2E-4 Bioretention Systems

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

Description: Bioretention and rain garden systems incorporate shouldow landscaped stormwater basins (depressions) with an engineered soil subgrade. 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 WQv is drained from the aggregate base by infiltration into the underlying soils and/or to an outlet through a perforated pipe subdrain. The piped outlet can discharge into a downstream earthen channel, detention structure, or storm sewer system. 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 runoff from residential, commercial, and institutional sites.
- Drainage area size typically up to 5 acres; for larger impervious area, 2-3 acres maximum is recommended; larger areas can be divided into smaller sub-areas with individual bioretention areas distributed throughout the site.
- Concave landscaped areas such as parking lot islands, road medians, and street rights-of-way.

Advantages/benefits:
- Reduce runoff rate and volume from impervious areas; provide opportunity for filtration and infiltration 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 higher seasonal water table levels. Good retrofit opportunities.
- Flexible landscaping options can provide an aesthetic feature.

Disadvantages/limitations:
- Not appropriate for steep slopes (> 15%).
- High sediment loads can cause premature failure; upstream practice is needed.
- Concentrated flows may need special consideration in design.

Maintenance requirements:
- Routine landscape maintenance - weeding and annual removal of undesirable vegetation.
- Removal of dead plant debris (mowing, pruning, or burning)
- Maintenance of sediment in grassed area.

A. Description

Bioretention areas (also referred to as bioretention filters or rain gardens) are structural stormwater controls that capture and temporarily store the water quality volume using soils and vegetation in shouldow basins or landscaped areas to remove pollutants from stormwater runoff.

Bioretention areas use vegetation and engineered soils as a treatment area to accept runoff from impervious surfaces. Stormwater flows into the bioretention area, ponds on the surface, and gradually infiltrates into the engineered soil layer. Example applications of bioretention and rain gardens are illustrated in Figure 1. The components of the bioretention system are illustrated in Figures 2 and 3. Bioretention systems 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 infiltrate 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 areas to break up the area in manageable sub-watersheds. Higher flow events ($> Q_2$), and runoff volume that exceed the infiltration capacity of these systems can be returned to the conveyance system or safely bypassed.

Vegetative systems in bioretention areas enhance infiltration and provide a significant 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 systems into new construction projects or to retrofit existing urban areas. Bioretention can be used in residential yards (rain gardens), as interior or perimeter structures in parking lots, for rooftop drainage at residential and commercial building sites, along highway and road drainage swales, 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 area. Systems 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 system 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 infiltration through the plant roots, improves soil structure, improves aesthetics, and reinforces long-term performance of subsurface infiltration. 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.

Mosquitoes are not a problem because bioretention areas and rain gardens do not retain standing water long enough for mosquito reproduction (four to 10 days). Properly designed bioretention and rain garden systems will infiltrate standing water with 4 to 12 hours.

Figure 1: Example bioretention applications

(a) Rain garden for single family residence

(b) Bioretention in landscaped parking lot median

(c) Newly planted bioretention area after storm

(d) New bioretention area after construction

Source: Georgia Stormwater Manual

Table 1: Bioretention design components

Pre-treatment area	Grass buffer strip or vegetated swales are commonly used pre-treatment devices. Required where a significant volume of debris or suspended material is anticipated such as parking lots and commercial areas.
Ponding area	Provides for surface storage of the storm runoff before it filters through the soil bed. Also provides for some evaporation of ponded water and settling of sediments in the runoff. Typically limited to a depth of 6-9 inches. Additional freeboard depth should be provided for online systems to allow surcharge above overflow outlet during larger storm runoff events (> Q_2).
Organic mulch layer	The organic mulch 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, and provides some filtration of larger sediment particles. Three to four inches of good quality coarse shredded hardwood mulch are recommended.
Planting soil bed (engineered soil matrix)	The planting soil bed provides water and nutrients to support plant life in the bioretention system. Stormwater filters through the planting soil bed and pollutants are removed through filtration, plant uptake, adsorption, and bacteriological decomposition. • Total depth = 4.5 to 5.5 feet; planting soil depth = 18-30 inches • Soil mixtures include: medium sand (50-60%), topsoil (sandy/clay loam) (20-25%), leaf compost (20-25%). Provides organic matter content and facilitates good plant root systems; and a permeable substrata w/~ 25% porosity. • Strive for organic matter content of 10%. • Maximum clay content of mixture ≤ 5%.
Stone aggregate sub-base layer	The aggregate layer at the bottom of the structure provides additional temporary storage capacity for the captured runoff after filtration. • An open-graded, clean, durable aggregate of 1-2 inches diameter will provide a porosity of 35-40%. • Depth of the aggregate layer can be varied to provide more storage volume • A nominal depth of 12-inches is typically provided.
Plant materials	Native species.
Inlet and outlet controls	Non-erosive flow velocities (≤ 0.5 fps).
Maintenance	Routine landscape maintenance (removal of dead plant debris); plant replacement as needed; mowing and/or burning.
Hydrologic design	Unified sizing criteria; system is sized to retain the WQv, recharge volume is minimum infiltration goal; runoff flows in excess of the Qp for the WQv design storm are usually bypassed; check capability to provide some peak flow attenuation for larger runoff events up to the Q_5.

B. Stormwater management suitability

Bioretention areas are designed primarily for stormwater quality, i.e. the removal of pollutants. Bioretention can provide limited runoff quantity control, particularly for smaller storm events. These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, bioretention areas 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 area safely bypasses higher flows.

1. **Water quality (WQv).** Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention area is designed to perform a specific function (see Figure 4).
   a. The grass filter strip (or grass channel) reduces incoming runoff velocity and filters particulates from the runoff.

   b. The ponding area provides for temporary storage of stormwater runoff prior to its evaporation, infiltration, or uptake and provides additional settling capacity.

   c. The organic or mulch layer provides filtration, as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material.

   d. The planting soil in the bioretention facility acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants.

   e. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants, and also serve to stabilize the surrounding soils.

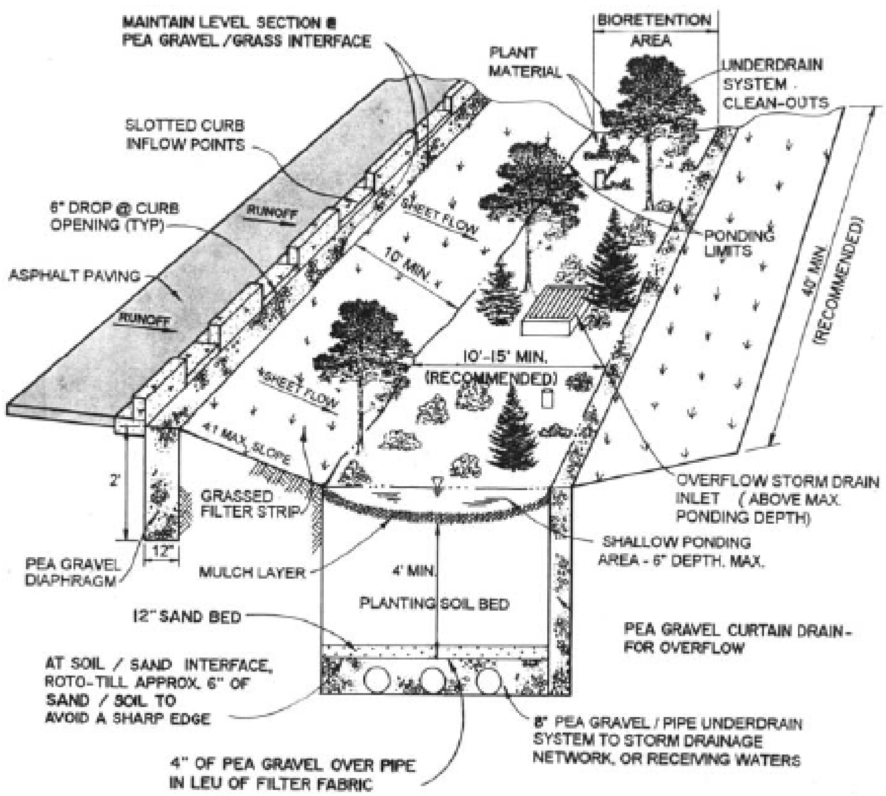
   f. Finally, a sand bed provides for positive drainage and aerobic conditions in the planting soil, and provides a final polishing treatment media.

2. **Channel protection (CPv).** For smaller sites, a bioretention area may be designed to capture the entire channel protection volume in either an off-line or online configuration. Given that a bioretention facility is typically designed to completely drain over 48 hours, the requirement of extended detention of the 1-year, 24-hour storm runoff volume will be met. For larger sites, where only the WQv is diverted to the bioretention facility, another structural control must be used to provide CPv extended detention.

3. **Overbank flood protection.** Another structural control must be used in conjunction with a bioretention area to reduce the post-development peak flow of storms greater than the 5-year storm (Qp) to pre-development levels (detention).

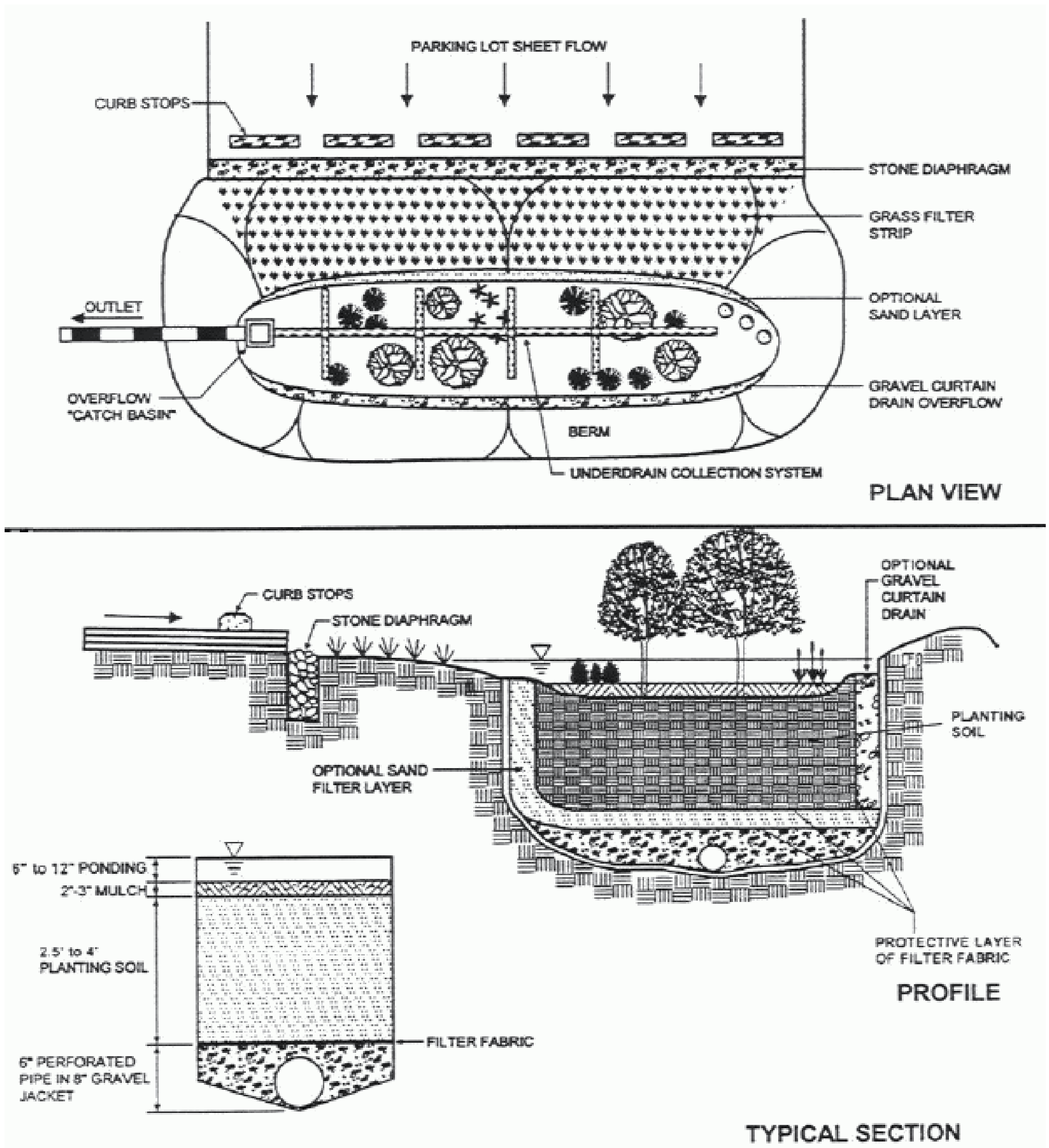
4. **Extreme flood protection.** Bioretention areas must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the ponding area, mulch layer, and vegetation.

Figure 2: Bioretention system components



Source: Claytor and Schueler, 1996

Figure 3: Bioretention system



Source: MDE, 2000

C. 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. 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 2: Pollutant removal efficiency of bioretention areas

Parameter	Removal Efficiency (%)
Total suspended solids	80
Total phosphorous	65-85
Total nitrogen	50
Pathogens	70-100
Heavy metals	45-95

Source: US EPA

More information on pollutant removal capabilities for bioretention BMPs can be found in the National Pollutant Removal Performance Database (www.cwp.org), the National Stormwater Best Management Practices Database (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. The following table summarizes the efficiency removal rates for various pollutants.

Table 3: Cumulative percent removal by depth

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

D. Application and feasibility

Bioretention systems are 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 facilities 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 percent of the area that drains to them), they can fit into existing parking lot islands or other landscaped areas. They can also treat runoff from intensively managed areas that have the potential for pollutants, such as golf courses. Figure 4 includes some example site configurations.

The following criteria should be evaluated to ensure the suitability of a bioretention area for meeting stormwater management objectives on a site or development:

1. **General feasibility:**
   - Suitable for residential subdivision usage – yes
   - Suitable for high-density/ultra urban areas – yes
   - Regional stormwater control – no

2. **Physical feasibility – physical constraints at project site:**
   - Drainage area: 5 acres maximum; 0.5 to 2 acres are preferred
   - Space required: Approximately 5-8% of the tributary impervious area is required; minimum 200 ft^2 area for small sites (10 feet x 20 feet)
   - Site slope: No more than 6% slope
   - Minimum head: Elevation difference needed at a site from the inflow to the outflow: 5 feet
   - Minimum depth to water table: A separation distance of 2 feet is recommended between the bottom of the bioretention facility and the elevation of the seasonally high water table.
   - Soils: No restrictions; engineered media required. For rain garden applications where no subdrain is provided, HSG D soils should be avoided, or the system may experience longer periods of standing water.

E. Planning and design criteria

1. **Initial considerations:**

   a. Determine the purpose of the bioretention system – what are the site requirements for water quality and quantity control?

   b. What design storm is required to meet the stormwater management criteria?

   c. Can bioretention be used for water quality and quantity control?

   d. Can the bioretention facility be used independently of other BMPs, or will it be installed along with other practices?

2. **Location and siting:**

   a. Bioretention areas should have a maximum contributing drainage area of 5 acres; 0.5 to 2 acres are preferred. Multiple bioretention areas can be used for larger areas.

   b. Bioretention areas can either be used to capture sheet flow from a drainage area or function as an off-line device. Online designs should be limited to a maximum drainage area of 0.5 acres.

   c. When used in an off-line configuration, the WQv is diverted to the bioretention area through the use of a flow splitter. Stormwater flows greater than the WQv are diverted to other controls or downstream. (See Part 2D for more discussion of off-line systems and design guidance for diversion structures and flow splitters).

   d. Bioretention systems 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, or other sources.

e. Bioretention area 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.

f. Available room for installation including setback requirements.

3. **General design.** A well-designed bioretention area consists of:

a. Grass filter strip (or grass channel) between the contributing drainage area and the ponding area.

b. Ponding area containing vegetation with a planting soil bed.

c. Organic/mulch layer.

d. Gravel and perforated pipe subdrain system to collect runoff that has filtered through the soil layers (bioretention areas can optionally be designed to infiltrate into the soil – see description of infiltration trenches for infiltration criteria).

e. A bioretention area design will also include some of the following:
   1) Optional sand filter layer to spread flow, filter runoff, and aid in aeration and drainage of the planting soil.
   2) Stone diaphragm at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter.
   3) Inflow diversion or an overflow structure consisting of one of five main methods:
      a) Use a flow diversion structure.
      b) For curbed pavements use an inlet deflector (see Figure 6).
      c) Use a slotted curb and design the parking lot grades to divert the WQv into the facility. Bypass additional runoff to a downstream catch basin inlet. Requires temporary ponding in the parking lot.
      d) Use a short deflector weir (maximum height 6 inches) designed to divert the maximum water quality peak flow into the bioretention area.
      e) An in-system overflow consisting of an overflow catch basin inlet and/or a pea gravel curtain drain overflow. (See Figure 2 for an overview of the various components of a bioretention area). Figure 3 provides a plan view and profile schematic of an online bioretention area. An example of an off-line facility is shown in Figure 5.

4. **General planning criteria:**

a. Facilities can be placed close to the source of runoff generation.

b. The site permits the dispersion of flows and bioretention facilities to be distributed uniformly. Distributed placement of bioretention areas across a development site results in smaller, more manageable subdrainage areas and therefore helps to control runoff closer to its source.

c. Potential bioretention facilities should be applied where subdrainage areas are limited to less than 1-2 acres, and preferably less than 1 acre.

d. Stormwater management site integration is a feasible alternative to end-of-pipe BMP design.

e. Availability of suitable site conditions (groundwater elevation and depth to bedrock).

f. Bioretention areas can either be used to capture sheet flow from a drainage area or function as an off-line device. Online systems take all the runoff water from an impervious surface. Online designs should be limited to a maximum drainage area of 0.5 acres. Multiple bioretention systems are preferred when managing larger impervious surfaced areas.

g. When used in an off-line configuration, the WQv is diverted to the bioretention area through the use of a flow splitter, diversion structure, and/or overflow outlet. Stormwater flows greater than the WQv are diverted to other controls or downstream (see Section 2F-1 for more discussion of off-line systems and design guidance for diversion structures and flow splitters).

h. Bioretention systems 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, or other sources.

i. Bioretention area 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.

j. Generally, commercial or residential drainage areas exceeding 1-3 acres in size will discharge flows greater than the 5 cfs for a 10-year storm event. When flows exceed this level, the designer should evaluate the potential for erosion to stabilized areas. Typically, flows greater than 5 cfs for the 10-year storm event will require pipe enclosure across developed lots. By using drainage dispersion techniques, retaining existing contours, concentrated quantities of flow can often be reduced below these thresholds, eliminating or reducing the need for a pipe conveyance system. This may be accomplished by dispersing larger drainage areas to multiple bioretention facilities.

F. Physical specifications and geometry

1. Recommended minimum dimensions of a bioretention area are 10 feet wide by 20 feet long. All designs except small residential applications should maintain a length to width ratio of at least 2:1.

2. The planting soil filter bed is sized using a Darcy's Law equation with a filter bed drain time of 48 hours and a coefficient of permeability (k) of 0.5 ft/day.

3. The maximum recommended ponding depth of the bioretention areas is 6 inches.

4. The planting soil bed must be at least 4 feet deep. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10-25%. The soil must have an infiltration rate of at least 0.5 inches per hour and a pH between 5.5 and 6.5. In addition, the planting soil should have a 1.5 to 3% organic content and a maximum 500 ppm concentration of soluble salts.

5. For online configurations, a grass filter strip with a pea gravel diaphragm is typically utilized (see Figure 5) as the pre-treatment measure. The required length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. Design guidance on filter strips for pre-treatment can be found in Part 2I.

6. For off-line applications, a grass channel with a pea gravel diaphragm flow spreader is used for pre-treatment. The length of the grass channel depends on the drainage area, land use, and channel slope. The minimum grassed channel length should be 20 feet. Design guidance on grass channels for pre-treatment can be found in Part 2I.

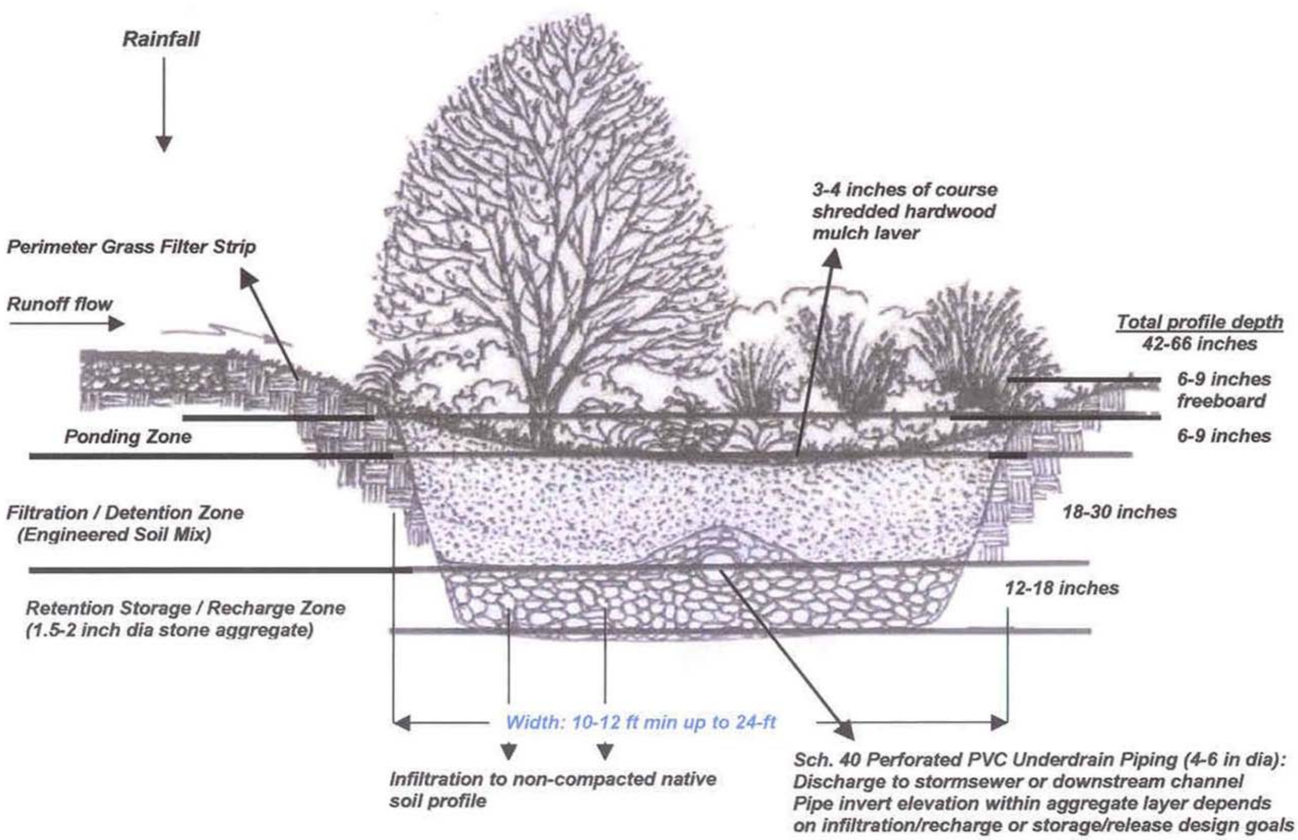
7. The mulch layer should consist of 2-4 inches of commercially-available fine shredded hardwood mulch or shredded hardwood chips.

8. The sand bed should be 12-18 inches thick. Sand should be clean and have less than 15% silt or clay content.

9. Pea gravel for the diaphragm and curtain, where used, should be ASTM D 448 size No. 6 (1/8” to ¼”).

10. The subdrain collection system is equipped with a 6-inch perforated PVC pipe (AASHTO M 252) in a 12-inch gravel layer. The pipe should have 3/8-inch perforations, spaced at 6-inch centers, with a minimum of 4 holes per row. The pipe is spaced at a maximum of 10 feet on center and a minimum grade of 0.5% must be maintained. A permeable filter fabric is placed between the gravel layer and the planting soil bed.

Figure 4: Bioretention system components



G. Structures

1. **Pre-treatment inlets.** Adequate pre-treatment and inlet protection for bioretention systems is provided when all of the following are provided:
   - Grass filter strip below a level spreader, or grass channel
   - Pea gravel diaphragm
   - Organic or mulch layer

2. **Outlet structures.** An outlet pipe is provided from the subdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary.

3. **Emergency spillway.** An overflow structure and non-erosive overflow channel are provided to safely pass flows that exceed the storage capacity from the bioretention area to a stabilized downstream area or watercourse. If the system is located off-line, the overflow should be set above the shouldow ponding limit. The high-flow overflow system within the structure typically consists of a yard drain catch basin, though any number of conventional systems could be used. The throat of the catch basin inlet is normally placed 6 inches above the mulch layer at the elevation of the shouldow ponding area.

H. Design procedures

1. **Step 1**. Compute runoff control volumes from the unified stormwater sizing criteria (See Part 2B).

   a. Calculate the WQv and Rev.

   b. Compute the CPv.

   c. Compute Qp or downstream stormsewer conveyance capacity (i.e. ≤ 5-yr peak discharge rate, Qp_5).

   d. Compute Qf.

   e. Determine total DA to be served by the bioretention BMPs; maximum DA less than 5 acres; divide larger DAs into smaller sub-areas of 1-2 acres if possible.

   f. Determine the actual amount of impervious area for the total DA and/or sub-areas.

2. **Step 2**. Determine if the development site and conditions are appropriate for the use of a bioretention area. Consider the application and feasibility and location and siting criteria.

3. **Step 3**. Confirm local design criteria and applicability.

   a. Consider any special site-specific design conditions/criteria.

   b. 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.

4. **Step 4.** Compute WQv peak discharge (Qwq).

   a. WQv (ft^3) = Rv x P x DA x 43,560 ft^2/acre x 1 ft/12 in
      1) P is design rainfall depth in inches (i.e. 1.25 inches)

2) DA is drainage area in acres
3) Rv = runoff coefficient for the DA served by the BMP
4) Rv = 0.05 + (0.009)(I), where I = impervious area in %

b. The peak rate of discharge for water quality design storm (Qwq) is needed for sizing of off-line diversion structures. (See Section 2C-6).
1) Using WQv (or total volume to be captured), compute CN.
2) Compute time of concentration using TR-55 method.
3) Determine appropriate unit peak discharge from time of concentration.
4) Compute Qwq from unit peak discharge, drainage area, and WQv.
5) An alternate method is to determine the Qwp using the Rational method; use the design rainfall depth and a 2-hour duration to provide a design rainfall intensity for use in the rational method equation (i.e. Q cfsec = C x I x A); use the Rv calculated above for the "C" runoff coefficient.

5. **Step 5**. Size flow diversion structure, if needed.

a. A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQv to the bioretention area.

b. Size low flow orifice, weir, or other device to pass Qwq.

6. **Step 6**. Determine size of bioretention ponding/filter area.

A. The required planting soil filter bed area is computed using the following equation (based on Darcy's Law):

$$A_f = \frac{WQv \times df}{[k \times (hf + df) \times (tf]}$$

where:
A_f = surface area of ponding area (ft^2)
WQv = water quality volume (or total volume to be captured)
df = filter bed depth (1.5 feet minimum)
k = coefficient of permeability of filter media (ft/day) (use 1 in/hr for a sandy loam for the engineered soil mix; if using a natural soil profile, use 0.5 ft/day for silt-loam)
hf = average height of water above filter bed (ft) - (typically 3-4.5 inches, which is half of the 6-9 inch ponding depth)
tf = design filter bed drain time (days); (2 days is recommended maximum)

B. Check value of Af determined from above equation – should be in the range of 10-15% of the total impervious drainage area.

7. **Step 7**. Set design elevations and dimensions of facility; see physical specifications and geometry.

8. **Step 8.** Design conveyances to facility (off-line systems). See the example figures to determine the type of conveyances needed for the site.

9. **Step 9.** Design pre-treatment. Provide pre-treatment with a grass filter strip (online configuration) or grass channel (off-line), and stone diaphragm. Nominal width of perimeter

grass filter strips should be 10-foot minimum, if possible.

10. **Step 10**. Size subdrain system. See physical specifications and geometry. Hydraulic capacity of the subdrain piping must be sufficient to convey the expected discharge from the soil filter layer: Avg Flow Rate, Q (cfsec) = inches/hour x total area of filter x 1 ft/12 in x 1 hr/3600 sec.

11. **Step 11**. Design emergency overflow. An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Non-erosive velocities (<10 fps) need to be ensured at the outlet point.

12. **Step 12.** Prepare vegetation and landscaping plan. A landscaping plan for the bioretention area should be prepared to indicate what type of vegetation is to be used (species, etc) and procedures for establishing vegetation.

I. Inspection and maintenance requirements

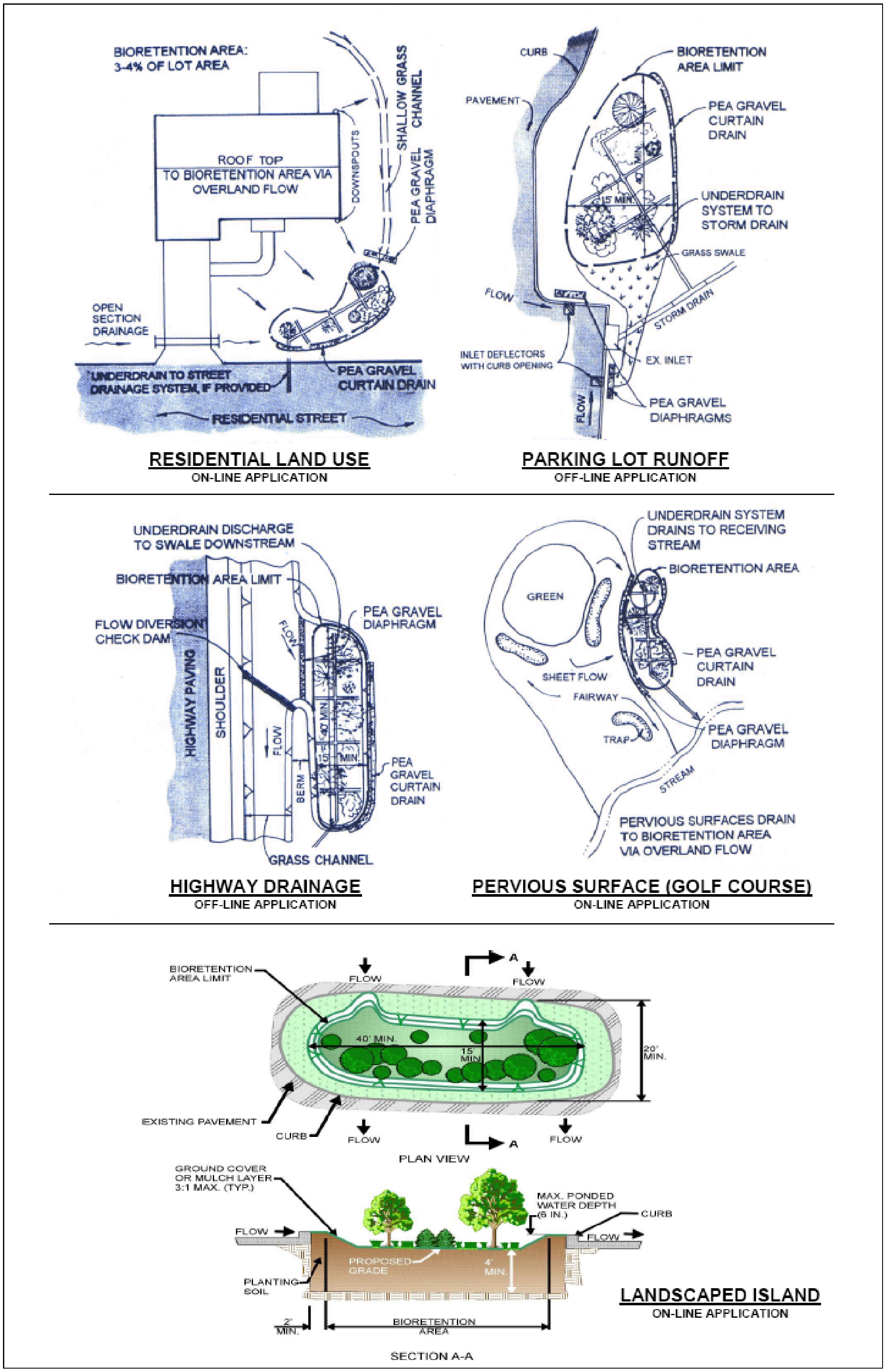
Adequate access must be provided for all bioretention facilities for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles.

Table 4: Typical maintenance activities for bioretention areas

Activity	Schedule
• Pruning and weeding to maintain appearance • Mulch replacement when erosion is evident • Remove trash and debris	As needed
• Inspect inflow points for clogging (off-line systems). Remove any sediment. • Inspect filter strip/grass channel for erosion or gullying. 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
• The planting soils should be tested for pH to establish acidic levels. If the pH is below 5.2, lime should be applied. If the soil pH is above 7.5, then gypsum can be applied to reduce the pH.	Annually
• Replace mulch over the entire area • Replace pea gravel diaphragm when necessary	2 to 3 years

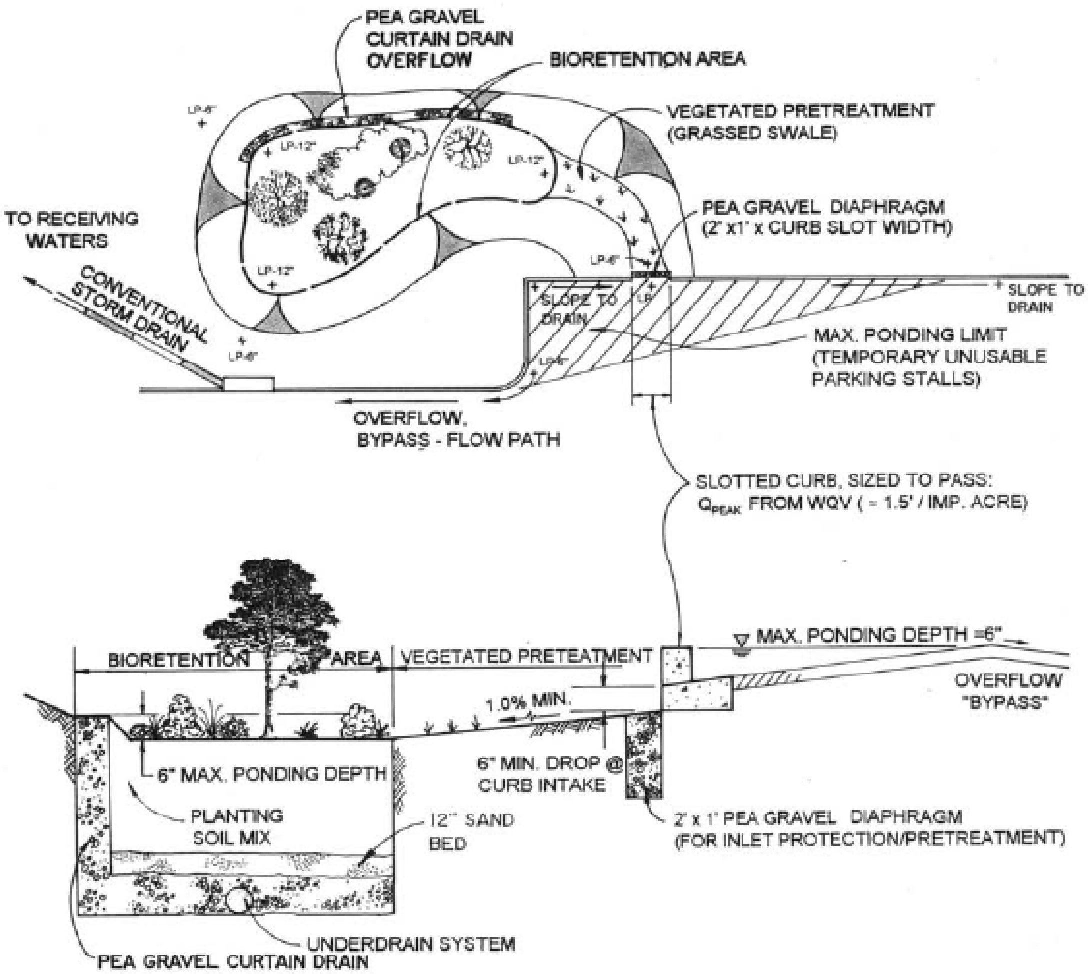
Source: EPA, 1999; Georgia SW Manual

Figure 5: Bioretention area applications



Source: Claytor and Schueler, 1996

Figure 6: Bioretention with slotted curb-cut diversion



Source: Prince George's County, MD, 2000

J. Design example

Bioretention System

Figure 7: Bucketsville, IA recreation center, Marshould County, IA

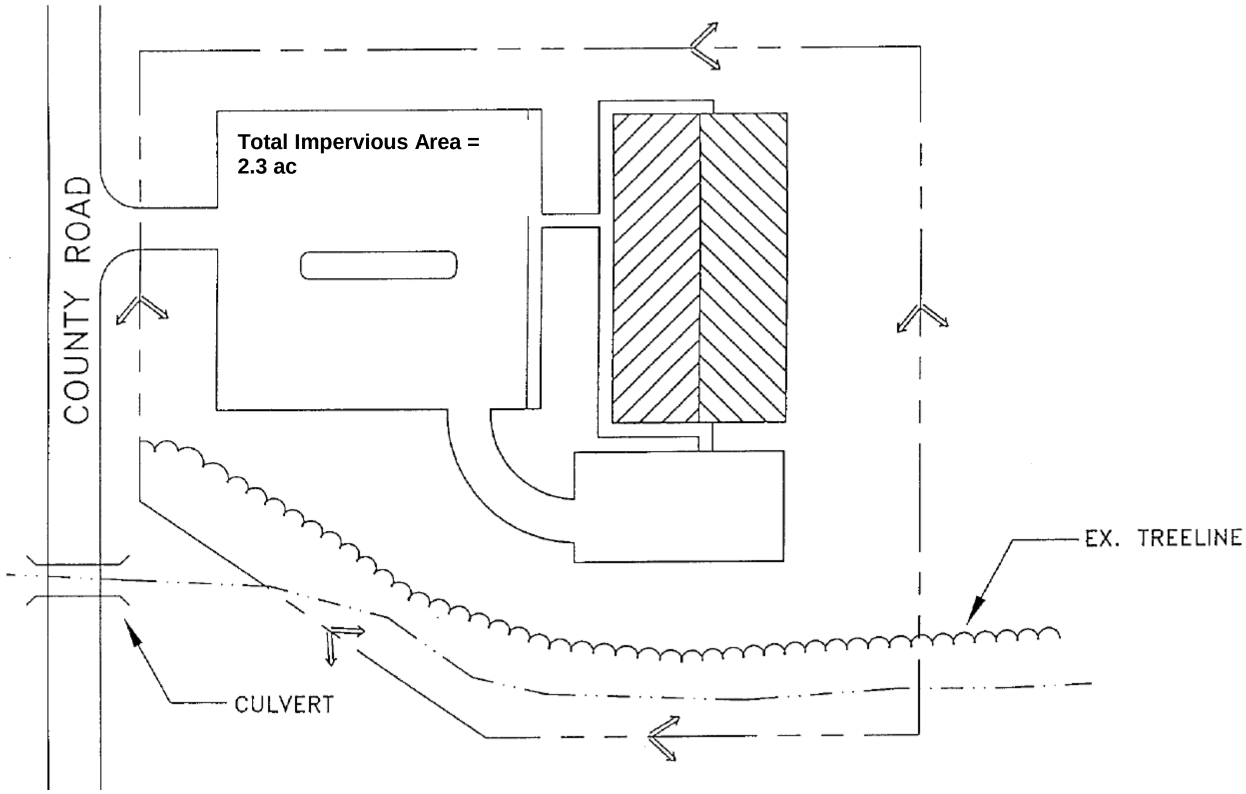


Table 5: Site data

Base Site Data	Hydrologic Data		
Total site drainage area (A) = 4 ac		Pre-	Post-
Impervious area = 2.3 ac; I = 2.2/4.0 = 57.5%	CN	68	84
Soils: HSG B (loam)	t_c	0.32	0.18

This example is focused on the design of a bioretention system to meet the water quality treatment requirements for the site. CPv and Qp are not addressed in this example other than determination for preliminary storage volume and peak discharge requirements. The CPv and Qp requirements will be handled by another set of downstream BMPs. Infiltration trenches provide water quality treatment (WQv) and recharge volume (Rev). Flows in excess of the WQv will be bypassed. The bypassed flow will be conveyed downstream and combined with other off-site flows in a conventional detention basin for Qp control.

1. **Step 1.** Compute runoff control volumes from unified sizing criteria.

   a. **Compute WQv:**
      Rv = 0.05 + (42.6)(0.009) = 0.43
      Runoff, Q_a = (1.25 in)(0.43) = 0.54 inches

WQv = (1.25 in)(Rv)(A)/12
= (1.25)(0.43)(6)(1 ft/12 in)(43,560 ft^2/ac)
= 11,706 ft^3 = 0.269 ac-ft

b. **Compute the channel protection volume (CPv):**

1) CPv is provided by 24-hour extended detention of the 1-year, 24-hour duration rainfall event. Use WINTR-55 method to (Section 2C-5) to determine the pre- and post-development peak discharges for the 1-year, 5-year, 10-year, 25-year, and 100-year 24-hour return period events. Summary of WINTR-55 data and results are provided in Table 5.

Condition	CN	Q_{1-yr}		Q_{5-yr}	Q_{10-yr}	Q_{25-yr}	Q_{100-yr}
		inches	cfs	cfs	cfs	cfs	cfs
Pre-developed	57	0.038	0.08	3.31	5.27	8.29	13.41
Post-developed	75	0.581	4.11	13.33	16.98	22.02	29.78

2) Procedure for determining the CPv using WINTR-55 methods is discussed in Sections 2B-1 and 2C-6; using results in Table 5 summary for 1-year post-developed condition:

q_u = 754 csm/in
T(extended detention time) = 24 hrs for CPv

Knowing qu and T, find qo/qi for the Type 2 Rainfall using Figure 1 in Section 2C-6:

From Figure 1 (plot of qo/qi vs. qu): qo/qi = 0.025

For a Type 11 rainfall distribution,

$Vs/Vr = 0.683 – 1.43(qo/qi) + 1.64 (qo/qi)^2 – 0.804 (q0/qi)^3$ **Equation 4**

Where Vs is the channel protection storage (CPv, and Vr equals the volume of runoff in inches.

Vs/Vr = 0.648

Therefore, Vs = CPv = (0.648)(0.581 inches)(1/12)(6 acres) = 0.188 ac-ft = **8,200 ft^3**

c. **Compute the overbank flood protection volume (Q_{p10}).** For this site, assume the post-development peak for the Q_5 through Q_{25} must be controlled to the pre-development levels. For example, the post-development Q_{10} of 17 cfs must be attenuated to the pre-development Q_{10} of 5.27 cfs.

q_i = 17 cfs q_o = 5.27 cfs q_o / q_i = 0.31

$Vs/Vr = 0.683 – 1.43(qo/qi) + 1.64 (qo/qi)^2 – 0.804 (qo/qi)^3$

Vs/Vr = 0.374

For 10-year control for a developed CN of 75, where the P10 is 4.7 inches and the 10-year runoff (Qa) is 2.205 inches:

Vs = Q_{p10} = (0.374)(2.205)(1/12)(6 acres) = **0.412 ac-ft = 17,961 ft^3**

(Note: The Qp_{25} would be computed in the same manner.)

Also note the procedure used above for calculating Vs/Vr is for preliminary storage calculations. At final design, a full reservoir routing will be completed to confirm the level of control with the outlet structure and final basin elevation/storage configuration. WINTR-55 can be used for completing a reservoir routing. The storage basin is considered a “reach” in the TR-20 routing procedure, and an initial primary spillway can be sized in this manner. WINTR-55 uses the storage-indication method for the pond routing.

d. **Determine the safe conveyance of the 100-yr design storm.** At final design, determine that the discharge conveyance channel is adequate to convey the 100-year event and discharge to the adjacent receiving stream channel, or provide additional storage in the detention structure used for CPv and Qpv.

2. **Step 2.** Determine if the development site and conditions are appropriate for use of bioretention area. Site specific data: Existing ground elevation at the facility location is 926 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 913 feet and underlying soil is loam (ML). Adjacent creek invert is at 912 feet.

3. **Step 3.** Confirm local design criteria and applicability. There are no additional local criteria that must be met for this design.

4. **Step 4.** Compute WQv peak discharge (Qwq). The procedure for determining the Qwq is covered in Section 2C-6. Since this structure will operate as an online facility, a flow diversion structure will not be used and the Qwq is not needed.

5. **Step 5.** Size flow diversion structure, if needed. Bioretention areas can be either online or off-line. Online facilities are generally sized to receive, but not necessarily treat, the 25-year event. Off-line facilities are designed to receive a more or less exact flow rate through a weir, channel, manhole, flow splitter, etc. This facility is situated to receive direct runoff from grass areas and parking lot curb openings and piping for the 25-year event (22 cfs), and no special flow diversion structure is incorporated.

6. **Step 6.** Determine size of bioretention ponding/filter area.

   $A_f = (WQv)\ (d_f)/[\ (k)\ (h_f + d_f)\ (t_f)]$

   where:
   A_f = surface area of filter bed (ft^2)
   d_f = filter bed depth (ft); 4 ft used in this design includes 18 inches of aggregate base, plus 30 inches of engineered media (sand + compost + loam topsoil)
   k = coefficient of permeability of filter media (ft/day) (Use 0.5 ft/day)
   h_f = average height of water above filter bed (ft); ½ of the design ponding depth. A ponding depth of 9 inches is used for this design.
   t_f = design filter bed drain time (days) (48 hours is recommended)

   $A_f = (11{,}706\ ft^3)(4\ ft)\ /\ [(0.5\ ft/day)(4.5\ in/12 + 4\ ft)(2\ days)$

   $A_f =$ **10,703 ft^2**

7. **Step 7.** Set design elevations and dimensions of facility. Assume a roughly 2:1 rectangular shape. Given a filter area requirement of 10,703 ft^2. If the L=2W, then L=146 ft and W will be 74 ft for a total area of LW (146 x 74) or 10,804 ft^2. See Figure 8. A more linear configuration is accomplished by setting the width equal to 30 ft and providing an overall length of 356 ft. The total area can also be divided into multiple cells, such as three cells at 30 ft wide and 120 ft long.

   Set top of facility at 924 feet, with the berm at 926 feet. The facility is 4 feet deep, which will provide 7 feet of separation distance (unsaturated zone) above the seasonally high water table. See Figure 9 for a typical section of the facility.

8. **Step 8.** Design conveyance to facility (off-line systems). This facility is not designed as an off-line system.

9. **Step 9.** Design pre-treatment. Provide pre-treatment with a grass filter strip to convey sheet flow from the pavement area and contributing pervious areas. A minimum filter strip width of 15 ft is provided.

10. **Step 10.** Size subdrain area. Base subdrain design on 10% of the A_f or 1,070 ft^2. Use 6-inch perforated plastic pipes surrounded by a 3-foot-wide gravel bed, 8-feet on center. The subdrain piping is set up off the bottom of the aggregate bed distance equal to the expected Rev volume. The subdrains are connected to a header pipe to convey the underflow to a downstream final conveyance. See Figures 8 and 9. (1070 ft^2)/3 ft per foot of subdrain = 356 ft, say 360 feet of perforated subdrain. For the three-cell configuration above, each cell would have 120 feet of perforated subdrain along its entire length.

11. **Step 11.** Design emergency overflow. The parking area, curb, and gutter are sized to convey the 25-year event to the facility. Should filtering rates become reduced due to facility age or poor maintenance, an overflow weir is provided to pass the 25-year event. Size this weir with 6 inches of head, using the weir equation:

    $Q = CLH^{3/2}$
    where:
    C = 2.65 (smooth crested grass weir)
    Q = 22 cfs
    H = 6 inches

    Solve for L: $L = Q / [(C)(H^{3/2})]$ or $(22.0 \text{ cfs}) / [(2.65)(.5)^{1.5}] = 23.5\text{-ft}$ (Use 24 ft)

    Outlet protection in the form of riprap or a plunge pool/stilling basin should be provided to ensure non-erosive velocities. See Figures 8 and 9.

12. **Step 12.** Prepare vegetation and landscaping plan. Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Select species locations (i.e., on center planting distances) so species will not “shade out” one another. Do not plant trees and shrubs with extensive root systems near pipe work.

Figure 8: Site plan for bioretention facility

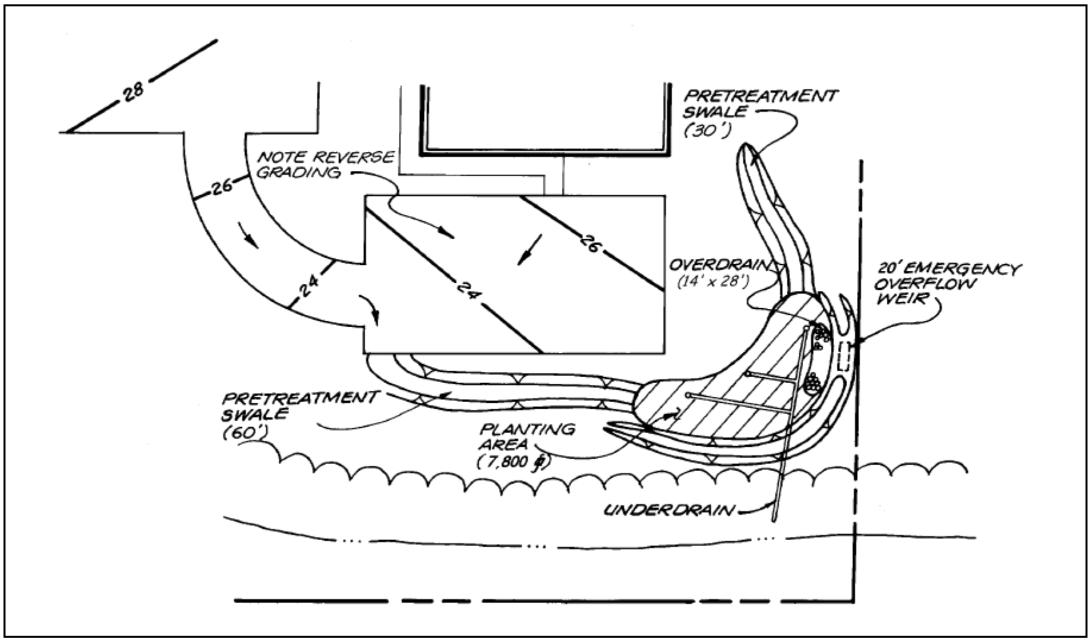


Figure 9: Profile of bioretention area

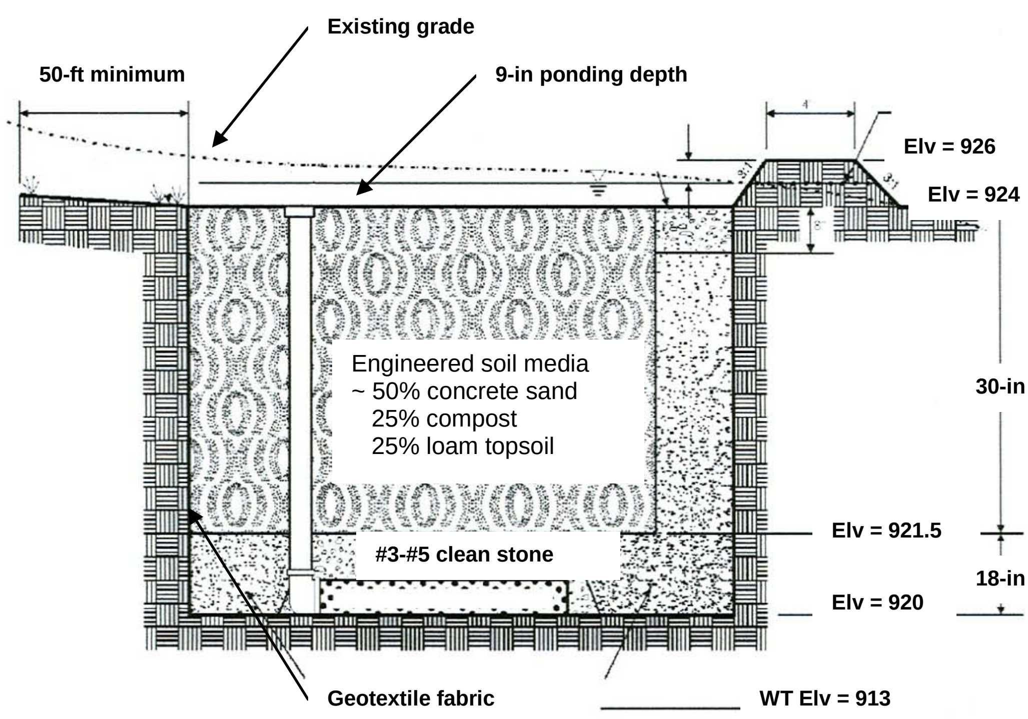


Table 5: WINTR-55 site data description and analysis results

--- Identification Data ---

User: SEJ   Date: 12/28/2006
Project: Bucketsville Recreation Center   Units: English
SubTitle: **Predeveloped**   Area Units: Acres
State: Iowa
County: Marshould
Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Bioretention _pre.w55

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
DA-1		Outlet	6	57	.328

Total area: 6 (ac)

------ Storm Data -------

Rainfall Depth by Rainfall Return Period

0.3-Yr (in)	1-Yr (in)	2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	100-Yr (in)
1.25*	2.38	3.2	4.1	4.7	5.5	6.7

* 1.25 inches is the WQv design storm depth

Storm Data Source: User-provided custom storm data (Section 2C-2) Bulletin 71, Table 2.
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

-------Sub-Area Land Use and Curve Number Details------

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1	Meadow -cont. grass (non grazed)	B	4	58
	Woods (good)	B	2	55
	Total Area / Weighted Curve Number		6	**57**

------Sub-Area Time of Concentration Details-------

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Travel Velocity (ft/sec)	Time (hr)
DA-1							
SHEET	100	0.0150	0.240				0.267
SHOULDOW	500	0.0200	0.050				0.061
			Time of Concentration				**0.328**

Pre-development runoff and peak discharge from TR-20 summary in WINTR-55

Storm	P	Runoff, Qa	Peak Discharge, Qp	Unit peak discharge, q_u	Total Runoff Volume
	inches	inches	ft^3/sec	csm	ft^3
1-yr	2.38	0.038	0.08	9.01	828
2-yr	3.2	0.038	1.05	112.17	828
5-yr	4.1	0.661	3.31	353.05	14,396
10-yr	4.7	0.948	5.27	561.84	20,647
25-yr	5.5	1.38	8.29	883.98	30,056
100-yr	6.7	2.12	13.41	1430.17	46,174

--- Identification Data ---

User: SEJ Date: 12/28/2006
Project: Bucketsville Recreation Center Units: English
SubTitle: **Post-developed** Area Units: Acres
State: Iowa
County: Marshould
Filename: C:\Documents and Settings\Stephen\Application Data\WinTR-55\Bioretention _post.w55

----- Sub-Area Data -----

Name	Description	Reach	Area(ac)	RCN	Tc
DA-1		Outlet	6	75	.228

Total area: 6 (ac)

------- Storm Data --------

Rainfall Depth by Rainfall Return Period

0.3-Yr (in)	1-Yr (in)	2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	100-Yr (in)
1.25	2.38	3.2	4.1	4.7	5.5	6.7

Storm Data Source: User-provided custom storm data (Section 2C-2) Bulletin 71, Table 2.
Rainfall Distribution Type: Type II
Dimensionless Unit Hydrograph: <standard>

----------Sub-Area Land Use and Curve Number Details--------

Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
DA-1				
	Open space; grass cover > 75% (good)	B	1.44	61
	Paved parking lots, roofs, driveways	B	2.56	98
	Woods (good)	B	2.00	55
	Total Area / Weighted Curve Number		6.00	75

--------Sub-Area Time of Concentration Details-------

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
DA-1							
SHEET	50	0.0150	0.240				0.153
SHOULDOW	600	0.0200	0.050				0.073
CHANNEL	50					7.250	0.002
				Time of Concentration			**0.228**

Post-development runoff and peak discharge from TR-20 summary in WINTR55

Storm	P	Runoff, Qa	Peak Discharge, Qi	Peak discharge Qi	Unit peak discharge, q_u	Total Runoff Volume
	inches	inches	ft^3/sec	csm	csm/in	ft^3
1-yr	2.38	0.581	4.11	437.81	754	12,654
2-yr	3.2	1.092	8.21	875.10	801	23,784
5-yr	4.1	1.739	13.33	1421.37	817	37,875
10-yr	4.7	2.205	16.98	1810.27	821	48,025
25-yr	5.5	2.858	22.02	2347.89	821	62,290
100-yr	6.7	3.883	29.78	3174.9	818	84,572