



BENEFITS			
Low = <30% Medium = 30-65% High = 65-100%			
	Low	Med	High
Suspended Solids		✓	
Nitrogen			
Phosphorous	✓		
Metals			
Bacteriological			
Hydrocarbons			✓

Description: Bioretention systems incorporate shallow landscaped level depressions that temporarily store and readily infiltrate runoff. They include both rain gardens and bioretention cells. A rain garden relies solely on soils with good percolation rates. Bioretention cells typically include a rock chamber, subdrain, and modified soil mix. In bioretention cells, stormwater runoff collected in the upper layer of the system is filtered through the surface vegetation, mulch layer, pervious soil layer, and then stored temporarily in a stone aggregate base layer. The Water Quality Volume (WQv) is drained from the aggregate base by infiltration into the underlying soils and/or to an outlet through a perforated pipe subdrain. Systems can operate either off-line or online. They are designed with a combination of plants that may include grasses, flowering perennials, shrubs, or trees. Integrated upstream treatment is provided by a perimeter grass filter strip or grass swale for initial capture of sediment.

Typical uses:

- Manages water quality runoff volume from residential, commercial, and institutional sites.
- Drainage area for each cell is typically 0.5-2.0 acres. Larger drainage areas should be divided into smaller sub-areas with individual bioretention cells distributed throughout the site.
- Suitable for landscaped depressional areas such as parking lot islands, road medians, and street right- of-ways.

Advantages/benefits:

- Reduce runoff rate and volume from impervious areas; provide opportunity for infiltration and filtration processes. Good for highly-impervious areas, such as parking lots.
- Removes fine sediments, heavy metals, nutrients, bacteria, and organics. Reduces thermal pollution from runoff across pavement surfaces.
- Flexible design options for varying site conditions; subdrain system allows use on sites with limiting soils. Good retrofit opportunities.
- Flexible landscaping options can provide an aesthetic feature.

Disadvantages/limitations:

- High entrance velocities and concentrated flows may need special design considerations.
- High sediment loads can cause premature failure; upstream practice is needed.
- High water table may require special design considerations.

Maintenance requirements:

- Routine landscape maintenance - removal of undesirable and dead vegetation.
- Replenish mulch layer.
- Removal of accumulated sediment in pretreatment areas.

A. Overview

- 1. Description.** Bioretention cells are structural stormwater controls. They capture and temporarily store the water quality volume using soils and vegetation in shallow basins or landscaped areas to remove pollutants from stormwater runoff.

Bioretention cells use vegetation and engineered soils in a treatment area to accept runoff from impervious surfaces. Stormwater flows into the bioretention cell, temporarily ponds on the surface, and gradually infiltrates into the modified soil layer. Examples of bioretention cells are shown in Figure C5-S4- 1. Components of a bioretention cell are illustrated in Figure C5-S4- 2 and Figure C5-S4- 3. Bioretention cells are intended to replicate the stable hydrologic functions of a native ecosystem. Bioretention functions as a soil and plant-based filtration system for stormwater runoff, and removes pollutants through a variety of physical, chemical, and biological processes in the upper engineered soil layer and the underlying native soils. The design can impact the processes and their function. Some of the major processes that occur through bioretention include interception, infiltration, settling, evapo-transportation, filtration, absorption, thermal attenuation, and biological degradation/decomposition.

The filtered runoff can be allowed to either percolate into the underlying soils or be temporarily stored in the aggregate subdrain system and discharged at a controlled rate to the storm sewer system or a downstream open channel. Runoff can be controlled closer to where it is generated by the uniform distribution of bioretention cells to break up the area in manageable sub- watersheds. Higher flow events ($> Q_2$), and runoff volume that exceeds the infiltration capacity of these systems can be returned to the conveyance system or safely bypassed.

Plants in bioretention cells enhance infiltration and provide an evapotranspiration component. Native species provide resistance to moisture changes, insects, and disease and provide uptake of runoff water and pollutants. Deep-rooted native plants (grasses and forbs) are recommended to maintain high organic matter content in the soil matrix, provide high infiltration rates, and provide uptake of runoff water. The mulch layer and organic matter component of the soil matrix provide filtration and a place for beneficial microbial activity. Aerobic conditions are necessary to maintain microbial activity for processing pollutants.

There are many ways to incorporate bioretention cells into new construction projects or to retrofit existing urban areas. Bioretention can be used in residential yards, as interior or perimeter structures in parking lots, for rooftop drainage at residential and commercial building sites, along highways and roads, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments.

A complementary upstream practice is provided to reduce the sediment loading to the bioretention cell. Bioretention cells are often built with grass filter strips around the bioretention area. These filter strips remove particulates and reduce runoff velocity. Filter strips also prevent crusting of pore spaces with fines and reduce maintenance. A freeboard storage area (temporary ponding) creates temporary storage for runoff prior to infiltration, evaporation, and uptake.

Each component of the bioretention cell is important. The engineered soil layer provides filtration and holds water and nutrients for the plants, enhances biological activity, encourages root growth, and provides storage of stormwater through the voids within the soil particles. The plant material evapo-transpires stormwater, creates pathways for percolation through the soil, improves soil structure, improves aesthetics, and reinforces long-term performance of subsurface percolation. Native plant material is recommended because of its deep root structure and ability to improve soil quality. The mulch layer acts as a filter for pollutants in runoff, protects underlying soil from drying and eroding, and provides an environment for microorganisms to degrade organic pollutants. It also provides a medium for biological growth, decomposition of organic material, and adsorption and bonding of heavy metals.

When bioretention cells are installed at locations such as gas stations or other sites where spills of hazardous materials could occur, the practices should be lined with an impermeable membrane. A shutoff valve should be installed at the lower end of the subdrain so that the materials can be contained within the practice and managed appropriately.

Mosquitoes are not a problem because bioretention cells do not retain standing water long enough for mosquito reproduction (4-10 days). Properly designed bioretention cells will infiltrate standing water within 4-12 hours.



(a) Cascading feature in two-stage bioretention cell.



(b) The grassed pretreatment area provides a long flow path to this bioretention cell. Curb cuts were installed after the young plants became established.



(c) Newly planted bioretention area with native grasses



(d) Terraced bioretention cells under construction.

Figure C5-S4- 1: Example bioretention applications

2. Applications for stormwater management (stormwater management suitability).

Bioretention cells are designed primarily for stormwater quality in the removal of pollutants. Bioretention can provide limited runoff quantity control, particularly for smaller storm events. These facilities may sometimes be used to meet channel protection requirements on smaller sites. However, bioretention cells will typically need to be used in conjunction with another structural control to provide channel protection as well as overbank flood protection. It is important to ensure that a bioretention cell safely bypasses higher flows.

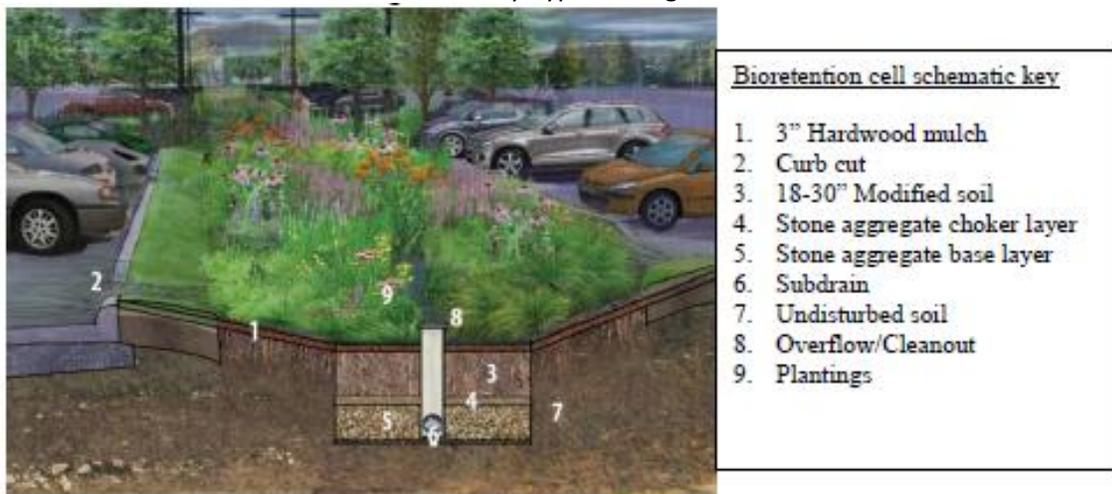
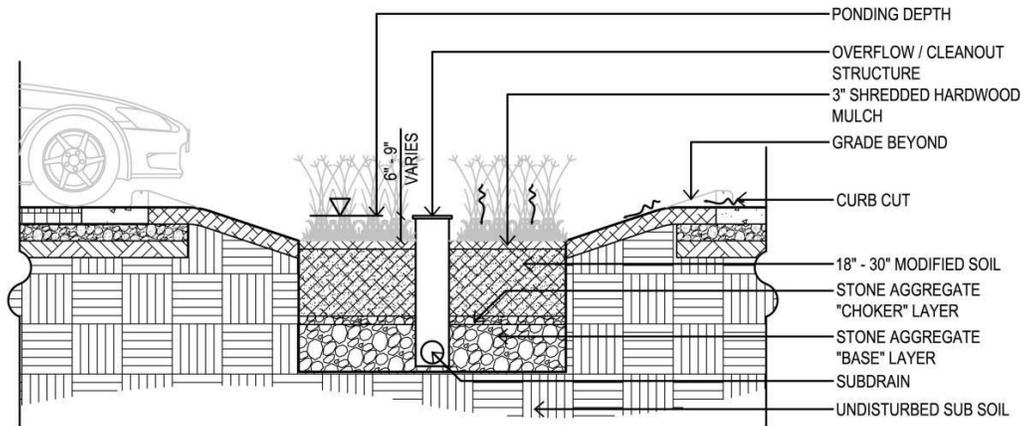
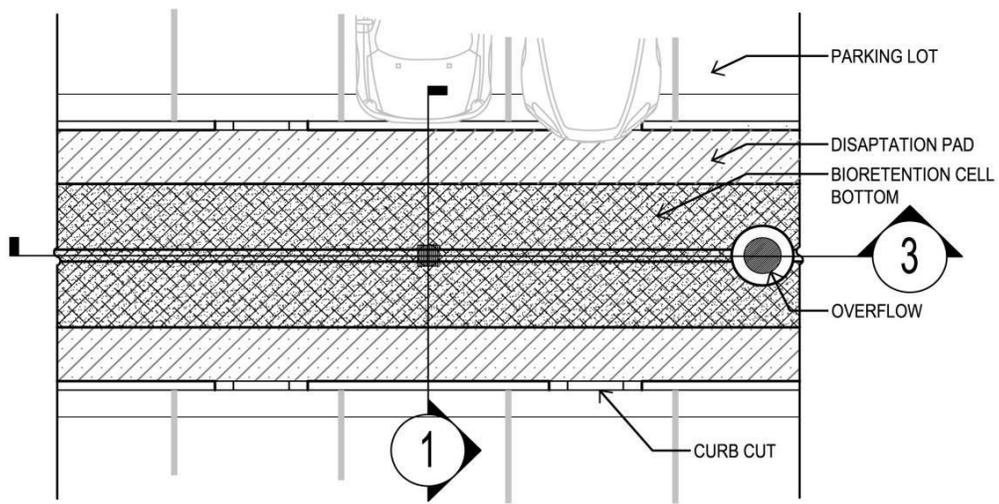


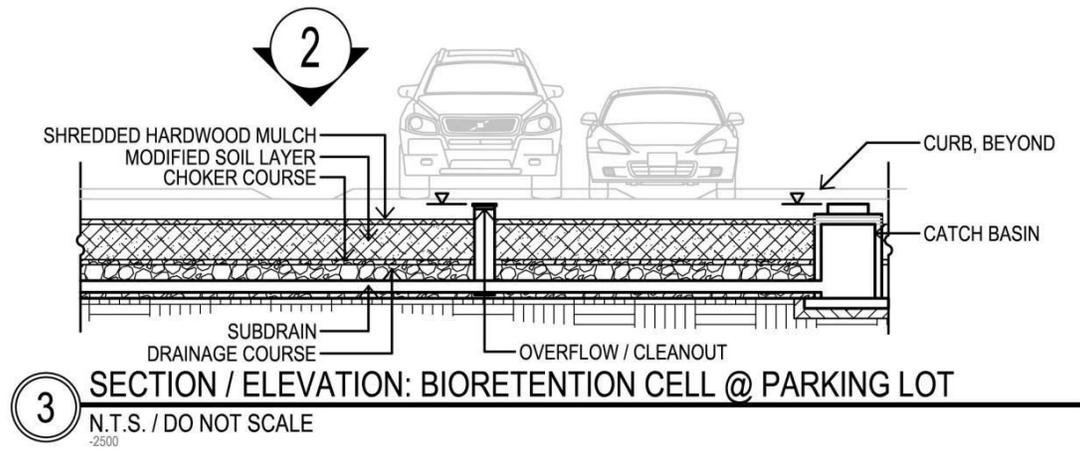
Figure C5-S4- 2: Bioretention cell schematic



1 SECTION: BIORETENTION CELL @ PARKING LOT
 1/4" = 1'-0"
 -0208



2 PLAN: BIORETENTION CELL @ PARKING LOT
 N.T.S. / DO NOT SCALE
 -2500



3 SECTION / ELEVATION: BIORETENTION CELL @ PARKING LOT
 N.T.S. / DO NOT SCALE
 -2500

Figure C5-S4- 3: Cross-section and plan views of a bioretention cell

- a. **Water quality.** Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention cell is designed to perform a specific function (see Figure C5-S4- 3).
- 1) Pretreatment practices reduce incoming runoff velocity and filter particulates from the runoff.
 - 2) The ponding area provides for temporary storage of stormwater runoff prior to its evaporation, infiltration, or uptake and provides additional pollutant settling capacity.
 - 3) The organic or mulch layer provides filtration, as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material.
 - 4) The modified soil in the bioretention cell acts as a filtration system, and clay organic matter in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants.
 - 5) Herbaceous and woody plants in the ponding area provide vegetative uptake of runoff and pollutants, and also serve to stabilize the surrounding soils, but will require maintenance such as trimming, pruning, and selective removal of volunteer species.
 - 6) Finally, an aggregate layer provides for positive drainage and aerobic conditions in the modified soil, and provides a final polishing treatment media.
- b. **Channel protection.** For smaller sites, a bioretention cell may be designed to capture the entire channel protection volume in either an off-line or on-line configuration. The requirement of extended detention of the 1-year, 24-hour storm runoff volume can be achieved by increasing the footprint of the practice, or combining additional storage above the WQv ponding depth, with a slow release stage of an intake or other surface outlet structure. For off-line systems on larger sites, where only the WQv is diverted to the bioretention cell, another structural control must be used to provide Cpv extended detention.
- c. **Overbank flood protection*.** Typically, another structural control must be used in conjunction with a bioretention cell to reduce the post-development peak flow of storms greater than the 5-year storm (Q_p) to pre-development levels (detention).
- d. **Extreme flood protection*.** Bioretention cells must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the ponding area, mulch layer, and vegetation.

*Refer to design procedures included in this section for more discussion of on- and offline systems as well as detention or attenuation of larger storm events.

(See Chapter 2, section 1 and Chapter 3, section 6 for more details on the Unified Sizing Criteria and Small Storm Hydrology)

3. **Pollutant removal capabilities.** In landscaped and residential areas, the major pollutants of concern are fertilizers such as nitrogen and phosphorus. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes, derived from sampling data, modeling, and professional judgment (Table C5-S4- 1). In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach. For additional information on monitoring BMP performance, see ASCE/EPA “Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements.”

Table C5-S4- 1: Pollutant removal efficiency of bioretention cells

Parameter	Removal Efficiency (%) Median values (N=10)
Total suspended solids	59
Total phosphorous	5
Total nitrogen	46
Nitrogen NO ₂ -NO ₃	43
Copper	81
Zinc	79

Source: CWP National Pollutant Performance Database, v3, ept., 2007

More information on pollutant removal capabilities for bioretention BMPs can be found in the National Stormwater Best Management Practices Database (<http://www.bmpdatabase.org/>) and the ASCE/EPA database.

The University of Maryland Engineering Department, completed an evaluation “Optimization of Bioretention,” of the effectiveness of pollutant removal. The experiment yielded valuable data on pollutant removal efficiency rates and processes for bioretention. This manual incorporates those findings into the design criteria. Table C5-S4- 2 summarizes the efficiency removal rates for various pollutants.

Table C5-S4- 2: Cumulative percent removal of pollutants by depth in bioretention cells

Laboratory/Field Summary (%)								
Depth	Cu	Pb	Zn	P	TKN	NH ₄	NO ₃	TN
1 ft	90	93	87	0	37	54	-97	-29
2 ft	93	99	98	73	60	86	-194	0
3 ft	93	99	99	81	68	79	23	43

Source: Davis, A.P. et al, University of Maryland, 1998

- 4. Application and feasibility.** Bioretention is suitable for a wide variety of development options, including commercial, high-density urban, and single-family residential areas. They can be used for new construction and also to retrofit urban landscapes. Their capacity to be used as a landscaped feature allows them to fit into many types of urban design. Bioretention cells are ideally suited to many ultra-urban areas, such as landscaped parking lot islands and along streets and boulevards. Ultra-urban areas are densely-developed urban areas in which little pervious surface exists. While they consume a fairly large amount of space (approximately 5%-10% of the impervious area that drains to them), they can fit into existing parking lot islands or other landscaped areas, when used as a standalone practice. They can also treat runoff from intensively managed areas that have the potential for pollutants, such as golf courses. Figure C5-S4- 3 includes an example site configuration.

The following criteria should be evaluated to ensure the suitability of a bioretention cell for meeting stormwater management objectives on a site or development. Table C5-S4- 3 provides a list of considerations when planning for a bioretention cell.

a. General feasibility:

- Suitable for use in developed or developing areas, provided that heavy sediment loads are not expected in post-construction conditions (i.e. may not be suitable in watersheds with on-going site construction, routinely disturbed areas, agricultural lands without conservation practices, etc.). Suitable for use in brownfield projects and areas with pollutant hotspots. Special considerations are needed in areas with karst topography, loess soils, or high water tables.
- Bioretention practices should be located where they are accessible to be maintained and where maintenance is assured by a designated responsible party.
- Bioretention practices are not recommended to be used as a single large BMP (regional stormwater control).

Flow velocities may be too high near the entrance to the practice, and/or the required area for treatment would likely be too large to be expected to be constructed with a level bottom. Divide larger watersheds into multiple, smaller sub- areas for treatment or review other water quality BMPs that are better at managing larger drainage areas.

b. Physical feasibility - physical constraints at project site:

- Drainage area: 0.5-2.0 acres of impervious area are preferred. Larger areas of imperviousness can be broken into smaller catchments.
- Space required: Approximately 3% to 7% of the tributary impervious area is required.
- Site slope: Special design considerations for sites with steep slopes.
- Minimum head: Need sufficient elevation to allow subdrain system to daylight downstream, or connect to available storm sewer system.
- Minimum depth to water table: A separation distance of 2 feet is recommended between the bottom of the bioretention cell and the elevation of the seasonally high water table.
- Soils: No restrictions; engineered media required. Since modified soils and a subdrain system are included in bioretention cells, cells do not need to rely on the percolation rates of subsoil layers to function. However, locating cells in areas with higher percolation rates allows opportunities to reduce the volume of surface runoff from a site and provide groundwater recharge.

Table C5-S4- 3: Planning criteria for bioretention cells

Site Conditions	The bottom of the aggregate layer should have 2 feet of vertical separation from expected high groundwater elevations or bedrock layers.
Source of Runoff	Bioretention cells can be placed close to the source of runoff generation.
Distributed Placement and Location	It is preferred to consider stormwater management during initial site design. Several, smaller bioretention cells can treat more manageable amounts of runoff closer to its source. Use site grading to divert runoff to smaller depressions in open spaces such as parking islands, landscaped areas, etc.
Site Integration	Stormwater management site integration is a preferred alternative to end-of-pipe BMP design, where feasible.
Location	Bioretention cell locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth.
Drainage Area	Potential bioretention cells should be applied where impervious surfaces within drainage subareas to each cell are limited to less than 2 acres.
Online or Offline	Offline systems employ some type of diversion structure, which typically diverts the first flush of flow to the treatment practice, but allows flows from larger events to bypass the practice. This can prevent erosion within the practice and re-suspension of captured sediments. A cell is considered online if all runoff from the upstream area enters the practice.
Flow Diversion for Offline cells	When used in an offline configuration, the WQv (and perhaps Cpv) is diverted to the bioretention area using a flow splitter, diversion structure, and/or overflow outlet. Larger stormwater flows are diverted to other controls downstream (see Chapter 6, section 1, F for more discussion of offline systems and design guidance for diversion structures and flow splitters).
Intermittent Flow	Bioretention cells are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, heavy irrigation, sump pumps, or other sources.

Storm Events	<p>Typically, bioretention cells are used to manage small storm events (this may include events smaller than the Water Quality event (WQv) or the Channel Protection event (Cpv-1-year event). Refer to Chapter 3, section 6 for additional information about small storms.</p> <p>Online systems may offer the possibility to attenuate or detain flows from larger storm events, with caution needs to prevent:</p> <ul style="list-style-type: none"> • Erosive flow velocities near inlets/outlets • Deep ponding could compact soil layers • Extended drawdown periods that could affect desired plants
--------------	---

B. Design Methods

1. Initial Design Consideration and Preliminary Investigation. For new development sites, it is urged that consideration is given to how post-construction water quality will be addressed early in the design process. Bioretention practices are most effective when they are located in numerous, well distributed locations to be used for stormwater treatment as close as possible to the source of runoff. Distributed practices allow for the creation of a chain of smaller treatment practices, reducing the impact on downstream areas if a single practice should fail. Sites with fewer, larger practices are generally less effective at achieving pollutant and runoff reductions, as each practice has a larger amount of runoff to treat; and should practices fail, a greater proportion of runoff would be mismanaged. Redevelopment sites may have less flexibility, but smaller distributed practices are still preferable to a single, larger practice.

Before choosing to employ a bioretention practice, review the feasibility information included earlier in this section. If feasible, proceed with designing a bioretention practice, starting with a review of the initial design considerations listed in

Table C5-S4- 4, as well as the preliminary investigation information in Table C5-S4- 5.

Table C5-S4- 4: Initial design considerations

Limiting Factors	Determine the depth to bedrock or typical groundwater elevation. Verify with geotechnical explorations or other methods.
Watershed Concerns	Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.
Separation Distances	Ensure that room is available for installation, including any setback and/or separation requirements. Recommended setbacks are 25 feet from the foundation of a building; 5 feet from a property line; 50 feet from a private well; 20 feet from a geothermal well field; 100 feet from a municipal well.
Intermittent Flows	Bioretention cells are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, heavy irrigation, or other sources.
Local Requirements	What are the local requirements for water quality and quantity control?
Character of Runoff Generator	What is the land use that will generate runoff directed to the cell? What is the expected watershed area, and how much of that is expected to be impervious?
Pollutants	What pollutants are expected to be present in runoff?
Multiple Practices	Will the bioretention cell be used independently of other BMPs, or will it be installed along with other practices? If part of a series of practices, what portion of the treatment required will be dedicated to each practice?
Online or Offline	Will the practice be an online or offline configuration? (See Chapter 4 for more discussion of offline systems and design guidance for diversion structures and flow splitters).

Quality Control	What design storm is required to meet stormwater water quality management criteria?
Quantity Control	For an online system is the cell being used for quantity control (or attenuation / detention) of a portion of larger storm events?
Aesthetics and Site Plans	Bioretention cell locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.
Plant Materials	Native species are recommended that are tolerant of expected moisture conditions, as their deep root structures can help preserve percolation rates. Consider salt tolerance where its use in ice removal is expected.
Maintenance	Review a typical maintenance plan, and determine the parties responsible for carrying it out. Consider access paths for equipment required for maintenance. See Table C5-S4- 8.

The following table includes information required to complete the design procedure for a bioretention cell within this section. Determine the values for each variable as accurately as possible. Assumed values may need to be used in preliminary design, and then revised later as site design proceeds and more accurate values can be determined.

Table C5-S4- 5: Preliminary investigations

Properties of the Drainage Area Tributary to the Bioretention Cell	Determine the expected drainage area to be routed to the bioretention cell and the projected amount of impervious surfaces. It is recommended that the impervious area to each cell not exceed 2 acres. Multiple cells can be designed to treat runoff from larger areas. Surface properties required to determine time of concentration will be needed for final design (refer to Chapter 1, section 4).
Space Required	The required temporary ponding area will be approximately 3-7% of the tributary impervious area. Most of the ponding area must be level, so remember that additional space will be needed for slope grading to establish the overflow elevation and match surrounding grades.
Slope	Cells are easier to construct away from steep slopes, but special elements such as retaining walls can be included for sites with steep slopes. Care must be taken not to compact the soils within the bioretention area during installation of any structural features around the cell.
Minimum Head	Make sure that there is sufficient elevation difference to pond water as needed and drain the soil and aggregate layers through a subdrain and/or outlet works to a finished surface, swale, or storm sewer system.
Water Table	A separation distance of 2 feet is recommended between the bottom of the bioretention cell and expected high groundwater levels.
Existing Site Soils	No restrictions when modified soils are used. However, soils with higher infiltration rates can be used to promote infiltration and groundwater recharge, reducing post-development surface runoff volumes.

- 2. Typical Components of a Bioretention Cell.** Before proceeding with final design, it is important to understand the function and purpose of the elements that make up this type of practice. Table C5-S4- 6 provides a summary of bioretention cell components and their function.

Table C5-S4- 6: Bioretention cell design components

Inlet Structures	Stormwater may be routed to bioretention cells in many ways, such as sheet flow off hard surfaces, or as concentrated flow from curb openings, downspouts, and pipe outlets. Inlet structures may also include features that divert only a portion of stormwater runoff to the cell (known as an offline configuration). Level spreaders can be used to disperse concentrated flows to sheet flows reducing flow depths and velocities, enhancing pretreatment possibilities.
Pretreatment Area	These areas are used to reduce velocities and capture heavier sediment and debris. They are needed to reduce the potential of clogging the porous soils desired in the cell. Features such as grass filter strips and swales can remove sediment and debris through filtration. Mechanical treatment systems, sediment traps, and ditch checks can be used to pond water in areas where heavier sediment particles can settle out. If designed and functioning properly, all of these pretreatment practices will capture sediment and debris, so provisions for regular maintenance and removal of collected materials is required.
Temporary Ponding Area	Provides for temporary surface storage of the runoff before it infiltrates into the soil bed. Typically limited to a depth of 6-9 inches. Additional freeboard depth can be provided for larger storm events in online systems. The ponding area is intended to drain dry within 4-12 hours after typical storm events, and should never have standing water longer than 24 hours after very rare events.
Organic Mulch Layer	The mulch layer should consist of 3 inches of fine, shredded hardwood mulch. This layer protects the soil bed from erosion, retains moisture in the plant root zone, provides a medium for biological growth and decomposition of organic matter, provides some filtration of larger sediment particles, and controls weeds.
Modified Soil Layer	The modified soil layer filters stormwater. Typically this layer is 18-30 inches deep and consists of a uniform mixture of 75-90% washed concrete sand, 0-10% approved organic material, 0-25% soil with a soil texture that includes A-horizon characteristics and meets specifications.
Choker Aggregate Layer	The choker layer separates the modified soil layer and aggregate subbase and prevents the modified soil from entering into the aggregate subbase. The 2-3 inch layer consists of clean, durable ¾ inch diameter chip.
Stone Aggregate Subbase Layer	The aggregate layer at the bottom of the structure provides additional temporary storage capacity for the captured runoff after filtration. The layer consists of an open-graded, clean, durable aggregate of 1-2 inches diameter with a porosity of 35-40%.
Subdrain	Perforated pipe underdrains are recommended. They provide the outlet for filtered water in areas with soils with poor percolation rates and act as a secondary outlet where soil percolation rates are better.
Outlet Structures	To avoid excessive ponding depths and drawdown times, outlet controls are needed to manage runoff from larger storm events. An overflow spillway set above the ponding depth can release flows in a non-erosive manner (velocities less than 3 feet per second). For online configurations, riser pipes, intakes, or weirs may be used to release runoff from larger storms more rapidly than it could infiltrate through the soil layers.
Hydrologic Design	The primary goal of the practice is to capture and treat runoff from the WQv event. For offline configurations, the majority of flows larger than those generated by the WQv will bypass the bioretention cell. For online configurations, where all runoff passes through the cell, some level of “detention” or temporary storage of larger flows may be possible, with caution to avoid excessive storage depths or drawdown periods that could compact the soil layers within the bioretention cell.

3. Alternative Soil Mixtures for Bioretention Cells

The water quality treatment needs and vegetation designs for bioretention cells vary from application to application, so the bioretention cell “modified soil” media recipe can be tailored to these specific needs. Varying the proportions of sand, organic material (compost or other source of organic matter), topsoil, and other constituents is permissible within specific ranges, based on the design needs. The baseline soil recipe for bioretention cells in Iowa is considered to be 75-90% washed concrete sand, 0-25% topsoil, and 0-10% compost (assuming the compost is about 50% organic matter, by weight). A few example reasons for alternative mixtures include:

- Receiving water bodies that are sensitive to nutrients, such as eutrophic lakes and ponds, as well as drainage areas with high nutrient loads (regularly fertilized landscapes, areas frequented by waterfowl or dogs, etc.) do not require soil media with more nutrients than good quality topsoil (compost is not needed in these cases).
- Bioretention cells that include woody vegetation (trees and shrubs), or cool season turf grass (from seed or sod) typically require less sand and more topsoil for moisture retention.
- Drainage areas with potential for metals and organic pollutants can benefit from increased compost and / or topsoil to enhance sorption and cationic exchange capacity.
- Designs for specific, targeted water treatment purposes may require specific engineered mixes, or even “Performance Enhancing Materials” (wood chips, iron filings, gypsum chips, activated carbon, etc.) to treat known source loads, or protect downstream water bodies impaired by specific pollutants.
- Typical bioretention cells include one single amended soil mixture, however there are cases where the soil media may benefit from different layers, each with varying composition for various purposes.

Standard bioretention cell modified soil media consists of (all percentages are by volume unless noted):

Washed Concrete Sand

- a. Formal Specification: Provide clean sand complying with IDOT 4110, Gradation No.1
- b. Sand for bioretention soil media should be “washed concrete sand” (ASTM Specification C33 or Iowa DOT Section 4110, Gradation #1), also referred to as “manufactured sand”, as long as it meets the specification, is washed of fines, and has not been contaminated after production.
- c. Sand is the media component that provides porosity for drainage, physical filtration of solids, and surface area for microbial growth (biological treatment)
- d. Sand should never be less than 50% of the mix, nor greater than 90% of the mix

Topsoil

- a. Formal Specification: Provide soil taken from the top 6 inches of the A-horizon, which has a dark brown to black color, a granular structure and clay content less than 25% verified with a “ribbon test” that yields no more than 1”.
- b. For best results, topsoil should contain at least 3% organic matter (% - Dry Weight; ASTM D2974-14).
- c. Clay content can be field estimated with the “ribbon test” - rolling a sample between the hands, then pressing out a ribbon (about 1/8” thick) between thumb and forefinger. If the ribbon can extend greater than 1” without breaking off, the clay content is too high.
- d. Topsoil should typically be 0 to 25% of the mix, but never more than 40% or performance may be dramatically reduced and replacement of the media may be required due to rapid fouling. If the clay content of the topsoil is greater than 10% the topsoil content should be reduced or amended to reduce the effect of the clay content, otherwise the soil infiltration rate may be reduced, possibly to the point of non-functioning. Bioretention cells with topsoil content greater than 15% should definitely not use topsoil with greater than 10% clay.
- e. Topsoil can be economically and rapidly tested by soil labs for basic composition, organic matter content, etc. Testing at least one or two samples per donor site is highly recommended. Precise soil amendments and therefore high performing bioretention cells can be designed with this basic knowledge.

Organic Material

- a. It’s important to disambiguate between “organic material” and “organic matter”, for the purposes herein:
 - i. Organic “material” is any plant-derived soil media amendment such as compost, shredded bark, pine needles, leaf litter, wood chips, etc.
 - ii. Organic “matter” is the scientific term for the fraction of the above products (by dry weight) that is not

“ash” after combustion (as determined by ASTM D2974-14). For example, typical compost is 40% to 60% organic matter, the rest is ash. Technically organic matter combusts to carbon dioxide and water at 550 degrees C, leaving behind only ash - the mineral component in organic material.

- b. The type of organic material specified for the soil media has a dramatic effect on the performance and specific water treatment properties of the overall cell, for example:
 - i. Bioretention cells intended for the reduction of nutrients (Nitrogen and Phosphorus) would perform best with an Internal Water Storage subdrain configuration, and woodchips or shredded bark instead of compost for the organic material (especially in the saturated IWS zone). The woody materials provide a carbon source for microbial denitrification, and they are much less likely to leach nutrients into drainage effluent than compost. Consult Iowa NRCS design guidelines on woodchip bioreactors for more information.
 - ii. Turfgrass bioretention cells require more nutrients and moisture holding capacity high up in the soil strata because of the shallow roots, so high-quality topsoil and compost (at least near the top of the soil) are important. Lower soil strata could have a higher sand fraction and no compost, which would reduce nutrient export.
- c. Compost
 - i. Formal Specification: Comply with SUDAS Section 9010, Part 2.07C
 - ii. All compost proposed for use in bioretention cells should be analyzed by a certified soil or compost testing lab; documentation should be submitted (dated within the previous 1 year) by the facility producing the material. The material must be certified as:
 1. “Stable” (CO₂ respiration) (TMECC 05.05A & TMECC 05.08)
 2. C:N ratio between 10:1 & 25:1 (TMECC 05.02A)
 3. “Mature” (Ammonia / Nitrate / Ph balance)
 4. “Free of harmful bacteria” (40 CFR 503 Class A Compost)
 5. “Free of harmful metals” (EPA 503 Metal Limits)
 6. “Capable of supporting vigorous plant growth” (cucumber seedling bioassay)
 7. Organic matter should be 40% to 60% of the compost (% - Dry Weight; ASTM D2974-14), otherwise adjust overall soil mixture ratios to meet this range

Is compost necessary?

Recent studies have shown that urban runoff - even from dense, highly impervious areas - typically has sufficient nutrients to sustain healthy growth of established plants, and that the potting soil that comes with potted plants (not necessarily true with small “plugs”) typically has enough nutrients to support them through establishment. Therefore, as long as good quality topsoil is included (100% sand is not acceptable for bioretention cells), the amended soil media in bioretention cells does not need to contain compost for sustaining most native, herbaceous vegetation. Of course, some vegetation may have specific needs so careful selection is important, however as a water treatment practice intended in part to remove nutrients from runoff, it is counterproductive to implement media with more embedded nutrients than is necessary.

Table C5-S4-7. Example Alternative Bioretention Cell Soil Mixes (percentages are volume based)

Application	Sand Content	Topsoil Content	Compost Content
Typical Bioretention Cells in Iowa	75-90%	0-25%	0-10%
Cells with Trees or Shrubs	50%	40%	10%
Turfgrass Cells	50%	40%	10%
High Nutrient Drainage Areas or Nutrient Sensitive Receiving Waters	85%	15%	0%

References

- Osman, Manal, et al 2019. A Review of Nitrogen Removal for Urban Stormwater Runoff in Bioretention Systems. Sustainability, November 2019, 5415.
- Hunt, William, et al 2012. Hydrologic and Water Quality Goals through Targeted Bioretention Design. Journal of Environmental Engineering, June 2012. 138, 698-707.

4. Bioretention Cell Design Option - Internal Water Storage

Internal Water Storage (“IWS”) is a design variation for bioretention cells that promotes enhanced exfiltration of stormwater into the earth below the cell, and also significantly increases the nitrogen removal function of the bioretention cell. This section will present an overview of why IWS is beneficial, how it works, a variety of options to implement IWS into the cell design, some ancillary design considerations, and recommended sizing and cell design parameters.

Background

The overall purpose of bioretention cells is to mitigate the negative consequences of stormwater runoff by increasing water quality and decreasing runoff volume and peak flow rate. Volume and rate decreases are achieved by promoting evapotranspiration and exfiltration (a runoff volume reduction) and by slowing runoff down via temporary detention and filtration (a runoff rate reduction). Water quality improvements are realized by settling and filtering sediment, sequestering heavy metals, and reducing pathogens and nutrients (primarily nitrogen and phosphorus) by a variety of plant- and soil-based mechanisms. The “benefits” discussed herein are determined by comparing the raw runoff water entering the cell versus the “drainage” water leaving the cell through the subdrains and returning to surface water systems, typically through a storm sewer system or by direct daylighting of the subdrain outlet (see Figure C5-S4-4). Any water and dissolved pollutants “lost” from this primary pathway by evapotranspiration and exfiltration is viewed as an additional benefit for the current purposes.

Iowa-based hydrology terms:

Infiltration - water from surface runoff that soaks into the surface of the soil or a stormwater Best Management Practice

Exfiltration (aka recharge) - water that moves from the stormwater BMP into the subsoil below it

Drainage (aka filtrate or effluent) - filtered water that leaves the practice and passes out through the subdrain and returns to surface waterways

Unfortunately, the nutrient reduction performance of bioretention cells is widely variable depending on a number of factors, and in some cases the nutrient concentration in the water leaving the cell through the subdrain can be higher than in the raw stormwater entering the cell. Important first steps for preventing this inadvertent increase in nutrient export include limiting the amount of compost in the amended soil mix to 10% or less (by volume; ~5% or less total organic matter), and using good quality compost and topsoil. However, recent studies have shown that nitrogen can sometimes still pass through, or even increase unless additional “performance enhancing” design upgrades are implemented. The simplest and most successful performance enhancement currently known for stormwater Best Management Practices that include subdrains (bioretention cells, enhanced rain gardens, etc.) is IWS.

Similar to natural soil, nitrogen exists within bioretention cell media in a variety of forms including nitrate and ammonium (the common “fertilizer” forms), nitrogen bound within organic compounds (some dissolved and some in organic solids), a variety of less common forms, and also the harmless gaseous form (N₂), which is about 78% of typical air. The nitrate, ammonium, and dissolved organic forms are very soluble in water, so they are easily exported from the cell when water moves through the media and out the subdrain. Without further intentional treatment, much of that nitrogen ends up contributing to harmful ecological problems in downstream surface waters such as algae blooms, eutrophication and hypoxia. Nitrogen is currently the primary focus for nutrient control in Iowa, and is the main driver for the implementation of IWS.

How IWS Works

The current best practice for removing nitrogen in its many forms from stormwater runoff is the leveraging of anaerobic microbes that “breathe” the oxidized forms of nitrogen when oxygen isn’t available. This is the same

concept that's employed in wastewater treatment plants and also agricultural bioreactors that are added to drainage tile systems. As the microbes metabolically process the nitrogen, they add electrons to each atom, which returns it to its natural, harmless N₂ gas state; this process is called denitrification. In order to create the oxygen-deprived state necessary for microbial denitrification, the soil containing the microbes must be saturated under water for several hours. The saturated zone must also contain sufficient carbon-based organic matter for the microbes to feed on, and the water needs to stay in the zone long enough to deplete the oxygen, then denitrify the nitrogen, before passing out of the cell by exfiltration or through the subdrains.

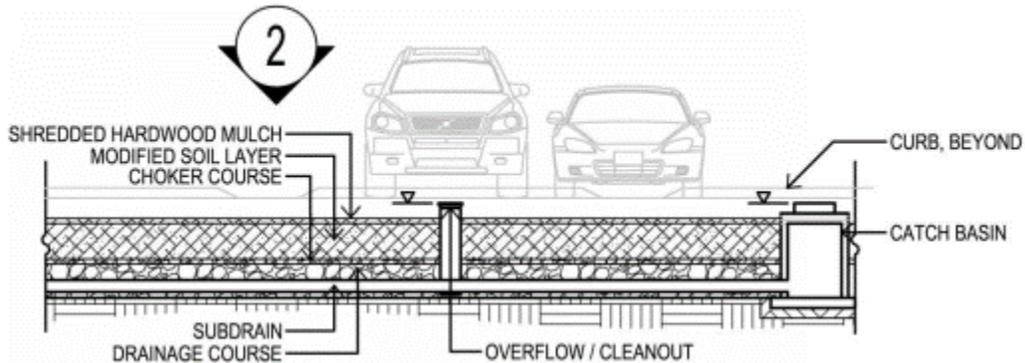


Figure C5-S4-4. Traditional bioretention cell without IWS

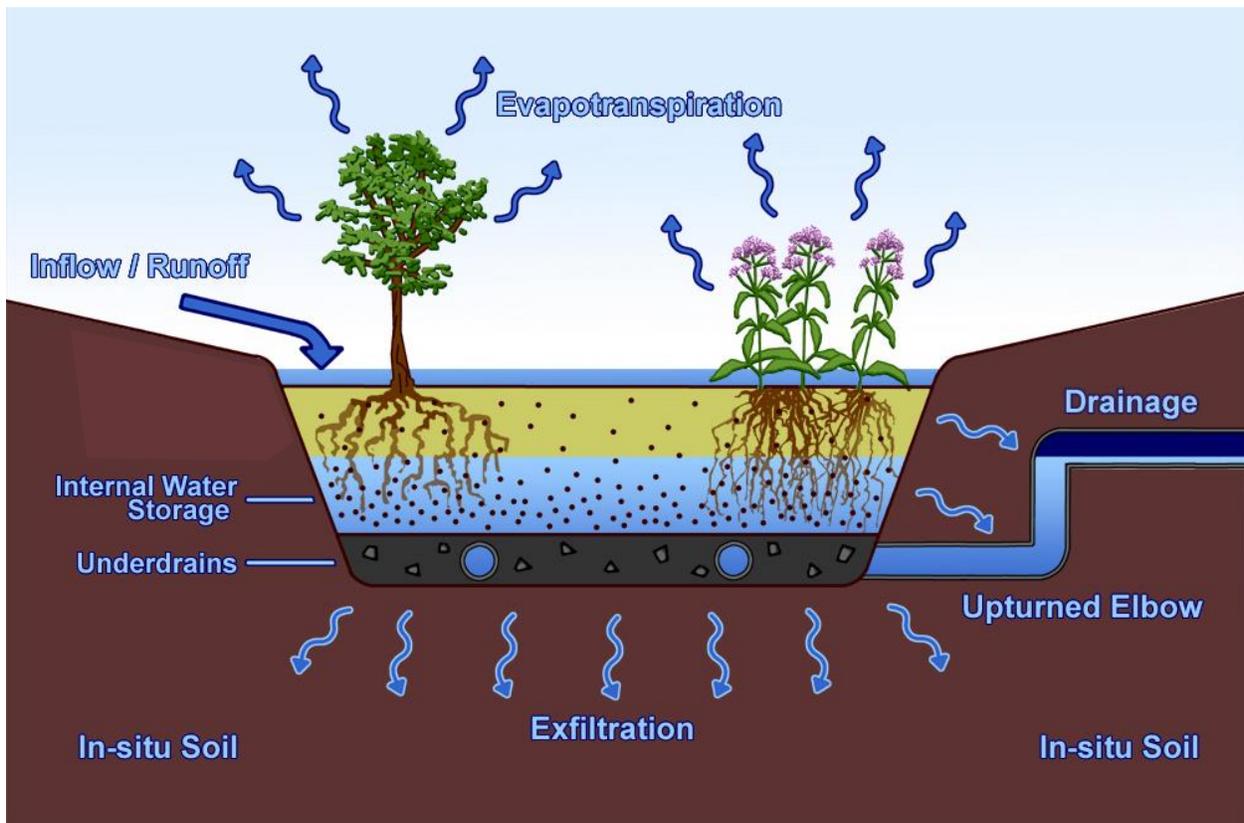


Figure C5-S4-5. A typical bioretention cell with IWS (Image Courtesy of Shawn Kennedy, NCSU)

Internal Water Storage systems provide the conditions necessary for denitrification by creating a pool of stored water in the lower layers of the cell (see Figure C5-S4-5). There are a variety of plumbing designs available to designers (see Design Alternatives below), but they all have some manner of controlling the level of water in the cell prior to discharge. Studies have shown that if the water is held in the IWS zone for six to eight hours, then denitrification is maximized, yielding the optimum “Hydraulic Retention Time” (HRT) for design.

IWS also provides additional benefits such as stormwater cooling and increased exfiltration. IWS promotes increased

exfiltration of filtered water into the soil below the cell because the pooled water has additional time to soak in, and the pool creates hydrostatic “head pressure” which drives the water into the soil faster than without IWS. The rate of exfiltration is controlled by the properties of the existing natural soils below the cell, the sum of which is called “permeability” (also described as “percolation” or “perc rate”). Interestingly, studies have shown that the increase in exfiltration with optimized IWS systems is consistently around 20%, regardless of the underlying soil type. Studies have also shown that IWS enhances the cooling of stormwater runoff. For watersheds sensitive to warm water runoff (such as trout streams or small pond tributaries) IWS can be implemented to help cool stormwater because of the increased underground detention time.

In summary, Internal Water Storage is a highly recommended design option that should be implemented in bioretention cells to improve nitrogen removal and exfiltration. A variety of research studies have been published over the last 15 years that document the performance of IWS. The results vary somewhat, due mostly to differences in configuration, overall cell design, and watershed setting, but the findings are consistent: when IWS features are implemented the reduction of nitrogen, and sometimes phosphorus, in the water leaving the cell via subdrains is dramatically improved. In most studies total nitrogen concentration reductions of over 60% were common, and some were well over 90%.

IWS System Design

There are two parameters to consider when designing an Internal Water Storage system for a bioretention cell: Hydraulic Retention Time (“HRT”), and IWS Depth (“ D_{IWS} ”). The IWS Depth is the depth of saturated soil media and underlying aggregate, measured from the bottom of the cell excavation up to the elevation of the subdrain flowline at the elevated outlet (the controlling weir elevation) (see Figure C5-S4-5). The HRT is the volume of the pore space within the IWS zone (see IWS Equation 1 and 2 below) divided by the theoretical subdrain flow rate (“ Q ” as determined in Step 10 of the Bioretention Cell Design Procedure below). For the initial design sizing the average subdrain flow rate during the Water Quality event (1.25-inch rain event over 24 hours) is typically used. However, the actual expected flow rate through the subdrain system should be checked during final design calculations, and the final design should be adjusted to maintain proper HRT for the design event. If the subdrain release rate is too fast based on the diameter of pipe, consider adding an orifice restrictor (a plug with a hole) on the elevated pipe outlet, instead of using smaller diameter pipe. For ease of cleanout, subdrain diameters such as 6” and 8” are easier to maintain than 4” or smaller pipe.

Selecting a System Depth - The depth of the soil media layer may need to be adjusted in an IWS system in order to accommodate the proper Hydraulic Retention Time in the lower saturated zone, and also maintain sufficient non-saturated soil depth at the top of the cell for the type of vegetation that will be used. Most plants that are used in bioretention require oxygen in the soil to grow and thrive. Some vegetation species are more sensitive to the “high water table” conditions that IWS systems replicate, whereas some species will actually benefit from having a higher water table and therefore more soil moisture available to shallow roots (e.g. cells with turfgrass). In order to provide adequate non-saturated depth for the vegetation, the total modified soil media layer may need to be deeper than in cells without IWS.

A minimum soil media depth of three feet is a typical starting point for design, however it may be more or less. Studies have shown that dissolved phosphorus reduction in bioretention cells is optimized when the cell includes 18 to 24 inches of non-saturated media (above the IWS zone), so a preferred starting point for the soil depth of the non-saturated zone above the top of the IWS zone is about 15 to 21 inches (assuming 3” of mulch on top of the soil). Therefore 18 inches is the minimum recommended non-saturated depth above the IWS zone. The remaining depth of the cell media layers below the elevated subdrain outlet (saturated soil media, choker aggregate, and storage aggregate) constitute the IWS Depth.

Calculating IWS Depth and HRT - Because HRT is dependent on the IWS Depth, an initial value for IWS Depth should be selected, then HRT should be calculated using the selected depth. This process should be iterated with varying IWS Depth until HRT is at least 6 hours, 8 hours is preferred, and an HRT of 9 hours or more is unnecessarily high. Also consider that full drawdown of the ponded IWS volume is preferred to occur within 48 hours. Full drawdown is preferred to occur by exfiltration, which is controlled by the underlying subsoil properties, however an appropriately-

sized weep hole could be added at the lowest subdrain flowline to augment the drawdown in especially tight soils if full drawdown is desired. Hydraulic modeling software should be used to model the system performance if a weep hole is implemented, to ensure that the combined outflow and exfiltration do not reduce HRT below the 6- to 8-hour standards.

Step 1: IWS Equation 1

$$V_{IWS} = D_{IWS} \times A_f \times 0.35$$

Where:

V_{IWS} = Volume of the pore space in the IWS zone (ft³)

D_{IWS} = Depth of the IWS Zone, from the bottom of the cell to the elevated outlet flowline (ft)

A_f = Area of the cell footprint, as determined in Step 8 of the Bioretention Cell Design Procedure (ft²). If the area of the actual footprint as designed is greater than A_f (which is the minimum required area), use the actual area.

0.35 = The soil porosity of typical bioretention soil media

Step 2: IWS Equation 2

$$HRT = V_{IWS} \div (Q \times 3600 \text{ sec/hr})$$

Where:

HRT = Hydraulic Retention Time (hrs)

V_{IWS} = Value from Equation 1 (ft³)

Q = Design Subdrain Flow Rate, as determined in Step 10 of the Bioretention Cell Design Procedure (ft³/s)

Design Example

The following Internal Water Storage design example is based on the full Bioretention Cell Design Example at the end of this section. The values for area of the cell (A_f) and design subdrain flow rate (Q) are copied from that example.

Given:

$A_f = 3,700 \text{ ft}^2$ (Area of the cell footprint, as determined in Step 8 of the Bioretention Cell Design Example)

$Q = 0.09 \text{ ft}^3/\text{s}$ (Design Subdrain Flow Rate, as determined in Step 10 of the Bioretention Cell Design Example)

Modified Soil Depth: The example problem uses a soil depth of 18 inches, however note that 18 inches is the recommended depth of non-saturated soil above the IWS zone, so using 18 inches of soil would not allow any carbon source to be in the saturated zone. For this example, let's start with 30 inches for a soil thickness and set 18 inches as the non-saturated depth, leaving 12 inches for the saturated soil thickness.

Rock Depth: The example problem uses a total rock thickness of 12 inches (storage rock and choker aggregate)

Therefore, $D_{IWS} = 2 \text{ ft}$ (Total depth of the IWS Zone, including 1 foot of rock and 1 foot of soil)

Step 1: IWS Equation 1

$$V_{IWS} = D_{IWS} \times A_f \times 0.35$$

$$V_{IWS} = 2 \text{ ft} \times 3,700 \text{ ft}^2 \times 0.35$$

$$V_{IWS} = 2,590 \text{ ft}^3$$

Step 2: IWS Equation 2

$$HRT = V_{IWS} \div (Q \times 3600 \text{ sec/hr})$$

$$HRT = 2,590 \text{ ft}^3 \div (0.09 \text{ ft}^3/\text{s} \times 3600 \text{ sec/hr})$$

$$HRT = 7.99 \text{ hours}$$

Because the HRT is about 8 hours this design will work well (minimum is 6 hrs, preferred is 8 hrs, 9 is unnecessary)

Selecting a Carbon Source

Microbial denitrification requires a significant carbon source within the IWS zone for long term performance. There are multiple potential carbon sources, but the typical sources are organic matter within the soil media and organic carbon compounds shed by plant roots. The organic matter within the soil is the primary source and can be provided by a variety of materials including compost, wood chips, biochar, shredded bark, pine needles, etc.

If the bioretention cell is designed to target nutrient reduction, compost is recommended to be eliminated from the soil media, or at least reduced to below 10% of the total soil mixture, by volume. As long as good quality topsoil is included in the soil media, compost is not actually necessary for establishing and maintaining most plants used in bioretention cells (specific plant needs vary and should be confirmed). However, if compost is eliminated the remaining soil component may not have enough biologically available organic carbon to sustain denitrification for the life of the cell. Wood chips, shredded bark, or pine needles are good low-nutrient carbon sources to add to the cell media, especially in the IWS zone.

Stratified Soil Layers

The competing desire to include compost and / or topsoil at the top of the cell for plant health, yet replace it with a low-nutrient carbon source at the bottom of the cell for denitrification introduces the possibility of varying the composition of the modified soil in layers, based on functional factors (e.g. rooting zone at the top, non-saturated zone, saturated zone at the bottom), see table C5-S4-8 below.

Designers may choose to use multiple soil media layers and vary the composition by depth for specific design functions. For example, a bioretention cell with IWS and traditional deep-rooted, wet tolerant, native vegetation may work well with a 36-inch modified soil media layer containing 80% sand, 15% topsoil, and 5% compost in the top 18 inches, and 85% sand, 15% wood chips in the bottom 18 inches. However, if the cell is to have turfgrass (which has shallow roots and high moisture and nutrient needs), then an alternative modified soil profile may be a better choice. In this case the top 12 inches could be 50% sand, 40% topsoil, and 10% compost, and the bottom 24 inches could be 85% sand and 15% wood chips. This is one example configuration that would meet the needs of the vegetation at the top of the cell, provide a low-nutrient carbon source for denitrification in the lower cell, save money on compost and topsoil, and perform better at nutrient reduction compared to a single mixture throughout the entire depth.

Table C5-S4-8. Example stratified soil options for optimizing plant health at the top of a cell and denitrification at the bottom

Strata Layer	Primary Function	Media Recommendation	Typical Thickness
Top - Root Zone	Plant health, filtration	Sand, Compost, Topsoil	6 to 18 inches ±
Intermediate Zone (optional)	Filtration, sorption	Sand, Topsoil	6 to 12 inches ±
Bottom - Saturated Zone	Denitrification	Sand, carbon source	IWS Depth (soil portion)

Cold Climate Consideration

In cases where there is increased risk of frost damage to the upturned piping it is recommended to install a small weep hole in the subdrain outlet. This is particularly important for northern locations, cells with shallower modified soil layers, or with the Upturned Elbow design variation (below) where the upturned portion is inside a storm structure. The weep hole should not be larger than necessary as the subdrain water is generally clear after initial

construction, and the hole should be included in drawdown calculations (as an orifice) to accurately reflect its impact on HRT.

IWS Design Variations

1. Upturned Elbow - This option includes a simple elbow or “T” fitting, to elevate the flowline of the subdrain within the outlet structure (see Figure C5-S4-6). Note that the subdrain is perforated but the upturned portion is solid.

Advantages - It's simple and inexpensive, doesn't require special parts, knowledge, or ongoing management. May be a viable retrofit option for existing cells.

Disadvantages - The internal plumbing may be too bulky in smaller outlet structures (e.g. 24 inch or smaller diameter structures), which may present installation, debris catchment, or maintenance issues.

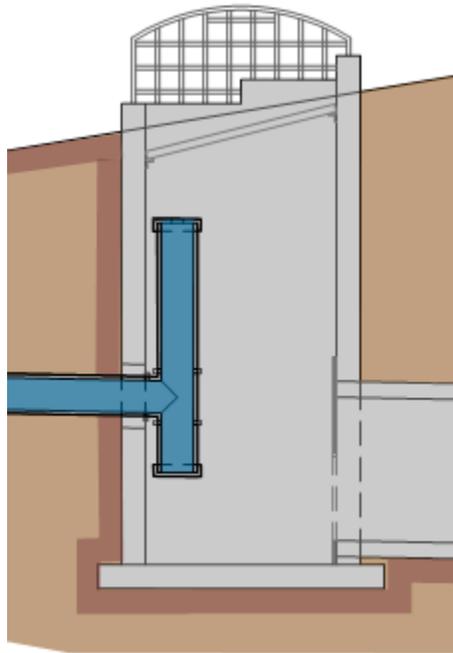


Figure C5-S4-6. Internal Water Storage subdrain with internal upturned elbow (note - the bottom of the “T” is a removable threaded plug (for maintenance), the top is open and determines the effective weir height (IWS Depth))

2. Inline Wye for IWS with Cleanout - This option is similar to above but includes a wye fitting, outside of the structure, to elevate the flowline of the primary subdrain outlet (the upper branch) and also provide a normally-closed extension of the subdrain flowline (the lower branch) (see Figure C5-S4-7a and b). The lower outlet is fitted with a threaded PVC plug, which is removable for cleaning the subdrain (jetting or vacuuming from the bottom end). Another design variant is to install a PVC gate valve on the lower outlet instead of a threaded plug, which could circumvent access issues because the valve actuator can be extended such that confined entry is not required.

Advantages - Simple and fairly inexpensive, doesn't require special parts, knowledge, or ongoing management. Does not add obstructions to the inside of the primary outlet structure.

Disadvantages - Access is required to remove the plug, if subdrain maintenance is required. Note that some jurisdictions require a minimum six-foot diameter structure if entrance is intended, which may be much larger than needed for hydraulic purposes. The designer should consider how to safely access the plug for removal and reinstallation (or consider a gate valve option). IWS Depth can't be modified easily.

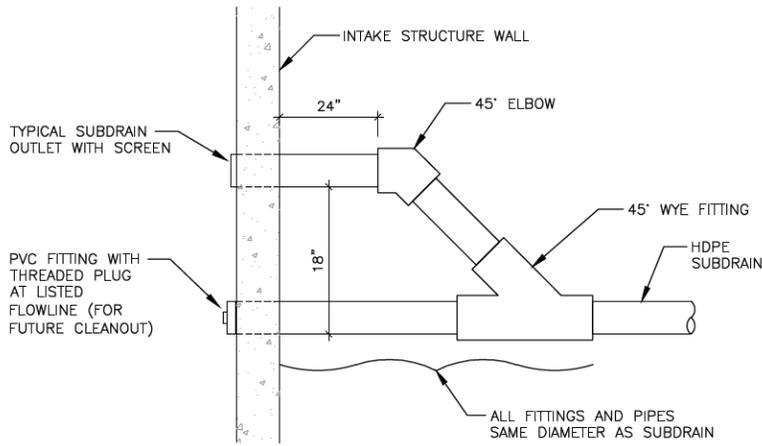


Figure C5-S4-7 A & B. Internal Water Storage subdrain with external wye for cleanout

3. Variable Water Level Control Structure (Manual - Stop Log Type) This option includes a special structure placed inline on the subdrain system. The structures (see Figures C5-S4-8 and C5-S4-9) typically have an inlet and outlet pipe, and the water level is controlled by the installation of multiple “stop-logs” or “flash-boards”, which are horizontal members that slide into a waterproof channel inside the structure. The number and size of stop-logs installed determines the effective weir height, and therefore the ponding elevation in the uphill basin, and stop-logs can be added or removed as needed. Several different manufacturers offer a variety of types and sizes of structures. Note that the pipe leaving the structure should be non-perforated to prevent it acting as an uncontrolled subdrain.

Advantages - This option provides an adjustable water level for those interested in fine tuning performance. The easily accessible wet well on the upstream side of the stop-logs provides a handy monitoring and sampling point. The stop-logs can typically be drilled to include weep holes. The water level control structure can also serve as an intake with a grated top. Stop logs can be easily removed to dewater the system for maintenance.

Disadvantages - Higher cost than just simple plumbing options. Some facility managers may not want a variable option, and want the elevation to be fixed for simplicity. Smaller structures may not provide enough space for access if outflow monitoring equipment is desired.

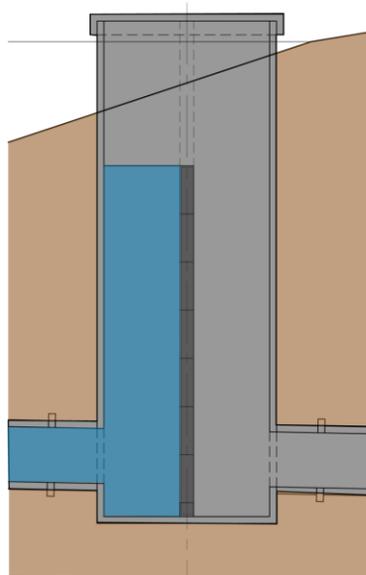


Figure C5-S4-8. Inline water level control structure with adjustable stoplogs



Figure C5-S4-9. Plastic catch basin with internal water level control stoplogs (see channel for stop logs inside structure)

4. Variable Water Level Control Structure (Automated Type) - This option includes a stop-log structure similar to above, but the weir elevation is set and adjusted by a mechanized system powered by a battery and integral solar panel. The system can also include a variety of sensors, programmable controllers, and cellular data connectivity for remote operation and monitoring.

Advantages - Besides the obvious benefits of remote operation and endless potential for “smart technology”, this alternative has a couple important features that could benefit an integrated IWS System. The system can be operated or programmed to release water at specific time intervals (to precisely control HRT), or at the onset of subsequent storms to make volume available within the IWS zone for new runoff.

Disadvantages - Significant cost and technical knowledge required to set up, operate, and maintain the system are the primary disadvantages. Potential for system malfunction during inclement weather (tornadoes, lightning strikes).

5. Storm Structure Weir Wall - This simple option includes a basic weir wall installed in the storm sewer structure (manhole or catch basin) that the bioretention cell subdrain terminates into. The weir could be permanent or temporarily fastened into place, and defines the ponding elevation within the adjacent cell.

Advantages - This option is relatively inexpensive (assuming the structure was already necessary), and can be easily customized by the designer. Weep holes and maintenance / monitoring access could be accommodated into the design. The option could be integrated into the primary overflow structure for the bioretention cell if the structure is large enough.

Disadvantages - Smaller structures may be difficult to access for subdrain cleaning once the weir is installed. Concrete weir walls would be difficult to modify if desired.

References and Additional Information

- Brown, RA and WF Hunt. 2009. “Effects of media depth on bioretention performance...” Proceedings, 2009 World Environmental and Water Resources Congress. Kansas City, MO, EWRI and ASCE
- Davis, AP, WF Hunt, RG Traver, and ME Clar. 2009. Bioretention Technology: An Overview of Current Practice and Future Needs. *Journal of Environmental Engineering*, 135(3): 109-117. doi:10.1061/(ASCE)0733-9372(2009)135:3(109)
- Davis, A, R Winston, B Seipp, T Schuyler. 2016. “Other Perspectives on Research on LID Performance Enhancement.” Chesapeake Stormwater Network. 8 December 2016. Webcast.
- Hodgins, B and B Seipp. 2018. Bioretention System Design Specifications (Issue Paper). Center for Watershed Protection, Inc., Ellicott City, Maryland.
- Webinar - Chesapeake Stormwater Network - Other Perspectives on Research on LID Performance Enhancement: <https://epawebconferencing.acms.com>
- Ryan Winston, PhD, Ohio State University
- Passepport, E, WF Hunt, DE Line, RA Smith, and RA Brown. 2009. Field Study of the Ability of Two Grassed Bioretention Cells to Reduce Stormwater Runoff Pollution. *Journal of Irrigation and Drainage Engineering*, 135 (4): 505-510.

5. **Bioretention Cell Sizing and Design Calculations.** The following design procedure, assumes that the designer has completed preliminary investigations, and understands the design components of a bioretention cell, as outlined in
6. Table C5-S4- 5 through Table C5-S4- . It is recommended that these calculations be completed as early as possible in the design process, so that adequate room is reserved for stormwater management as site design development continues. Calculations can be adjusted as final site design is completed. (Note: “!” = pay special attention)

Step 1: Compute the required WQv treatment volume

Refer to: Chapter 3, section 6 for additional details on Small Storm Hydrology.

Use the following information:

(DA) = Drainage area to be treated, in acres

(I) = Impervious cover of drainage area, in %

(P) = WQ event rainfall depth, in inches (recommend using 1.25” for Iowa)

Step 1a: Compute $(R_v) = 0.05 + 0.009(I)$

i.e. 75% impervious => (I) = 75

Step 1b: Compute $WQv = (R_v) \times (P) \times (DA) \times 43,560 \text{ SF/ac} \times (1 \text{ ft}/12\text{in})$

*WQv is calculated in **cubic feet***

Step 2: Compute the peak runoff rates for other key rainfall events:

Refer to: Chapter 3, section 1 - General Information for Stormwater Hydrology

Chapter 3, section 2 - Rainfall and Runoff Analysis

Chapter 3, section 3 - Time of Concentration

Chapter 3, section 5 - NRCS TR-55 Methodology

Chapter 3, section 7 - Runoff Hydrograph Determination

The peak rates of flow and volumes of runoff will need to be determined for the following events:

Use method outlined in Chapter 3, section 6, C, to compute the peak rate of flow (in cubic feet per second) and volume of stormwater runoff (in cubic feet) for the Channel Protection Volume (Cpv).

Use methods such as the NRCS TR-20, TR-55 (Chapter 3, section 7) or other acceptable methods to generate hydrographs to determine peak rates of flow (in cubic feet per second) and runoff volumes (in cubic feet) for the following events:

Overbank Flood Protection Volume Requirements (Q_p); Chapter 2, section 1, F

2-year (50% annual recurrence or AR), 5-year (20% AR)

10-year (10% AR) - only if applicable to local storm sewer design

Extreme Flood Volume Requirements (Q_r); Chapter 2, section 1, F

10-year (10% AR) - if not applicable to local storm sewer design

25-year (4% AR), 50-year (2% AR), 100-year (1% AR)

Note: The annual recurrence (AR) is the likelihood of a certain rainfall event of a given depth and duration occurring once during any given calendar year.

Step 3: Identify if the bioretention system is intended to be an online or offline system.

- If planning for an online system, there is no need to design a flow diversion structure; proceed to Step 4.
- If planning for an offline system, a diversion weir, flow splitter, or other practice needs to be designed to route

flows from the WQ event to the bioretention cell, while allowing most of the flows from larger events to bypass the system (via parallel storm sewer system or other conveyance). Refer to Chapter 6, section 1, F for additional design information. Include calculation details for the diversion structure with this design procedure.

Step 4: Select, Locate, and Size Pretreatment Practice(s).

Forebays, grass filter strips, grass swales, and mechanical separators are some of the options that can be used as pretreatment. Bioretention practices can fail if too much debris or sediment is allowed to enter the cell, reducing the ability of the modified soil layer to infiltrate stormwater. Pretreatment is needed to filter or capture larger sediment particles, trash, and debris before it can enter the ponding area. Collected materials will need to be removed over time, so consider how the facility is expected to be maintained when evaluating methods of pretreatment.

- For grass swales, refer to Chapter 9, section 2, E for general sizing requirements. The target flow velocity for water quality treatment is 1 fps during the WQv event. Chapter 9, section 2 includes methods on how to modify the value of “n” for Manning’s equation to evaluate shallow flow in grass swales.
- For filter strips, refer to Chapter 9, section 4, C, 4 for sizing requirements.
- Forebays should have a storage volume of 0.1 inches per impervious acre drained (Chapter 3, section 11). Sediment will need to be mechanically removed from the forebay over time, so a depth marker and durable, solid materials are recommended for the bottom (to be certain when excavation is complete). The volume of WQv to be used to size the ponding area of the bioretention cell can be reduced by the amount addressed in the pretreatment area(s) (typically no more than 10% of WQv).

Step 5: Review Entrance Designs

To reduce the potential for surface erosion or displacement of mulch and planting materials, it is recommended that flow velocities entering the ponding area should not exceed 3 feet per second (for all storm events reviewed). For online systems, the peak velocity of flow entering the cell during the largest Q_f event (1% AR) should be checked. Redesign the cross-section of the entrance as needed. Provide stabilization at pipe outlets and areas of rapid expansion as necessary (USDOT FHA HEC-14 is a recommended resource for energy dissipater design).

Step 6: Select Desired WQ Event Ponding Depth

A WQv ponding depth of 6-9 inches should be planned over the level bottom of the bioretention cell. The bioretention cell will need an overflow spillway, or staged outlet structure (set above the WQv ponding depth) to avoid excessive ponding during larger storms. More detail is included in *Step 11*.

Step 7: Design Cross-Sectional Elements

A 3 inch depth layer of fine, shredded hardwood mulch is recommended to prevent erosion, retain moisture for plants, and control weeds.

The modified soil layer should be 18-30 inches deep and consist of a uniform mixture of 75-90% washed concrete sand, 0-10% approved organic material, 0-25% soil with a soil texture that includes A-horizon characteristics and meets specifications.

- The greater depths of modified soil (24-30 inches) are usually considered when trees or shrubs are planned within the bioretention cell or extended filtration time is required to remove certain types of pollutants are determined to be necessary. This would be determined by a known pollutant source or watershed based removal goal.

The aggregate layer is recommended to be at least 12 inches deep. Material should be 1-2 inch clean aggregate. The aggregate layer should have a porosity of 35-40%.

- The depth of the aggregate layer can be increased to provide for additional storage, or to enhance infiltration to subsoil layers. However, it is desired that the aggregate layer should drain out within 48 hours after a storm event. Percolation rates of virgin subsoils or the capacity of the subdrain system may limit the depth of storage that can be provided below a subdrain outlet. For example, subsoils with percolation rates of 0.50 inch/hour may

be able to drain down 24 inches of water stored in the aggregate layer below the subdrain over the 48 hour drawdown period.

Step 8: Calculate the Recommended Footprint of WQ Ponding Area

The footprint area for temporary ponding of the WQv can be determined by the following equation:

$$A_f = \frac{WQv \times d_f}{[k(h_f + d_f)t_f]}$$

Solve for (A_f) = Required ponding area to treat WQv, in square feet

Where:

WQv = Water Quality Volume, in cubic feet (from *Step 1*)

d_f = filter bed layer depth, in feet (from *Step 7*, includes mulch, soil and aggregate)

h_f = average WQv ponding depth, in feet (value from *Step 6*, divided by 2)

t_f = desired time to drain modified soil layer, in days (recommend to use 1 day)

k = coefficient of permeability, in feet/day

- If the modified soil mix described in *Step 7* is used, use a value of 2 feet/day.
- After solving for the required ponded area, check to see if it falls in the range of 3-7% of the impervious area that drains to it.
- If existing soils have permeability rates of greater than 1 inch/hour, and the cell can be constructed in a manner to prevent compaction of such soils, the modified soil layer may not be needed. In this case, the permeability rate of site soils can be used for the value of (k). However, this is usually the case only for Hydrologic Group A soils and designers are cautioned to not over-estimate the permeability of existing soils.

Step 9: Design Surface Geometry of WQv Ponding Area

The bottom of the ponding area should be level, typically ranging from 10-30 feet in width. The cell should typically be at least two times longer than it is wide, as measured along the direction of flow (longer flow paths through the system increase filtration and percolation). Length to width ratios may not be applicable when runoff enters the cell along the side via sheet flow through a pretreatment vegetative strip, or if multiple concentrated entry points are used to distribute flow entry across the cell. [For concentrated inflow points, refer back to *Steps 4* and *5* to provide proper pretreatment at entry points and to reduce the potential of local erosion within the ponding area.] Non-uniform shapes fitted into the contours of the finished landscape may be more aesthetically pleasing, where possible.

- Minimum widths are established to ensure that side slopes don't encroach into the level bottom. Minimum widths do not need to apply near the extreme ends of the ponding area. Maximum widths are required to allow the cell to be constructed from the edges (no heavy equipment placed on excavated subsoils), and a true level bottom is maintained. Cells that are too large may be not be truly level, leading to low points where runoff collects, minimizing the real area dedicated to infiltration.
- If you cannot reach the required ponding area (A_f) from *Step 8* using the dimensions above, it is recommended to use multiple bioretention cells or use other water quality BMPs to treat the remaining volume. Bioretention cells can be used in series or parallel.

Grades around the perimeter of the cell are recommended to be 6:1 or flatter; however slopes may be steeped to 3:1 where space is limited. Review the need for adequate sediment and erosion controls on steeper slopes to prevent side slope erosion into the modified soil layer (turf reinforcement mats, wattles, or sod are examples of practices that could be employed for surface stabilization).

- After preparing a preliminary grading plan for the bioretention area, double check to make sure that the area

ponded to the desired depth is greater than or equal to (A_f).

Step 10: Subdrain System Design

For a bioretention cell, the subdrain system is needed to drain the aggregate layer over a 24 hour period. The design flow rate can be determined from the following equation:

$$Q = kA_f \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \left(\frac{1 \text{ hour}}{3,600 \text{ sec}} \right)$$

Solve for (Q) = Average subdrain flow rate (in cubic feet per second)

Where:

A_f = Required ponding area to treat WQv, in square feet (from Step 8)

k = coefficient of permeability, in feet/day (from Step 8, based on modified soil - minimum k)

After solving for Q, use typical engineering methods to size pipe diameter.

- Subdrain materials should comply with requirements for Type 1 Subdrains under SUDAS Specifications Section 4040. A minimum size of 8 inches is recommended for cleaning and inspection.
- The length of pipe should be determined, so that the area within 1 foot either side of the subdrain is at least 10% of the required ponding area (A_f). (i.e. A cell with a ponding area of 1,000 SF would need $(1,000 \text{ SF}) \times 10\% / (1 \text{ feet} \times 2) = 50$ feet of subdrain.)
- Subdrains should be installed at least 3 inches above the bottom of the aggregate layer. Note that the portion of the aggregate layer below the invert of the subdrain can only be drained through infiltration into the native soils below; refer to notes within Step 7.

Step 11: Staged Outlet Design for Online Systems

Offline systems may not need a staged outlet structure, as flows to the bioretention cell are limited at the inlet of the system. Review the rest of this step, and then proceed to Step 12 if warranted.

Online systems will receive flows from larger storms, which will pond water to depths greater than those selected in Step 6. Without other means of release, all water diverted to the bioretention cell would need to filter through the soil and aggregate layers. To prevent excessive ponding depths and long drawdown periods, a staged outlet is necessary to release larger storms more quickly.

Inlet structures, riser pipes, weirs, or stabilized spillways are options for features that can be used as a second stage for controlled release of stormwater runoff. It is recommended to set an opening for the second stage at or just above the desired maximum WQv ponding depth. Refer to Chapter 3, section 12 on how to correctly size the selected type of control structure.

- For online systems, it is recommended to complete a stage-storage model of the basin created above the bioretention cell with inflow hydrographs generated in Step 2 to determine storage volumes, depths, and release rates for all relevant storm events. To prevent compaction of the modified soil layer, excessive storage depths and drawdown times should be avoided. For the C_{pv} , check that ponding depths above the soil layer do not exceed 24 inches and surface drawdown does not exceed 24 hours. For the Q_p - Q_f events, check that ponding depths above the soil layer do not exceed 48 inches and surface drawdown does not exceed 30 hours.

Step 12: System Outlet and Overland Spillway Design Considerations

Check peak flow velocities near pipe outlets and spillways expected to be overtopped during large storms. For all storm events reviewed, velocities at any pipe outlets should be less than 5 feet per second, and stabilization provided (refer to HEC-14). Overflow spillways should be designed with sufficient width to keep velocities less than 5 feet per second, and be properly stabilized or reinforced to withstand such velocities. Refer to Chapter 3, section 12, H for additional information.

Calculation Example

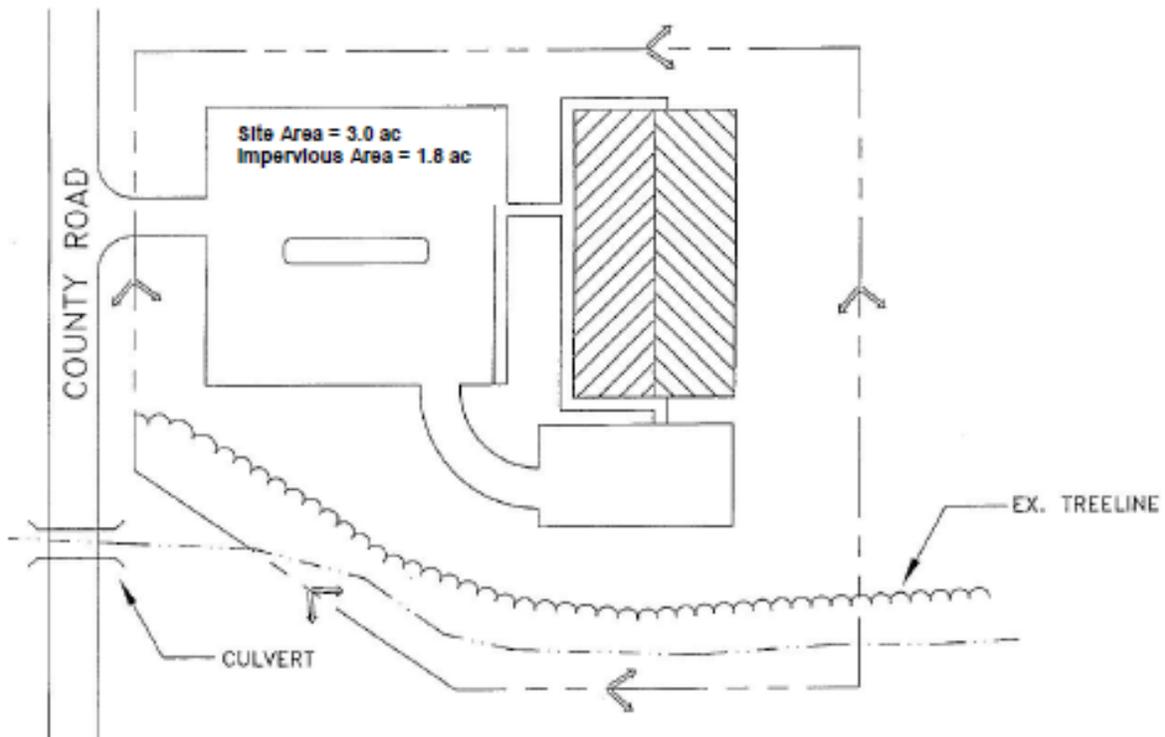


Figure C5-S4- 4: Recreation Center

Table C5-S4- 9: Site data

Base Site Data	Hydrologic Data		
Total site drainage area (A) = 3 ac		Pre-	Post-
Impervious area = 1.80 ac; I = 1.80 / 3.0 = 60%	CN	58	88
Soils: pre-developed HSG B (loam) developed use HSG C for compaction	t_c	25 min 0.42 hr	10 min 0.17 hr

Step 1: Compute the required WQ_v treatment volume

$$(DA) = 3 \text{ acres}$$

$$(I) = 60 \%$$

$$(P) = 1.25 \text{ inches}$$

Step 1a: Compute $R_v = 0.05 + 0.009(I)$

$$= 0.05 + 0.009(60) = 0.59$$

Step 1b: Compute $WQ_v = R_v(P)(DA)(43,560 \text{ sf/ac}) \left(\frac{1ft}{12in}\right)$

$$= (0.59)(1.25")(3ac)(43,560 \text{ sf/ac}) \left(\frac{1ft}{12in}\right)$$

$$= 8,031 \text{ cubic feet}$$

Step 2: Compute the peak runoff rates for other key rainfall events:

Use method outlined in Chapter 3, section 6, C, to compute the peak rate of flow (in cubic feet per second) and volume of stormwater runoff (in cubic feet) for the Channel Protection Volume (Cpv).

For this example, TR-55 software was used, with results as follows:

1-year, 24-hour storm; For Central Iowa = 2.91" rainfall depth Type II rainfall distribution, shape factor 484 (default values)

Condition	CN	T _c minutes	Peak rate cfs	Volume watershed inches	Volume cubic feet
Pre-developed	58	25	0.06	0.10	1,100
Post-developed	88	10	5.5	1.3	14,400

Use methods such as the NRCS TR-20, TR-55 (Chapter 3, section 7) or other acceptable methods to generate hydrographs to determine peak rates of flow (in cubic feet per second) and runoff volumes (in cubic feet) for the following events:

	Storm Event	Rainfall	Pre-developed		Post-developed	
		Depth inches	Peak Rate cfs	Volume cubic feet	Peak Rate cfs	Volume cubic feet
Q _p	2-year	2.91	0.29	2,600	7.5	20,000
	5-year	3.64	0.96	5,500	10.2	27,000
	10-year	4.27	1.8	8,500	13	33,000
Q _f	25-year	5.15	3.1	13,000	16	43,000
	50-year	5.87	4.5	18,000	19	51,000
	100-year	6.61	5.9	23,000	21	59,000

Step 3: Identify if the bioretention system is intended to be an online or offline system.

This facility is planned to be an offline system. To size the diversion structure, we need to calculate peak rates of flow (in cubic feet per second) and runoff volumes (in cubic feet) for the WQv event. For this example, we will complete TR-55 calculations, using adjusted curve numbers (CNs) for this small event. Refer to Chapter 3, section 6 for additional information.

Storm Event	Curve Number	Rainfall	Post-developed	
	NRCS Adjusted	Depth inches	Peak Rate cfs	Volume cubic feet
WQv	94	1.25	3.1	8,035

- Using an adjusted CN value, the volume of runoff from this calculation should be close to the value of WQv calculated in Step 1. (8,031 CF ≈ 8,035 CF)

Assume for this example that runoff is directed from the site through a pipe to a manhole where the diversion weir will be placed. Refer to Chapter 6, section 1, F for additional design information.

Step 3a: Size outlet pipe to bioretention practice

- To reduce the potential for erosion, it is recommended to have outlet velocities of less than 10 fps at the pipe outlet. Try a 10 inch outlet pipe (Area of pipe = 0.545 square feet).

$$\text{Rearranged continuity equation: } V = \frac{Q}{A} = \frac{3.1 \text{ cfs}}{0.545 \text{ sf}} = 5.7 \text{ fps} < 10 \text{ fps}$$

Step 3b: Set diversion weir elevation

Determine the head required to divert all flow from the WQv event toward the practice. Use the orifice equation: $Q = CA(2gh)^{0.5}$ where $C = 0.60$ and $g = 32.2 \text{ ft/s}^2$

Rearranged:

$$h = \frac{\left(\frac{Q}{CA}\right)^2}{2g}$$
$$h = \frac{\left[\frac{3.1 \text{ cfs}}{0.60 \times 0.545 \text{ sf}}\right]^2}{2 \times 32.2 \text{ ft/s}^2}$$
$$h = 1.40 \text{ ft}$$

The top elevation of the weir should be set 1.40 feet above the center of the 10 inch outlet pipe (or 1.82 feet above the flowline of the 10 inch outlet pipe).

Step 3c: Set diversion weir width

The width of the weir needs to fit within the diversion structure, allowing most of the flows that exceed WQv to bypass the system. Best to check this using the largest storm that the pipe is expected to handle. In many cases, this may be a 5- to 10-year event. In this example, we will use the 10-year event, and assume that larger storms surcharge the storm system and flow overland on a path that will bypass the bioretention practice.

- If surcharge flows are directed toward the practice, then the system should be designed as an online system as a diversion structure will fail to route large storms around the practice.

Use the weir equation: $QCLh^{3/2}$ where $C = 3.33$

Assume $L = 4$ feet (weir is to fit within a standard manhole diameter)

Use $Q =$ peak runoff from 10-year event from Step 2 - WQv event peak flow
 $= 13 \text{ cfs} - 3.1 \text{ cfs} = 9.9 \text{ cfs}$

Rearranged:

$$h = \left(\frac{Q}{CL}\right)^{2/3}$$
$$h = \left[\frac{9.9 \text{ cfs}}{3.33 \times 4 \text{ ft}}\right]^{2/3}$$
$$h = 0.82 \text{ ft}$$

This is the expected high water level above the top of the weir crest, inside the 4 foot diameter manhole during a 10-year storm event.

Step 3d: Double check flow through the diversion pipe to the practice during the maximum storm event, to avoid overloading the practice.

- It is best to double check the flow through the outlet pipe to the bioretention area, to calculate the maximum expected peak flow to the practice.

$$Q = CA(2gh)^{0.5}$$

$$Q = 0.60 \times 0.545sf \times \{[2 \times 32.2 ft/s^2 \times (0.82ft + 1.40ft)]\}^{0.5}$$

$$Q = 3.90cfs$$

During the 10-year event (4.27 inches in 24-hour for Central Iowa) flow to the practice only increases about 0.8 cfs (25%) over the WQv design flow, meaning at least 9.1 cfs would bypass the practice (70% of the peak flow). This appears to be acceptable.

Step 4: Select, Locate, and Size Pretreatment Practice(s).

Alternatives to evaluate for pretreatment are:

For grass swales, refer to Chapter 9, section 2, E for sizing requirements.

Using a site imperviousness of 60%, and a slope of less than 2%; a 45 foot long, 2 foot wide swale is needed to meet pretreatment requirements.

If the 10 inch discharge pipe is connected to a level spreader to convert concentrated flow to sheet flow, a filter strip could be used. For filter strips, refer to Chapter 9, section 4, C, 4 for sizing requirements. The chart uses a maximum inflow approach length for impervious areas of 75 feet. To have an equivalent impervious approach length maximum of 75 feet, the 1.8 acres (78,408 square feet) of impervious surfaces in this example needs to be spread over a width of 1,045 feet (= 78,408 sf/75 feet). Providing this length does not seem feasible. A filter strip might be a better option with a level spreader in a smaller watershed area, or as an online system receiving sheet flow runoff from paved areas that are less than 75 feet in length.

A forebay with a storage volume of 0.1 inches per impervious acre drained is an option.

Storage required:

$$\begin{aligned} &= DA \left(\frac{I}{100} \right) (0.1in) \left(\frac{1ft}{12in} \right) (43,560 sf/ac) \\ &= (3ac) \left(\frac{60}{100} \right) (0.1in) \left(\frac{1ft}{12in} \right) (43,560 sf/ac) \\ &= 653cf \text{ (or 8\% of WQv)} \end{aligned}$$

A 15 foot wide by 15 foot long by 3 foot deep wet forebay would meet this requirement (675 cf).

A combination of practices could also be considered to meet pretreatment requirements, with each practice meeting a certain portion of the requirement. For this example, it is assumed that only the grass swale option will be chosen.

Assume a 4 foot wide swale is used (larger than required, but easier to construct) that is 45 feet long and has a longitudinal slope of 1.5% and side slopes of 4:1.

- It is recommended to double check that the maximum flow velocity for water quality treatment of 1 fps is met during the WQv event. The methods described in Chapter 9, section 2 can be used modify Manning's equation to evaluate shallow flow in grass swales.

An iterative procedure, spreadsheets or analysis software may be used.

For the channel section selected and an estimated depth of flow of 7 inches (0.583 feet):

Manning's coefficient (n) = 0.105 Area = 3.67 SF Wetted Perimeter = 8.78 feet Velocity = 0.97 fps (< 1.0 fps)

$$Q = 3.5 \text{ cfs } (> \text{ WQv} = 3.1 \text{ cfs})$$

- If WQv velocity > 1.0 fps, try widening the swale, or decrease the longitudinal slope.

Step 5: Review Entrance Designs

For larger events, solve the Manning's equation at the end of the pretreatment swale selected in Step 4. Again, an iterative procedure, spreadsheets or analysis software may be used.

For the channel section selected in Step 4, and at a depth of flow of 7.5 inches (0.625 feet):

$$\text{Manning's coefficient (n)} = 0.098 \quad \text{Area} = 4.06 \text{ SF} \quad \text{Wetted Perimeter} = 9.15 \text{ feet} \quad \text{Velocity} = 1.08 \text{ fps } (< 3.0 \text{ fps})$$

$$Q = 4.4 \text{ cfs } (> \text{ WQv} = 3.9 \text{ cfs})$$

Step 6: Select Desired WQ Event Ponding Depth

A WQv ponding depth of 6 inches (0.50 feet) has been selected for this example.

Step 7: Design Cross-Sectional Elements

Use the following:

- A 3 inch depth layer of fine, shredded hardwood mulch.
- A modified soil layer should be 18 inches deep (minimum).
- A stone aggregate layer is recommended of 12 inches deep.
- Total depth = 0.25 + 1.50 + 1.00 = 2.75 feet

Step 8: Calculate the Recommended Footprint of WQ Ponding Area

The footprint area for temporary ponding of the WQv can be determined by the following equation:

$$A_f = \frac{WQv \times d_f}{[k(h_f + d_f)t_f]}$$

Solve for (A_f) = Required ponding area to treat WQv, in square feet

Where:

$$\text{WQv} = 8,031 \text{ cubic feet (from Step 1)}$$

$$d_f = 2.75 \text{ feet (from Step 7)}$$

$$h_f = 0.50 \text{ feet} / 2 = 0.25 \text{ feet (value from Step 6, divided by 2)}$$

$$t_f = 1 \text{ day (recommended drain time of soil layer for WQv event)}$$

$$k = 2 \text{ feet/day (used recommended modified soil mix)}$$

$$A_f = \frac{[8,031cf \times 2.75ft]}{[2 \text{ ft/day} \times (0.25ft + 2.75ft) \times 1day]}$$

$$A_f = \frac{22,085cf \times ft}{6.00sf}$$

$$A_f = 3,681sf (4.7\% \text{ of impervious area}) \text{ Recommend to round up to 3,700 square feet}$$

Step 9: Design Surface Geometry of WQv Ponding Area

The bottom of the ponding area should be level, typically ranging from 10-30 feet in width. The cell should typically be at least two times longer than it is wide, as measured along the direction of flow (longer flowpaths through the system increase filtration and percolation).

Start with a cell twice as long as wide:

$$\begin{aligned}L &= 2W \\ WL &= 3,700sf \\ W \times 2 \times W &= 3,700sf \\ W^2 &= 1850sf \\ W &= 43.0ft\end{aligned}$$

Preliminary rough dimensions: Width = 43 feet, Length = 86 feet.

Check minimum and maximum widths, maybe adjust to: Width = 25 feet, Length = 148 feet.

Step 10: Subdrain System Design

For a bioretention cell, the subdrain system is needed to drain the aggregate layer over a 24-hour period. The design flow rate can be determined from the following equation:

$$Q(\text{in cfs}) = kA_f \left(\frac{1\text{day}}{24\text{hours}} \right) \left(\frac{1\text{hour}}{3,600\text{sec}} \right)$$

Where:

(A_f) = 3,700 square feet (from Step 8)

(k) = 2 feet/day (from Step 8, based on modified soil - minimum k)

$$Q = \left(2 \frac{ft}{day} \right) (3,700sf) \left(\frac{1day}{24hour} \right) \left(\frac{1hour}{3,600sec} \right)$$

$$Q = 0.09cfs$$

The minimum recommended diameter of 8 inches will have sufficient capacity.

The length of pipe should be determined, so that the area within 1 foot either side of the subdrain is at least 10% of the required ponding area (A_f).

$$\text{Length of subdrain} = A_f \times 10\% / (1ft \times 2)$$

$$3,700sf \times 10\% / (1ft \times 2) = 185.0ft$$

Use at least 185 feet of 8-inch subdrain, set 3 inches above the bottom of the aggregate layer. Either the cell dimensions will need to be changed to be at least 185 feet long (i.e. 20' x 185' = 3,700 CF) and a single run of subdrain used, or parallel/perpendicular runs of subdrain will be needed to get to 185 feet of subdrain length (i.e. two parallel runs of 93 feet each). The upstream end of each subdrain should have a cleanout, extended to the surface for maintenance.

For this example, adjust ponding area size to 20 feet wide by 185 feet long, with a single 185 foot long subdrain and cleanout.

Step 11: Staged Outlet Design for Online Systems

This calculation is an example of an offline system. A staged outlet structure would not be needed in this case. However, an overflow spillway should be provided to prevent ponding deeper than the desired ponding depths. Referring to Chapter 3, section 12, design an earthen spillway to crest 9 inches above the level surface of the mulch layer. The spillway should have a minimum bottom width of 10 feet, a section depth of 2 feet, side slopes of 3:1 or flatter and longitudinal slopes ranging from 1-10%. Steeper slopes may require additional stabilization measures.

Step 12: System Outlet and Overland Spillway Design Considerations

This example is an offline system, with the subdrain discharging to a storm sewer system. If the subdrain did daylight, flows of 0.09 cfs would likely require minimal erosion protection.

For an online system, check exit velocities at pipe outlets and overflow spillways.

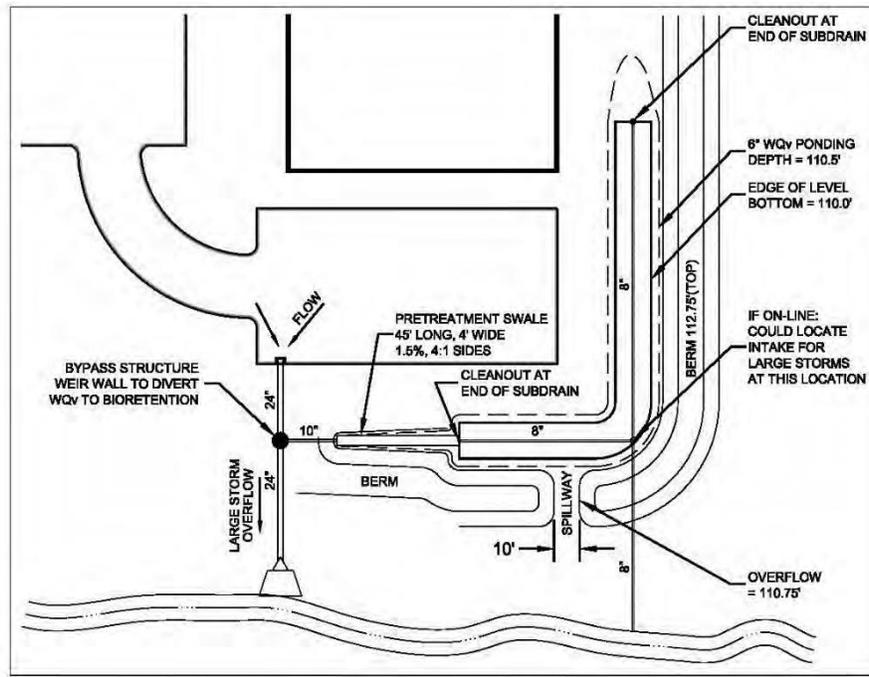


Figure C5-S4- 10: Site plan for the bioretention cell

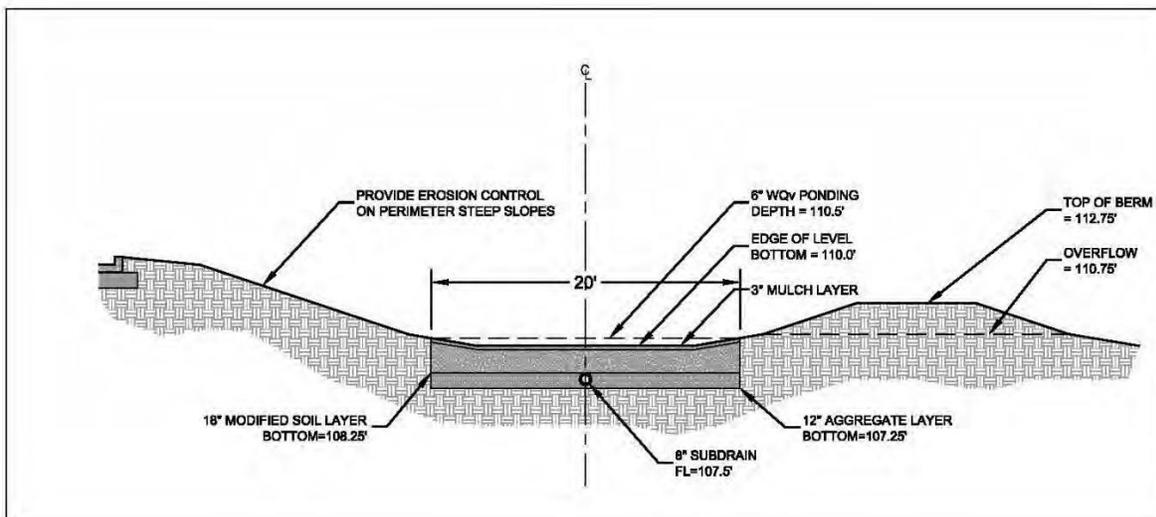


Figure C5-S4- 11: Section view of bioretention cell

C. Construction

- 1. Preconstruction meeting.** Design and installation staff should meet prior to any on-site construction to discuss the placement of all permanent stormwater management practices. This discussion should focus on minimizing soil compaction, identifying areas where infiltration practices will be placed, staging of construction to ensure site stabilization prior to the installation of bioretention cells and a discussion of the design details associated with the

installation of the bioretention cell.

2. **Staging.** The construction project should be staged so the bioretention cell is installed during the final construction stage. Prior to bioretention cell installation, all soils within the area that will drain to the bioretention cell must be stabilized with permanent vegetation and/or other erosion, sediment, and velocity controls. If the bioretention facility is to be used as a sediment basin prior to use as a bioretention facility, it should be excavated to the dimensions, side slopes, and 1 foot above the bottom of the modified soil layer elevations shown on the drawings.
3. Construction considerations:
 - a. **Staking.** The bioretention cell area should be staked prior to any site construction to minimize traffic and compaction. This would not apply to situations where a sediment basin is converted to a bioretention cell.
 - b. **Construction site stabilization.** Contributing drainage areas should be permanently stabilized against erosion and sedimentation prior to construction of bioretention cells.
 - c. **Weather.** Construction of the bioretention cell should not begin or be conducted during rainy weather resulting in saturated soil conditions.
 - d. **Excavation.** After all vegetation is established within the drainage area of the bioretention cell, all sediment in the bioretention cell should be completely removed.

Excavators and backhoes, operating on the ground adjacent to the bioretention cell, should be used to excavate the cell area to the greatest extent possible. Otherwise, excavation should be performed using low ground-contact pressure equipment.

Any discharge of sediment that affects the performance of the bioretention cell will require reconstruction of the bioretention cell as originally specified to restore its defined performance.

- e. **Compaction avoidance and remediation.** Heavy equipment should not be used within the perimeter of the bioretention cell before, during, or after placement of the modified soil layer. After placement of the under drain system and before the modified soil layer is placed, the bottom of the excavation should be roto-tilled to a minimum depth of 6 inches to alleviate compaction. Should the soils be severely compacted, ripping or deep tillage equipment may be needed to break up the compacted layers prior to roto-tilling.
- f. **Placement of modified soil layer.** Any ponded water should be removed from the bottom of the excavation and discharged to a vegetated area but not discharged directly to a storm sewer.

The modified soil layer should be placed and graded using low ground-contact pressure equipment, or by excavators and/or backhoes operating on the ground adjacent to the bioretention facility. Heavy equipment should not be used within the perimeter of the bioretention facility before, during, or after placement of this layer.

The modified soil layer should be placed in horizontal layers not to exceed 12 inches for the entire area of the bioretention cell. It should be saturated over the entire area of the cell after each lift of the modified soil layer is placed, until water flows from the underdrain, to lightly consolidate the mixture. Water for saturation should be applied by spraying or sprinkling in a manner to avoid separation of the BSM components. An appropriate sediment control device should be used to treat any sediment-laden water discharged from the underdrain during this process.

If the modified soil layer becomes contaminated with sediment or other deleterious material during, or after, construction of the cell, the contaminated material should be removed and replaced with uncontaminated material.

Final grading of the modified soil layer should be performed after a 24-hour settlement period. Upon completion of final grading, the surface of this layer should be roto-tilled to a depth of 6 inches.

- g. Planting, mulch, netting.** Mulch should first be spread in cells prior to planting. When using wood mulch, select fibrous, hardwood mulch. Netting may be needed on top of the surface of the mulch to minimize floating of the mulch.

Plants may require watering over several months to aid establishment, especially during drought periods.

Pesticides, herbicides, or fertilizer should not be used during landscape construction, plant establishment, or maintenance.

When small plants are used, consider delaying curb cuts or placing diversions in front of the cuts until plants are established.

4. Plant selection and arrangement.

Plant selection should be based on amount of sunlight received by the site during the growing season, the desired plant height and if native or non-native species are preferred.

5. Maintenance. Bioretention cells require seasonal maintenance. It is imperative that they be maintained to function properly and provide continuous visual aesthetics.

Table C5-S4- 10: Bioretention cell maintenance requirements

Activity	Schedule
<ul style="list-style-type: none"> • Prune and thin out plants when needed. Remove weeds throughout the growing season, preferably by pulling or trimming. Replace plants when needed. • Replace mulch when erosion is evident and/or weed growth is excessive. • Remove trash and debris from pretreatment area and bioretention cell. 	Fall, spring, as needed
<ul style="list-style-type: none"> • Inspect inflow points for clogging (offline systems). Remove any sediment. • Inspect filter strip/grass channel for erosion or gullyng. Re-seed or sod as necessary. • Trees and shrubs should be inspected to evaluate their health and remove any dead or severely diseased vegetation. 	Semi-annually
<ul style="list-style-type: none"> • Look for evidence of standing water in the observation port. This may be a sign of hydraulic failure. 	Annually
<ul style="list-style-type: none"> • Replace pea gravel diaphragm when necessary. • Replace modified soil layer when ponding greatly exceeds the design drainage time. 	As necessary