed for the water quality or “first flush” event, typically the first 1”-1.5” of rainfall, to treat stormwater pollutants. In certain situations, BRCs can also provide stream channel protection through minimizing peak discharges.

Site Selection

Bioretention works well in dense, urban developments because of the flexibility of its space constraints. Conventional stormwater treatment systems may be inefficient in treating first flush events due to large acreages needed to capture the required volume of stormwater. However, BRCs are versatile systems that store stormwater beneath the media surface, addressing the spatial constraints of ultra-urban areas.

Sizing: BRCs are most effective when used to treat small to moderate quantities of stormwater or small drainage areas that are close to the source of stormwater runoff. These qualities make this SCM an excellent candidate for retrofits (for more information on retrofits, see Retrofits under Construction). The maximum drainage area recommended for bioretention is 5 acres, but 0.5 to 2 acres is preferred. Larger drainage areas can be treated by distributing multiple, decentralized BRCs throughout a watershed. Sizing criteria may depend on the infiltration characteristics of the media, flood mitigation, and pollutant removal needs. This practice does not require a large space; however, a minimum of 200 ft^2 footprint is recommended or approximately 5 – 8 % of the contributing impervious area draining to the system. BRCs perform well when treating small storm events and are well suited for small lots, such as parking lot islands, both as an initial installation practice or retrofit.

Table 4.1.1

Site Selection: Constraints & Limitations for Bioretention

Shallow Water Table	Locations where the seasonally high water table is less than 6' from the surface or less than 2' from the bottom of the cell are not suitable
Slope	Locations with 5% or less slope are recommended and flatter locations work best
Utilities	Call Alabama 811 before construction to locate utilities (for more information, visit: www.al1call.com)
Unstable Soils or High Sediment loads	Locations that are not under active construction, changing soil conditions, or will not experience high sediment loads are recommended; clayey soils can clog media
Continuous Flow	Locations that will not experience continuous flow and are allowed to drain are recommended
Regional Stormwater Control	Bioretention is best suited in small drainage areas; if regional stormwater control is necessary, another SCM should be selected

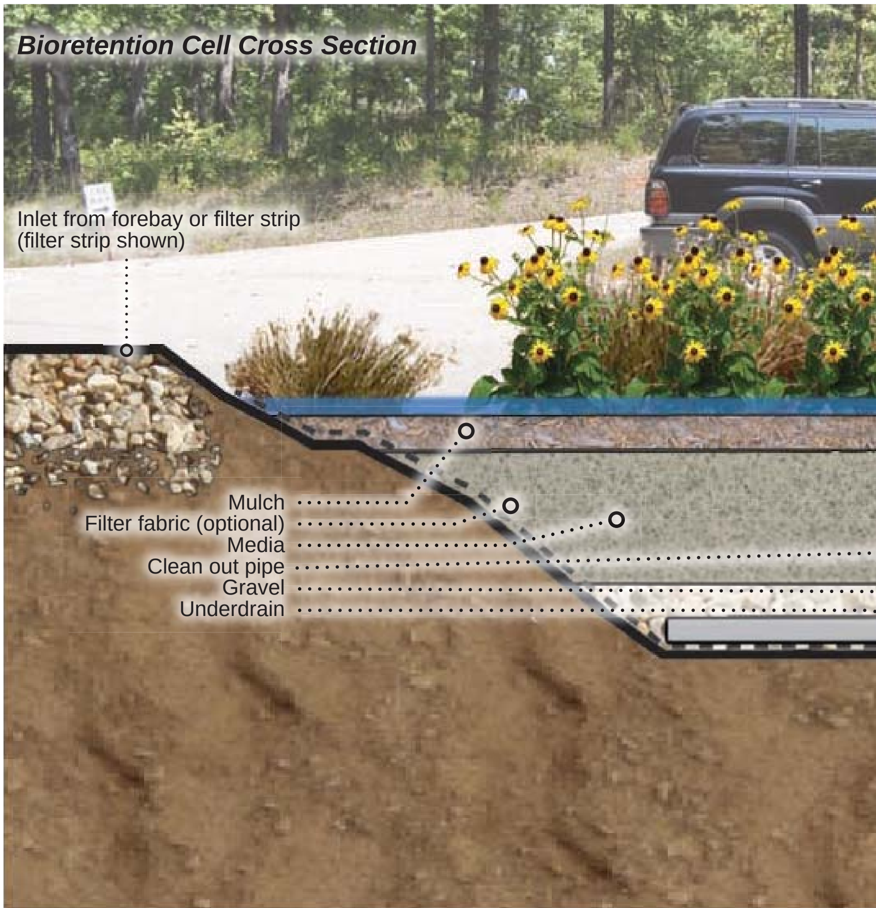
Evaluating Soils: Use the USDA Web Soil Survey to identify soil map units and to make initial interpretations for potential uses and limitations of a site. However, since most soil map units have inclusions of other soils that may be quite different, detailed evaluations should be made at the proposed site by a professional soil scientist or soil classifier. On-site evaluations should properly identify a soil or the hydrologic soil group (HSG) and the final decision for use should be made based on the detailed determination of soil series or HSG. For a detailed list of HSG properties, see Table A.3 in Appendix A on Stormwater Hydrology.

USDA's online Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) can be used as a guide to determine the needed soil information for the site, such as the hydrologic soil group (HSG) and depth to water table.

In-situ Soil: BRCs perform best when sited in well-drained soils such as hydrologic soil group (HSG) A or B (see Chapter 5.1 on Rain Gardens for more information on infiltration testing). In particular, the internal water storage (IWS) layer requires well-drained surrounding soils to function properly. The HSG and an infiltration test will determine if a BRC is a good fit for the soils on site.

Depth to Groundwater: BRCs are suited to sites where the depth to water table is > 6' or where the seasonally high water table is at least 2' from the bottom of the cell to decrease the chance of groundwater contamination. BRCs or any SCM should not release runoff filtering a "hotspot" into groundwater. Hotspots are defined as commercial, industrial, or other operations that produce higher levels of stormwater pollutants and/or have concentrated pollutants.

Site Specific Constraints: The layout of a BRC depends on site-specific constraints such as underlying soils, existing vegetation, drainage, utility location, safety, sight distances, aesthetics, maintenance ease, and equipment access. Bioretention is not recommended in areas with slopes > 5% or where mature trees must be removed. Large trees have extensive root systems and removing them is a time and energy consuming process. If BRCs are sited adjacent to "messy trees" such as sycamore, water oak, or magnolia, it should be clearly understood that more frequent maintenance will be required to minimize clogging of the cell media. Messy trees have excessive leaf litter, fruiting structures, and other debris compared with other trees. A BRC should not be sited in



areas where it will receive high sediment loads, as this will also lead to clogging of the cell media. The contributing drainage area should be stabilized prior to construction of all SCMs, and this is especially imperative for bioretention to prevent clogging and promote proper infiltration rates.

Design

Appropriate watershed and site information should be collected before beginning the design of any SCM. Layout should consider the pretreatment device, IWS layer, and overflow devices. Future maintenance should also be considered, particularly access to a pretreatment device such as a forebay.

Components

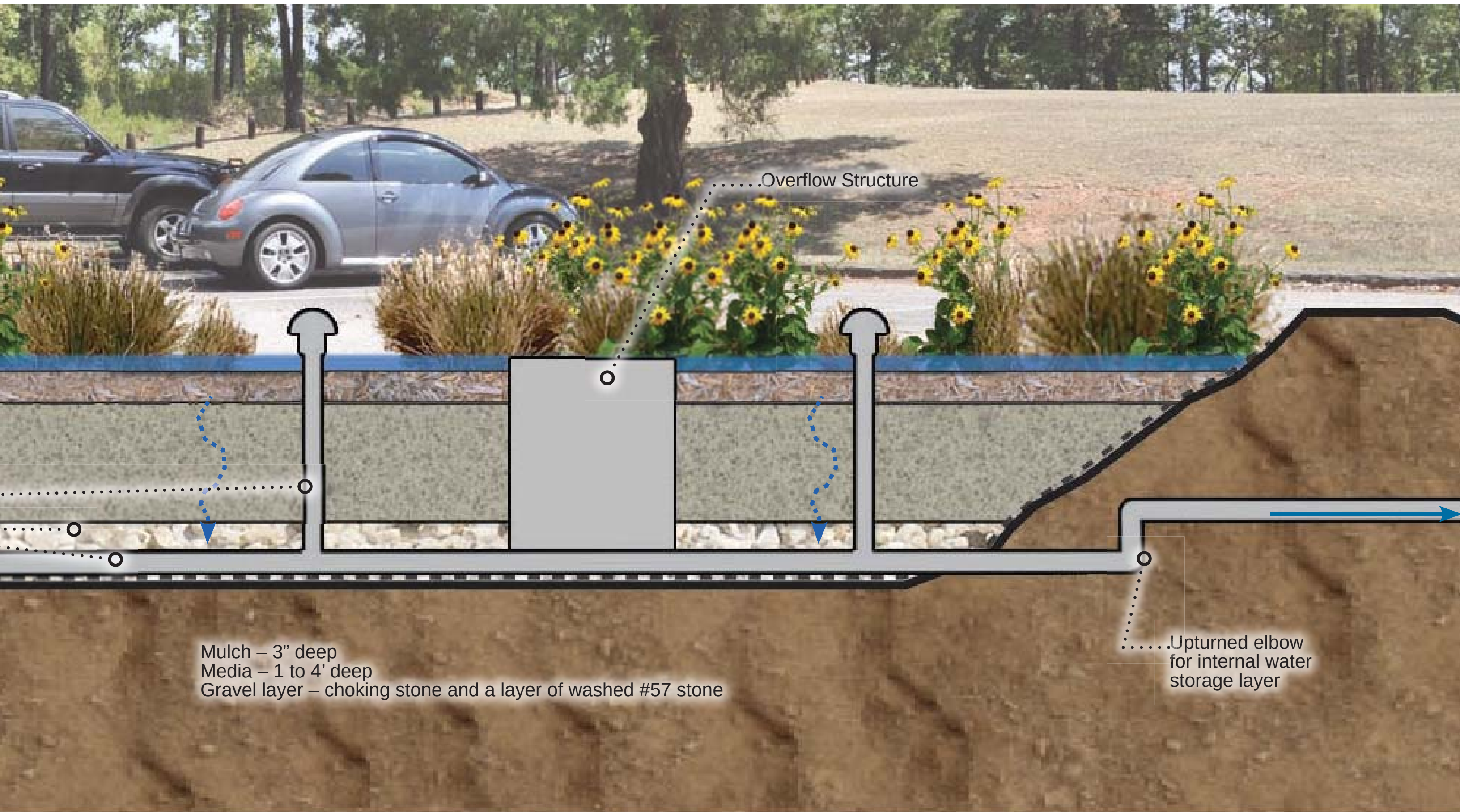
The bioretention system is made up of three primary components: a pretreatment device, BRC, and an overflow or bypass structure.

Pretreatment: Pretreatment devices serve as preventative maintenance for SCMs. Pretreatment devices slow runoff velocities, provide easier maintenance access, and reduce total suspended solids (TSS) in the system by encouraging sedimentation. If pretreatment is not used with bioretention, the mulch layer will require more frequent replacement due to sediment capture and settling on the mulch surface.

Stormwater runoff should sheet flow into a BRC. Swales, forebays, or a minimum of 3' wide sod filter strips are recommended as pretreatment devices for energy dissipation and an even distribution of runoff flow. When selecting a pretreatment device for bioretention, the number of inlets or directions from which stormwater will enter the cell, should be considered, as well as maintenance access and frequency.

Grassed filter strips: Grassed filter strips are recommended if stormwater enters the system via sheet flow over a parking lot or other impervious surface into the cell from all sides of the system (multiple inlets). The filter strip pretreatment system is made up of an 8" wide strip of gravel followed by 4' of sod. For more information on designing filter strips, see Chapter 5.5 on Level Spreaders and Grassed Filter Strips.

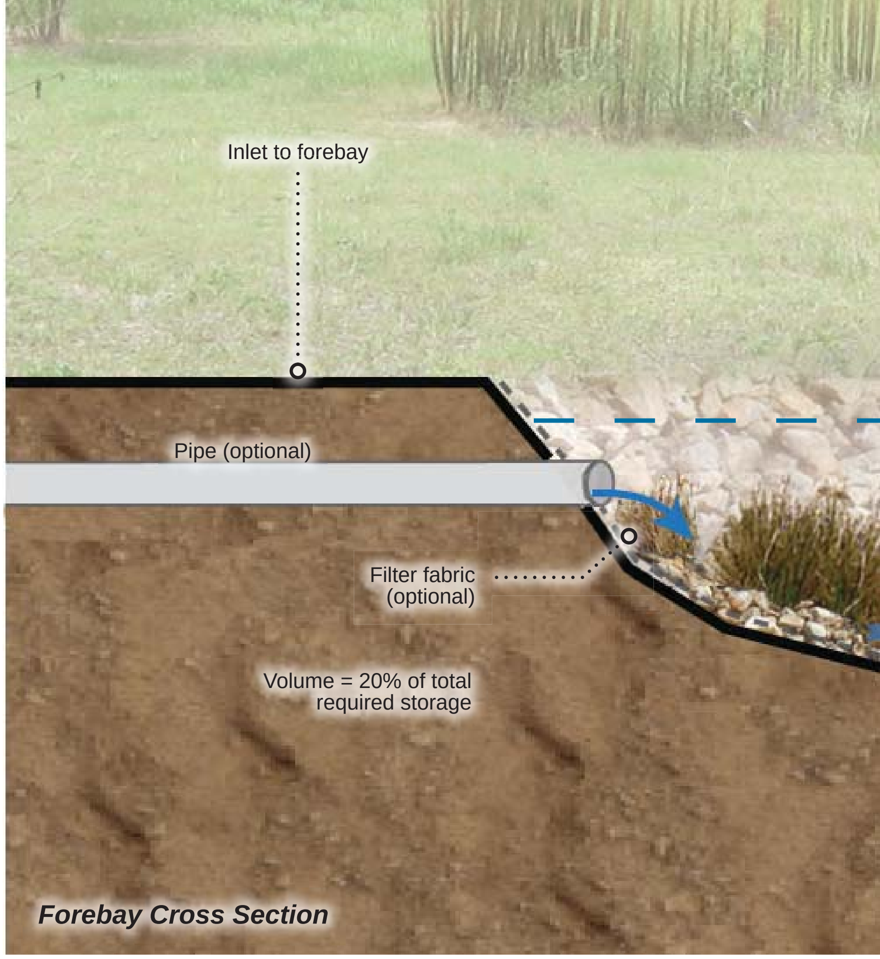
Forebay: A forebay is the best form of pretreatment when runoff is concentrated, channelized, or constricted, such as discharge from a pipe. A forebay is an 18 - 30" deep pool and is used in situations where standing water is not considered a safety concern. The forebay is deepest at the point of runoff entry and is shallowest at the exit point, which dissipates energy throughout the forebay and provides diffuse flow into the BRC.



Additional Components

Underdrain: A perforated pipe is used as the underdrain to promote draining of the cell completely within 48 - 96 hours. The underdrain should be placed in a 3' wide bed of ASTM #57 aggregate at a minimum thickness of 3", covered with 6" of #57 aggregate, and topped with an additional layer of #89 aggregate (layer thickness shall be 2", minimum). Double-washed stone is preferred. Wrapping the underdrain pipe in silt sock or textile is discouraged to prevent clogging from smaller silt particles. The range of pipe diameter used for underdrains is 4 - 8". Due to the potential for clogging, multiple underdrains and clean out pipes are recommended.

The need for underdrains is driven by permeability of the in-situ soil surrounding the BRC. In-situ soils with a saturated hydraulic conductivity less than 2"/hr require underdrains to help drain effluent from the media, which is discharged to another SCM or the stormwater conveyance network. If the saturated hydraulic conductivity is 2"/hr or greater, underdrains are not required. More information about the determination of saturated hydraulic conductivity and its properties can be found in Stormwater Hydrology in Appendix A.



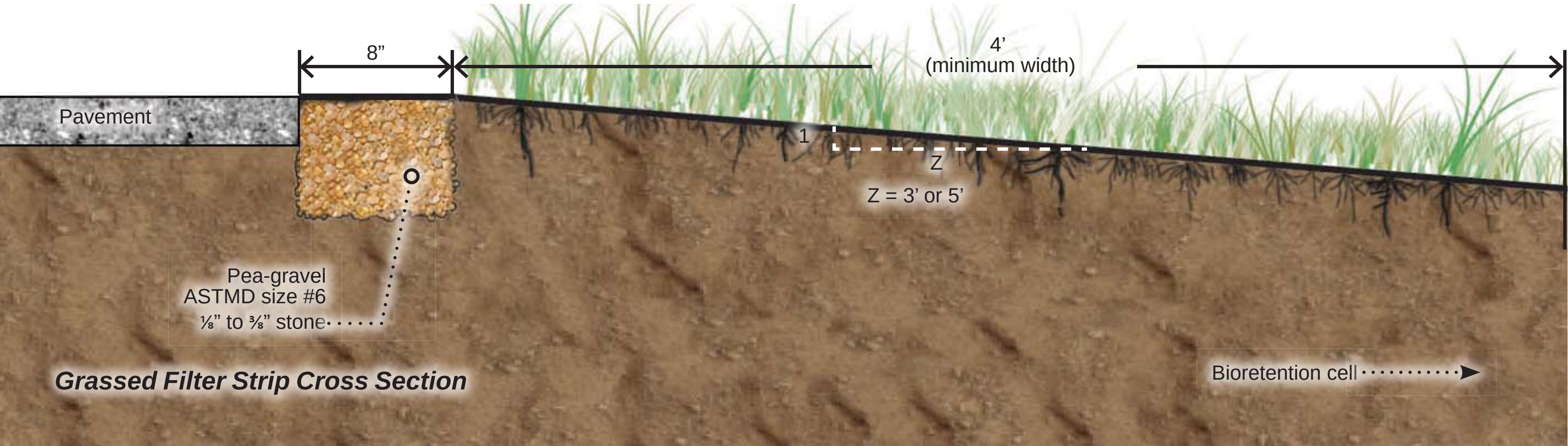
Forebay Cross Section

Clean Out Pipes: Clean out pipes are used to maintain the underdrain system when it is clogged. The addition of clean out pipes can decrease future maintenance costs associated with media excavation.

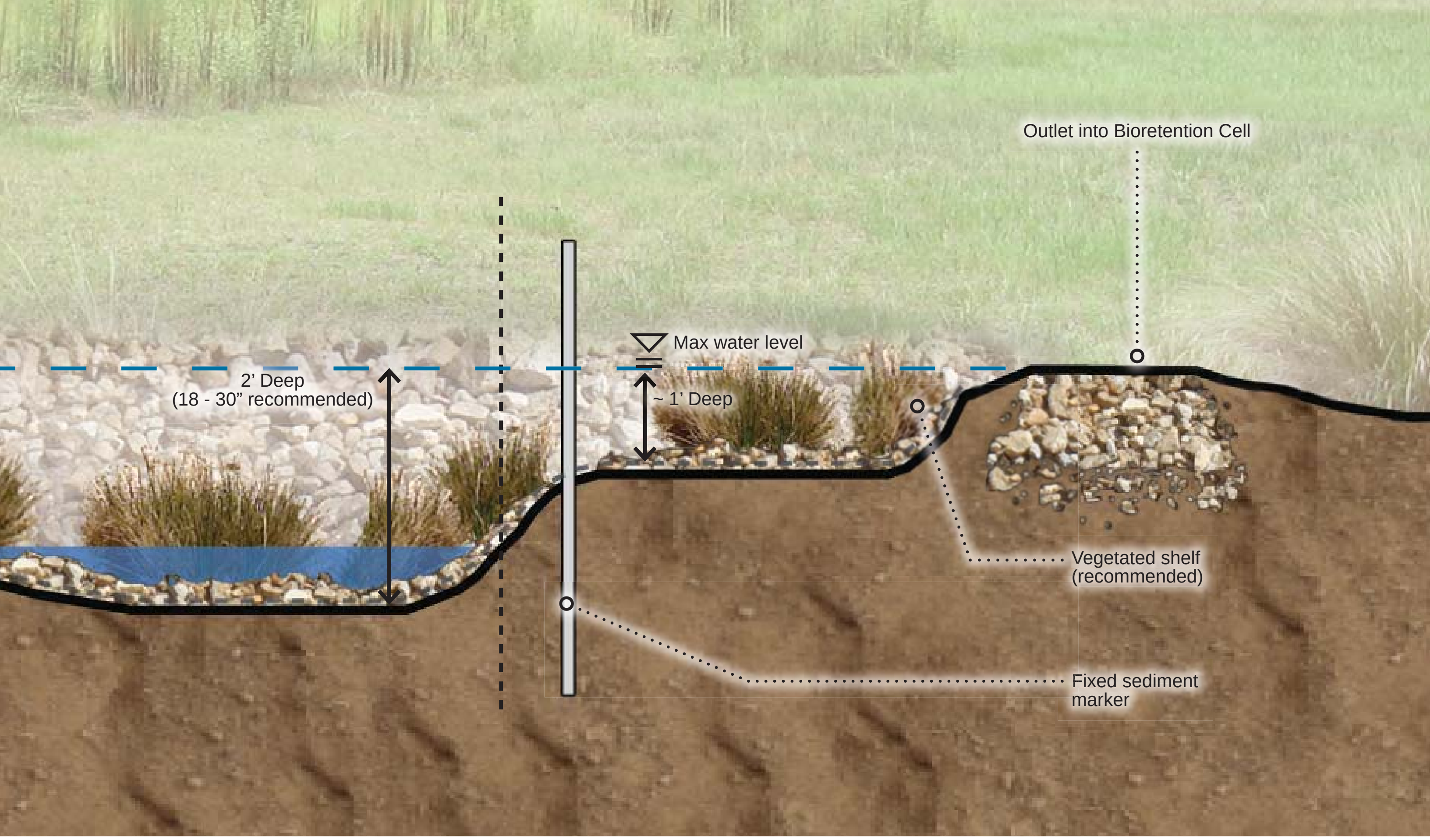
Soil Media Type: The soil media is to be a homogenous soil mix of 85 - 88% washed sand (by volume), 8 - 12% fines (silt and clay) and 3 - 5% organic matter (hardwood mulch or other aged organic component). The mix should be uniform and free of debris greater than 1" diameter. The amount of fines determines the percentage of other media materials. An increased fines content (12%) should be used when targeting a nitrogen reduction and decreased fines content (8%) should be used when targeting phosphorus. See the Construction Section for information on soil testing of the BRC media.

Ponded water should drain within 12 hours, and stormwater should infiltrate the cell to 2' below the surface within 48 hours. The pore-spaces of the media should drain completely with the exception of the volume used for the internal water storage (IWS), which should drain within 96 hours (4 days) based on the design storm.

Internal Water Storage: The IWS layer is created in the bottom of the cell by adding a 90^{o} upturned elbow to the underdrain. This elbow is arranged perpendicular to the horizontal underdrain, and forces water to remain in the lower portion of the media, creating a saturated, anaerobic zone that promotes increased nitrogen reduction (through dentrification) and infiltration. The IWS layer holds water following a rain event, but should drain within 4 days. The addition of an IWS layer may reduce the frequency of outflow in exceptionally permeable soils, such as sandy soils of the Coastal Plains. The use of IWS also allows for temperature reduction benefits because the coolest water is the first to exit the cell as it is pulled from the bottom of the BRC.

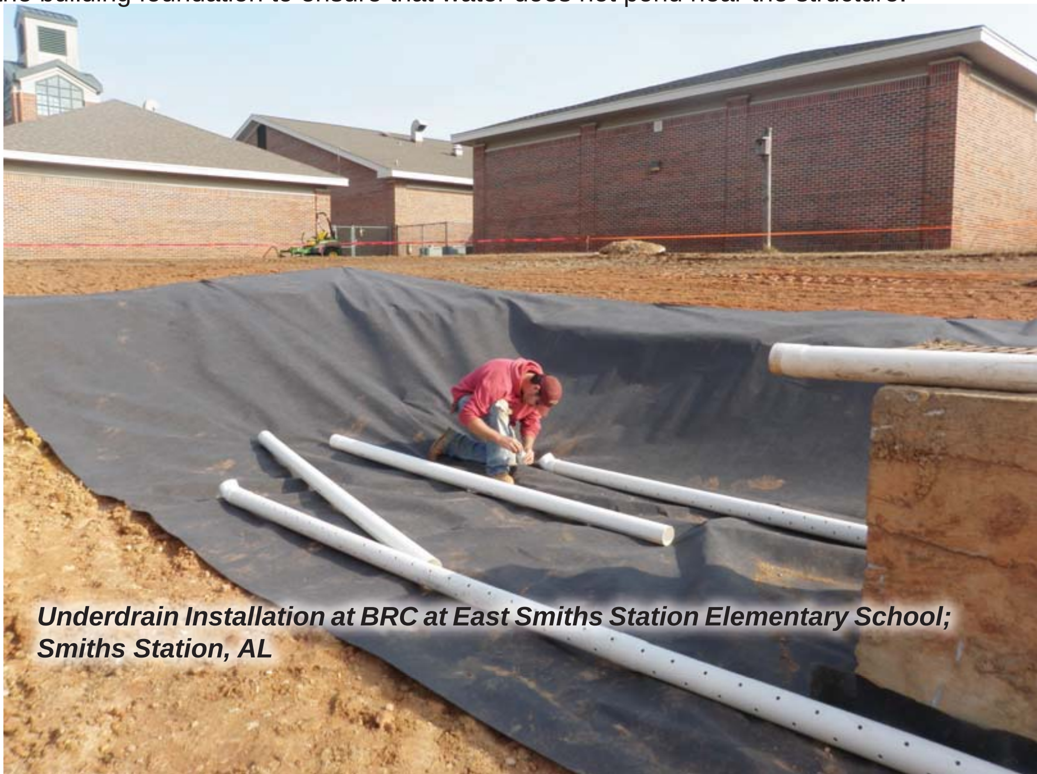


Grassed Filter Strip Cross Section



Similar to underdrains, the use of IWS is dependent on the permeability of the underlying soils. The underlying soils must have a hydrologic soil group (HSG) A or B with limited clay content, to be effective. Media depths above the underdrain layer must be at least 3' to use IWS, with at least 12 - 18" separating the outlet and bowl surface depths (see Internal Water Storage Cross Section). BRCs with a properly designed IWS and acceptable surrounding soil conditions may have increased nutrient reduction rates ranging from 40 - 60% nitrogen and 45% - 60% phosphorus depending on location and in-situ soil. For more information, see the Pollutant Removal Section.

Overflow Structure: BRCs are designed to use an overflow structure such as a bypass or stormwater conveyance overflow. This allows water in excess of the treatment volume to overflow into the existing stormwater conveyance network or to another appropriate SCM such as a filter strip, infiltration swale, level spreader/ grassed filter strip system, or grassed swale. If the BRC is sited adjacent to a building or other structure, the overflow device should release overflow downhill from the building foundation to ensure that water does not pond near the structure.



Underdrain Installation at BRC at East Smiths Station Elementary School; Smiths Station, AL

Design Guidance

The following steps and equations can be used for basic BRC design.

1. **Determine runoff volume to be treated (Design storm)**

   In this handbook, the Discrete Curve Number Method is used to determine the runoff volume or the water quality volume required for treatment. Bioretention is a water quality SCM and these calculations do not consider water quantity or stormwater volume control. BRCs may provide some volume control and standard calculations would apply. For a detailed explanation of the Discrete Curve Number Method and other methods that can be employed, please refer to Stormwater Hydrology in Appendix A.

   Information needed for use in the Discrete Curve Number Method include: **drainage area, pervious and impervious land area, curve numbers (CN), maximum potential retention after rainfall begins (S), precipitation depth (P), and runoff depth (Q).**

   The Discrete Curve Number Method is outlined in EQN 4.1.1 and 4.1.2.

EQN 4.1.1

$$S = \left(\frac{1000}{CN}\right) - 10$$

EQN 4.1.2

$$Q = \frac{[P - (0.2S)]^2}{P + (0.8S)}$$

EQN 4.1.3

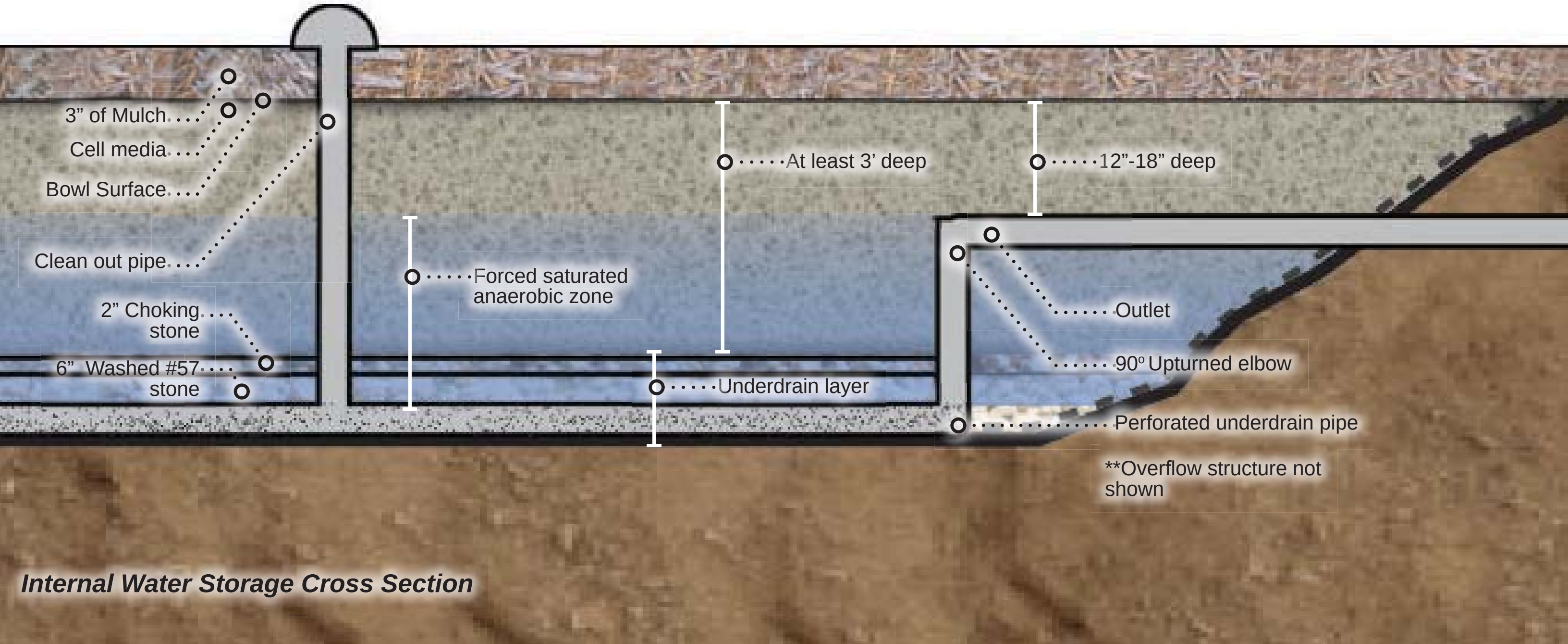
$$SA = \frac{V}{Avg.\ Pond}$$

2. **Determine required surface area**

   A BRC is designed to hold approximately the first inch of runoff (first flush) from the entire drainage area. For more information on the first flush, see Appendix A on Stormwater Hydrology. Ponding depths should be no more than 12” for safety reasons. The ponding depth is dependent on the cell’s ability to drain and a deeper maximum ponding depth may be acceptable as long as vegetation is tolerant.

   To determine the required **surface area (SA)**, an assigned **average ponding depth (Avg. Pond)** is divided into the required **treatment volume (V)**, as shown in EQN 4.1.3. The required **treatment volume (V)**, is equal to the runoff depth calculated in EQN 4.1.2.

   Once the required SA is determined (with existing site constraints considered), the dimensions (length and width) of the SA can be determined.



Internal Water Storage Cross Section

EQN 4.1.4

$$SA = l * w$$

l = length of BRC
w = width of BRC

EQN 4.1.5

$$\text{Base Length } (L) = l - 2(s)$$

$$\text{Base Width } (W) = w - 2(s)$$

s = side slope dimension (i.e. for 3:1 side slopes, s = 3)

EQN 4.1.6

$$\text{Base Area } (A) = L * W$$

EQN 4.1.7

$$\text{Quantity} = A * d$$

3. **Determine dimensions (length and width) of the BRC based on site constraints.**

   Surface area (SA) is the top surface of the bioretention area. SA calculated by these equations is the minimum size required to capture the design storm event. It is recommended that no dimension should be less than 10' to allow for vegetation and aesthetics. To prevent erosion, a side slope of 3:1 or flatter is recommended. The base of the BRC is calculated using the dimensions determined and subtracting the side slope dimensions. The length and width of the base is determined using EQNs 4.1.4 and 4.1.5. This calculation is assuming a rectangular BRC. If other shapes are used EQN 4.1.4 is not applicable.

   The calculated base length and width can be used to determine the base area. The base area is calculated using using EQN 4.1.6.

   The base area is used to calculate soil media depths. The side slope is only applied to the bowl of BRC and affects up to the first foot of depth.

4. **Determine soil media depth**

   The soil media depth is typically determined by the pollutant to be removed and the depth of media needed to support vegetation. Table 4.1.2 illustrates the minimum depth of media required for pollutant removal effectiveness. Selected vegetation type for the cell may require that the media depth be greater than the depth required for pollutant removal (Table 4.1.3).

5. **Determine quantity of BRC media and aggregates needed**

   The quantity of BRC media is calculated using the **base area (A)** and the depth of media, washed sand, choking stone, and #57 stone desired (Table 4.1.4). Quantity of a material (cubic feet) equals the **depth of the material, d** (feet) multiplied by the **base area, A** (square feet), as shown in EQN 4.1.7.

   Using EQN 4.1.8, the quantity in cubic feet can be converted to cubic yards; which is typically the unit of quantities when ordering material.

6. **Determine number and size of underdrains**

Table 4.1.2

Target Pollutant	Media Depth (ft)
Metals and Oils	1
Pathogens	2
Nutrients	3
Temperature	4

**There is no recommended media depth for TSS removal because sedimentation occurs before runoff infiltrates the BRC.

Table 4.1.3

Recommended Depth (in)	Vegetation Type
≤24	Herbaceous perennials and grasses
≥24	Shrubs
≥36	Small trees

Table 4.1.4

Material	Recommended Depth (in)
Bioretention Media	36 or pollutant dependent
Washed Sand	4
Choking Stone	2
#57 Stone	6

All fill materials should be washed and generally void of debris, to prevent clogging of the system.

Depending on the permeability of in-situ soil, BRCs require underdrains to function properly. Typically 4” – 8” pipes are used. To calculate the number of underdrains required to drain a BRC within 48-96 hours EQNs 4.1.9, 4.1.10, 4.1.11, and 4.1.12 are used.

First, the **total ponding (TP)** is calculated using EQN 4.1.9.

Next, the **peak inflow**, Q_p is calculated using EQN 4.1.10. where, **k is the permeability** of the surrounding soil in inches per hour, **TP is total ponding** in feet, and **d is total depth of material**. The media composition is the primary factor in determining permeability. The values determined in the infiltration test can be used for permeability.

Before the number of pipes can be determined the flow, $\mathbf{Q_{BRC}}$ must be calculated. Flow can be calculated using EQN 4.1.11.

Using a modified Manning’s equation, EQN 4.1.12, the number of pipes is calculated.

7. **Check drawdown time**

BRCs should completely drain within 48 - 96 hours for the design rainfall volume captured. Ponded water on the surface of the cell is required to drain to 2’ below the surface within a maximum of 48 hours. Using the **Volume, V** calculated in EQNs 4.1.2/4.1.3 on page 24 and the **flow** $\mathbf{Q_{BRC}}$, calculated in EQN 4.1.12, the time it takes for the BRC to drain or the drawdown time can be calculated. EQN 4.1.13 illustrates this calculation.

8. **Select the appropriate overflow or bypass**

Overflow devices should be sized to pass rainfall events in excess of the water quality volume. These can be attached to existing infrastructure or a weir can also be used for overflow into a large grassed area or adjacent SCM.

EQN 4.1.8

$$\text{Quantity to order } (yd^3) = ft^3 * 0.037037$$

EQN 4.1.9

$$\text{Total Ponding } (TP) = d + \text{Avg. Ponding}$$

EQN 4.1.10

$$Q_P = \frac{k * TP}{d}$$

EQN 4.1.11

$$Q_{BRC} = \frac{\left(\frac{Q_P}{3600}\right)}{12} * SA$$

EQN 4.1.12

$$N = \frac{\left(16 * \left\{\frac{Q_{BRC} * n}{s^{0.5}}\right\}^{3/8}\right)}{D}$$

Q_{BRC} = flow
n = manning’s n
s = slope
D = diameter of pipe (in.)

EQN 4.1.13

$$\text{Time } (hr) = \frac{\left(\frac{V}{Q_{BRC}}\right)}{3600}$$

Bioretention Design Example

For the design example, a location in central Alabama has been selected. The site is **1.6 acres** total, with **0.65 acres** of parking lot (**curve number 98**) and **0.95 acres** of lawn that is in fair condition (**curve number 69**) draining to the BRC. The water quality design storm event precipitation depth is **1.2” (P)**. The soil has a HSG B and a depth to water table greater than 6’. **For this design example numbers are rounded to two significant digits**

1. To calculate runoff, use EQNs 4.1.1 and 4.1.2, for the Discrete Curve Number Method.

EQN 4.1.1

$$S = \left(\frac{1000}{CN}\right) - 10$$

EQN 4.1.2

$$Q = \frac{\left[P - (0.2S)\right]^2}{P + (0.8S)}$$

Using the provided curve numbers (CNs), precipitation depth, and equations, the following runoff depths are determined:

Parking Lot (CN=98): S = 0.20”, Q = 0.99”= 0.08’

Fair Condition Lawn (CN=69): S = 4.49”, Q = 0.02” = 0.00’

To determine the runoff volume, the calculated runoff depths are to be multiplied by their respective areas and summed. Using calculations to two significant digits the Fair Condition Lawn does not contribute any significant runoff volume.

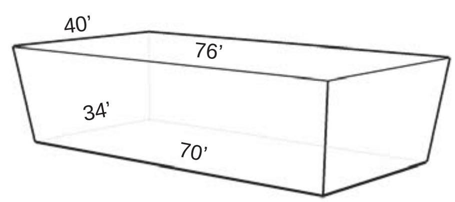
Parking Lot: $0.08\ ft * 0.65 * \left(\frac{43{,}560ft^2}{1ac}\right) = 2{,}265ft^3$

Total Runoff Volume = 2,265 ft^3

2. Calculate the surface area (SA) of the bioretention cell using EQN 4.1.3. Average ponding depth **(Avg. Pond)** is typically 9”.

EQN 4.1.3

$$SA = \frac{V}{Avg.\ Pond}$$



V= 2,265 ft^3; Avg.Pond = (9”/(1ft/12”) = 0.75ft

SA = 3,020 ft^2

*SA should be 3 - 10% of the total watershed area.

3. Dimensions that can be easily constructed should be prioritized. For this example, a 40’x 76’ cell is to be used.

Using EQN 4.1.4 the length, 40’ and the width 76’ can be used to determine if the required **SA** of 3,020 ft^2 is met.

EQN 4.1.4

$$SA = {\scriptstyle (length)}\ l * {\scriptstyle (width)}\ w$$

SA = 40*76 = 3,040, which is greater than the calculated required SA of 3020 ft^2.

Continued on next page

Using the dimension 40' and 76' and a side slope of 3:1 the base length and base width can be calculated using EQN 4.1.5. To accomodate for the 9" of ponding and 3" of mulch a 1 foot depth is used to calculate the base footprint.

EQN 4.1.5

$$\text{Base Length } (L) = l - 2(s) = 40-(2*3) = 34'$$
$$\text{Base Width } (W) = w - 2(s) = 76-(2*3) = 70'$$

The BRC **bottom surface area (A)** or footprint dimension is 34' by 70'. The **Base Area (A)** can be calculated using EQN 4.1.6.

EQN 4.1.6

$$\text{Base Area } (A) = L * W = 34*70 = 2{,}380ft^2$$

4. The soil media depth chosen is 3' for nutrient removal and to support desired vegetation. See the Vegetation section for more information on Vegetation Design.
5. The footprint calculated in EQN 4.1.6 is needed in order to determine the quantity of media fill (aggregates) that is required.

For the design example, with a bowl depth of 12" (9" Avg.Pond and an additional 3" of mulch) and 3:1 side slopes (minimum recommended), the bottom surface area of the cell is 40' x 74' (as calculated in EQN 4.1.6).

Table 4.1.5

Material	Recommended Depth (in)	Amount Needed (yd^3)
Bioretention Media	36 or pollutant dependent	280*
Washed Sand	4	31
Choking Stone	2	16
#57 Stone	6	47

*Using 36" depth of media

For example the Bioretention media quantity was calculated using EQN 4.1.7.

EQN 4.1.7

$$\text{Quantity} = A * d = 2{,}380ft^2 * 3' = 7{,}140\ ft^3$$

Material quantities are usually specified in cubic yards. Using EQN 4.1.8 bioretention media quantity will be converted to cubic yards.

EQN 4.1.8

$$\text{Quantity to order } (yd^3) = ft^3 * 0.037037$$
$$7140 * 0.037037 = 264.44yd^3 \sim 265yd^3$$

6. The saturated hydraulic conductivity for this HSG B soil is greater than 2"/hr; therefore, underdrains are not necessary. However, a 4" perforated pipe is used in the bottom of this cell for IWS. The underdrain is connected at 1 foot higher than the media material stone base. Often an 18" high density polyethylene (HDPE) pipe with Nyloplast® grate is connected to an existing overflow structure.

Even though underdrains are not necessary the following calculations illustrate underdrain calculations and drawdown time.

EQN 4.1.9

$$\text{Total Ponding } (TP) = d + \text{Avg. Ponding} = 36+9 = 45\text{" or } 3.75'$$

EQN 4.1.10

$k = 2"/hr$, $TP = 3.75'$, and $d = 3'$

$$Q_P = \frac{k * TP}{d} = \frac{2 * 3.75}{3} = 2.5in/hr$$

Continued on next page

The flow is calculated using the peak flow, Q_p and the SA calculated in EQN 4.1.4. (For this calculation three significant digits are used due to the magnitude of the variables).

EQN 4.1.11

$$Q_{BRC} = \frac{\left(\frac{Q_P}{3600}\right)}{12} * SA = \frac{(2.5/3600)}{12} * 3020 = 0.175 cfs$$

The number of pipes is calculated using flow, Q, manning's n, the pipe slope and the diameter of pipe.

EQN 4.1.12

$$N = \frac{\left(16 * \left\{\frac{Q_{BRC} * n}{s^{0.5}}\right\}^{3/8}\right)}{D} = \frac{\left(16 * \left\{\frac{0.175 * 0.011}{0.0125^{0.5}}\right\}^{3/8}\right)}{4} = \frac{\left(16 * \left\{\frac{0.002}{0.112}\right\}^{3/8}\right)}{4} = \frac{(16 * 0.221)}{4} = 0.88$$

with N<1 this confirms that an underdrain is not required.

7. A properly designed BRC will drawdown in <96 hours. To calculate drawdown time EQN 4.1.13

EQN 4.1.13

$$Time\ (hr) = \frac{\left(\frac{V}{Q_{BRC}}\right)}{3600} = \frac{\left(\frac{2265 ft^3}{0.175 cfs}\right)}{3600} = 3.6 hrs$$

8. A stormwater conveyance drop inlet will be raised and used as the overflow or bypass to the BRC.

Construction

The BRC should be installed in a stable drainage area to minimize sediment entry into the cell. If construction is to occur nearby, the BRC should be protected from sediment clogging by lining the perimeter of the cell with silt fencing, straw bales, or other appropriate sediment control measures.

Please review proper sediment control practices in the Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas (http://swcc.alabama.gov/pages/erosion_handbook.aspx).

Excavation: Construction should never occur on saturated soils. Furthermore, construction of the cell should be sequenced where precipitation does not fall on the area excavated for the cell as this will decrease infiltration by causing soil surfaces to seal. Preferably, excavation should be done following several consecutive warm and dry days. If a storm is predicted before the cell media will be installed, the cell should be covered.

Compaction: An excavator or backhoe with a bucket that has teeth should be used to excavate the area for the cell. The bottom of the cell should be loosened or scarified (using the teeth on the bucket to rake it) to a depth of 12" below the required bottom elevation with care taken to avoid compaction. Any soil compaction on the bottom of the cell will cause future exfiltration problems and the internal water storage (IWS) layer may not be able to drain sufficiently between rain events. An experienced operator should be hired and it is the responsibility of the designer to communicate to them the importance of minimizing compaction on the bottom of the cell and on the existing surrounding soil.

Media Recipe: The BRC media "recipe" recommended is 85 – 88 % washed sand (by volume), 8 – 12 % fines (clay and silt), and 3 – 5 % aged organics. The percentage of each media component is dependent on the target pollutant to be treated by the cell. If treating nitrogen, 12% fines are recommended to achieve an infiltration rate of 1"/hr. For cells treating phosphorus and metals, 8 % fines are suggested to achieve an infiltration rate of 2"/hr.

Soil Testing: A routine soil test should be performed on a sample of the cell media prior to installation. The soil test will determine the amount of extractable phosphorus present in the media. It is important that the extractable phosphorus of the media be low to very low regardless of the pollutant targeted. When media is used with a high phosphorus content, the BRC is likely to export phosphorus rather than reduce it. Soil media can be sent to the Auburn University Soil Testing Lab (http://www.aces.edu/anr/soillab/) to be analyzed.

Mulch: Triple or double shredded hardwood mulch is recommended for BRCs because it has fewer tendencies to float away and clog overflow structures. However, other mulch types such as pine bark are acceptable when hardwood mulch is not available. Do not use grass clippings for mulch, as this will increase nitrogen loading into the BRC. Mulch should be aged a minimum of six months. Using mulch that has not been properly aged or composted results in the depletion of soil nitrogen during mulch decomposition and can lead to a nitrogen deficiency in plants. Mulch inhibits weed growth, prevents erosion, encourages microorganism activity, provides a surface for excess water to evaporate, and keeps the underlying media from drying out completely during periods of drought. The mulch layer reduces cell media compaction during heavy rains and prevents the spread of fungal disease or other soil borne pathogens that might spread by water splashing from the soil to plants. Sediment is deposited on the mulch surface as stormwater enters the BRC and thus, the mulch serves as pretreatment for the cell to prevent clogging.

Retrofits: Retrofitting an existing facility with bioretention will require different design and construction techniques compared to bioretention in new developments. An IWS layer can be used in bioretention retrofits. An IWS layer reduces the amount of trenched pipe, uses fewer materials, and reduces the cost of the system outlet. This is not only economically appealing, but makes retrofits an option at locations with restricted outlet depth, where the stormwater conveyance is shallow, or when an overflow system is already in place. Existing infrastructure such as a catch basin can also be used as an overflow structure for retrofits.

Vegetation

Plants installed in the BRC should be selected based on the cell media depth in accordance with Table 4.3.1. In addition, plants should be tolerant of short term flooding and extended periods of drought. Vegetation used in BRCs should be tolerant of fluctuating hydrology ranging from extremely wet during heavy rainfall conditions to extremely dry during periods of low rainfall. Most bioretention plants have a facultative (FAC) or facultative wet (FACW) wetland indicator status. FAC and FACW plants are able to withstand short duration floods and maintain root growth that increases the root surface area available for water and mineral uptake. Surrounding soil and annual rainfall will affect the vegetation selection. For example, more drought tolerant plants should be placed in BRCs located in sandier soil conditions as these tend to be drier compared to more clayey soil sites. See Vegetation in Appendix D for more information on wetland indicator status.

Plant Sizes: Recommended plant container sizes include 3-gallon shrubs, 1-quart or larger herbaceous perennials, and trees that are at least 2.5” diameter. Cost will often determine size of plants installed; younger and smaller plants are less expensive than mature, larger plants. In general, using larger plant container sizes reduces plant mortality rates since these plants have stronger root systems and may establish more quickly. Less common species may also be more expensive than commonly produced plants. Prior to design, nurseries should be contacted for a list of available species, price list, and any available price breaks for large purchases. Mulch and plants should be inspected upon delivery and be free of weed seeds to reduce future maintenance and weed removal. Plants should also be inspected for general health, insects, and disease problems prior to installation. To aid in installation, plants can be tagged by species and laid out according to the planting plan.

Plant Establishment: Vegetation in the BRC can be planted at anytime of the year, however, timing can determine water inputs necessary for plant establishment and overall chances for survival. Vegetation installation is recommended for fall because this season requires less irrigation. Planting in the spring is acceptable, but plants will require more irrigation compared to a fall installation. Summer installation is not recommended because plants will require weekly watering and the chance for plant mortality is greater during this time due to heat and drought experienced. Small trees may need staking until they are established. Organic matter in the cell media will aid in plant establishment and help jump-start the nitrogen removal process.

Lime and Fertilizer: The soil test performed on the bioretention media will indicate any lime requirements that should be mixed into the media prior to installation. Current findings suggest that nutrients present in stormwater runoff are sufficient to aid in establishment of plants.

Plant Spacing: Plants should be spaced based on their mature plant width. In most cases, a triangular spacing grid is used so that plants are equally spaced within rows, but the rows are staggered. The triangular grid plant quantity equation can be used to estimate the number of plants per area. The equation utilizes the maximum amount of available space and is sometimes an overestimate as it does not take walking space or maintenance access into account. See Chapter 5.1 on Rain Gardens for more information on design using a plant quantity equation.

It is recommended that the BRC be sketched to scale in order to place plants. Sketching using a circle template will help to eliminate overcrowding because mature plant sizes are used. The circle template method allows the designer to design the cell at a bird's eye or plan view. Vegetation plans that use plants that colonize or reseed areas should allow for plants to spread and include extra space per plant. Also, empty mulched areas within the cell will allow surface water evaporation from mulched surfaces, pathogen die off, and maintenance access.

Turfgrass Bioretention: Turfgrass BRCs have been used successfully, but their long-term functionality is unknown due to thatch buildup and decreased infiltration into the cell. Turfgrass BRCs should be sodded using bermudagrass or centipedegrass.

Vegetation Design Guidelines

- Woody vegetation such as shrubs or trees should not be sited near the inlet to the BRC.
- Local landscape ordinances should be abided by, and this may affect the vegetation plan.
- A diverse plant community is recommended to decrease insect and disease infestations.
- If pathogens are a target pollutant, plants should be loosely spaced to allow for increased sunlight and pathogen die off.
- Plants with taproots should not be used due to their potential to damage underdrain pipes.
- Do not specify noxious or invasive plants that may displace other vegetation and create dense monocultures.
- Contract specifications should require the use of native vegetation instead of exotic plants. When native plants are not available, non-native ornamental varieties may be used when they are not considered invasive. Contact the Alabama Invasive Plant Council if you are unsure whether a plant is invasive (http://www.se-eppc.org/alabama/).
- A mixture of evergreen and deciduous vegetation should be used to ensure nutrient uptake occurs throughout the year. Using all deciduous vegetation can result in clogging due to leaf debris inhibiting infiltration into the mulch layer and may also require more frequent maintenance.

Table 4.1.6
Bioretention Plant List

Botanical Name	Common Name	Habit	Prefers
Clethra alnifolia	summersweet clethra	deciduous shrub	sun to part shade
Conoclinium coelestinum	mistflower	herbaceous perennial	sun to part shade
Ilex glabra	inkberry holly	evergreen shrub	part shade
Ilex verticillata	winterberry	deciduous shrub	sun to part shade
Ilex vomitoria	yaupon holly	evergreen shrub	sun to part shade
Itea virginica	sweetspire	deciduous shrub	sun to part shade
Liatris spicata	blazing star	herbaceous perennial	sun
Lindera benzoin	spicebush	deciduous shrub	sun to part shade
Morella cerifera	wax myrtle	evergreen shrub	sun to part shade
Muhlenbergia capillaris	muhly grass	herbaceous grass	sun to part shade
Panicum virgatum	switchgrass	herbaceous grass	sun to part shade
Rudbeckia fulgida	orange coneflower	herbaceous perennial	sun to part shade
Stokesia laevis	stoke's aster	herbaceous perennial	sun to part shade
Vernonia gigantea	giant ironweed	herbaceous perennial	sun
Vernonia novenboracensis	New York ironweed	herbaceous perennial	sun
Viburnum dentatum	witherod	deciduous shrub	sun to part shade
Viburnum nudum	possumhaw	deciduous shrub	sun to part shade

Vegetation Design Example 1

This bioretention cell is 46’ x 80’ and uses a mixture of small trees, shrubs, and perennials. It is symmetrical and can be viewed from all sides with the tallest plants located in the center of the cell. The vegetation provides year round seasonal interest.

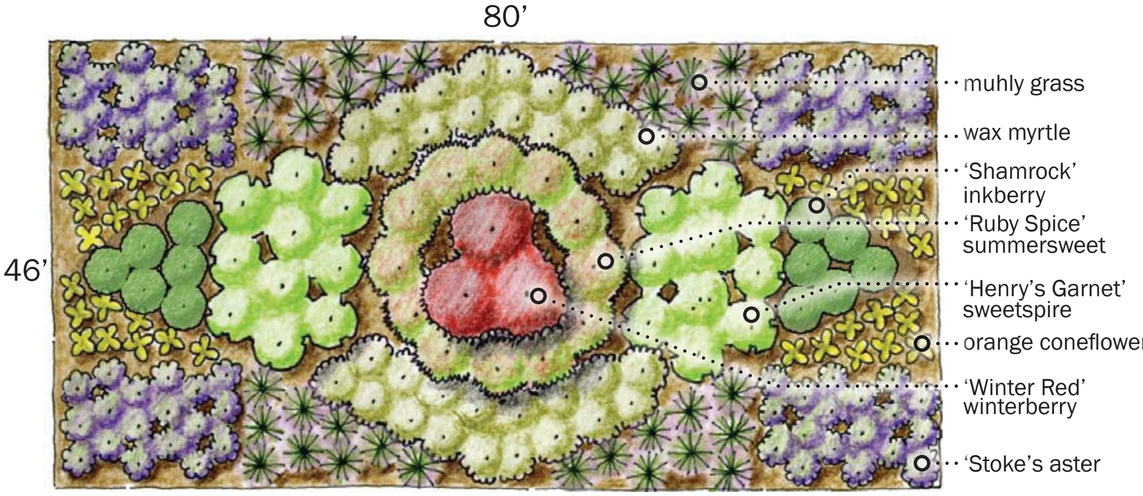


Table 4.1.7
Design 1 Plant List

Botanical Name	Common Name	Seasonal Interest	Quantity
Clethra alnifolia ‘Ruby Spice’	‘Ruby Spice’ summersweet	Summer bloom	12
Ilex glabra ‘Shamrock’	‘Shamrock’ inkberry	Evergreen	6
Ilex verticillata ‘Winter Red’	‘Winter Red’ winterberry	Red berries in late fall and winter	3
Itea virginica ‘Henry’s Garnet’	‘Henry’s Garnet’ sweetspire	Spring bloom, red fall color	20
Morella cerifera ‘Tom’s Dwarf’	‘Tom’s Dwarf’ waxmyrtle	Evergreen	34
Muhlenbergia capillaris	muhly grass	Fall bloom	36
Rudbeckia fulgida	orange coneflower	Summer and fall bloom	36
Stokesia laevis	Stoke’s aster	Spring and summer bloom	72

Vegetation Design Example 2

The BRC is 46’ x 80’ and uses a mixture of shrubs and perennials. It can be viewed from all sides and has year round seasonal interest.

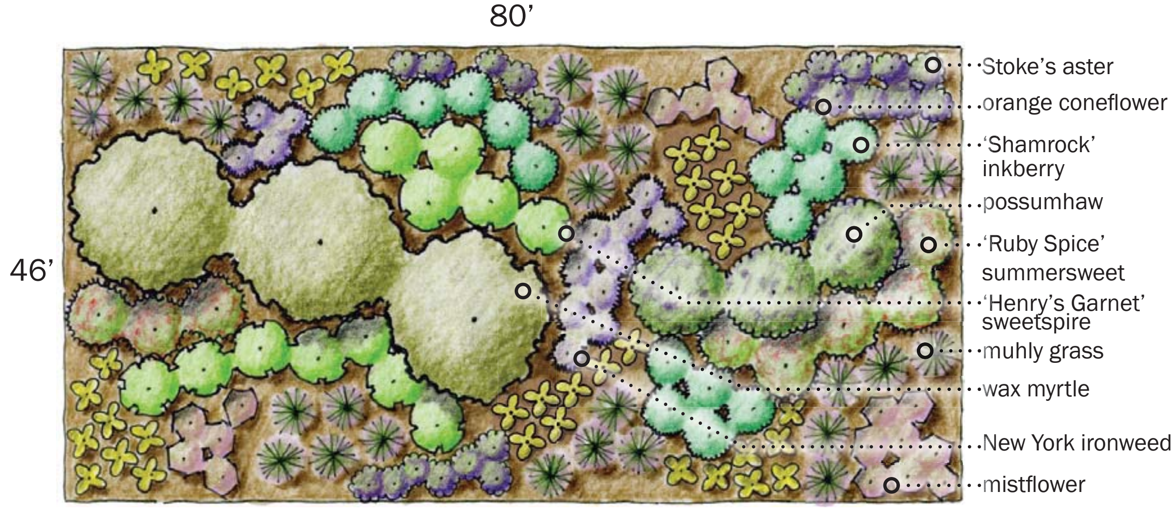


Table 4.1.8
Design 2 Plant List

Botanical Name	Common Name	Seasonal Interest	Quantity
Clethra alnifolia ‘Ruby Spice’	‘Ruby Spice’ summersweet	Summer bloom	8
Conoclinium coelestinum	mistflower	Summer and fall bloom	18
Ilex glabra ‘Shamrock’	‘Shamrock’ inkberry	Evergreen	16
Itea virginica	sweetspire	Spring bloom, red fall color	12
Morella cerifera	waxmyrtle	Evergreen	3
Muhlenbergia capillaris	muhly grass	Fall bloom	27
Rudbeckia fulgida	orange coneflower	Summer and fall bloom	21
Stokesia laevis	Stoke’s aster	Spring and summer bloom	21
Viburnum nudum	possumhaw	Summer bloom, berries in fall	3
Vernonia novenboracensis	ironweed	Summer bloom	15

Maintenance

Clogging: The most common failure mechanism of a BRC is clogging of the cell media. The underdrain pipe can be unclogged via the clean out pipe(s). However, if water remains ponded on the cell surface and clogging persists, it may be necessary to remove and replace the top few inches of media. Following this replacement, if the cell surface continues to remain ponded for longer than 12 hours, then the cell media is likely clogged and will need to be completely replaced. Extended surface ponding provides favorable conditions for mosquito breeding and is detrimental to plants unaccustomed to extended flooding.

Mulch: The top 1 to 2” of mulch and 4” of media have been shown to accumulate sediment and metals. Periodic replacement of these top layers can facilitate removal of sediment bound phosphorus and metals. Upon the need to dispose of any potentially contaminated mulch or media associated with BRCs, the ADEM Environmental Services Branch should be contacted for guidance associated with the requirements for waste determination and disposal procedures. For more information, please call 334-271-7700 or 1-800-533-2336.

Table 4.1.9
Maintenance Schedule

Task	How Often	Comments
Mulching	As needed, full replacement every 2 to 3 years	Bare areas from erosion should be replaced as necessary. Mulching can be done any time of the year, but the best time is late spring after soil has warmed. Mulch should be replaced annually if the watershed is high in heavy metals.
Re-planting	When plants die	If plants consistently suffer from mortality consider using more appropriate plant species for the area.
Weeding	Twice a year	Weeding should decrease over time as vegetation establishes.
Inspect plants	Monthly until establishment, then twice a year	Inspect for diseased or insect infested vegetation.
Inspection	After 0.5” or greater rainfall event	Visually inspect all components including any pretreatment, pipes, or IWS where applicable.
Fertilization	At planting	Most BRCs are used in nutrient sensitive watersheds. Fertilizing beyond plant establishment will increase nutrients leaving the BRC.
Unclog Underdrain Pipes	As needed	Ponded surface water should drain away within 12 hours or less (i.e. eliminate standing water conditions). If water remains ponded on the surface of the cell for longer than 12 hours this may indicate that the underdrain pipe or cell media is clogged.
Pruning	Annually	Pruning will help maintain plant shape. See Vegetation in Appendix D for pruning recommendations.
Sediment Removal	As needed	If sediment clogs the media, the top few inches may need to be removed and replaced. Removed sediment should be properly disposed of as it may contain toxic materials such as heavy metals. Contact the ADEM Environmental Services Branch for guidance at 334-271-7700 or 1-800-533-2336.
Trash Removal	As needed	In high traffic areas, frequent trash removal will be necessary.
Mulch removal from outlets	As needed	Mulch may collect in the outlet or overflow during heavy rains.

Mulch should be maintained at a 3” depth. Plants may grow roots into mulch that is too deep which causes stress to the plant during dry weather conditions. Mulch should be replaced when it decomposes or becomes matted. Some erosion may occur at the inlet and in other areas of the cell. However, if designed properly, erosion should only occur occasionally following extreme wet weather conditions. If erosion occurs frequently, the design should be reworked and flow velocities, drainage areas, and sizing should be considered.

Plant Replacement: Plants should be replaced when mortality occurs. Up to 10% of plants may die in the first year and over time, survival rates should increase. Stem surfaces can be scraped using a razor blade or other sharp tool to determine whether a plant is still alive. The plant is considered to be alive when green tissue is found after scraping the stem. Dead plants are not only unsightly, but can provide favorable environments for insects and diseases to overwinter.

Pollutant Removal

Table 4.1.10
Pollutant Removal Table

Sediment	Nutrients		Metals	Pathogens
	N	P		
a.85%	40%	45%	No Data	No Data
b.80%	50%	60%	MOD	No Data
c.80%	50%	60%	MOD	No Data

a. NCDENR, 2007*
b. City of Auburn, 2011
c. Georgia Manual, 2001

* Research has demonstrated pollutant removal efficiencies of 60% for both N and P in the Coastal Plains.

Bioretention pollutant removal is dependent on the presence of plants, microorganisms, specialized cell media, and mulch; the absence of one of these components decreases the pollutant removal efficiency associated with the BRC. Bioretention shows greater than 35% reduction in nutrients and a minimum of 80% reduction in total suspended solids (TSS). Nutrient removal is more variable compared to TSS, which is likely due to the complexities of chemical breakdown processes and the behavior of nutrients.

Total Suspended Solids: Although most TSS is removed through sedimentation, some suspended fine particles are removed via filtration through the top layer of media and mulch.

Total Nitrogen: An IWS layer creates anaerobic conditions to a facilitate reduction in nitrogen through denitrification. Nitrogen is removed 30” below the media surface. Nitrogen uptake by plants is increased when plant tissue is harvested frequently.

Total Phosphorus: It is critical to soil test cell media prior to installation to determine that the extractable phosphorus is low to very low, especially if phosphorus reduction is a primary concern. Research has shown phosphorus removal depends on the phosphorus content originally found in the BRC media. Media with high extractable phosphorus is likely to leach phosphorus from the BRC. Two-thirds of phosphorus is bound to sediment and is deposited on the mulch layer and surface layer of media as stormwater enters the BRC; thus, mulch can be removed and replaced to assist in phosphorus reduction. The remaining third is soluble phosphorus, which is removed at a depth of 12” or more below the media surface. Phosphorus has the most variable range of pollutant reduction.

Metals: Studies have shown a reduction in metals, but an average pollutant removal efficiency has not been assigned. Most metal removal occurs in the surface/mulch layer of a BRC since metals are often bound to sediments and may be removed by filtration and adsorption processes.

Pathogens: Pathogens are killed on the surface of the cell through sun-exposure and drying, and can be removed throughout the cell through sedimentation and filtration. For pathogens, a range of 70 - 92% removal of fecal coliform or *E. coli* has been reported, but a pollutant removal average is not assigned.

Temperature: When temperature reduction is a goal, media depth is an important factor of planning and design. Temperature is reduced at approximately 48” below the media surface.

Vegetation: Vegetation in these systems has the vital role of transpiration cooling effects, nutrient uptake, and pollutant removal. Most importantly, vegetated BRCs are more efficient in breaking down, removing, and mineralizing harmful pollutants such as hydrocarbons, pesticides, chlorinated solvents, and surfactants compared to cells lacking vegetation. Vegetated BRCs show higher phosphorus reduction compared to non-vegetated cells. BRCs with at least 2.7’ of media can retain up to 92% of phosphorus because vegetation increases BRC media sorption (binding) capacity. Deep root systems, high growth rates, and plant maturity are reported to have the highest rates of pollutant removal.

Plant Roots: Plant roots aerate soils and exude nutrients and carbon, which favors microorganism habitat and growth. Roots also contribute to chemical and physical processes that improve soil structure, increase infiltration capacity, and cell media permeability in the BRC.

Transpiration: Through transpiration, plants in BRCs create cooler microclimates. On a daily basis, plants can transpire amounts nearly equal to their total water content. This is significant since herbaceous and woody plants may contain up to 70 and 50%, respectively, of water in their fresh weight.

Microorganisms: Microorganisms present in the media degrade petroleum-based products as well as other organic materials such as decomposing plant leaves. Additionally, microorganisms can aid in nutrient uptake.

Bioretention cell 3 months post installation, East Smiths Station Elementary School; Smiths Station, AL

References

Alabama Soil and Water Conservation Committee. 2009. Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas. Montgomery, AL.

Brown, R.A., W.F. Hunt, and S.G. Kennedy. 2009. Designing Bioretention with an Internal Water Storage (IWS) Layer: Design guidance for an innovative bioretention feature. North Carolina Cooperative Extension. AG-588-19W.

Brown, R.A. and W.F. Hunt. 2009. Improving Exfiltration from BMPs: Research and Recommendations. North Carolina Cooperative Extension.

Christian, K. J., A. N. Wright, J. L. Sibley, E. F. Brnatley, J. A. Howe. and C. LeBleu. 2012. Effect of Phosphorus Concentration on Growth of Muhlenbergia capillaris in Flooded and Non-Flooded Conditions. Journal of Environmental Horticulture 30(4): 219-222.

City of Auburn Manual. 2011.

Davis, Allen P., William F. Hunt, Robert G. Traver, and Michael Clar. 2009. Bioretention Technology: An Overview of Current Practice and Future Needs. Journal of Environmental Engineering. March.

Davis, Allen P. 2007. Field Performance of Bioretention: Water Quality. Environmental Engineering Science, 24(8) 1048-1063.

Davis, A. P., M. Shokouhian, H. Sharma, and C. Minami, C. 2006. Water Quality Improvement Through Bioretention Media: Nitrogen and Phosphorus Removal. Water Environment Research 78 (3), 284–293.

Davis, A. P., M. Shokouhian, H. Sharma, and C. Minami. 2001. Laboratory Study of Biological Retention for Urban Storm Water Management, Water Environment Research 73(1), 5-14.

Dylewski, K. L., A. N. Wright, K. M. Tilt, and C. LeBleu. 2012. Effect of Previous Flood Exposure on Flood Tolerance and Growth of Three Landscape Shrub Taxa Subjected to Repeated Short-term Flooding. Journal of Environmental Horticulture 30:58-64.

Dylewski, K.L., A. N. Wright, K.M. Tilt, and C. LeBleu. 2011. Effects of Short Interval Cyclic Flooding on Growth and Survival of Three Native Shrubs. HortTechnology 21(4): 461-465.

Evans, Erv. Mulching Trees and Shrubs. Consumer Horticulture Fact Sheet. Raleigh, NC: NC State University Cooperative Extension, 2000. http://www.ces.ncsu.edu/depts/hort/consumer/factsheets/trees-new/text/muching.html. Accessed August 8, 2012.

Georgia Stormwater Manual. 2001.

Henderson, C., M. Greenway, and I. Phillips. 2006. Removal of dissolved nitrogen, phosphorus and carbon from stormwater biofiltration mesocosms. In A. Deletic and T. Fletcher, eds. Proceedings, 7th International Conference on Urban Drainage Modeling, and 4th International Conference on Water Sensitive Urban Design, Melbourne, Australia, 2-7 April 2006.

Hinman, C. Low Impact Development: Technical Guidance Manual for Pugent Sound. Olympia, WA: Puget Sound Action Team, Washington State University, Pierce County Extension, 2005.

Hunt, W.F., J.T. Smith, S.J. Jadlocki, J.M. Hathaway, P.R. Eubanks. 2008. Pollutant Removal and Peak Flow Mitigation by a BRC in Urban Charlotte, N.C. Journal of Environmental Engineering. 134(5) : 403-408.

Hunt, W.F. and N. White. 2001. Designing Rain Gardens (Bio-Retention Areas). North Carolina Cooperative Extension. AG-588-3.

Hunt, W.F. and W.G. Lord. 2006. Bioretention Performance, Design, Construction, and Maintenance. North Carolina Cooperative Extension. AGW-588-05.

Jernigan, K. J. and A. N. Wright. 2011. Effect of repeated short interval flooding events on root and shoot growth of four landscape shrub taxa. Journal of Environmental Horticulture 29(4) 220-222.

Li, Houng, and A. P. Davis. 2008. Urban Particle Capture in Bioretention Media. I: Laboratory and Field Studies. Journal of Environmental Engineering. 134.

Low Impact Development Center, Drainage, Bioretention Specifications http://www.lowimpactdevelopment.org/epa03/biospec.htm

Lucas, W.C. and M. Greenway. 2008. Nutrient retention in vegetated and non-vegetated bioretention mesocosms. Journal Irrigation and Drainage Engineering. 134: 5.

North Carolina Department of the Environment and Natural Resources. 2007. Stormwater Best Management Practices Manual, Ch 12: Bioretention (Chapter revised 2009). North Carolina Division of Water Quality, Raleigh, NC.

Passeport, E., W. F. Hunt, D. E. Line, R. A. Smith, R. A. Brown. 2009. Field study of the ability of two grassed BRCs to reduce stormwater runoff pollution. Journal of Irrigation and Drainage Engineering. 135(4): 505-510.

Rendig, V. and H. Taylor. 1989. Principles of Soil-Plant Interrelationships. McGraw-Hill Publishing Company. New York.

Roseen, R.M., T. P. Ballestero, J.J. Houle, P.Avellaneda, J. Briggs, G. Fowler, and R. Wildey. 2009. Seasonal Performance Variations for Storm-Water Management Systems in Cold Climate Conditions. Journal of Environmental Engineering. 135(3):128-137.

Rusciano, G. M. and C.C. Obropta. 2007. Bioretention column study: fecal coliform and total suspended solids reduction. Transactions of the ASABE, 50(4): 1261:1269.

US Environmental Protection Agency. 2006. 2006 Summer Report. Section 319 National Monitoring Program Projects, NCSU Water Quality Group, Raleigh, NC.

US Environmental Protection Agency.. 1999. Stormwater Technology Factsheet: Bioretention. Washington, D.C.

US Environmental Protection Agency. 2000. Introduction to Phytoremediation. EPA-600-R- 99-107. Cincinnati, OH.

::This page::
::intentionally left blank::