Chapter 4
Treatment BMPs

Contents

Tables

1.0 Overview

Treatment BMPs in Volume 3

- Grass Swale
- Grass Buffer
- Bioretention (Rain Garden)[1]
- Green Roof
- Extended Detention Basin
- Retention Pond
- Sand Filter Basin
- Constructed Wetland Pond
- Constructed Wetland Channel
- Permeable Pavement Systems
- Underground Practices

[1]Also known as Porous Landscape Detention

UDFCD has established design criteria, procedures, and details for a number of BMPs providing treatment of post-construction urban runoff. Additionally, general guidance has been developed and included for green roofs and underground BMPs. As discussed in Chapter 2, BMPs provide treatment through a variety of hydrologic, physical, biological, and chemical processes. The functions provided by BMPs may include volume reduction, treatment and slow release of the water quality capture volume (WQCV), and combined water quality/flood detention. Ideally, site designs will include a variety of source control and treatment BMPs combined in a "treatment train" that controls pollutants at their sources, reduces runoff volumes, and treats pollutants in runoff. Sites that are well designed for treatment of urban runoff will include all of the steps in the Four Step Process discussed in Chapter 1.

Building upon concepts and procedures introduced in Chapters 1 through 3, this chapter provides design procedures for treatment BMPs. Table 4-1 provides a qualitative overview of key aspects of the post-construction treatment BMPs included in this chapter. The table includes the degree to which the BMP is able to provide various functions, general effectiveness for treating targeted pollutants and other considerations such as life cycle costs. The table indicates which BMPs provide a conveyance function or a WQCV function. This distinction is important because not all treatment BMPs provide the WQCV. Wherever practical, combinations of BMPs in a treatment train approach are recommended. For example, BMPs that provide sedimentation functions can potentially improve the lifespan and reduce the maintenance frequency of filtration-oriented BMPs when the two BMPs are paired in series. Table 4-1 is based on best professional judgment from experiences in the Denver area along with data from the International Stormwater BMP Database (www.bmpdatabase.org) and is intended for general guidance only. Specific BMP designs and site-specific conditions may result in performance that differs from the general information provided in the table. In the case of underground and proprietary BMPs, wide variations in unit treatment processes make it difficult to provide generalized characterizations. Additionally, with regard to pollutant removal, in some cases, BMPs may be able to reduce pollutant concentrations, but this does not necessarily mean that the BMPs are able to treat runoff to numeric stream standards. For example, various studies have indicated that bioretention and retention pond BMPs may be able to reduce fecal indicator bacteria in urban runoff, but not necessarily meet instream primary contact recreational standards (WWE and Geosyntec 2010).

After reviewing physical site constraints, treatment objectives, master plans, and other factors, the designer can select the BMPs for implementation at the site and complete the engineering calculations and specifications for the selected BMPs. This chapter provides Fact Sheets for treatment BMPs that can be used in conjunction with the WQCV and volume reduction calculations in Chapter 3 in order to properly size and design the BMPs for the site. For new developments and significant redevelopments, designers should provide treatment of the WQCV with a slow release designed in accordance with criteria for the selected BMP. Additionally, sites that drain to impaired or sensitive receiving waters or that include onsite operations requiring additional treatment may need to implement measures that go beyond the minimum criteria provided in the Fact Sheets in this chapter.

2.0 Treatment BMP Fact Sheets

Fact sheets for each treatment BMP are provided as stand-alone sections of this chapter. The Fact Sheets are numbered with a "T" designation, indicating "Treatment" BMP. Fact Sheets typically include the following information:

- **Description**: Provides a basic description of the BMP.
- **Site Selection**: Identifies site-specific factors that affect the appropriateness of the BMP for the site.
- **Designing for Maintenance**: Identifies maintenance-related factors that should be considered during the BMP selection and design phase.
- **Design Procedure and Criteria:** Provides quantitative procedures and criteria for BMP design.
- **Construction Considerations**: Identifies construction-phase related factors that can affect long-term performance of the BMP.
- **Design Example**: Provides a design example corresponding to the UDFCD design spreadsheets accompanying this manual.

Designers should review each section of the Fact Sheet because successful long-term performance of the BMP includes all of these considerations, not simply the design procedure itself. Additionally, some Fact Sheets include call-out boxes with supplemental information providing design tips or other practical guidance that can enhance the benefits and performance of the BMP.

As part of the 2010 update of this manual, underground BMPs were added as treatment BMPs. UDFCD does not provide endorsement or approval of specific practices; instead, guidance is provided identifying when use of underground BMPs may be considered and the minimum criteria that should be met when site constraints do not enable aboveground treatment of runoff or when underground devices are used to provide pretreatment for site-specific or watershed-specific purposes.

Table 4-1. General Overview of Treatment BMPs Included in Volume 3

Overview	Grass Swale	Grass Buffer	Bioretention (Rain Garden)	Green Roof[5]	Extended Detention Basin	Sand Filter	Retention Pond	Constructed Wetland Pond	Constructed Wetland Channel	Permeable Pavement	Underground BMPs
Functions											
LID/Volume Red.	Yes	Yes	Yes	Yes	Somewhat	Yes	Somewhat	Somewhat	Somewhat	Yes	Variable
WQCV Capture	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Variable
WQCV+Flood Control	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Variable
Fact Sheet Includes EURV Guidance	No	No	No	No	Yes	No	Yes	Yes	No	No	No
Typical Effectiveness for Targeted Pollutants[3]											
Sediment/Solids	Good	Good	Very Good[1]	Unknown	Good	Very Good[1]	Very Good	Very Good	Unknown	Very Good[1]	Variable
Nutrients	Moderate	Moderate	Moderate	Unknown	Moderate	Good	Moderate	Moderate	Unknown	Good	Variable
Total Metals	Good	Good	Good	Unknown	Moderate	Good	Moderate	Good	Unknown	Good	Variable
Bacteria	Poor	Poor	Moderate	Unknown	Poor	Moderate	Moderate	Poor	Moderate	Unknown	Variable
Other Considerations											
Life-cycle Costs[4]	Low	Low	Moderate	Unknown	Moderate	Moderate	Moderate	Moderate	Low	High[2]	Moderate

[1] Not recomended for watersheds with high sediment yields (unless pretreatment is provided).

[2] Does not consider the life cycle cost of the conventional pavement that it replaces.

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

[5] Water quality data for green roofs are not yet robust enough to provide meaningful conclusions about pollutant removal. By reducing volume, green roofs have the de facto capability to reduce pollutant loads; however, on a concentration basis, more data is needed to better define effectiveness.

3.0 References

Wright Water Engineers and Geosyntec Consultants. 2010. *International Stormwater Best Management Practices Database Pollutant Category Summary: Fecal Indicator Bacteria.* Prepared for WERF, FHWA and EWRI-ASCE.

Description

Grass buffers are densely vegetated strips of grass designed to accept sheet flow from upgradient development. Properly designed grass buffers play a key role in LID, enabling infiltration and slowing runoff. Grass buffers provide filtration (straining) of sediment. Buffers differ from swales in that they are designed to accommodate overland sheet flow rather than concentrated or channelized flow.

Photograph GB-1. A flush curb allows roadway runoff to sheet flow through the grass buffer. Flows are then further treated by the grass swale. Photo courtesy of Muller Engineering.

Site Selection

Grass buffers can be incorporated into a wide range of development settings. Runoff can be directly accepted from a parking lot, roadway, or the roof of a structure, provided the flow is distributed in a uniform manner over the width of the buffer. This can be achieved through the use of flush curbs, slotted curbs, or level spreaders where needed. Grass buffers are often used in conjunction with grass swales. They are well suited for use in riparian zones to assist in stabilizing channel banks adjacent to major drainageways and receiving waters. These areas can also sometimes serve multiple functions such as recreation.

Hydrologic Soil Groups A and B provide the best infiltration capacity for grass buffers. For Type C and D soils, buffers still serve to provide filtration (straining) although infiltration rates are lower.

Grass Buffer	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs	Low

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design the following should be considered to ensure ease of maintenance over the long-term:

- Where appropriate (where vehicle safety would not be impacted), install the top of the buffer 1 to 3 inches below the adjacent pavement so that growth of vegetation and accumulation of sediment at the edge of the strip does not prevent runoff from entering the buffer. Alternatively, a sloped edge can be used adjacent to vehicular traffic areas.
- Amend soils to encourage deep roots and reduce irrigation requirements, as well as promote infiltration.

- Design and adjust the irrigation system (temporary or permanent) to provide water in amounts appropriate for the selected vegetation. Irrigation needs will change from month to month and year to year.
- Protect the grass buffer from vehicular traffic when using this BMP adjacent to roadways. This can be done with a slotted curb (or other type of barrier) or by constructing a reinforced grass shoulder (see Fact Sheet T-10.5).

Benefits

- Filters (strains) sediment and trash.
- Reduces directly connected impervious area. (See Chapter 3 for quantifying benefits.)
- Can easily be incorporated into a treatment train approach.
- Provides green space available for multiple uses including recreation and snow storage.
- Straightforward maintenance requirements when the buffer is protected from vehicular traffic.

Limitations

- Frequently damaged by vehicles when adjacent to roadways and unprotected.
- A thick vegetative cover is needed for grass buffers to be effective.
- Nutrient removal in grass buffers is typically low.
- High loadings of coarse solids, trash, and debris require pretreatment.
- Space for grass buffers may not be available in ultra urban areas (lot-line-to-lot-line).

Design Procedure and Criteria

The following steps outline the grass buffer design procedure and criteria. Figure GB-1 is a schematic of the facility and its components:

1. **Design Discharge**: Use the hydrologic procedures described in the *Runoff* chapter of Volume 1 to determine the 2-year peak flow rate (Q_2) of the area draining to the grass buffer.

2. **Minimum Width:** The width (W), normal to flow of the buffer, is typically the same as the contributing basin (see Figure GB-1). An exception to this is where flows become concentrated. Concentrated flows require a level spreader to distribute flows evenly across the width of the buffer. The minimum width should be:

$$W = \frac{Q_2}{0.05} \qquad \text{Equation GB-1}$$

   Where:

   W = width of buffer (ft)

   Q_2 = 2-year peak runoff (cfs)

3. **Length:** The recommended length (L), the distance along the sheet flow direction, should be a minimum of 14 feet. This value is based on the findings of Barrett et al. 2004 in *Stormwater Pollutant Removal in Roadside Vegetated Strips* and is appropriate for buffers with greater than 80% vegetative cover and slopes up to 10%. The study found that pollutant removal continues throughout a length of 14 feet. Beyond this length, a point of diminishing returns in pollutant reduction was found. It is important to note that shorter lengths or slightly steeper slopes will also provide some level of removal where site constraints dictate the geometry of the buffer.

4. **Buffer Slope:** The design slope of a grass buffer in the direction of flow should not exceed 10%. Generally, a minimum slope of 2% or more in turf is adequate to facilitate positive drainage. For slopes less than 2%, consider including an underdrain system to mitigate nuisance drainage.

5. **Flow Characteristics (sheet or concentrated)**: Concentrated flows can occur when the width of the watershed differs from that of the grass buffer. Additionally, when the product of the watershed flow length and the interface slope (the slope of the watershed normal to flow at the grass buffer) exceeds approximately one, flows may become concentrated. Use the following equations to determine flow characteristics:

Use of Grass Buffers

Sheet flow of stormwater through a grassed area provides some benefit in pollutant removal and volume reduction even when the geometry of the BMP does not meet the criteria provided in this Fact Sheet. These criteria provide a design procedure that should be used when possible; however, when site constraints are limiting, this treatment concept is still encouraged.

$$\text{Sheet Flow: } FL(SI) \leq 1$$ Equation GB-2

$$\text{Concentrated Flow: } FL(SI) > 1$$ Equation GB-3

Where:

FL = watershed flow length (ft)

SI = interface slope (normal to flow) (ft/ft)

6. **Flow Distribution:** Flows delivered to a grass buffer must be sheet flows. Slotted or flush curbing, permeable pavements, or other devices can be used to spread flows. The grass buffer should have relatively consistent slopes to avoid concentrating flows within the buffer.

A level spreader should be used when flows are concentrated. A level spreader can be a slotted drain designed to discharge flow through the slot as shown in Photo GB-2. It could be an exfiltration trench filled with gravel, which allows water to infiltrate prior to discharging over a level concrete or rock curb. There are many ways to design and construct a level spreader. They can also be used in series when the length of the buffer allows flows to re-concentrate. See Figure GB-2 for various level spreader sections.

Photograph GB-2. This level spreader carries concentrated flows into a slotted pipe encased in concrete to distribute flows evenly to the grass buffer shown left in the photo. Photo courtesy of Bill Wenk.

Photos GB-3 and GB-4 show a level spreader that includes a basin for sedimentation. Concentrated flows enter the basin via stormsewer. The basin is designed to drain slowly while overflow is spread evenly to the downstream vegetation. A small notch, orifice, or pipe can be used to drain the level spreader completely. The opening should be small to encourage frequent flows to overtop the level spreader but not so small that it is frequently clogged.

Photograph GB-3. This level spreader includes the added benefit of a sedimentation basin prior to even distribution of concentrated flows from the roadway into the grass buffer. Photo courtesy of Bill Wenk.

7. **Soil Preparation**: In order to encourage establishment and long-term health of the selected vegetation, it is essential that soil conditions be properly prepared prior to installation. Following site grading, poor soil conditions often exist. When possible, remove, strip, stockpile, and reuse on-site topsoil. If the site does not contain topsoil, the soils should be amended prior to vegetation. Typically 3 to 5 cubic yards of soil amendment (compost) per 1,000 square feet, tilled 6 inches into the soil is required in order for vegetation to thrive, as well as to enable infiltration of runoff. Additionally, inexpensive soil tests can be conducted to determine required soil amendments. (Some local governments may also require proof of soil amendment in landscaped areas for water conservation reasons.)

Photograph GB-4. Maintenance access is provided via the ramp located at the end of the basin. Photo courtesy of Bill Wenk.

8. **Vegetation:** This is the most critical component for treatment within a grass buffer. Select durable, dense, and drought tolerant grasses to vegetate the buffer. Also consider the size of the watershed as larger watersheds will experience more frequent flows. The goal is to provide a dense mat of vegetative cover. Grass buffer performance falls off rapidly as the vegetation coverage declines below 80% (Barrett et al.2004).

Turf grasses such as Kentucky bluegrass are often selected due to these qualities[1]. Dense native turf grasses may also be selected where a more natural look is desirable. Once established, these provide the benefit of lower irrigation requirements. See the *Revegetation* chapter in Volume 2 of this manual with regard to seed mix selection, planting and ground preparation. Depending on soils and anticipated flows, consider erosion control measures until vegetation has been established.

9. **Irrigation**: Grass buffers should be equipped with irrigation systems to promote establishment and survival in Colorado's semi-arid environment. Systems may be temporary or permanent, depending on the type of vegetation selected. Irrigation application rates and schedules should be developed and adjusted throughout the establishment and growing season to meet the needs of the selected plant species. Initially, native grasses require the same irrigation requirements as bluegrass. After the grass is established, irrigation requirements for native grasses can be reduced. Irrigation practices have a significant effect on the function of the grass buffer. Overwatering decreases the permeability of the soil, reducing the infiltration capacity and contributing to nuisance baseflows. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less filtering and increased susceptibility to erosion and rilling over the long term.

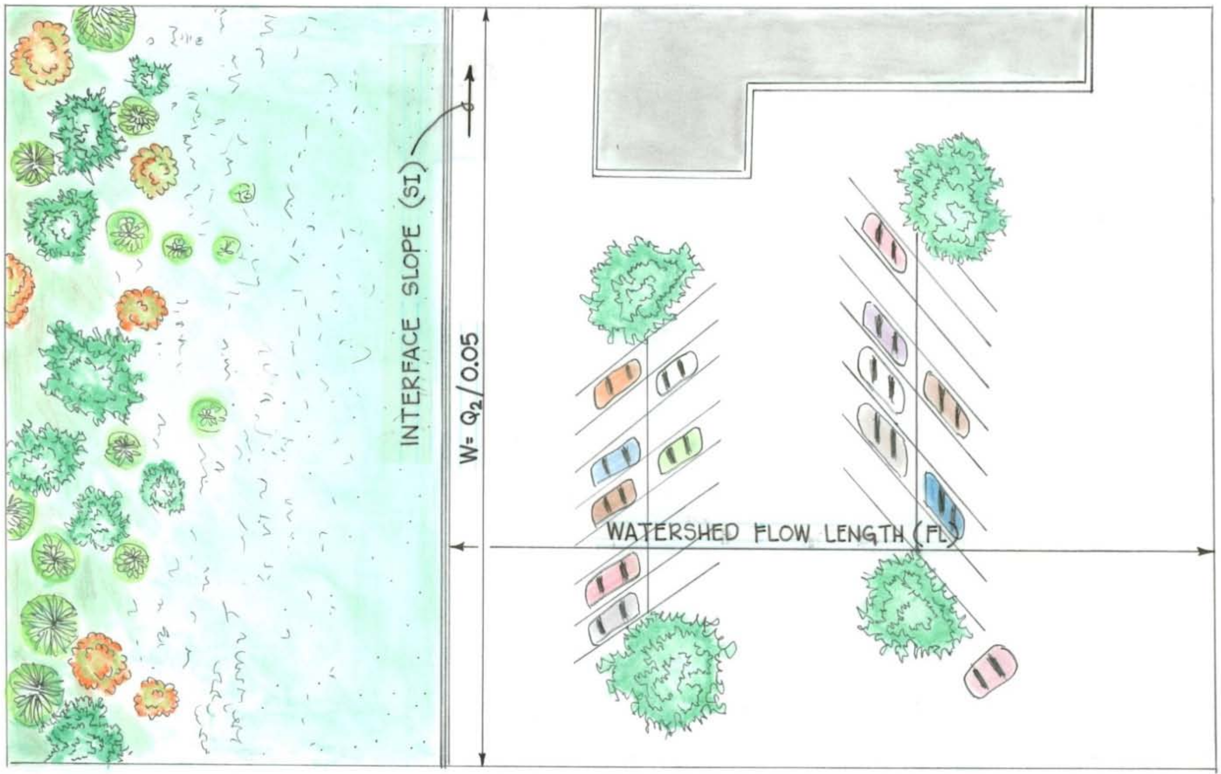
10. **Outflow Collection**: Provide a means for downstream conveyance. A grass swale can be used for this purpose, providing additional LID benefits.

Construction Considerations

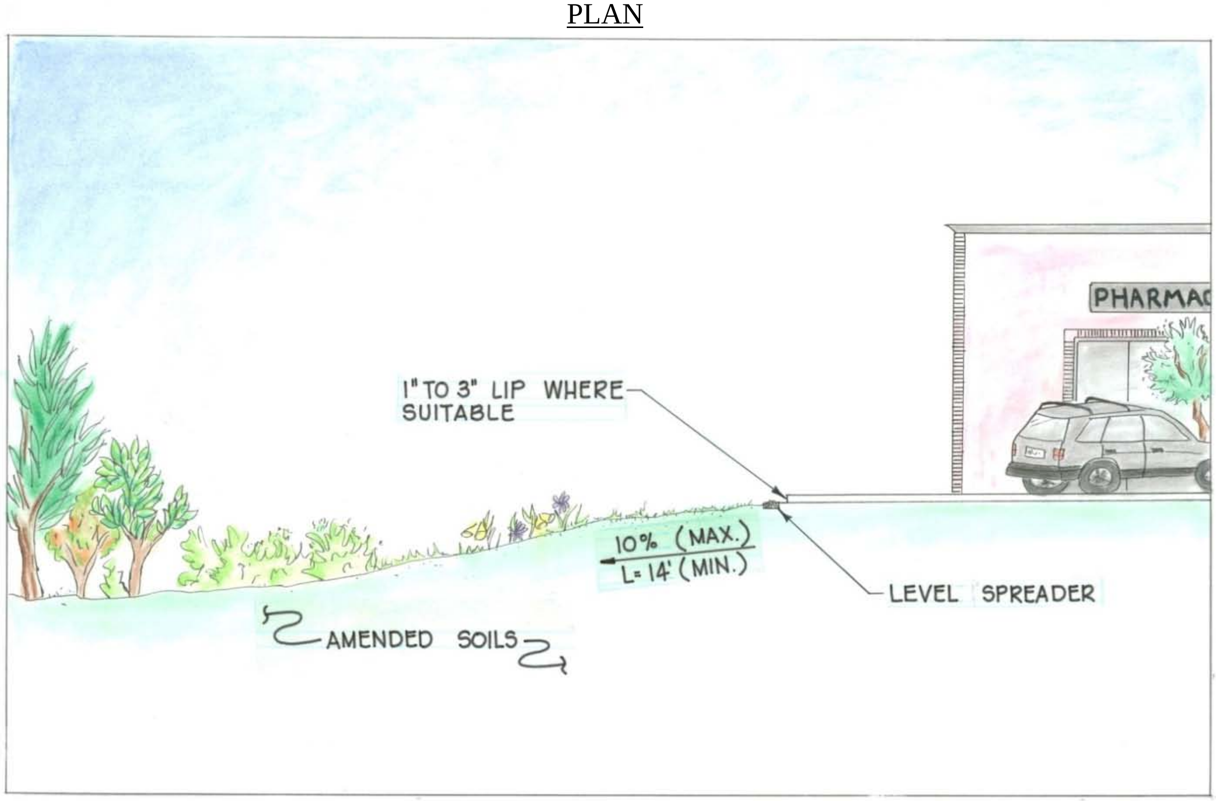
Success of grass buffers depends not only on a good design and long-term maintenance, but also on installing the facility in a manner that enables the BMP to function as designed. Construction considerations include:

- The final grade of the buffer is critical. Oftentimes, following soil amendment and placement of sod, the final grade is too high to accept sheet flow. The buffer should be inspected prior to placement of seed or sod to ensure appropriate grading.
- Perform soil amending, fine grading, and seeding only after tributary areas have been stabilized and utility work crossing the buffer has been completed.
- When using sod tiles stagger the ends of the tiles to prevent the formation of channels along the joints. Use a roller on the sod to ensure there are no air pockets between the sod and soil.
- Avoid over compaction of soils in the buffer area during construction to preserve infiltration capacities.
- Erosion and sediment control measures on upgradient disturbed areas must be maintained to prevent excessive sediment loading to grass buffer.

[1] Although Kentucky bluegrass has relatively high irrigation requirements to maintain a lush, green aesthetic, it also withstands drought conditions by going dormant. Over-irrigation of Kentucky bluegrass is a common problem along the Colorado Front Range, and it can be healthy, although less lush, with much less irrigation than is typically applied.



PLAN



PROFILE

Figure GB-1. Typical Grass Buffer Graphic by Adia Davis.

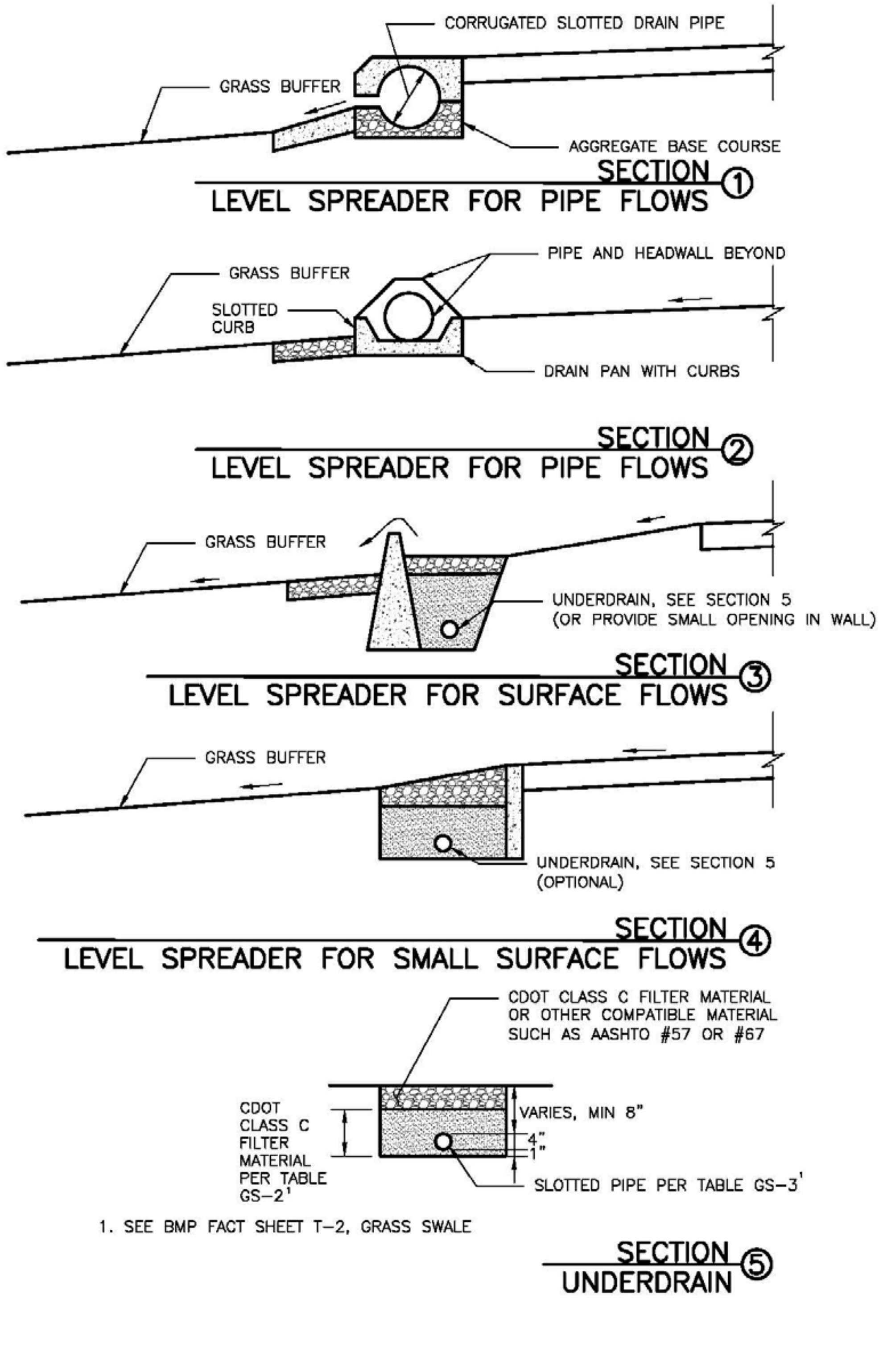


Figure GB-2. Typical Level Spreader Details

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Grass Buffer (GB)

Sheet 1 of 1

Designer: R. Dunn
Company: BMP, Inc.
Date: November 24, 2010
Project: Filing 37
Location: NE Corner of 34th Ave. and 105th St., north entrance road

1. Design Discharge A) 2-Year Peak Flow Rate of the Area Draining to the Grass Buffer	Q_2 = 5.0 cfs
2. Minimum Width of Grass Buffer	W_G = 100 ft
3. Length of Grass Buffer (14' or greater recommended)	L_G = 15 ft
4. Buffer Slope (in the direction of flow, not to exceed 0.1 ft / ft)	S_G = 0.100 ft / ft
5. Flow Characteristics (sheet or concentrated) A) Does runoff flow into the grass buffer across the entire width of the buffer? B) Watershed Flow Length C) Interface Slope (normal to flow) D) Type of Flow Sheet Flow: $F_L * S_I \leq 1$ Concentrated Flow: $F_L * S_I > 1$	Choose One: (●) Yes ( ) No F_L= 20 ft S_I= 0.020 ft / ft SHEET FLOW
6. Flow Distribution for Concentrated Flows	Choose One (●) None (sheet flow) ( ) Slotted Curbing ( ) Level Spreader ( ) Other (Explain):
7 Soil Preparation (Describe soil amendment)	Till 5 CY of compost per 1000 SF to a depth of 6 inches.
8 Vegetation (Check the type used or describe "Other")	Choose One ( ) Existing Xeric Turf Grass (●) Irrigated Turf Grass ( ) Other (Explain):
9. Irrigation (*Select None if existing buffer area has 80% vegetation AND will not be disturbed during construction.)	Choose One (●) Temporary ( ) Permanent ( ) None*
10. Outflow Collection (Check the type used or describe "Other")	Choose One (●) Grass Swale ( ) Street Gutter ( ) Storm Sewer Inlet ( ) Other (Explain):

Notes:

References

Barrett, M., Lantin, A. and S. Austrheim-Smith. 2004. *Stormwater Pollutant Removal in Roadside Vegetated Buffer Strips.* Prepared for the Transportation Research Board: Washington, DC.

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook, Vegetated Buffer Strip*.

Description

Grass swales are densely vegetated trapezoidal or triangular channels with low-pitched side slopes designed to convey runoff slowly. Grass swales have low longitudinal slopes and broad cross-sections that convey flow in a slow and shallow manner, thereby facilitating sedimentation and filtering (straining) while limiting erosion. Berms or check dams may be incorporated into grass swales to reduce velocities and encourage settling and infiltration. When using berms, an underdrain system should be provided. Grass swales are an integral part of the Low Impact Development (LID) concept and may be used as an alternative to a curb and gutter system.

Photograph GS-1. This grass swale provides treatment of roadway runoff in a residential area. Photo courtesy of Bill Ruzzo.

Site Selection

Grass swales are well suited for sites with low to moderate slopes. Drop structures or other features designed to provide the same function as a drop structures (e.g., a driveway with a stabilized grade differential at the downstream end) can be integrated into the design to enable use of this BMP at a broader range of site conditions. Grass swales provide conveyance so they can also be used to replace curb and gutter systems making them well suited for roadway projects.

Grass Swale	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs	Low
[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).	

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:

- Consider the use and function of other site features so that the swale fits into the landscape in a natural way. This can encourage upkeep of the area, which is particularly important in residential areas where a loss of aesthetics and/or function can lead to homeowners filling in and/or piping reaches of this BMP.

- Provide access to the swale for mowing equipment and design sideslopes flat enough for the safe operation of equipment.
- Design and adjust the irrigation system (temporary or permanent) to provide appropriate water for the selected vegetation.
- An underdrain system will reduce excessively wet areas, which can cause rutting and damage to the vegetation during mowing operations.
- When using an underdrain, do not put a filter sock on the pipe. This is unnecessary and can cause the slots or perforations in the pipe to clog.

Benefits

- Removal of sediment and associated constituents through filtering (straining)
- Reduces length of storm sewer systems in the upper portions of a watershed
- Provides a less expensive and more attractive conveyance element
- Reduces directly connected impervious area and can help reduce runoff volumes.

Limitations

- Requires more area than traditional storm sewers.
- Underdrains are recommended for slopes under 2%.
- Erosion problems may occur if not designed and constructed properly.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for stormwater treatment in a grass swale. Figure GS-1 shows trapezoidal and triangular swale configurations.

1. **Design Discharge**: Determine the 2-year flow rate to be conveyed in the grass swale under fully developed conditions. Use the hydrologic procedures described in the *Runoff* Chapter in Volume 1.

2. **Hydraulic Residence Time**: Increased hydraulic residence time in a grass swale improves water quality treatment. Maximize the length of the swale when possible. If the length of the swale is limited due to site constraints, the slope can also be decreased or the cross-sectional area increased to increase hydraulic residence time.

3. **Longitudinal Slope**: Establish a longitudinal slope that will meet Froude number, velocity, and depth criteria while ensuring that the grass swale maintains positive drainage. Positive drainage can be achieved with a minimum 2% longitudinal slope or by including an underdrain system (see step 8). Use drop structures as needed to accommodate site constraints. Provide for energy dissipation downstream of each drop when using drop structures.

4. **Swale Geometry**: Select geometry for the grass swale. The cross section should be either trapezoidal or triangular with side slopes not exceeding 4:1 (horizontal: vertical), preferably flatter. Increase the wetted area of the swale to reduce velocity. Lower velocities result in improved pollutant removal efficiency and greater volume reduction. If one or both sides of the grass swale are also to be used as a grass buffer, follow grass buffer criteria.

5. **Vegetation**: Select durable, dense, and drought tolerant grasses. Turf grasses, such as Kentucky bluegrass, are often selected due to these qualities[1]. Native turf grasses may also be selected where a more natural look is desirable. This will also provide the benefit of lower irrigation requirements, once established. Turf grass is a general term for any grasses that will form a turf or mat as opposed to bunch grass, which will grow in clumplike fashion. Grass selection should consider both short-term (for establishment) and long-term maintenance requirements, given that some varieties have higher maintenance requirements than others. Follow criteria in the *Revegetation* Chapter of Volume 2, with regard to seed mix selection, planting, and ground preparation.

Native grasses provide a more natural aesthetic and require less water once established.

6. **Design Velocity**: Maximum flow velocity in the swale should not exceed one foot per second. Use the Soil Conservation Service (now the NRCS) vegetal retardance curves for the Manning coefficient (Chow 1959). Determining the retardance coefficient is an iterative process that the UD-BMP workbook automates. When starting the swale vegetation from sod, curve "D" (low retardance) should be used. When starting vegetation from seed, use the "E" curve (very low vegetal retardance).

7. **Design Flow Depth**: Maximum flow depth should not exceed one foot at the 2-year peak flow rate. Check the conditions for the 100-year flow to ensure that drainage is being handled without flooding critical areas, structures, or adjacent streets.

Table GS-1. Grass Swale Design Summary for Water Quality

Design Flow	Maximum Froude Number	Maximum Velocity	Maximum Flow Depth
2-year event	0.5	1 ft/s	1 ft

Use of Grass Swales

Vegetated conveyance elements provide some benefit in pollutant removal and volume reduction even when the geometry of the BMP does not meet the criteria provided in this Fact Sheet. These criteria provide a design procedure that should be used when possible; however, when site constraints are limiting, vegetated conveyance elements designed for stability are still encouraged.

[1] Although Kentucky bluegrass has relatively high irrigation requirements to maintain a lush, green aesthetic, it also withstands drought conditions by going dormant. Over-irrigation of Kentucky bluegrass is a common problem along the Colorado Front Range. It can be healthy, although less lush, with much less irrigation than is typically applied.

8. **Underdrain:** An underdrain is necessary for swales with longitudinal slopes less than 2.0%. The underdrain can drain directly into an inlet box at the downstream end of the swale, daylight through the face of a grade control structure or continue below grade through several grade control structures as shown in Figure GS-1.

   The underdrain system should be placed within an aggregate layer. If no underdrain is required, this layer is not required. The aggregate layer should consist of an 8-inch thick layer of CDOT Class C filter material meeting the gradation in Table GS-2. Use of CDOT Class C Filter material with a slotted pipe that meets the slot dimensions provided in Table GS-3 will eliminate the need for geotextile fabrics. Previous versions of this manual detailed an underdrain system that consisted of a 3- to 4-inch perforated HDPE pipe in a one-foot trench section of AASHTO #67 coarse aggregate surrounded by geotextile fabric. If desired, this system continues to provide an acceptable alternative for use in grass swales. Selection of the pipe size may be a function of capacity or of maintenance equipment. Provide cleanouts at approximately 150 feet on center.

Table GS-2. Gradation Specifications for Class C Filter Material
(Source: CDOT Table 703-7)

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

Table GS-3. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4”	1-1/16”	0.032”	0.413”	1.90 in^2
6”	1-3/8”	0.032”	0.516”	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

9. **Soil preparation:** Poor soil conditions often exist following site grading. When the section includes an underdrain, provide 4 inches of sandy loam at the invert of the swale extending up to the 2-year water surface elevation. This will improve infiltration and reduce ponding. For all sections, encourage establishment and long-term health of the bottom and side slope vegetation by properly preparing the soil. If the existing site provides a good layer of topsoil, this should be striped, stockpiled, and then replaced just prior to seeding or placing sod. If not available at the site, topsoil can be imported or the existing soil may be amended. Inexpensive soil tests can be performed following rough grading, to determine required soil amendments. Typically, 3 to 5 cubic yards of soil amendment per 1,000 square feet, tilled 4 to 6 inches into the soil is required in order for vegetation to thrive, as well as to enable infiltration of runoff.

10. **Irrigation:** Grass swales should be equipped with irrigation systems to promote establishment and survival in Colorado's semi-arid environment. Systems may be temporary or permanent, depending on the type of grass selected. Irrigation practices have a significant effect on the function of the grass swale. Overwatering decreases the permeability of the soil, reducing the infiltration capacity of the soil and contributing to nuisance baseflows. Conversely, under watering may result in delays in establishment of the vegetation in the short term and unhealthy vegetation that provides less filtering (straining) and increased susceptibility to erosion and riling over the long term.

Construction Considerations

Success of grass swales depends not only on a good design and maintenance, but also on construction practices that enable the BMP to function as designed. Construction considerations include:

- Perform fine grading, soil amendment, and seeding only after upgradient surfaces have been stabilized and utility work crossing the swale has been completed.
- Avoid compaction of soils to preserve infiltration capacities.
- Provide irrigation appropriate to the grass type.
- Weed the area during the establishment of vegetation by hand or mowing. Mechanical weed control is preferred over chemical weed killer.
- Protect the swale from other construction activities.
- When using an underdrain, ensure no filter sock is placed on the pipe. This is unnecessary and can cause the slots or perforations in the pipe to clog.

Photograph GS-2. This community used signage to mitigate compaction of soils post-construction. Photo courtesy of Nancy Styles.

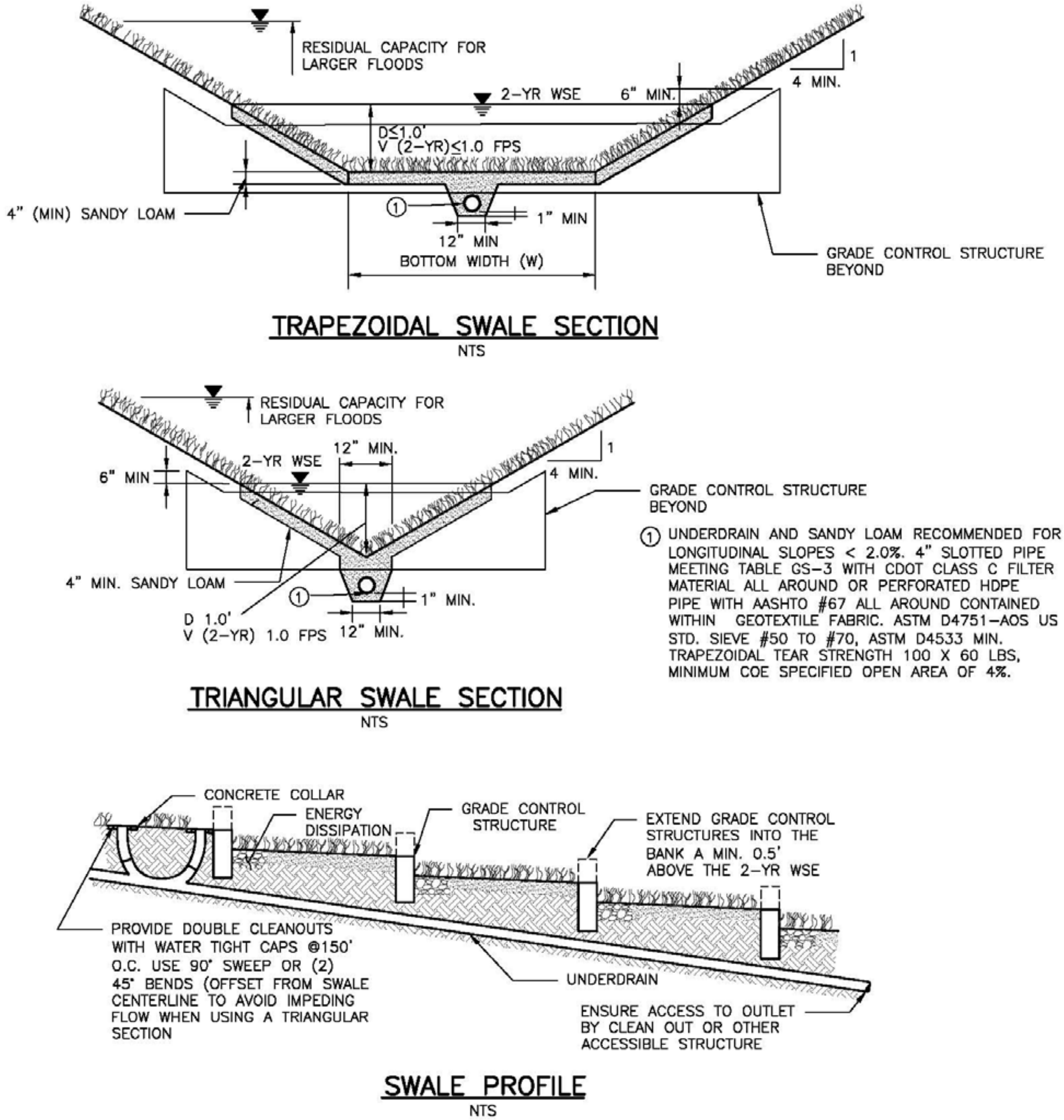


Figure GS-1. Grass Swale Profile and Sections

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Grass Swale (GS)

Sheet 1 of 1

Designer:	**M. Levine**
Company:	**BMP Inc.**
Date:	**November 24, 2010**
Project:	**Filing 30**
Location:	**Swale between north property line and 52nd Ave.**

1. Design Discharge for 2-Year Return Period	Q_2 = 4.00 cfs
2. Hydraulic Residence Time	
A) : Length of Grass Swale	L_S = 400.0 ft
B) Calculated Residence Time (based on design velocity below)	T_{HR}= 6.7 minutes
3. Longitudinal Slope (vertical distance per unit horizontal)	
A) Available Slope (based on site constraints)	S_{avail} = 0.020 ft / ft
B) Design Slope	S_D = 0.010 ft / ft
4. Swale Geometry	
A) Channel Side Slopes (Z = 4 min., horiz. distance per unit vertical)	Z = 4.00 ft / ft
B) Bottom Width of Swale (enter 0 for triangular section)	W_B = 4.00 ft
5. Vegetation	Choose One
A) Type of Planting (seed vs. sod, affects vegetal retardance factor)	○ Grass From Seed ◉ Grass From Sod
6. Design Velocity (1 ft / s maximum)	V_2 = 1.00 ft / s
7. Design Flow Depth (1 foot maximum)	D_2 = 0.62 ft
A) Flow Area	A_2 = 4.0 sq ft
B) Top Width of Swale	W_T = 9.0 ft
C) Froude Number (0.50 maximum)	F = 0.26
D) Hydraulic Radius	R_H = 0.44
E) Velocity-Hydraulic Radius Product for Vegetal Retardance	VR = 0.44
F) Manning's n (based on SCS vegetal retardance curve D for sodded grass)	n = 0.088
G) Cumulative Height of Grade Control Structures Required	H_D = 4.00 ft
8. Underdrain (Is an underdrain necessary?)	Choose One ◉ YES ○ NO — AN UNDERDRAIN IS REQUIRED IF THE DESIGN SLOPE < 2.0%
9. Soil Preparation (Describe soil amendment)	Till 5 CY of compost per 1000 SF to a depth of 6 inches.
10. Irrigation	Choose One ◉ Temporary ○ Permanent

Notes:

References

Chow, Ven Te. 1959. *Open Channel Flow*. McGraw Hill: New York, NY.

Description

A BMP that utilizes bioretention is an engineered, depressed landscape area designed to capture and filter or infiltrate the water quality capture volume (WQCV). BMPs that utilize bioretention are frequently referred to as rain gardens or porous landscape detention areas (PLDs). The term PLD is common in the Denver metropolitan area as this manual first published the BMP by this name in 1999. In an effort to be consistent with terms most prevalent in the stormwater industry, this document generally refers to the treatment process as *bioretention* and to the BMP as a *rain garden*.

Photograph B-1. This recently constructed rain garden provides bioretention of pollutants, as well as an attractive amenity for a residential building. Treatment should improve as vegetation matures.

The design of a rain garden may provide detention for events exceeding that of the WQCV. There are generally two ways to achieve this. The design can provide the flood control volume above the WQCV water surface elevation, with flows bypassing the filter usually by overtopping into an inlet designed to restrict the peak flow for a larger event (or events). Alternatively, the design can provide and slowly release the flood control volume in an area downstream of one or more rain gardens.

This infiltrating BMP requires consultation with a geotechnical engineer when proposed near a structure. A geotechnical engineer can assist with evaluating the suitability of soils, identifying potential impacts, and establishing minimum distances between the BMP and structures.

Bioretention (Rain Garden)	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Moderate
Total Metals	Good
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Terminology

The term *bioretention* refers to the treatment process although it is also frequently used to describe a BMP that provides biological uptake and retention of the pollutants found in stormwater runoff. This BMP is frequently referred to as a *porous landscape detention (PLD) area* or *rain garden*.

Benefits

- Bioretention uses multiple treatment processes to remove pollutants, including sedimentation, filtering, adsorption, evapotranspiration, and biological uptake of constituents.
- Volumetric stormwater treatment is provided within portions of a site that are already reserved for landscaping.
- There is a potential reduction of irrigation requirements by taking advantage of site runoff.

Limitations

- Additional design and construction steps are required for placement of any ponding or infiltration area near or upgradient from a building foundation and/or when expansive (low to high swell) soils exist. This is discussed in the design procedure section.
- In developing or otherwise erosive watersheds, high sediment loads can clog the facility.

Site Selection

Bioretention can be provided in a variety of areas within new developments, or as a retrofit within an existing site. This BMP allows the WQCV to be treated within areas designated for landscape (see design step 7 for appropriate vegetation). In this way, it is an excellent alternative to extended detention basins for small sites. A typical rain garden serves a tributary area of one impervious acre or less, although they can be designed for larger tributary areas. Multiple installations can be used within larger sites. Rain gardens should not be used when a baseflow is anticipated. They are typically small and installed in locations such as:

- Parking lot islands
- Street medians
- Landscape areas between the road and a detached walk
- Planter boxes that collect roof drains

Bioretention requires a stable watershed. Retrofit applications are typically successful for this reason. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils, consider another BMP or provide pretreatment before runoff from these areas reaches the rain garden. The surface of the rain garden should be flat. For this reason, rain gardens can be more difficult to incorporate into steeply sloping terrain; however, terraced applications of these facilities have been successful in other parts of the country.

When bioretention (and other BMPs used for infiltration) are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. Oversaturated subgrade soil underlying a structure can cause the structure to settle or result in moisture-related problems. Wetting of expansive soils or bedrock can cause swelling, resulting in structural movements. A geotechnical engineer should evaluate the potential impact of the BMP on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. Additional minimum requirements include:

- In locations where subgrade soils do not allow infiltration, the growing medium should be underlain by an underdrain system.
- Where infiltration can adversely impact adjacent structures, the filter layer should be underlain by an underdrain system designed to divert water away from the structure.
- In locations where potentially expansive soils or bedrock exist, placement of a rain garden adjacent to structures and pavement should only be considered if the BMP includes an underdrain designed to divert water away from the structure and is lined with an essentially impermeable geomembrane liner designed to restrict seepage.

Designing for Maintenance

Recommended maintenance practices for all BMPs are in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:

- Do not put a filter sock on the underdrain. This is not necessary and can cause the BMP to clog.
- The best surface cover for a rain garden is full vegetation. Do not use rock mulch within the rain garden because sediment build-up on rock mulch tends to inhibit infiltration and require frequent cleaning or removal and replacement. Wood mulch handles sediment build-up better than rock mulch; however, wood mulch floats and may clog the overflow depending on the configuration of the outlet, settle unevenly, or be transported downstream. Some municipalities may not allow wood mulch for this reason.
- Consider all potential maintenance requirements such as mowing (if applicable) and replacement of the growing medium. Consider the method and equipment for each task required. For example, in a large rain garden where the use of hand tools is not feasible, does the shape and configuration of the rain garden allow for removal of the growing medium using a backhoe?
- Provide pre-treatment when it will reduce the extent and frequency of maintenance necessary to maintain function over the life of the BMP. For example, if the site is larger than 2 impervious acres, prone to debris or the use of sand for ice control, consider a small forebay.
- Make the rain garden as shallow as possible. Increasing the depth unnecessarily can create erosive side slopes and complicate maintenance. Shallow rain gardens are also more attractive.
- Design and adjust the irrigation system (temporary or permanent) to provide appropriate water for the establishment and maintenance of selected vegetation.

Is Pretreatment Needed

Designing the inflow gutter to the rain garden at a minimal slope of 0.5% can facilitate sediment and debris deposition prior to flows entering the BMP. Be aware, this will reduce maintenance of the BMP, but may require more frequent sweeping of the gutter to ensure that the sediment does not impede flow into the rain garden.

Design Procedure and Criteria

The following steps outline the design procedure and criteria, with Figure B-1 providing a corresponding cross-section.

1. **Basin Storage Volume**: Provide a storage volume based on a 12-hour drain time.

    - Find the required WQCV (watershed inches of runoff). Using the imperviousness of the tributary area (or effective imperviousness where LID elements are used upstream), use Figure 3-2 located in Chapter 3 of this manual to determine the WQCV based on a 12-hour drain time.
    - Calculate the design volume as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right]A \qquad \text{Equation B-1}$$

    Where:

    V= design volume (ft^3)

A = area of watershed tributary to the rain garden (ft^2)

2. **Basin Geometry:** A maximum WQCV ponding depth of 12 inches is recommended to maintain vegetation properly. Provide an inlet or other means of overflow at this elevation. Depending on the type of vegetation planted, a greater depth may be utilized to detain larger (more infrequent) events. The bottom surface of the rain garden, also referred to here as the filter area, should be flat. Sediment will reside on the filter area of the rain garden; therefore, if the filter area is too small, it may clog prematurely. Increasing the filter area will reduce clogging and decrease the frequency of maintenance. Equation B-2 provides a **minimum** filter area allowing for some of the volume to be stored beyond the area of the filter (i.e., above the sideslopes of the rain garden).

   Note that the total surcharge volume provided by the design must also equal or exceed the design volume. Use vertical walls or slope the sides of the basin to achieve the required volume. Use the rain garden growing medium described in design step 3 only on the filter area because this material is more erosive than typical site soils. Sideslopes should be no steeper than 4:1 (horizontal:vertical).

$$A \geq (2/3)\frac{\mathrm{V}}{1\ \mathrm{foot}} \qquad \text{Equation B-2}$$

   Where:

   V= design volume (ft^3)

   A = minimum filter area (flat surface area) (ft^2)

   The one-foot dimension in this equation represents the maximum recommended WQCV depth in the rain garden. The actual design depth may differ; however, it is still appropriate to use a value of one foot when calculating the minimum filter area.

3. **Growing Medium:** For partial and no infiltration sections, provide a minimum of 18 inches of growing medium to enable establishment of the roots of the vegetation (see Figure B-1). Previous versions of this manual recommended a mix of 85% sand and 15% peat (by volume). Peat is a material that typically requires import to Colorado and mining peat has detrimental impacts to the environment (Mazerolle 2002). UDFCD partnered with the University of Colorado to perform a study to find a sustainable material to replace peat. The study was successful in finding a replacement that performed well for filtering ability, clogging characteristics, as well as seed germination. This mixture consists of 85% coarse sand and a 15% compost/shredded paper mixture (by volume). The study used thin (approximately 1/4 inch) strips of loosely packed shredded paper mixed with an equal volume of compost. Based on conversations with local suppliers, compost

Benefits of Shredded Paper in Rain Garden Growing Media

- Shredded paper, similar to other woody materials, captures nutrients from the compost and slowly releases them as the paper decomposes. Compost alone will leach more nutrients than desired.
- As the paper decomposes, nutrients stored in the material are available to the vegetation.
- Paper temporarily slows the infiltration rate of the media and retains moisture, providing additional time for a young root system to benefit from moisture in the growing media.

containing shredded paper is not an uncommon request, although not typically provided in the proportions recommended in this BMP Fact Sheet. Compost suppliers have access to shredded paper through document destruction companies and can provide a mixture of Class 1 compost and shredded paper. The supplier should provide the rain garden compost mixture premixed with coarse sand. On-site mixing is not recommended.

Rain Garden Compost Mixture (by volume)

- 50% Class 1 STA registered compost (approximate bulk density 1000 lbs/CY)
- 50% loosely packed shredded paper (approximate bulk density 50 to 100 lbs/CY)

When using diamond cut shredded paper or tightly packed paper, use the bulk densities provided to mix by weight.

Rain Garden Growing Medium

The supplier should premix the rain garden compost mixture (above) with coarse sand, in the following proportions, prior to delivery to the site:

- 15% rain garden compost mixture described above (by volume)
- 85% coarse sand (either Class C Filter Material per Table B-2 or sand meeting ASTM C-33) (by volume)

Table B-1 provides detailed information on Class 1 compost. Be aware, regular testing is not required to allow a compost supplier to refer to a product as a specific STA class. However, regular testing is required and performed through the United States Compost Council (USCC) Seal of Testing Assurance (STA) Program to be a STA registered compost. To ensure Class 1 characteristics, look for a Class 1 STA registered compost.

Other Rain Garden Growing Medium Amendments

The growing medium described above is designed for filtration ability, clogging characteristics, and vegetative health. It is important to preserve the function provided by the rain garden growing medium when considering additional materials for incorporation into the growing medium or into the standard section shown in Figure B-1. When desired, amendments may be included to improve water quality or to benefit vegetative health as long as they do not add nutrients, pollutants, or modify the infiltration rate. For example, a number of products, including steel wool, capture and retain dissolved phosphorus (Erickson 2009). When phosphorus is a target pollutant, proprietary materials with similar characteristics may be considered. Do not include amendments such as top soil, sandy loam, and additional compost.

Full Infiltration Sections

A full infiltration section retains the WQCV onsite. For this section, it is not necessary to use the prescribed rain garden growing medium. Amend the soils to provide adequate nutrients to establish vegetation. Typically, 3 to 5 cubic yards of soil amendment (compost) per 1,000 square feet, tilled 6 inches into the soil, is required for vegetation to thrive. Additionally, inexpensive soil tests can be conducted to determine required soil amendments. (Some local governments may also require proof of soil amendment in landscaped areas for water conservation reasons.)

Table B-1. Class 1 Compost

Characteristic	**Criteria**
Minimum Stability Indicator (Respirometry)	Stable to Very Stable
Maturity Indicator Expressed as Ammonia N / Nitrate N Ratio	< 4
Maturity Indicator Expressed as Carbon to Nitrogen Ratio	< 12
Maturity Indicator Expressed as Percentage of Germination/Vigor	80+ / 80+
pH – Acceptable Range	6.0 – 8.4
Soluble Salts – Acceptable Range (1:5 by weight)	0 – 5 mmhos/cm
Testing and Test Report Submittal Requirement	Seal of Testing Assurance (STA)/Test Methods for the Examination of Composting and Compost (TMECC)
Chemical Contaminants	Equal or better than US EPA Class A Standard, 40 CFR 503.13, Tables 1 & 3 levels
Pathogens	Meet or exceed US EPA Class A standard, 40 CFR 503.32(a) levels

4. **Underdrain System**: Underdrains are often necessary and should be provided if infiltration tests show percolation drawdown rates slower than 2 times the rate needed to drain the WQCV over 12 hours, or where required to divert water away from structures as determined by a professional engineer. Percolation tests should be performed or supervised by a licensed professional engineer and conducted at a minimum depth equal to the bottom of the bioretention facility. Additionally, underdrains are required where impermeable membranes are used. Similar to the terminology used for permeable pavement sections, there are three basic sections for bioretention facilities:

    - **No-Infiltration Section:** This section includes an underdrain and an impermeable liner that does not allow for any infiltration of stormwater into the subgrade soils. It is appropriate to use a no-infiltration system when either of the following is true:

        - Land use or activities could contaminate groundwater when stormwater is allowed to infiltrate, or

        - The BMP is located over potentially expansive soils or bedrock and is adjacent (within 10 feet) to structures.

    - **Partial Infiltration Section:** This section does not include an impermeable liner and, therefore; allows for some infiltration. Stormwater that does not infiltrate will be collected and removed by an underdrain system.

- **Full Infiltration Section:** This section is designed to infiltrate all of the water stored into the subgrade below. Overflows are managed via perimeter drainage to a downstream conveyance element. UDFCD recommends a minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours.

When using an underdrain system, provide a control orifice sized to drain the design volume in 12 hours or more (see Equation B-3). Use a minimum orifice size of 3/8 inch to avoid clogging. This will provide detention and slow release of the WQCV, providing water quality benefits and reducing impacts to downstream channels. Space underdrain pipes a maximum of 20 feet on center. Provide cleanouts to enable maintenance of the underdrain. Cleanouts can also be used to conduct an inspection (by camera) of the underdrain system to

Important Design Considerations

The potential for impacts to adjacent buildings can be significantly reduced by locating the bioretention area at least 10 feet away from the building, beyond the limits of backfill placed against the building foundation walls, and by providing positive surface drainage away from the building.

The BMP should not restrict surface water from flowing away from the buildings. This can occur if the top of the perimeter wall for the BMP impedes flow away from the building.

Always adhere to the slope recommendations provided in the geotechnical report. In the absence of a geotechnical report, the following general recommendations should be followed for the first 10 feet from a building foundation.

1) Where feasible, provide a slope of 10% for a distance of 10 feet away from a building foundation.

2) In locations where non-expansive soil or bedrock conditions exist, the slope for the surface within 10 feet of the building should be at least 5% away from the building for unpaved (landscaped) surfaces.

3) In locations where potentially expansive soil or bedrock conditions exist, the design slope should be at least 10% away from the building for unpaved (landscaped) surfaces.

4) For paved surfaces, a slope of at least 2% away from the building is adequate. Where accessibility requirements or other design constraints do not apply, use an increased minimum design slope for paved areas (2.5% where non-expansive soil or bedrock conditions exist).

ensure that the pipe was not crushed or disconnected during construction.

Calculate the diameter of the orifice for a 12-hour drain time using Equation B-3 (Use a minimum orifice size of 3/8 inch to avoid clogging.):

$$D_{12\text{ hour drain time}} = \sqrt{\frac{V}{1414\, y^{0.41}}}$$ Equation B-3

Where:

D = orifice diameter (in)

y = distance from the lowest elevation of the storage volume (i.e., surface of the filter) to the center of the orifice (ft)

V = volume (WQCV or the portion of the WQCV in the rain garden) to drain in 12 hours (ft^3)

In previous versions of this manual, UDFCD recommended that the underdrain be placed in an aggregate layer and that a geotextile (separator fabric) be placed between this aggregate and the growing medium. This version of the manual replaces that section with materials that, when used together, eliminate the need for a separator fabric.

The underdrain system should be placed within an 6-inch-thick section of CDOT Class C filter material meeting the gradation in Table B-2. Use slotted pipe that meets the slot dimensions provided in Table B-3.

Table B-2. Gradation Specifications for CDOT Class C Filter Material
(Source: CDOT Table 703-7)

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4”)	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

Table B-3. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4”	1-1/16”	0.032”	0.413”	1.90 in^2
6”	1-3/8”	0.032”	0.516”	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

5. **Impermeable Geomembrane Liner and Geotextile Separator Fabric:** For no-infiltration sections, install a 30 mil (minimum) PVC geomembrane liner, per Table B-5, on the bottom and sides of the basin, extending up at least to the top of the underdrain layer. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration. The geomembrane should be field-seamed using a dual track welder, which allows for non-destructive testing of almost all field seams. A small amount of single track and/or adhesive seaming should be allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs. The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. Place CDOT Class B geotextile separator fabric above the geomembrane to protect it from being punctured during the placement of the filter material above the liner. If the subgrade contains angular rocks or other material that could puncture the geomembrane, smooth-roll the surface to create a suitable surface. If smooth-rolling the surface does not provide a suitable surface, also place the separator fabric between the geomembrane and the underlying subgrade. This should only be done when necessary because fabric placed under the geomembrane can increase seepage losses through pinholes or other geomembrane defects. Connect the geomembrane to perimeter concrete walls around the basin perimeter, creating a watertight seal between the geomembrane and the walls using a continuous batten bar and anchor connection (see Figure B-3). Where the need for the impermeable membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Use watertight PVC boots for underdrain pipe penetrations through the liner (see Figure B-2).

Table B-4. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction
[2] As measured in accordance with ASTM D 4632

Table B-5. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m^2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

6. **Inlet/Outlet Control:** In order to provide the proper drain time, the bioretention area can be designed without an underdrain (provided it meets the requirements in step 4) or the outlet can be controlled by an orifice plate. Equation B-3 is a simplified equation for sizing an orifice plate for a 12-hour drain time.

Photograph B-2. The curb cut shown allows flows to enter this rain garden while excess flows bypass the facility. Note: trees are not recommended inside a rain garden

7. How flow enters and exits the BMP is a function of the overall drainage concept for the site. Inlets at each rain garden may or may not be needed. Curb cuts can be designed to both allow stormwater into the rain garden as well as to provide release of stormwater in excess of the WQCV. Roadside rain gardens located on a steep site might pool and overflow into downstream cells with a single curb cut, level spreader, or outlet structure located at the most downstream cell. When selecting the type and location of the outlet structure, ensure that the runoff will not short-circuit the rain garden. This is a frequent problem when using a curb inlet located outside the rain garden for overflow.

   For rain gardens with concentrated points of inflow, provide for energy dissipation. When rock is used, provide separator fabric between the rock and growing medium to minimize subsidence.

8. **Vegetation:** UDFCD recommends that the filter area be vegetated with drought tolerant species that thrive in sandy soils. Table B-6 provides a suggested seed mix for sites that will not need to be irrigated after the grass has been established.

   All seed must be well mixed and broadcast, followed by hand raking to cover seed and then mulched. Hydromulching can be effective for large areas. Do not place seed when standing water or snow is present or if the ground is frozen. Weed control is critical in the first two to three years, especially when starting with seed.

   Do not use conventional sod. Conventional sod is grown in clay soil that will seal the filter area, greatly reducing overall function of the BMP. Several successful local installations have started with seed.

Designing for Flood Protection

Provide the WQCV in rain gardens that direct excess flow into to a landscaped area providing the flood control volume. Design the flood control outlet to meter the major event (100-year event) and slowly release the difference in volume between the EURV and the WQCV. (This assumes that the runoff treated by the rain gardens is routed directly into the outlet or infiltrates.) Providing treatment in this manner will reduce inundation in the landscaped area to a few times per year, resulting in an area better suited for multipurpose uses.

When using an impermeable liner, select plants with diffuse (or fibrous) root systems, not taproots. Taproots can damage the liner and/or underdrain pipe. Avoid trees and large shrubs that may interfere with restorative maintenance. Trees and shrubs can be planted outside of the area of growing medium. Use a cutoff wall to ensure that roots do not grow into the underdrain or place trees and shrubs a conservative distance from the underdrain.

9. **Irrigation:** Provide spray irrigation at or above the WQCV elevation or place temporary irrigation on top of the rain garden surface. Do not place sprinkler heads on the flat surface. Remove temporary irrigation when vegetation is established. If left in place this will become buried over time and will be damaged during maintenance operations.

   Irrigation schedules should be adjusted during the growing season to provide the minimum water necessary to maintain plant health and to maintain the available pore space for infiltration.

Table B-6. Native Seed Mix for Rain Gardens [2]

Common Name	**Scientific Name**	**Variety**	**PLS[2] lbs per Acre**	**Ounces per Acre**
Sand bluestem	Andropogon hallii	Garden	3.5	
Sideoats grama	Bouteloua curtipendula	Butte	3	
Prairie sandreed	Calamovilfa longifolia	Goshen	3	
Indian ricegrass	Oryzopsis hymenoides	Paloma	3	
Switchgrass	Panicum virgatum	Blackwell	4	
Western wheatgrass	Pascopyrum smithii	Ariba	3	
Little bluestem	Schizachyrium scoparium	Patura	3	
Alkali sacaton	Sporobolus airoides		3	
Sand dropseed	Sporobolus cryptandrus		3	
Pasture sage[1]	Artemisia frigida			2
Blue aster[1]	Aster laevis			4
Blanket flower[1]	Gaillardia aristata			8
Prairie coneflower[1]	Ratibida columnifera			4
Purple prairieclover[1]	Dalea (Petalostemum) purpurea			4
Sub-Totals:			27.5	22
Total lbs per acre:			**28.9**	

[1] Wildflower seed (optional) for a more diverse and natural look.
[2] PLS = Pure Live Seed.

Aesthetic Design

In addition to providing effective stormwater quality treatment, rain gardens can be attractively incorporated into a site within one or several landscape areas. Aesthetically designed rain gardens will typically either reflect the character of their surroundings or become distinct features within their surroundings. Guidelines for each approach are provided below.

Reflecting the Surrounding

- Determine design characteristics of the surrounding. This becomes the context for the drainage improvement. Use these characteristics in the structure.
- Create a shape or shapes that "fix" the forms surrounding the improvement. Make the improvement part of the existing surrounding.
- The use of material is essential in making any new improvement an integral part of the whole. Select materials that are as similar as possible to the surrounding architectural/engineering materials. Select materials from the same source if possible. Apply materials in the same quantity, manner, and method as original material.
- Size is an important feature in seamlessly blending the addition into its context. If possible, the overall size of the improvement should look very similar to the overall sizes of other similar objects in the improvement area.
- The use of the word texture in terms of the structure applies predominantly to the selection of plant material. The materials used should as closely as possible, blend with the size and texture of other plant material used in the surrounding. The plants may or may not be the same, but should create a similar feel, either individually or as a mass.

Reflective Design

A reflective design borrows the characteristics, shapes, colors, materials, sizes and textures of the built surroundings. The result is a design that fits seamlessly and unobtrusively in its environment.

Creating a Distinct Feature

Designing the rain garden as a distinct feature is limited only by budget, functionality, and client preference. There is far more latitude in designing a rain garden that serves as a distinct feature. If this is the intent, the main consideration beyond functionality is that the improvement create an attractive addition to its surroundings. The use of form, materials, color, and so forth focuses on the improvement itself and does not necessarily reflect the surroundings, depending on the choice of the client or designer.

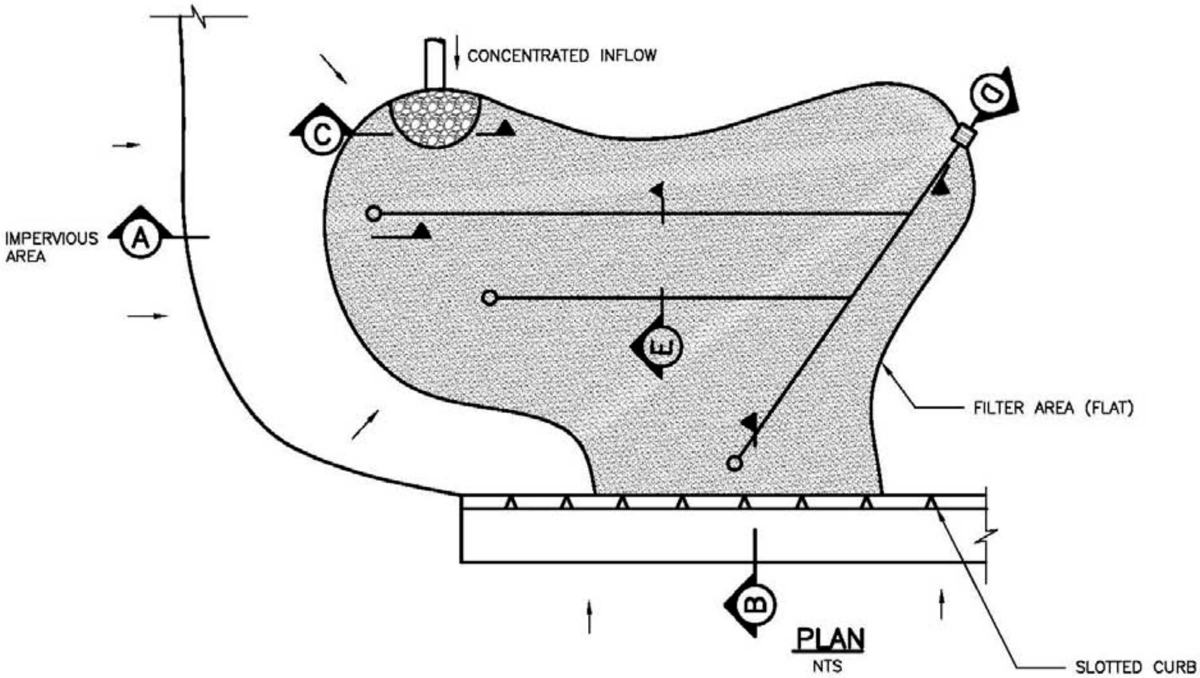
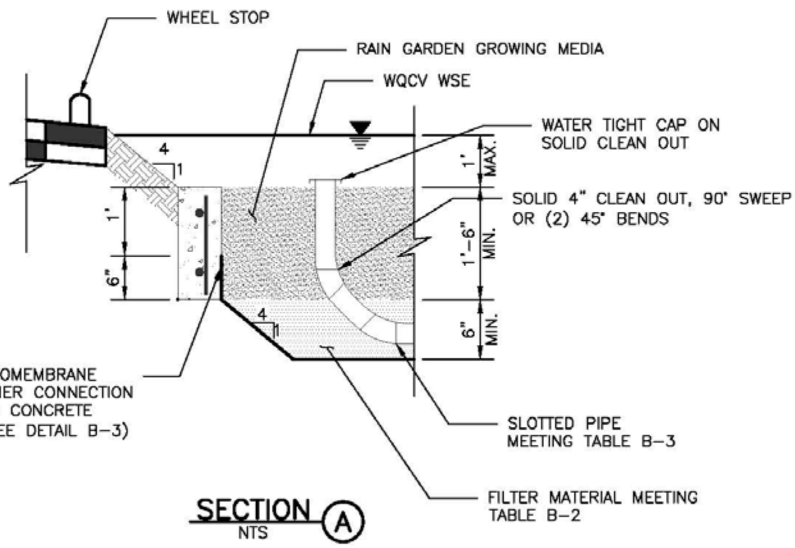
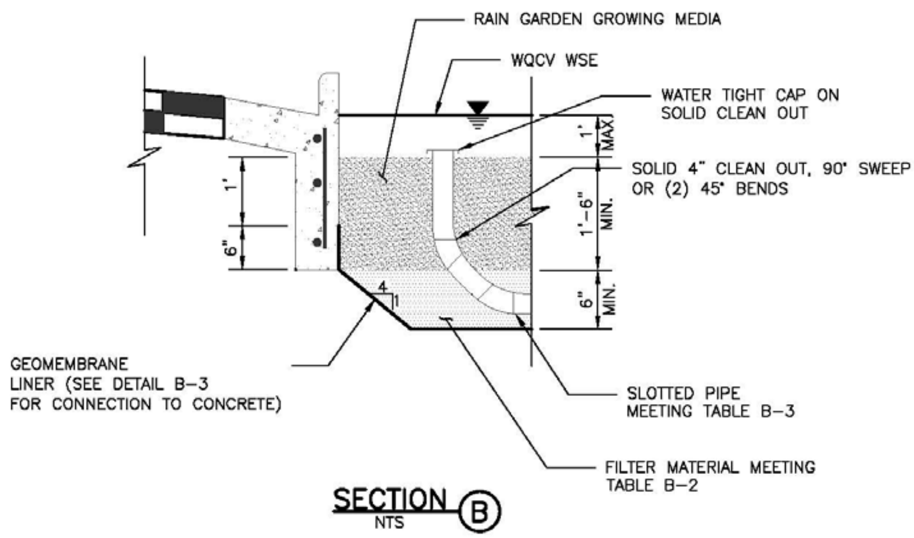
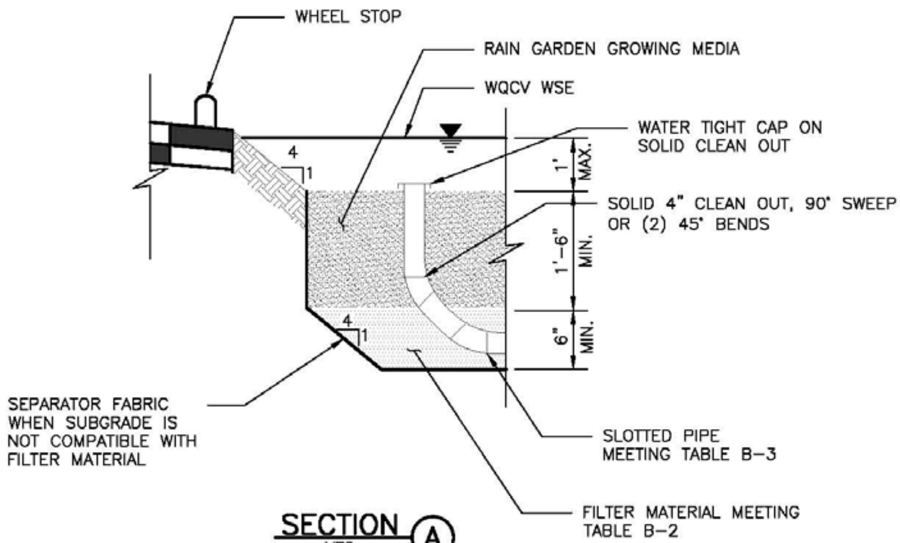


Figure B-1 – Typical Rain Garden Plan and Sections

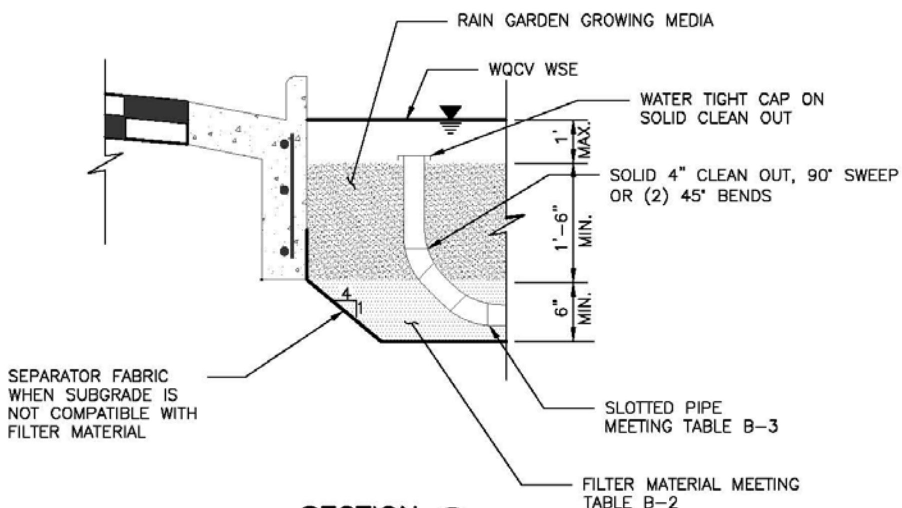




NO–INFILTRATION SECTIONS



SECTION (A)
NTS



SECTION (B)
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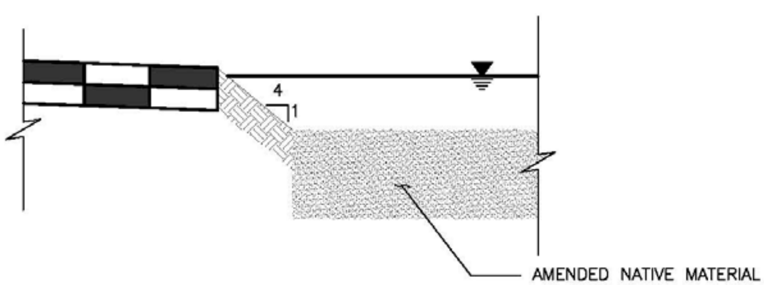
PARTIAL INFILTRATION SECTIONS



SECTION (A)
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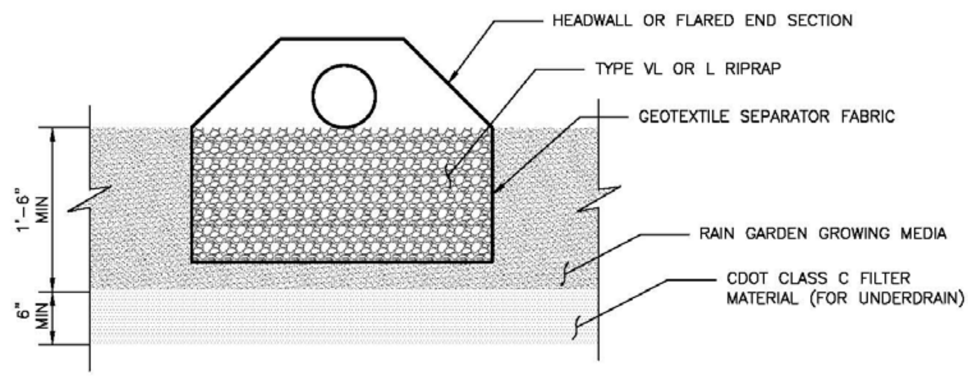
FULL INFILTRATION SECTION



SECTION (C)
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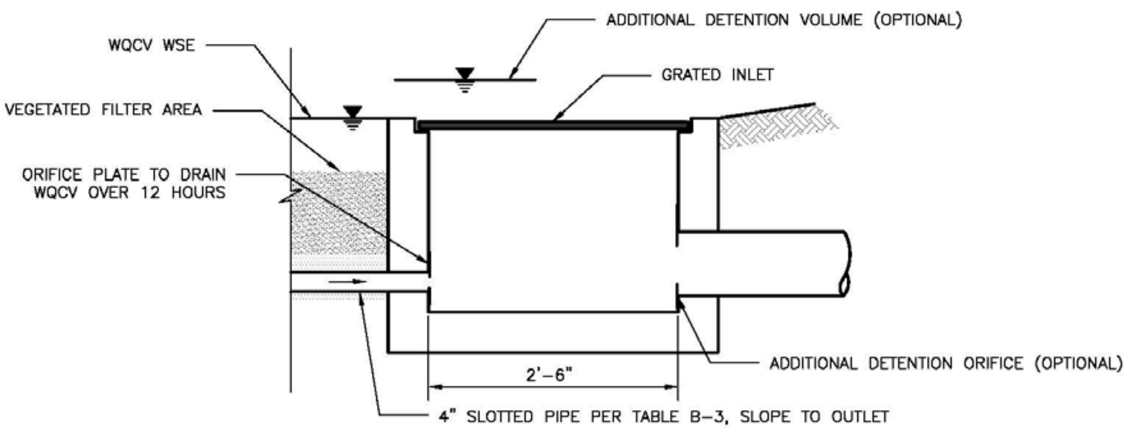

SECTION (D)
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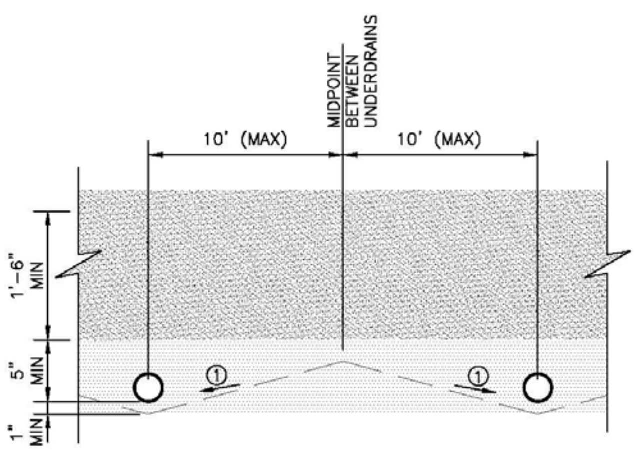


① SLOPE (STRAIGHT GRADE) SUBGRADE (2–10%) TO UNDERDRAIN TO REDUCE SATURATED SOIL CONDITIONS BETWEEN STORM EVENTS (OPTIONAL)

SECTION (E)
NTS

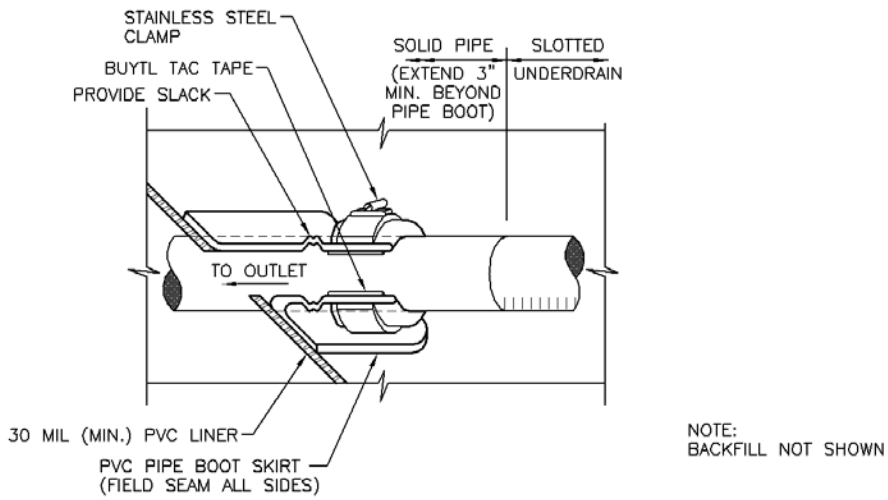


Figure B-2. Geomembrane Liner/Underdrain Penetration Detail

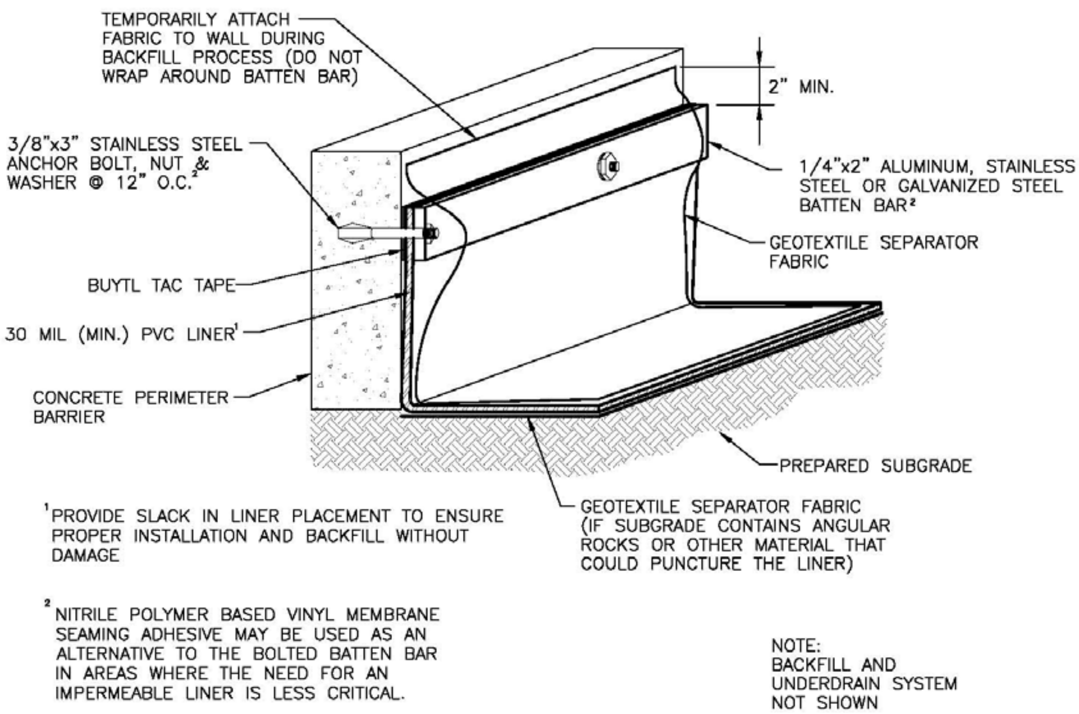


Figure B-3. Geomembrane Liner/Concrete Connection Detail

Construction Considerations

Proper construction of rain gardens involves careful attention to material specifications, final grades, and construction details. For a successful project, implement the following practices:

- Protect area from excessive sediment loading during construction. This is the most common cause of clogging of rain gardens. The portion of the site draining to the rain garden must be stabilized before allowing flow into the rain garden. This includes completion of paving operations.
- Avoid over compaction of the area to preserve infiltration rates (for partial and full infiltration sections).
- Provide construction observation to ensure compliance with design specifications. Improper installation, particularly related to facility dimensions and elevations and underdrain elevations, is a common problem with rain gardens.
- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner.
- Provide necessary quality assurance and quality control (QA/QC) when constructing an impermeable geomembrane liner system, including but not limited to fabrication testing, destructive and non-destructive testing of field seams, observation of geomembrane material for tears or other defects, and air lace testing for leaks in all field seams and penetrations. QA/QC should be overseen by a professional engineer. Consider requiring field reports or other documentation from the engineer.
- Provide adequate construction staking to ensure that the site properly drains into the facility, particularly with respect to surface drainage away from adjacent buildings. Photo B-3 and Photo B-4 illustrate a construction error for an otherwise correctly designed series of rain gardens.

Photograph B-3. Inadequate construction staking may have contributed to flows bypassing this rain garden.

Photograph B-4. Runoff passed the upradient rain garden, shown in Photo B-3, and flooded this downstream rain garden.

Construction Example

Photograph B-5. Rain garden is staked out at the low point of the parking area prior to excavation.

Photograph B-6. Curb and gutter is installed. Flush curbs with wheel stops or a slotted curb could have been used in lieu of the solid raised curb with concentrated inflow.

Photograph B-7. The aggregate layer is covered with a geotextile and growing media. This photo shows installation of the geotextile to separate the growing media from the aggregate layer below. Cleanouts for the underdrain system are also shown. Note: The current design section does not require this geotextile.

Photograph B-8. Shrubs and trees are placed outside of the ponding area and away from geotextiles.

Photograph B-9. This photo was taken during the first growing season of this rain garden. Better weed control in the first two to three years will help the desired vegetation to become established.

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Rain Garden (RG)

Sheet 1 of 2

Designer:	J. Tann
Company:	BMP, Inc.
Date:	November 24, 2010
Project:	Shops at 56th
Location:	NW corner of 56th Ave. and 27th St.

1. Basin Storage Volume	
A) Effective Imperviousness of Tributary Area, I_a (100% if all paved and roofed areas upstream of rain garden)	I_a = 95.0 %
B) Tributary Area's Imperviousness Ratio ($i = I_a/100$)	i = 0.950
C) Water Quality Capture Volume (WQCV) for a 12-hour Drain Time (WOCV= $0.8 * (0.91* i^3 - 1.19 * i^2 + 0.78 * i)$	WQCV = 0.36 watershed inches
D) Contributing Watershed Area (including rain garden area)	Area = 32,000 sq ft
E) Water Quality Capture Volume (WQCV) Design Volume Vol = (WQCV / 12) * Area	V_{WQCV} = 954 cu ft
F) For Watersheds Outside of the Denver Region, Depth of Average Runoff Producing Storm	d_6 = ____ in
G) For Watersheds Outside of the Denver Region, Water Quality Capture Volume (WQCV) Design Volume	$V_{WQCV\ OTHER}$ = ____ cu ft
H) User Input of Water Quality Capture Volume (WQCV) Design Volume (Only if a different WQCV Design Volume is desired)	$V_{WQCV\ USER}$ = ____ cu ft
2. Basin Geometry	
A) WQCV Depth (12-inch maximum)	D_{WQCV} = 12 in
B) Rain Garden Side Slopes (Z = 4 min., horiz. dist per unit vertical) (Use "0" if rain garden has vertical walls)	Z = 0.00 ft / ft
C) Mimimum Flat Surface Area	A_{Min} = 636 sq ft
D) Actual Flat Surface Area	A_{Actual} = 955 sq ft
E) Area at Design Depth (Top Surface Area)	A_{Top} = 955 sq ft
F) Rain Garden Total Volume (V_T= ((A_{Top} + A_{Actual}) / 2) * Depth)	V_T= 955 cu ft
3. Growing Media	Choose One ◉ 18" Rain Garden Growing Media ○ Other (Explain):
4. Underdrain System	
A) Are underdrains provided?	Choose One ◉ YES ○ NO
B) Underdrain system orifice diameter for 12 hour drain time	
i) Distance From Lowest Elevation of the Storage Volume to the Center of the Orifice	y = 2.7 ft
ii) Volume to Drain in 12 Hours	Vol_{12} = 954 cu ft
iii) Orifice Diameter, 3/8" Minimum	D_O = 0.67 in

Design Procedure Form: Rain Garden (RG)	
	Sheet 2 of 2
Designer: J. Tann	
Company: BMP, Inc.	
Date: November 24, 2010	
Project: Shops at 56th	
Location: NW corner of 56th Ave. and 27th St.	
5. Impermeable Geomembrane Liner and Geotextile Separator Fabric A) Is an impermeable liner provided due to proximity of structures or groundwater contamination?	Choose One ○ YES ○ NO
6. Inlet / Outlet Control A) Inlet Control	Choose One ○ Sheet Flow- No Energy Dissipation Required ◉ Concentrated Flow- Energy Dissipation Provided
7. Vegetation	Choose One ◉ Seed (Plan for frequent weed control) ○ Plantings ○ Sand Grown or Other High Infiltration Sod
8. Irrigation A) Will the rain garden be irrigated?	Choose One ◉ YES ○ NO NO SPRINKLER HEADS ON THE FLAT SURFACE
Notes:	

References

Erickson, Andy. 2009. Field Applications of Enhanced Sand Filtration. University of Minnesota *Stormwater Management Practice Assessment Project Update*. http://wrc.umn.edu.

Guo, James C.Y., PhD, Anu Ramaswami, PhD, and Shauna M. Kocman, PhD Candidate. 2010. *Sustainable Design of Urban Porous Landscape Detention Basin.* University of Colorado Denver

Mazzerolle, Marc J. 2002. *Detrimental Effects of Peat Mining on Amphibian Abundance and Species Richness in Bogs.* Elsevier Science Limited.

Description

Photograph GR-1. EPA Region 8 building in downtown Denver. Photo courtesy of Weston Solutions.

Green roofs could be defined as "contained" living systems on top of human-made structures. This green space can be below, at, or above grade involving systems where plants are not planted in the ground (Source: Green Roofs for Healthy Cities).

There are two main types of green roofs: extensive and intensive. Extensive green roofs are shallow, usually with 4 inches of substrate, and do not typically support a large diversity of plant species because of root zone limitations. Intensive green roofs are more like rooftop gardens with deep substrate (from 4 inches to several feet) and a wide variety of plants. Most buildings are not designed to withstand the additional weight loading for intensive roofs. For this reason, they are typically limited to new construction. Extensive green roofs are shallower and generally much better suited to the structural capabilities of existing buildings and therefore, are installed more often. Because of this, extensive green roofs are the focus of this design guidance.

The design of a green roof involves many disciplines in addition to stormwater engineers, including structural engineers, architects, landscape architects, horticulturists, and others. This Fact Sheet is intended only to provide an overview of green roof information relative to stormwater quality and quantity management that is applicable in the Denver Metropolitan area. *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*, prepared by the University of Colorado Denver with input from UDFCD, should be used as a more comprehensive design and maintenance document. This document is available at www.growwest.org.

Green Roof [5]	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	Unknown
Nutrients	Unknown
Total Metals	Unknown
Bacteria	Unknown
Other Considerations	
Life-cycle Costs	Unknown

[5] Water quality data for green roofs are not yet robust enough to provide meaningful conclusions about pollutant removal. By reducing volume, green roofs have the de facto capability to reduce pollutant loads; however, on a concentration basis more data are needed to better define effectiveness.

As Low Impact Development (LID) strategies have been emphasized increasingly throughout the U.S., green roofs have been implemented in some parts of the country, most frequently in areas with humid climates and relatively high annual rainfall. Although there are some green roofs in Colorado, they have not been widely installed, and research is in progress regarding the best design approach and plant list for the metro Denver climate. Colorado's low annual precipitation, low average relative humidity, high solar radiation due to elevation, high wind velocities and predominantly sunny days make growing plants on a roof more difficult than in other climates. Because of this, plant selection, growing medium, and supplemental irrigation requirements are key considerations for which design criteria continue to evolve. Because the technical community has expressed interest in exploring the water quality and volume reduction benefits of this technique, information on green roofs is provided in this Fact Sheet based on industry literature and academic research.

It should be noted that the U.S. Green Building Council LEED rating system recognizes a second kind of green roof that includes reflective, high albedo roof materials that are not designed for stormwater purposes.

Green roofs provide multiple environmental, social, economic, and aesthetic benefits that extend beyond stormwater management objectives.

Benefits

- Reduces runoff rates and volumes.
- Reduces heat island effect in urban areas.
- May qualify for multiple LEED credits.
- May extend roof lifespan by reducing daily temperature fluctuations and providing shading from ultraviolet light.
- May provide energy savings from additional insulation & evapotranspirative cooling.
- Provides aesthetically pleasing open space in ultra urban areas.

Limitations

- Limited experience in Colorado.
- Initial installation costs are greater than conventional roof (although lifecycle costs may be less).
- Supplemental irrigation required in semi-arid climate.
- Maintenance during vegetation establishment (first two years) may be significant.

Site Selection

Green roofs can be installed on commercial or residential buildings as well as on underground structures such as the parking garage shown in Photo GR-6. Green roofs may be particularly well suited for ultra urban areas where development is typically lot-line-to-lot-line and garden space is at a premium. Green roofs are particularly valuable when their use extends to a place of enjoyment for those that inhabit the building. Several Colorado examples are provided at the end of this Fact Sheet.

For existing buildings, the structural integrity of the building must be verified prior to consideration of retrofitting the building with a green roof. For both existing and new construction, it is essential that the design team be multi-disciplinary. This team may include a structural engineer, stormwater engineer, architect, landscape architect, and horticulturist. It is recommended that all members of the design team be involved early in the process to ensure the building and site conditions are appropriate for green roof installation.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6. During design, the following should be considered upfront to ensure ease of maintenance for green roofs over the long-term:

- Access for equipment and inspections following construction.

- The irrigation system, growing media, and plant selection are critical factors determining long-term maintenance requirements and survival of the green roof vegetation under hot, dry conditions; otherwise, vegetation may have to be repeatedly replanted and/or the irrigation system replaced.

- If an underdrain system is used, provide cleanouts as appropriate for both inspection and maintenance. There is potential over the long term for the roof underdrain system to become clogged with soil/media that migrates down beneath the plant root zone. The ability to access the underdrain system for cleanout is important.

Design Procedure and Criteria

Green roofs contain a high quality water proofing membrane and root barrier system, drainage system, filter fabric, a lightweight growing media, and plants. Green roofs can be modular, already prepared in trays, including drainage layers, growing media and plants, or each component of the system can be installed separately on top of the structure.

As shown in Figure GR-1, basic elements of green roof design include:

- **Structural Support**: Roof structure that supports the growing medium, vegetation, and live loads associated with rainfall, snow, people, and equipment.

- **Waterproof Membrane:** This prevents water from entering the building.

- **Root Barrier:** This protects the waterproof membrane by preventing roots from reaching the membrane.

- **Drainage Layer**: This is sometimes an aggregate layer or a proprietary product.

- **Filter Membrane**: This prevents fine soil and substrate from being washed out into the drainage layer.

- **Growing Medium**: Although the growing medium is typically not "soil," the terms *soil matrix*, *soil media* and *growth substrate* are sometimes used.

- **Vegetation**: Native/naturalized, drought-tolerant grasses, perennials, and shrubs with relatively shallow root depths are possibilities for roof plantings.

- **Irrigation**: Even vegetation with low water requirements will require supplemental irrigation in Denver.

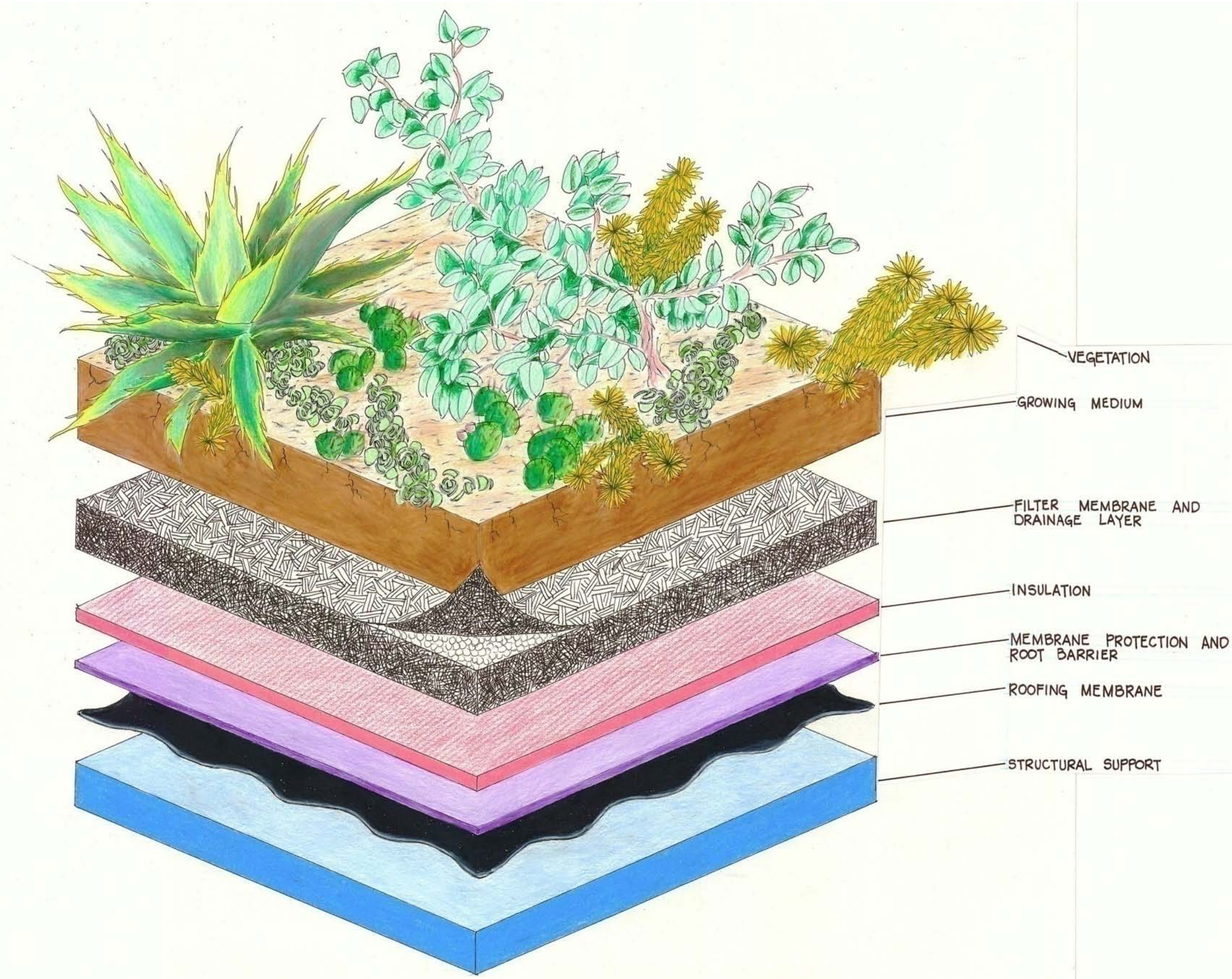


Figure GR-1. Typical Green Roof Cross Section. Graphic by Adia Davis.

Design considerations for green roofs include:

1. **Providing Stormwater Treatment and Slow Release**: An early version of the USDCM provided guidance on rooftop detention. This was removed because rooftop controls can be easily modified by maintenance personnel unfamiliar with its purpose. In contrast, green roof vegetation benefits from stormwater detained in the growing medium and the volume the system details should be recognized when designing for the water quality capture volume (WQCV).

   The WQCV for the Denver area is the runoff resulting from a storm event of approximately 0.6 inches of rainfall. Based on the data that the EPA has collected to date from the Region 8 green roof in Denver, it appears the green roof retains and evapotranspires 98 to 100% of the WQCV even without a restriction on the outlet for drain time control. This is largely due to wetting and subsequent evapotranspiration in the growing media. The data show few exceptions to this, which may be attributed to successive rain events. For this reason, UDFCD recognizes green roofs as a volumetric BMP, able to capture the WQCV for the area of the green roof, without constructing a controlled release at the outlet. This is for roofs that meet or exceed the EPA green roof section, which is a modular system using trays that allow for 4 inches of growing medium. An intensive roof should also be considered to capture the WQCV.

   Volume Reduction Data for the EPA Green Roof in Denver

   Stormwater performance data collected from the EPA Region 8 office green roof in Denver, Colorado has indicated that green roofs can be effective at detaining and infiltrating stormwater runoff. This is especially true for snowmelt events and for smaller precipitation events (generally <1" rainfall in a 24-hour period).

   Data from the EPA green roof are available for download and analysis at **www.epa.gov/region8/greenroof**. These data may be useful in considering additional volume reductions associated with the growing media and evapotranspiration from the vegetation.

   A green roof can also be designed to accept runoff from a traditional roof. This can be done for additional water quality and/or irrigation benefits or, if designed with a slow controlled release, the green roof can provide the WQCV for an area in excess of the area of the green roof. Use Figure 3-2 located in Chapter 3 to determine the WQCV (watershed inches) based on a 12-hour drain time. The design volume can be calculated as follows:

   $$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation GR-1}$$

   Where:

   V = design volume (ft^3)

   A = the watershed area tributary to the green roof (ft^2)

   The volume should be provided within the void space of the drainage layer and the growing media. This is a function of the material selected. The outlet can be controlled by an orifice or orifices located at one central location or at each roof drain. This is also a function of the overall drainage design.

2. **Structural Integrity**: Consult a structural engineer to ensure the load bearing capacity of the existing roof is adequate for the system to be installed. If new construction, the green roof should be part of the building design.

3. **Impermeable Membrane and Waterproofing**: Check waterproofing warranty and consult the warranty company to ensure the policy will not be voided by a green roof application. A leak test is recommended following installation of the impermeable membrane.

4. **Drainage System:** A filter membrane is required to keep the growing media from clogging the drainage media; however, roots can pass through the filter membrane. Roots are not expected to pass through the waterproof/repellant membrane. Other components of the drainage system must be kept free of debris and plant material in order to convey drainage properly.

Photograph GR-2. The metal edge shown in Photo GR-2 has perforations near the bottom to allow flow into the drain.

   Photos GR-2 and Photo GR-3 show a stainless steel edge that separates growing media from the rock that surrounds the roof drains. This provides both material separation as well as a root barrier. The plate is perforated to allow the growing media to drain.

   Roof outlets, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft. A drainage barrier should also be used at the roof border with the parapet wall and for any joints where the roof is penetrated, or joins with vertical structures.

Photograph GR-3. Metal edging separates growing media from rock that surrounds the roof drain. It also serves to facilitate regular maintenance by limiting plant and root growth near the drain.

5. **Growing Medium**: Growing medium is a key issue with regard to plant health, irrigation needs, and potential stormwater benefits. The growing medium is not the same thing as "soil." Most extensive green roof substrate is predominantly made up of expanded slate, expanded shale, expanded clay, or another lightweight aggregate such as pumice. However, such lightweight aggregates have some limitations. These materials typically drain very quickly and leave little water or nutrients available to plants. Therefore, additional research is necessary on substrate mixes appropriate for use on extensive green roofs in Colorado. For intensive green roof applications where weight is explicitly factored into the structural design, the soil matrix can include materials with higher water retention characteristics such as organic matter (e.g., compost), provided the structural design accounts for the saturated load.

6. **Planting Method**: In general, the planting method will be either "modular" (tray approach) or "continuous" (planted *in situ*).

   - Modular systems are self-contained trays, which can vary in size, and have relatively shallow depth (2 to 8 inches deep). When modular trays are planted with groundcover and placed close together, the roof often has the appearance of a continuous system once the vegetation is established. Due to the variations in green roof designs, it is important to consult with a multi-disciplinary team to determine the type of roof design most appropriate for the short-term and long-term conditions expected at the site.

   - Continuous systems are "built in place" on the roof with layers designed to work together to provide a healthy environment for plants. Continuous roof approaches range from rolled sedum mats to hand-planted buffalograss plugs.

7. **Plant Selection:** General categories of potentially viable plants for Colorado green roofs include native, alpine (grows in shallow rocky soils), and xeric plants (e.g., sedum). Plants must meet certain criteria to optimize their chance of survival on a green roof. Due to the shallow, well-drained materials in extensive green roof systems, plants must be drought resistant. However, not all drought resistant plants are well-suited for green roofs. For example, some plants avoid drought by rooting deeply to access a more stable supply of water. Such plants would not be suitable for a shallow green roof. Grasses with strong rhizome growth such as bamboo and varieties of Chinese reeds should be avoided, as these have the potential to compromise the roof membrane. While there are several species that could potentially adapt to extensive green roof systems, the most commonly used species are stonecrops or sedums because of their prostrate growth form, shallow root systems, and drought tolerance. Another favorable attribute of sedums is that the foliage tends to remain greener than grasses throughout the entire year, even in northern climates. However, drawbacks to a monoculture for green roofs are the same as for a monoculture in agricultural applications – risk of widespread vegetation loss if conditions (e.g., drought, disease, temperature, etc.) change from the anticipated range.

   Characteristics of plants, which tend to work well on green roofs in a semi-arid climate include:

   - Self seeding,
   - Perennial,
   - Low or compact growth format,
   - Diffuse or fibrous root system,
   - Low water use, and
   - Cressulacean Acid Metabolism (CAM), which is common in sedums (stonecrops) where plant stomata are closed during the day to conserve water.

Growing Media Research by Colorado State University at the EPA Green Roof in Denver

CSU researchers are evaluating alternative growing media for green roofs and report that most extensive green roof media are predominantly made up of expanded slate, shale, or clay. While these materials are generally very well-drained, lightweight, and resistant to blowing away and decomposing, they do have some limitations. They typically drain too quickly (too much macro-pore space, not enough micro-pore space) and do not hold nutrients very well (low cation exchange capacity [CEC]). A material that has all of the benefits of expanded slate, shale and clay, while having more micro-pore space and higher CEC is ideal. One example of a material that may fit this description is zeolite. Zeolites are currently being utilized as amendments for shallow, well-drained golf greens (see http://greenroof.agsci.colostate.edu/).

8. **Irrigation:** Irrigation is needed for successful green roofs in Colorado. The decision to use drip or overhead spray irrigation is determined based on growing media characteristics and plant needs. Drip irrigation is more efficient when installed below the vegetation layer to avoid heating of the drip line and to get a more effective watering of the roots. Overhead irrigation should be considered for shallow depth applications because drip irrigation may not spread laterally when applied over a rapidly draining media. Current CSU experiments are determining the extent of irrigation requirements for various plants. Initial results suggest non-succulents dry out faster (need more frequent irrigation), whereas the sedums and other succulent plants require less frequent irrigation; however, sedums and succulents tend to die rather than go dormant during prolonged dry periods.

9. **Wind:** Select growing media and install material layers in a manner to withstand expected average and storm wind conditions.

10. **Roof Microclimates**: Consider the effect of roof microclimates on the vegetation, including factors such as shading, localized strong winds, and reflected solar radiation from surrounding buildings. Solar panels can provide partial shade to vegetation that may not perform well when exposed to the typical green roof environment.

11. **Roof Gradient**: Green roofs may be installed on flat or steep roofs. For flat roofs (e.g., roof slopes less than 2%) a deeper drainage course is recommended to avoid water logging. For steep roofs (e.g., slopes greater than 30%), structural anti-shear protection will normally be needed to prevent sloughing of materials.

Combining solar panels with green roofs is mutually beneficial. Solar panels stay cooler and vegetation receives partial shade, reducing irrigation requirements.

12. **Protection of Roof Drainage Features**: Drainage features on the roof such as area drains, scuppers, downspouts, etc. must be kept free of debris and plant material in order to convey drainage properly. Roof outlets, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft. A drainage barrier should also be used at the roof border with the parapet wall and for any joints where the roof is penetrated or where the roof joins with vertical structures.

Additional Design Guidance

Until more experience is gained in Colorado with regard to green roofs, the following design guidance documents may provide additional assistance; with the understanding that the guidelines may need adjustment for Denver's climate:

- **"FLL Guidelines"**: The FLL Guidelines are green roof standards developed by the German Research Society for Landscape Development and Landscape Design. (FLL is derived from the German title: "Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.") These guidelines include the planning, execution and upkeep of green-roof sites. The 2002 edition of these widely consulted guidelines is available for purchase in English through http://www.roofmeadow.com/technical/fll.php.

- **ASTM Book of Standards, v. 04-12, 2005:**

    - ASTM E2396-E2399: ASTM has recently developed a new set of standards for green roofs; however, it is important to recognize these standards were developed outside of Colorado.

    - ASTM E2396-05: Standard test method for saturated water permeability of granulated drainage media (falling-head method) for green roof systems.

    - ASTM E-2398-05: Standard test method for water capture and media retention of geocomposite drain layers for green roof systems.

    - ASTM E2397-05: Standard practice for determination of dead loads and live loads associated with green roof systems.

- **BOCA Codes**, International Code Council (ICC): Building Officials and Code Administrators International Inc. (BOCA), now known as the International Code Council (ICC), publish codes that establish minimum performance requirements for all aspects of the construction industry. BOCA codes at the Library of Congress are located in the Law Library Reading Room. Some state codes are available at no cost through the eCodes sections of the ICC Website, while others must be purchased http://www.iccsafe.org/.

- **Leadership in Energy and Environmental Design (LEED):** The LEED Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED standards are available through the U.S. Green Building Council: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19. Attainment of a desired LEED building rating (e.g., gold, platinum) is based on accumulation of "points" achieved by implementing practices in six different credit categories. A variety of LEED points are potentially achievable through use of green roofs. For example, under the "Sustainable Sites" category, eligible points could include Site Development credits for protecting or restoring habitat and maximizing open space, Stormwater Design credits for quality and quantity, and Heat Island Effect credits for roofs. Green roofs may also contribute to achievement of "Energy and Atmosphere" points for optimizing energy performance for buildings. Green roofs may play a supporting role in a variety of other credits, as well as being eligible for "Innovation in Design" credits.

Websites for Additional Design Ideas

Colorado

Colorado State University: http://greenroof.agsci.colostate.edu/
Green Roofs of Colorado: http://www.greenroofsco.com/
Denver Botanic Gardens: http://www.botanicgardens.org/content/green-roof

Other Research Programs and Resources

Pennsylvania State University
Michigan State University
North Carolina State University
Southern Illinois University
LBJ Wildflower Center/University of Texas at Austin
Green Roofs for Healthy Cities

GreenRoofs.com

American Society of Landscape Architects: http://land.asla.org/050205/greenroofcentral.html
Low Impact Development Center: http://www.lid-stormwater.net/

Construction Considerations

Success of green roofs depends not only on a good design and maintenance, but also on construction practices that enable the BMP to function as designed. Construction considerations include:

- **Permit Requirements, General Coordination, and Warranties:** Investigate permitting requirements for green roofs in the local jurisdiction. Significant coordination between architects, engineers, roofers, and landscapers is needed. Contractually, it is common to have the roofer warranty the impermeable membrane, whereas the landscaper would be responsible for the growing media, vegetation, and other landscaping. Typically, irrigation systems have warranties, but plants do not, with the exception of situations where a maintenance contract is in place. Where a maintenance contract is in place, some landscapers or greenhouses will provide plant warranties.

- **Roof Membrane:** Inspect the roof membrane (the most crucial element of a green roof) and conduct a leak test prior to installing the remaining layers of the roof.

- **Installation Safety:** Most landscapers are accustomed to working on the ground, so safety training is important. If the green roof will be accessible to the public, safety at roof edges should be of paramount concern.

Colorado Examples

There are several green roof installations in Colorado designed to achieve varying goals that include reductions in stormwater volume, pollutants, and/or urban heat island effects, as well as aesthetic goals. These are briefly described below.

- **EPA Building (Denver):** Installed in 2006, this is a modular, 20,000 square foot, extensive green roof, currently planted primarily with sedum and equipped with spray irrigation. This roof is designed to be monitored for several purposes:
  - Biological/horticultural viability,
  - Stormwater benefits, and
  - Heat island reduction effects.

  The extensive planting scheme consists of sedums selected in accordance with USDA hardiness zone classification in 2-inch by 4-inch modules with a 4-inch depth.

Photograph GR- 4: A modular, extensive green roof in the spring on the Environmental Protection Agency Region 8 Headquarters in downtown Denver. Photo courtesy of Jennifer Bousselot.

- **Denver Botanic Gardens:** Located inside Denver Botanic Gardens, this publicly accessible green roof, installed in 2007, is a semi-intensive retrofit of a 1950s structure. The main purpose of the roof is to identify and test a broad palette of plants that may be feasible for Colorado green roofs. The roof is fully exposed to the south and currently features approximately 60 genera.

  The roof is fitted with both drip and spray irrigation. Four irrigation zones are monitored and adjusted according to weather and temperature. All green roof irrigation is recorded and stored in a central database.

Photograph GR-5. A continuous green roof system at the Denver Botanic Gardens. It is a predominantly extensive system with some intensive areas. Photo courtesy of Denver Botanic Gardens

Photograph GR-6. Intensive green roof installation above a parking garage.

- **REI Parking Garage Roof (Denver):** This is an example of an intensive roof, where a deeper growing media is present. The roof is irrigated.
- **Denver Museum of Contemporary Art:** Installed in 2006, this intensive green roof was designed for aesthetic appeal more than stormwater benefits. Also known as the "Sky Trapezium," it was designed primarily as an art exhibit inspired by the prairie and features native grasses. This roof is equipped with irrigation.
- **CSU Building Roof (Fort Collins):** A small modular extensive green roof installed in 2008 is present on the microbiology building at CSU.
- **Residential Applications:** There are numerous residential applications in Colorado; however, information on the design, vegetation, and performance has not been compiled.

References

Dunnett, N. 2004. *Planting Green Roofs and Living Walls*. Timber Press, Inc: Portland, Oregon.

Green Roofs for Healthy Cities website. http://www.greenroofs.org/index.php/about-green-roofs accessed 17 March 2010.

Snodgrass, E. 2006. *Green Roof Plants: A Resource and Planting Guide*. Timber Press, Inc.: Portland, Oregon.

Werthmann, C. 2007 *Green Roof: A Case Study: Michael Van Valkenburgh Associates' Design for the Headquarters of the American Society of Landscape Architects*. Princeton Architectural Press: New York, New York.

Description

Photograph EDB-1: This EDB includes a concrete trickle channel and a micropool with a concrete bottom and grouted boulder sideslopes. The vegetation growing in the sediment of the micropool adds to the natural look of this facility and ties into the surrounding landscape.

An extended detention basin (EDB) is a sedimentation basin designed to detain stormwater for many hours after storm runoff ends. This BMP is similar to a detention basin used for flood control, however; the EDB uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal. The EDB's 40-hour drain time for the water quality capture volume (WQCV) is recommended to remove a significant portion of total suspended solids (TSS). Soluble pollutant removal is enhanced by providing a small wetland marsh or "micropool" at the outlet to promote biological uptake. The basins are sometimes called "dry ponds" because they are designed not to have a significant permanent pool of water remaining between storm runoff events.

An extended detention basin can also be designed to provide Full Spectrum Detention. In this case, the EDB is sized for 100-year peak reduction and the excess urban runoff volume (EURV) is used instead of the WQCV. The EURV is designed with a drain time of approximately 72 hours. Widespread use of Full Spectrum Detention is anticipated to reduce impacts on major drainageways by reducing post-development peak discharges to better resemble pre-development peaks. Refer to the *Storage* chapter of Volume 2 for additional information on Full Spectrum Detention.

Extended Detention Basin	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Moderate
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

EDBs are well suited for watersheds with at least five impervious acres up to approximately one square mile of watershed. Smaller watersheds can result in an orifice size prone to clogging. Larger watersheds and watersheds with baseflows can complicate the design and reduce the level of treatment provided. EBDs are also well suited where flood detention is incorporated into the same basin.

> Use the WQCV (or the EURV) when designing an EDB only for water quality. Use the EURV when incorporating water quality into a flood control facility.

The depth of groundwater should be investigated. Groundwater depth should be 2 or more feet below the bottom of the basin in order to keep this area dry and maintainable.

Designing for Maintenance

Recommended maintenance practices for all BMPs are provided in the BMP Maintenance chapter of this manual. During design the following should be considered to ensure ease of maintenance over the long-term:

- Always provide a micropool (see step 7).
- Provide a design slope of at least 3% in the vegetated bottom of the basin (either toward the trickle channel or toward the micropool). This will help maintain the appearance of the turf grass in the bottom of the basin and reduce the possibility of saturated areas that may produce unwanted species of vegetation and mosquito breeding conditions. Verify slopes during construction, prior to vegetation.
- Follow trash rack sizing recommendations to determine the minimum area for the trash rack (see design step 9).
- Provide adequate initial surcharge volume for frequent inundation (see design step 3).
- Provide stabilized access to the forebay, outlet, spillway, and micropool for maintenance purposes.
- Provide access to the well screen. The well screen requires maintenance more often than any other EDB component. Ensure that the screen can be reached from a point outside of the micropool. When the well screen is located inside the outlet structure, provide an access port within the trash rack or use a sloped trash rack that consists of bearing bars (not horizontal) that are 6 inches on center.
- Provide a hard-bottom forebay that allows for removal of sediment.
- Where baseflows are anticipated, consider providing a flow-measuring device (e.g. weir or flume with staff gage and rating curve) at the forebay to assist with future modifications of the water quality plate. Typically, the baseflow will increase as the watershed develops. It is important that the water quality plate continue to function, passing the baseflow while draining the WQCV over approximately 40 hours. Measuring the actual baseflow can be helpful in determining if and when the orifice place should be replaced.

EDBs providing combined water quality and flood control functions can serve multiple uses such as playing fields or picnic areas. These uses are best located at higher elevation within the basin, above the WQCV pool level.

Benefits

- The relatively simple design can make EDBs less expensive to construct than other BMPs, especially for larger basins.
- Maintenance requirements are straightforward.
- The facility can be designed for multiple uses.

Limitations

- Ponding time and depths may generate safety concerns.
- Best suited for tributary areas of 5 impervious acres or more. EDBs are not recommended for sites less than 2 impervious acres.
- Although ponds do not require more total area compared to other BMPs, they typically require a relatively large continuous area.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for an EDB:

1. **Basin Storage Volume**: Provide a design volume equal to 120% of the WQCV or 100% of the EURV. This volume begins at the lowest orifice in the outlet structure. The additional 20% for the WQCV is for sediment accumulation and the resultant loss in storage volume. Additional volume for sediment storage is not necessary when designing for the EURV, as the water quality perforations extend above the depth of the WQCV.

   - Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).

   - Find the required storage volume. Determine the required WQCV or EURV (watershed inches of runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 (for EURV).

   - Calculate the design volume as follows:

   For WQCV:

   $$V = \left[\frac{\text{WQCV}}{12}\right] 1.2\, A \qquad \text{Equation EDB-1}$$

   For EURV:

   $$V = \left[\frac{\text{EURV}}{12}\right] A \qquad \text{Equation EDB-2}$$

   Where:

   V = design volume (acre ft)

   A = watershed area tributary to the extended detention basin (acres)

   1.2 factor = multiplier to accommodate sediment accumulation

2. **Basin Shape**: Always maximize the distance between the inlet and the outlet. It is best to have a basin length (measured along the flow path from inlet to outlet) to width ratio of at least 2:1. A longer flow path from inlet to outlet will minimize short circuiting and improve reduction of TSS. To achieve this ratio, it may be necessary to modify the inlet and outlet points through the use of pipes or swales.

3. **Basin Side Slopes**: Basin side slopes should be stable and gentle to facilitate maintenance and access. Slopes that are 4:1or flatter should be used to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics. Side slopes should be no steeper than 3:1. The use of walls is highly discouraged due to maintenance constraints.

4. **Inlet**: Dissipate flow energy at concentrated points of inflow. This will limit erosion and promote particle sedimentation. Inlets should be designed in accordance with UDFCD drop structure criteria

for inlets above the invert of the forebay, impact basin outlet details for at grade inlets, or other types of energy dissipating structures.

5. **Forebay Design**: The forebay provides an opportunity for larger particles to settle out in an area that can be easily maintained. The length of the flow path through the forebay should be maximized, and the slope minimized to encourage settling. The appropriate size of the forebay may be as much a function of the level of development in the tributary area as it is a percentage of the WQCV. When portions of the watershed may remain disturbed for an extended period of time, the forebay size will need to be increased due to the potentially high sediment load. Refer to Table EDB-4 for a design criteria summary. When using this table, the designer should consider increasing the size of the forebay if the watershed is not fully developed.

   The forebay outlet should be sized to release 2% of the undetained peak 100-year discharge. A soil riprap berm with 3:1 sideslopes (or flatter) and a pipe outlet or a concrete wall with a notch outlet should be constructed between the forebay and the main EDB. It is recommended that the berm/pipe configuration be reserved for watersheds in excess of 20 impervious acres to accommodate the minimum recommended pipe diameter of 8 inches. When using the berm/pipe configuration, round up to the nearest standard pipe size and use a minimum diameter of 8 inches. The floor of the forebay should be concrete or lined with grouted boulders to define sediment removal limits. With either configuration, soil riprap should also be provided on the downstream side of the forebay berm or wall if the downstream grade is lower than the top of the berm or wall. The forebay will overtop frequently so this protection is necessary for erosion control. All soil riprap in the area of the forebay should be seeded and erosion control fabric should be placed to retain the seed in this high flow area.

6. **Trickle Channel:** Convey low flows from the forebay to the micropool with a trickle channel. The trickle channel should have a minimum flow capacity equal to the maximum release from the forebay outlet.

   - **Concrete Trickle Channels:** A concrete trickle channel will help to establish the bottom of the basin long-term and may also facilitate regular sediment removal. It can be a "V" shaped concrete drain pan or a concrete channel with curbs. A flat-bottom channel facilitates maintenance. A slope between 0.4% - 1% is recommended to encourage settling while reducing the potential for low points within the pan.

   - **Soft-bottom Trickle Channels**: When designed and maintained properly, soft-bottom trickle channels can allow for an attractive alternative to concrete. They can also improve water quality. However, they are not appropriate for all sites. Be aware, maintenance of soft bottom trickle channels requires mechanical removal of sediment and vegetation. Additionally, this option provides mosquito habitat. For this reason, UDFCD recommends that they be considered on a case-by-case basis and with the approval of the local jurisdiction. It is recommended that soft bottom trickle channels be designed with a consistent longitudinal slope from forebay to micropool and that they not meander. This geometry will allow for reconstruction of the original design when sediment removal in the trickle channel is necessary. The trickle channel may also be located along the toe of the slope if a straight channel is not desired. The recommended minimum depth of a soft bottom trickle channel is 1.5 feet. This depth will help limit potential wetland growth to the trickle channel, preserving the bottom of the basin.

     Riprap and soil riprap lined trickle channels are not recommended due to past maintenance experiences, where the riprap was inadvertently removed along with the sediment during maintenance.

7. **Micropool and Outlet Structure**: Locate the outlet structure in the embankment of the EDB and provide a permanent micropool directly in front of the structure. Submerge the well screen to the bottom of the micropool. This will reduce clogging of the well screen because it allows water to flow though the well screen below the elevation of the lowest orifice even when the screen above the water surface is plugged. This will prevent shallow ponding in front of the structure, which provides a breeding ground for mosquitoes (large shallow puddles tend to produce more mosquitoes than a smaller, deeper permanent pond).

   Basins with micropools have fewer mosquitoes. Micropools reduce shallow wet areas where breeding is most favorable .

   Micropool side slopes may be vertical walls or stabilized slopes of 3:1 (horizontal:vertical). For watersheds with less than 5 impervious acres, the micropool can be located inside the outlet structure (refer to Figures OS-7 and OS-8 provided in Fact Sheet T-12). The micropool should be at least 2.5 feet in depth with a minimum surface area of 10 square feet. The bottom should be concrete unless a baseflow is present or anticipated or if groundwater is anticipated. Riprap is not recommended because it is often inadvertently removed during maintenance operations.

   Where possible, place the outlet in an inconspicuous location as shown in Photo EDB-3. This urban EDB utilizes landscaped parking lot islands connected by a series of culverts (shown in Photo EDB-4) to provide the required water quality and flood control volumes.

   The outlet should be designed to release the WQCV over a 40-hour period. This can be done through an orifice plate as detailed in BMP Fact Sheet T-12. Use reservoir routing calculations as discussed in the *Storage* Chapter of Volume 2 or use equation EDB-3, a simplified orifice sizing equation (see Technical Memorandum dated July 13, 2010 available at www.udfcd.org).

$$A_O = \frac{88V^{\left(0.95/H^{0.085}\right)}}{T_D\ S^{0.09}\ H^{\left(2.6S^{0.3}\right)}} \qquad \text{Equation EDB-3}$$

   Where:

   A_O = area per row of orifices spaced on 4" centers (in^2)
   V = design volume (WQCV or EURV, acre ft)
   T_D = time to drain the prescribed volume (hrs) (i.e., 40 hours for WQCV or 72 hours for EURV)
   H = depth of volume (ft)
   S = slope (ft/ft)

   Refer to BMP Fact Sheet T-12 for schematics pertaining to structure geometry, grates, trash racks, orifice plate, and all other necessary components.

Additional Guidelines for Incorporating Flood Control:

When designing for flood control using Full Spectrum Detention, the outlet is typically designed to drain the EURV in 72 hours. However, the owner may want to modify the design (reduce the EURV drain time) for a number of reasons including wanting to provide larger orifices for maintenance purposes or, when designing BMPs in series, to ensure that the maximum detention time for the system does not exceed 72 hours. Modifications can be permitted as long as the outlet drains the WQCV (not the EURV) over a period of at least 40 hours. The *UD-BMP* workbook can be used to ensure this condition is met while adjusting the drain time for the EURV.

When using Full Spectrum Detention a separate 5- or 10-year orifice or weir is not necessary. In order to best replicate historic release rates, design the outlet structure to overtop at the EURV elevation. The velocity of flows into the structure at the 100-year peak discharge should not exceed a velocity of 2 feet per second. This criterion is a safety precaution, limiting the risk of pinning. Use the continuity equation to ensure this criterion:

$$V = \frac{Q_{100}}{A} \leq 2 \qquad \text{Equation EDB-4}$$

Where:

V = velocity of flow through the trash rack (ft/s)

Q_{100} = peak discharge through the outlet structure (cfs)

A = open area of the trash rack (ft^2)

The outlet may have flared or parallel wing walls as shown in Figures EDB-1 and EDB-2, respectively. Either configuration should be recessed into the embankment to minimize its profile. Additionally, the trash rack should be sloped with the basin side-slopes.

8. **Initial Surcharge Volume**: Providing a surcharge volume above the micropool for frequently occurring runoff minimizes standing water and sediment deposition in the remainder of the basin. This is critical to turf maintenance and mosquito abatement in the basin bottom. The initial surcharge volume is not provided in the micropool nor does it include the micropool volume. It is the available storage volume that begins at the water surface elevation of the micropool and extends upward to a grade break within the basin (typically the invert of the trickle channel).

Photograph EDB-2. The initial surcharge volume of this EDB is contained within the boulders that surround the micropool.

The area of the initial surcharge volume, when full, is typically the same or slightly larger than that of the micropool. The initial surcharge volume should have a depth of at least 4 inches. For watersheds of at least 5 impervious acres, the initial surcharge volume should also be at least 0.3% of the WQCV. The initial surcharge volume is considered a part of the WQCV and does not need to be provided in addition to the WQCV. It is recommended that this area be shown on the grading plan or in a profile for the EDB. When baseflows are anticipated, it is recommended that the initial surcharge volume be increased. See the inset on page EDB-9 for additional guidelines for designing for baseflows.

9. **Trash Rack**: Provide a trash rack (or screen) of sufficient size at the outlet to provide hydraulic capacity while the rack is partially clogged. Openings should be small enough to limit clogging of the individual orifices. For this reason, it is recommended that a well screen be used when circular orifices are used. Size any overflow trash rack so it does not interfere with the hydraulic capacity of the outlet pipe. See BMP Fact Sheet T-12 for detailed trash rack design guidance.

Photograph EDB-3. Although walls may complicate maintenance access, this outlet structure is relatively hidden from public view. This photo was taken shortly following a storm event.

Photograph EDB-4. A series of landscape islands connected by culverts provide water quality and flood control for this site.

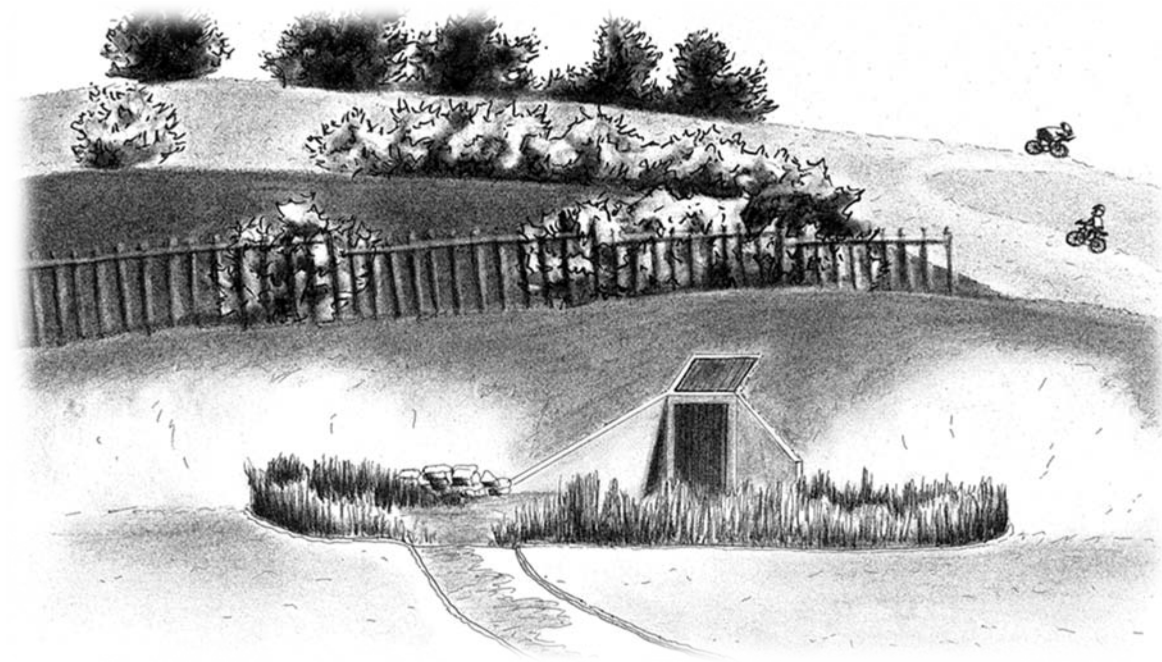


Figure EDB-1. Flared Wall Outlet Structure Configuration. Graphic by Adia Davis.

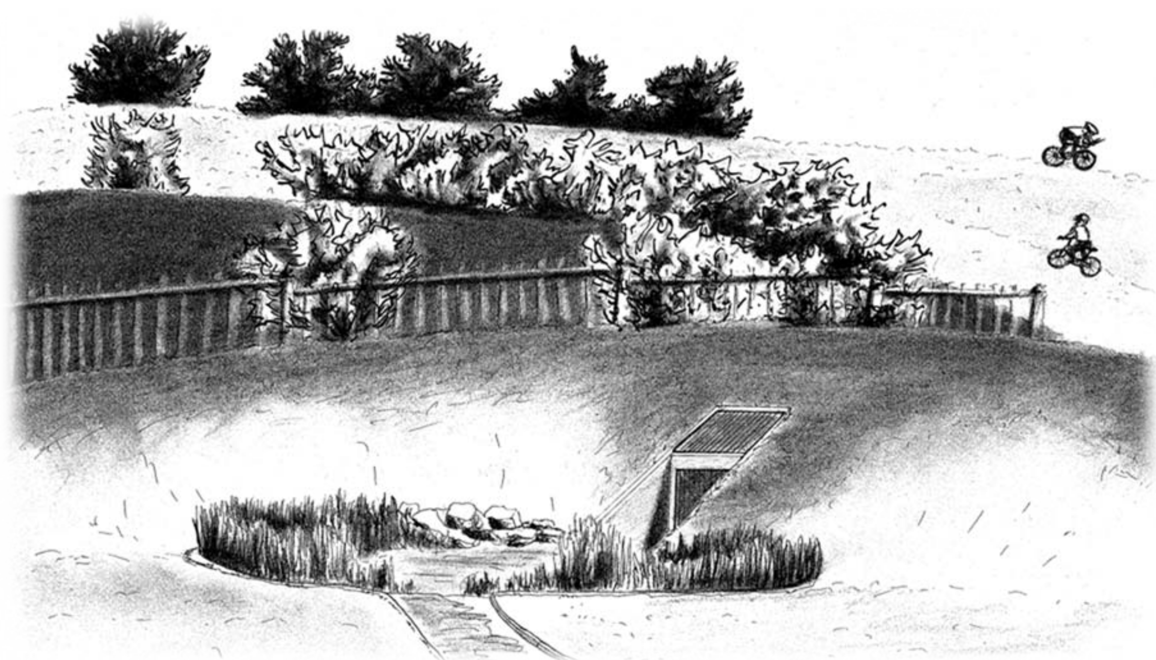


Figure EDB-2. Parallel Wall Outlet Structure Configuration. Graphic by Adia Davis.

10. **Overflow Embankment:** Design the embankment to withstand the 100-year storm at a minimum. If the embankment falls under the jurisdiction of the State Engineer's Office, it must be designed to meet the requirements of the State Engineer's Office. The overflow should be located at a point where waters can best be conveyed downstream. Slopes that are 4:1 or flatter should be used to allow for conventional maintenance equipment and for improved safety, maintenance, and aesthetics. Side slopes should be no steeper than 3:1 and should be planted with turf forming grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to 95% of maximum dry density for ASTM D698 (Standard Proctor) or 90% for ASTM D1557 (Modified Proctor). Spillway structures and overflows should be designed in accordance with the *Storage* Chapter of Volume 2 as well as any local drainage criteria. Buried soil riprap or reinforced turf mats installed per manufacturer's recommendations can provide an attractive and less expensive alternative to concrete.

11. **Vegetation:** Vegetation provides erosion control and sediment entrapment. Basin bottom, berms, and side slopes should be planted with turf grass, which is a general term for any grasses that will form a turf or mat, as opposed to bunch grass which will grow in clumplike fashion. Xeric grasses with temporary irrigation are recommended to reduce maintenance requirements, including maintenance of the irrigation system as well as frequency of mowing. Where possible, place irrigation heads outside the basin bottom because irrigation heads in an EDB can become buried with sediment over time.

12. **Access:** Provide appropriate maintenance access to the forebay and outlet works. For larger basins, this means stabilized access for maintenance vehicles. If stabilized access is not provided, the maintenance plan should provide detail, including recommended equipment, on how sediment and trash will be removed from the outlet structure and micropool. Some communities may require vehicle access to the bottom of the basin regardless of the size of the watershed. Grades

Designing for Baseflows

Baseflows should be anticipated for large tributary areas and can be accommodated in a variety of ways. Consider the following:

- If water rights are available, consider alternate BMPs such as a constructed wetland pond or retention pond.
- Anticipate future modifications to the outlet structure. Following construction, baseflows should be monitored periodically. Intermittent flows can become perennial and perennial flows can increase over time. It may be determined that outlet modifications are necessary long after construction of the BMP is complete.
- Design foundation drains and other groundwater drains to bypass the water quality plate directing these drains to a conveyance element downstream of the EDB. This will reduce baseflows and help preserve storage for the WQCV.
- When the basin is fully developed and an existing baseflow can be approximated prior to design, the water quality orifices should be increased to drain the WQCV in 40 hours (or EURV in 72 hours) while also draining the baseflow. This requires reservoir routing using an inflow hydrograph that includes the baseflow. The *UD-Detention* workbook available at www.udfcd.org may be used for this purpose.
- Increase the initial surcharge volume of the pond to provide some flexibility when baseflows are known or anticipated. Baseflows are difficult to approximate and will continue to increase as the watershed develops. Increasing the initial surcharge volume will accommodate a broader range of flows.

should not exceed 10% for haul road surfaces and 20% for skid-loader and backhoe access. Stabilized access includes gravel, concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement. The recommended cross slope is 2%.

Aesthetic Design

Since all land owners and managers wish to use land in the most efficient manner possible, it is important that EDBs become part of a multi-use system. This encourages the design of EDBs as an aesthetic part of a naturalized environment or to include passive and/or active open space. Within each scenario, the EDB can begin to define itself as more than just a drainage facility. When this happens, the basin becomes a public amenity. This combination of public amenity and drainage facility is of much greater value to a landowner. Softened and varied slopes, interspersed irrigated fields, planting areas and wetlands can all be part of an EDB.

The design should be aesthetic whether it is considered to be an architectural or naturalized basin. Architectural basins incorporate design borrowed or reflective of the surrounding architecture or urban forms. An architectural basin is intended to appear as part of the built environment, rather than hiding the cues that identify it as a stormwater structure. A naturalized basin is designed to appear as though it is a natural part of the landscape. This section provides suggestions for designing a naturalized basin. The built environment, in contrast to the natural environment, does not typically contain the randomness of form inherent in nature. Constructed slopes typically remain consistent, as do slope transitions. Even dissipation structures are usually a hard form and have edges seldom seen in nature. If the EDB is to appear as though it is a natural part of the landscape, it is important to minimize shapes that provide visual cues indicating the presence of a drainage structure. For example, the side sides should be shaped more naturally and with varying slopes for a naturalized basin.

Suggested Methods for a Naturalized Basin

- Create a flowing form that looks like it was shaped by water.
- Extend one side of the basin higher than the other. This may require a berm.
- Shape the bottom of the basin differently than the top.
- Slope of one side of the basin more mildly than the opposing side.
- Vary slope transitions both at the top of the bank and at the toe.
- Use a soft-surface trickle channel if appropriate and approved.
- When using rock for energy dissipation, the rock should graduate away from the area of hard edge into the surrounding landscape. Other non-functional matching rock should occur in other areas of the basin to prevent the actual energy dissipation from appearing out of context.
- Design ground cover to reflect the type of water regime expected for their location within the basin.

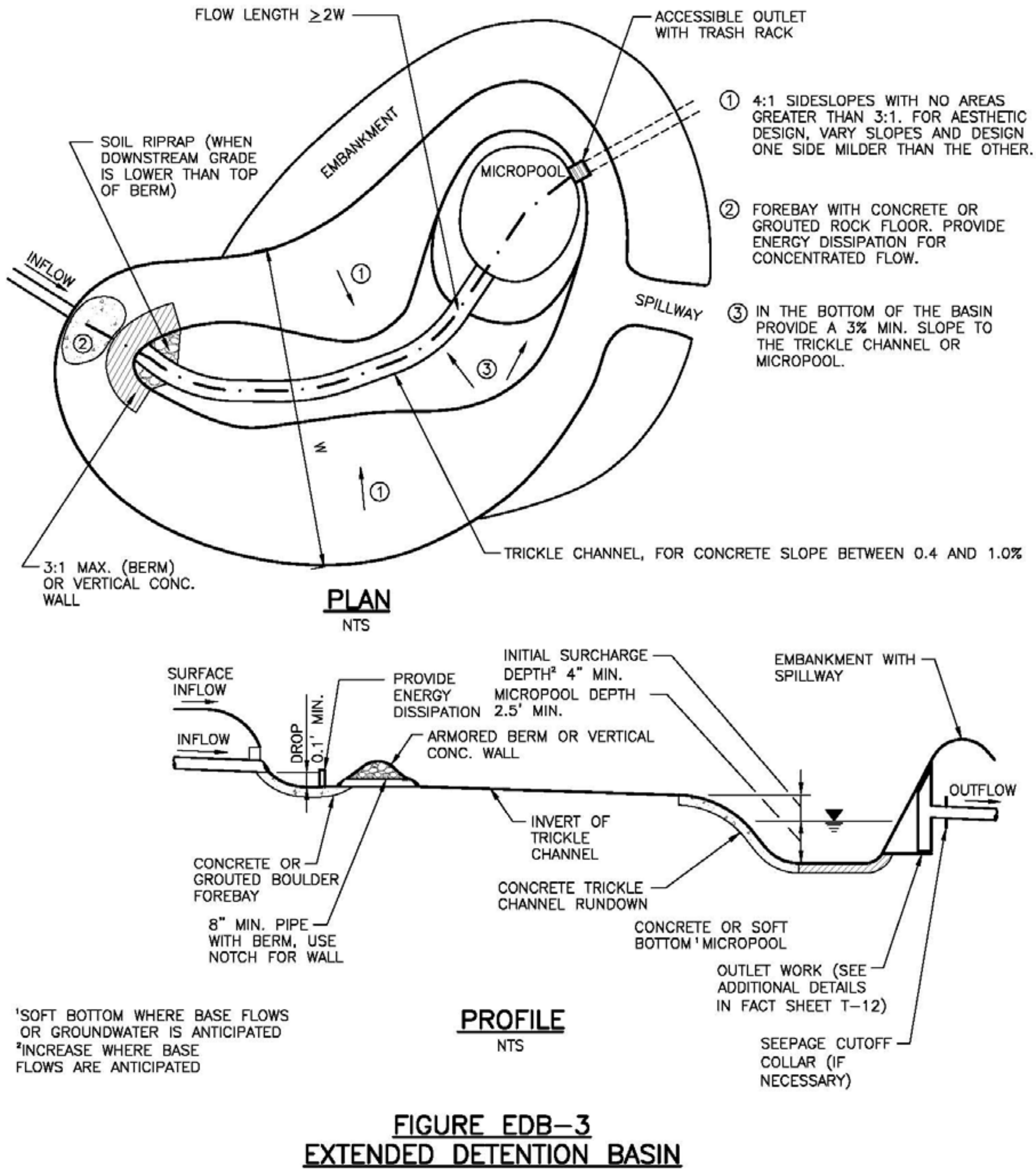


Figure EDB-3. Extended Detention Basin (EDB) Plan and Profile

Additional Details are provided in BMP Fact Sheet T-12. This includes outlet structure details including orifice plates and trash racks.

Table EDB-4. EDB Component Criteria

	On-Site EDBs for Watersheds up to 1 Impervious Acre[1]	**EDBs with Watersheds up to 2 Impervious Acres**[1]	**EDBs with Watersheds up to 5 Impervious Acres**	**EDBs with Watersheds over 5 Impervious Acres**	**EDBs with Watersheds over 20 Impervious Acres**
Forebay Release and Configuration	A forebay and trickle channel may not be necessary for this size site. Specific site operations should be considered to determine if a forebay will serve to reduce the maintenance requirements.	Release 2% of the undetained 100-year peak discharge by way of a wall/notch configuration	Release 2% of the undetained 100-year peak discharge by way of a wall/notch configuration	Release 2% of the undetained 100-year peak discharge by way of a wall/notch configuration	Release 2% of the undetained 100-year peak discharge by way of a wall/notch or berm/pipe[2] configuration
Minimum Forebay Volume		1% of the WQCV	2% of the WQCV	3% of the WQCV	3% of the WQCV
Maximum Forebay Depth		12 inches	18 inches	18 inches	30 inches
Trickle Channel Capacity		≥ the maximum possible forebay outlet capacity	≥ the maximum possible forebay outlet capacity	≥ the maximum possible forebay outlet capacity	≥ the maximum possible forebay outlet capacity
Micropool	Area ≥ 10 ft^2	Area ≥ 10 ft^2	Area ≥ 10 ft^2	Area ≥ 10 ft^2	Area ≥ 10 ft^2
Initial Surcharge Volume	Depth ≥ 4 inches	Depth ≥ 4 inches	Depth ≥ 4 inches	Depth ≥ 4 in. Volume ≥ 0.3% WQCV	Depth ≥ 4 in. Volume ≥ 0.3% WQCV

[1] EDBs are not recommended for sites with less than 2 impervious acres. Consider a sand filter or rain garden.

[2] Round up to the first standard pipe size (minimum 8 inches).

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Extended Detention Basin (EDB)

Sheet 1 of 4

Designer:	**H. Dauel**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivison D**
Location:	**NE Corner of 34th Ave. and 83rd St.**

1. Basin Storage Volume	
A) Effective Imperviousness of Tributary Area, I_a	I_a = 75.0 %
B) Tributary Area's Imperviousness Ratio ($i = I_a / 100$)	i = 0.750
C) Contributing Watershed Area	Area = 17.000 ac
D) For Watersheds Outside of the Denver Region, Depth of Average Runoff Producing Storm	d_6 = ______ in
E) Design Concept (Select EURV when also designing for flood control)	Choose One: ○ Water Quality Capture Volume (WQCV) ◉ Excess Urban Runoff Volume (EURV)
F) Design Volume (1.2 WQCV) Based on 40-hour Drain Time ($V_{DESIGN} = (1.0 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i) / 12 * Area * 1.2)$	V_{DESIGN}= 0.509 ac-ft
G) For Watersheds Outside of the Denver Region, Water Quality Capture Volume (WQCV) Design Volume ($V_{WQCV\ OTHER} = (d_6*(V_{DESIGN}/0.43))$	$V_{DESIGN\ OTHER}$= ______ ac-ft
H) User Input of Water Quality Capture Volume (WQCV) Design Volume (Only if a different WQCV Design Volume is desired)	$V_{DESIGN\ USER}$= ______ ac-ft
I) Predominant Watershed NRCS Soil Group	Choose One: ○ A ○ B ◉ C / D
J) Excess Urban Runoff Volume (EURV) Design Volume For HSG A: EURVA = (0.1878i - 0.0104)*Area For HSG B: $EURV_B$ = (0.1178i - 0.0042)*Area For HSG C/D: $EURV_{C/D}$ = (0.1043i - 0.0031)*Area	EURV = 1.277 ac-f t
2. Basin Shape: Length to Width Ratio (A basin length to width ratio of at least 2:1 will improve TSS reduction.)	L : W = 2.0 : 1
3. Basin Side Slopes A) Basin Maximum Side Slopes (Horizontal distance per unit vertical, 4:1 or flatter preferred)	Z = 4.00 ft / ft
4. Inlet A) Describe means of providing energy dissipation at concentrated inflow locations:	Based on UDFCD detail for modified impact stilling basin for conduits 18 to 48 inches.

Design Procedure Form: Extended Detention Basin (EDB)

Sheet 2 of 4

Designer:	**H. Dauel**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivison D**
Location:	**NE Corner of 34th Ave. and 83rd St.**

5. Forebay	
A) Minimum Forebay Volume (V_{FMIN} = 3% of the WQCV)	V_{FMIN} = 0.013 ac-ft
B) Actual Forebay Volume	V_F = 0.015 ac-ft
C) Forebay Depth (D_F = 18 inch maximum)	D_F = 12.0 in
D) Forebay Discharge	
i) Undetained 100-year Peak Discharge	Q_{100} = 50.00 cfs
ii) Forebay Discharge Design Flow ($Q_F = 0.02 * Q_{100}$)	Q_F = 1.00 cfs
E) Forebay Discharge Design	Choose One: ○ Berm With Pipe; ● Wall with Rect. Notch; ○ Wall with V-Notch Weir — (flow too small for berm w/ pipe)
F) Discharge Pipe Size (minimum 8-inches)	Calculated D_P = in
G) Rectangular Notch Width	Calculated W_N = 6.0 in
6. Trickle Channel	
A) Type of Trickle Channel	Choose One: ● Concrete; ○ Soft Bottom
F) Slope of Trickle Channel	S = 0.0100 ft / ft
7. Micropool and Outlet Structure	
A) Depth of Micropool (2.5-feet minimum)	D_M = 2.5 ft
B) Surface Area of Micropool (10 ft^2 minimum)	A_M = 125 sq ft
C) Outlet Type	Choose One: ● Orifice Plate; ○ Other (Describe):
D) Depth of Design Volume (EURV or 1.2 WQCV) Based on the Design Concept Chosen Under 1.E.	H = 2.30 feet
E) Volume to Drain Over Prescribed Time	EURV = 1.277 ac-ft
F) Drain Time (Min T_D for WQCV= 40 hours; Max T_D for EURV= 72 hours)	T_D = 72 hours
G) Recommended Maximum Outlet Area per Row, (A_o)	A_o = 1.3 square inches
H) Orifice Dimensions: i) Circular Orifice Diameter or	$D_{orifice}$ = 1 - 5 / 16 inch inches
ii) Width of 2" High Rectangular Orifice	$W_{orifice}$ = inches
I) Number of Columns	n_c = 1 number
J) Actual Design Outlet Area per Row (A_o)	A_o = 1.4 square inches
K) Number of Rows (nr)	n_r = 6 number
L) Total Outlet Area (A_{ot})	A_{ot} = 9.3 square inches
M) Depth of WQCV (H_{WQCV}) (Estimate using actual stage-area-volume relationship and V_{WQCV})	H_{WQCV} = 0.8 feet
N) Ensure Minimum 40 Hour Drain Time for WQCV	$T_{D\ WQCV}$ = 49.7 hours

Design Procedure Form: Extended Detention Basin (EDB)

Sheet 3 of 4

Designer:	**H. Dauel**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivison D**
Location:	**NE Corner of 34th Ave. and 83rd St.**

8. Initial Surcharge Volume

A) Depth of Initial Surcharge Volume (Minimum recommended depth is 4 inches) — D_{IS} = 6.0 in

B) Minimum Initial Surcharge Volume (Minimum volume of 0.3% of the WQCV) — V_{IS} = 55.5 cu ft

C) Initial Surcharge Provided Above Micropool — V_s= 62.5 cu ft

9. Trash Rack

A) Type of Water Quality Orifice Used

Choose One
- (●) Circular (up to 2" diameter)
- ( ) Rectangular (2" high)

B) Water Quality Screen Open Area: $A_t = 38.5*(e^{-0.095D})*A_{ot}$ — A_t = 317 square inches

C) For 2", or Smaller, **Circular Opening** (See Fact Sheet T-12):

i) Width of Water Quality Screen and Concrete Opening ($W_{opening}$) — $W_{opening}$ = 12.0 inches

ii) Height of Water Quality Screen (H_{TR}) — H_{TR} = 55.6 inches

iii) Type of Screen, Describe if "Other"

Choose One
- (●) S.S. Well Screen with 60% Open Area*
- ( ) Other (Describe):

D) For 2" High **Rectangular Opening**:

i) Width of Rectangular Opening ($W_{orifice}$) — W = inches

ii) Width of Water Quality Screen Opening ($W_{opening}$) — $W_{opening}$ = ft

iii) Height of Water Quality Screen (H_{TR}) — H_{TR} = ft

iv) Type of Screen, Describe if "Other"

Choose One
- ( ) Aluminum Amico-Klemp SR Series (or equal)
- ( ) Other (Describe):

v) Cross-bar Spacing — inches

vi) Minimum Bearing Bar Size

Design Procedure Form: Extended Detention Basin (EDB)

Sheet 4 of 4

Designer:	**H. Dauel**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivison D**
Location:	**NE Corner of 34th Ave. and 83rd St.**

10. Overflow Embankment A) Describe embankment protection for 100-year and greater overtopping:	Buried soil riprap at SE corner. Overflow is 12 feet wide and 12 inches lower than the surrounding embankment. Undetained peak velociies are less than 5 fps.
B) Slope of Overflow Embankment (Horizontal distance per unit vertical, 4:1 or flatter preferred)	Z_E = 4.00 ft / ft
11. Vegetation	Choose One ○ Irrigated ◉ Not Irrigated
12. Access A) Describe Sediment Removal Procedures	Aggregate turf pavement access at SE corner of basin allows access to the bottom of the basin for all standard maintenance.

Notes:

Description

Photograph SF-1. The vegetation on the surface of the filter and the shallow design depth of this sand filter, help the BMP blend into its surroundings. Photo courtesy of Fred Bromberger.

A sand filter is a filtering or infiltrating BMP that consists of a surcharge zone underlain by a sand bed with an underdrain system (when necessary). During a storm, accumulated runoff collects in the surcharge zone and gradually infiltrates into the underlying sand bed, filling the void spaces of the sand. The underdrain gradually dewaters the sand bed and discharges the runoff to a nearby channel, swale, or storm sewer. It is similar to a BMP designed for bioretention in that it utilizes filtering, but differs in that it is not specifically designed for vegetative growth. For this reason, it can have a greater depth and be designed for a larger contributing area. A sand filter is also similar to an extended detention basin (EDB) in that it is a dry basin, which can be easily designed to include the flood control volume above the WQCV or EURV. However, a sand filter does not require a forebay or micropool because the solids that would be deposited in these components in an EDB will be retained on the surface of the sand bed in a sand filter. Sand filters can be vegetated with species that will tolerate both wet and dry conditions and occasional inundation. The rain garden growing media is recommended for sand filters where vegetation is desired. Sand filters can also be placed in a vault. Underground sand filters have additional requirements. See Fact Sheet T-11 for additional discussion on underground BMPs.

Sand/Media Filter	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Good
Total Metals	Good
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

Sand filters require a stable watershed. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils, consider another BMP or provide pretreatment before runoff from these areas reach the rain garden.

When sand filters (and other BMPs used for infiltration) are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. Oversaturated subgrade soil underlying a structure can cause the structure to settle or result in moisture-related problems. Wetting of expansive soils or bedrock can cause swelling, resulting in structural movements. A geotechnical engineer should evaluate the potential impact of the BMP on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. Additional minimum requirements include:

- In locations where subgrade soils do not allow infiltration, the filter layer should be underlain by an underdrain system.

- Where infiltration can adversely impact adjacent structures, the filter layer should be underlain by an underdrain system designed to divert water away from the structure.

- In locations where potentially expansive soils or bedrock exist, placement of a sand filter adjacent to structures and pavement should only be considered if the BMP includes an underdrain designed to divert water away from the structure, and is lined with an impermeable geomembrane liner designed to restrict seepage.

Benefits

- Filtering BMPs provide effective water quality enhancement including phosphorus removal.

Limitations

- This BMP may clog and require maintenance if a moderate to high level of silts and clays are allowed to flow into the facility.

- This BMP should not be located within 10 feet of a building foundation without an impermeable membrane. See *Bioretention* (BMP Fact Sheet T-3) of this manual for additional information.

- The sand filter should not be put into operation while construction or major landscaping activities are taking place in the watershed.

Designing for Maintenance

Recommended maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design the following should be considered to ensure ease of maintenance over the long-term:

- Do not put a filter sock on the underdrain. This is not necessary and can cause the BMP to clog.

- Install cleanouts. Cleanouts can be used for inspection (by camera) immediately following construction to ensure that the underdrain pipe was not crushed during construction. They can also be used to for ongoing maintenance practices. Consider locating cleanouts in the side slopes of the basin and above the depth of ponding.

- Provide vegetated side slopes to pre-treat runoff by filtering (straining). This will reduce the frequency of maintenance.

Design Procedure and Criteria

The following steps outline the design procedure and criteria for a sand filter.

1. **Basin Storage Volume**: Provide a storage volume above the sand bed of the basin equal to the WQCV based on a 24-hour drain time. Although the BMP will be designed to drain in 12 hours, sizing the basin for a longer drain time will ensure containment of the WQCV as infiltration through the filter layer slows over time.

- Determine the imperviousness of the tributary area (or effective imperviousness where LID techniques are implemented). Determine the required WQCV (watershed inches of runoff) using Figure 3-2 in Chapter 3 of this manual. The volume should be based on a drain time of 24 hours.

- Calculate the design volume as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation SF-1}$$

Where:

V = design volume (ft^3)

A = watershed area tributary to the sand filter (ft^2)

2. **Basin Geometry:** Use equation SF-2 to calculate the minimum filter area, which is the flat surface of the sand filter. Sediment will reside on the filter area of the sand filter. Therefore, if the filter area is too small, the filter may clog prematurely. If this is of particular concern, increasing the filter area will decrease the frequency of maintenance. The following equation provides the minimum filter area allowing for some of the volume to be stored beyond the area of the filter. **Note that the total volume must also equal or exceed the design volume.**

The side slopes of the basin should be stable and maintainable. For vegetated side slopes, a 4:1 (horizontal: vertical) minimum slope is recommended. Use vertical walls where side slopes are steeper than 3:1

$$A = \frac{2\text{V}}{9} \qquad \text{Equation SF-2}$$

Where:

A = minimum filter area (flat surface area) (ft^2)

V = design volume (ft^3)

3. **Filter Material**: Provide, at a minimum, an 18-inch layer of CDOT Class C filter material (see Table SF-1). Maintain a flat surface on the top of the sand bed.

Table SF-1. Gradation Specifications for CDOT Class C Filter Material
(Source: CDOT Table 703-7)

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

4. **Underdrain System**: Underdrains are typically required for sand filters and should be provided if infiltration tests show rates slower than 2 times that required to drain the WQCV over 12 hours, or where required to divert water away from structures as determined by a professional engineer. Percolation tests should be performed or supervised by a licensed professional engineer and conducted at a minimum depth equal to the bottom of the sand filter. Additionally, underdrains are required where impermeable membranes are used. There are three basic types of sand filters:

   - **No-Infiltration:** This section includes an underdrain and an impermeable liner that does not allow for infiltration of stormwater into the subgrade soils. It is appropriate to use a no-infiltration system when any of the following is true:

     - Land use or activities could contaminate groundwater when stormwater is allowed to infiltrate, or

     - The BMP is located over potentially expansive soils or bedrock or is adjacent (within 10 feet) to structures.

   - **Partial Infiltration:** This section does not include an impermeable liner, allowing for some infiltration. Stormwater that does not infiltrate will be collected and removed by an underdrain system.

   - **Full Infiltration:** This section is designed to infiltrate all of the water stored into the subgrade below. UDFCD recommends a minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours.

   When using an underdrain system, provide a control orifice sized to drain the design volume in approximately 12 hours or more (see Equation SF-3). Use a minimum orifice size of 3/8 inch to avoid clogging. This will provide detention and slow release of the WQCV to offset hydromodification. Provide cleanouts to allow inspection of the drainpipe system during and after construction to ensure that the pipe was not crushed or disconnected during construction and to allow for maintenance of the underdrain. Space underdrain pipes a maximum of 20 feet on-center.

$$D_{12\text{ hour drain time}} = \sqrt{\frac{V}{1414\,y^{0.41}}} \qquad \text{Equation SF-3}$$

   Where:

   D = orifice diameter (in)

   y = distance from the lowest elevation of the storage volume (ft) (i.e., surface of the filter) to the center of the orifice

   V = volume to drain in 12 hours (WQCV) (ft^3)

   In previous versions of this manual, UDFCD recommended that the underdrain be placed in an aggregate layer and that a geotextile (separator fabric) be placed between this aggregate and the growing medium. This version of the manual replaces that section with materials that, when used together, eliminate the need for a separator fabric.

The underdrain system should be placed below the 18-inch (minimum) filter layer. The underdrain system should be placed within an 5-inch-thick section of CDOT Class C filter material meeting the gradation in Table SF-1. Areas of the underdrain layer may be deeper due to the slope of the underdrain. If no underdrain is required, the minimum section can be reduced to the 18-inch filter layer. Use slotted pipe that meets the slot dimensions provided in Table SF-2.

Table SF-2. Dimensions for Slotted Pipe

Pipe Size	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4"	1-1/16"	0.032"	0.413"	1.90 in^2
6"	1-3/8"	0.032"	0.516"	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

Table SF-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction
[2] As measured in accordance with ASTM D 4632

5. **Impermeable Geomembrane Liner and Geotextile Separator Fabric:** For no-infiltration sections, install a minimum 30-mil thick PVC geomembrane liner, per Table SF-4, on the bottom and sides of the basin, extending up at least to the top of the underdrain layer. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration. The geomembrane should be field-seamed using a dual track welder, which allows for non-destructive testing of almost all field seams. A small amount of single track and/or adhesive seaming should be allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs. The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. Place CDOT Class B geotextile separator fabric above the geomembrane to protect it from being punctured during the placement of the filter material above the liner. If the subgrade contains angular rocks or other material that could puncture the geomembrane, smooth-roll the surface to create a suitable surface. If smooth-rolling the surface does not provide a suitable surface, also place the separator fabric between the geomembrane and the underlying subgrade. This should only be done when necessary because fabric placed under the geomembrane can increase seepage losses through pinholes or other geomembrane defects. Connect the geomembrane to perimeter concrete walls around the basin perimeter, creating a watertight seal between the geomembrane and the walls using a continuous batten bar and anchor connection (see Figure SF-3). Where the need for the impermeable membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Use watertight PVC boots for underdrain pipe penetrations through the liner (see Figure SF-2).

Table SF-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m^2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

6. **Inlet Works**: Provide energy dissipation at all inlet points into the sand filter. Use an impact basin for pipes and a baffle chute or grouted sloping boulder drop if a channel or swale is used, or install a Type VL or L riprap basin underlain with geotextile fabric at the inlet (see Figure SF-1). Fill all rock voids with the filter material specified in Table SF-1.

7. **Outlet Works**: Slope the underdrain into a larger outlet structure. As discussed in Step 4, use an orifice plate to drain the WQCV over approximately 12 hours. Flows exceeding the WQCV should also drain into the outlet structure. Additional flow restrictions may be incorporated to provide Full Spectrum Detention, as discussed in the *Storage* chapter of Volume 2, or peak reduction for other specific storm events.

   For Full Spectrum Detention, perform reservoir routing calculations to design the outlet structure. The *UD-Detention* workbook, available at www.udfcd.org, can be used for this purpose. The design could include a second orifice located at the WQCV elevation or could include a downstream point of control designed to drain the full excess urban runoff volume (EURV) in approximately 72 hours.

Construction Considerations

Proper construction of sand filters involves careful attention to material specifications and construction details. For a successful project, do the following:

- Protect area from excessive sediment loading during construction. The portion of the site draining to the sand filter must be stabilized before allowing flow into the sand filter.

- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner.

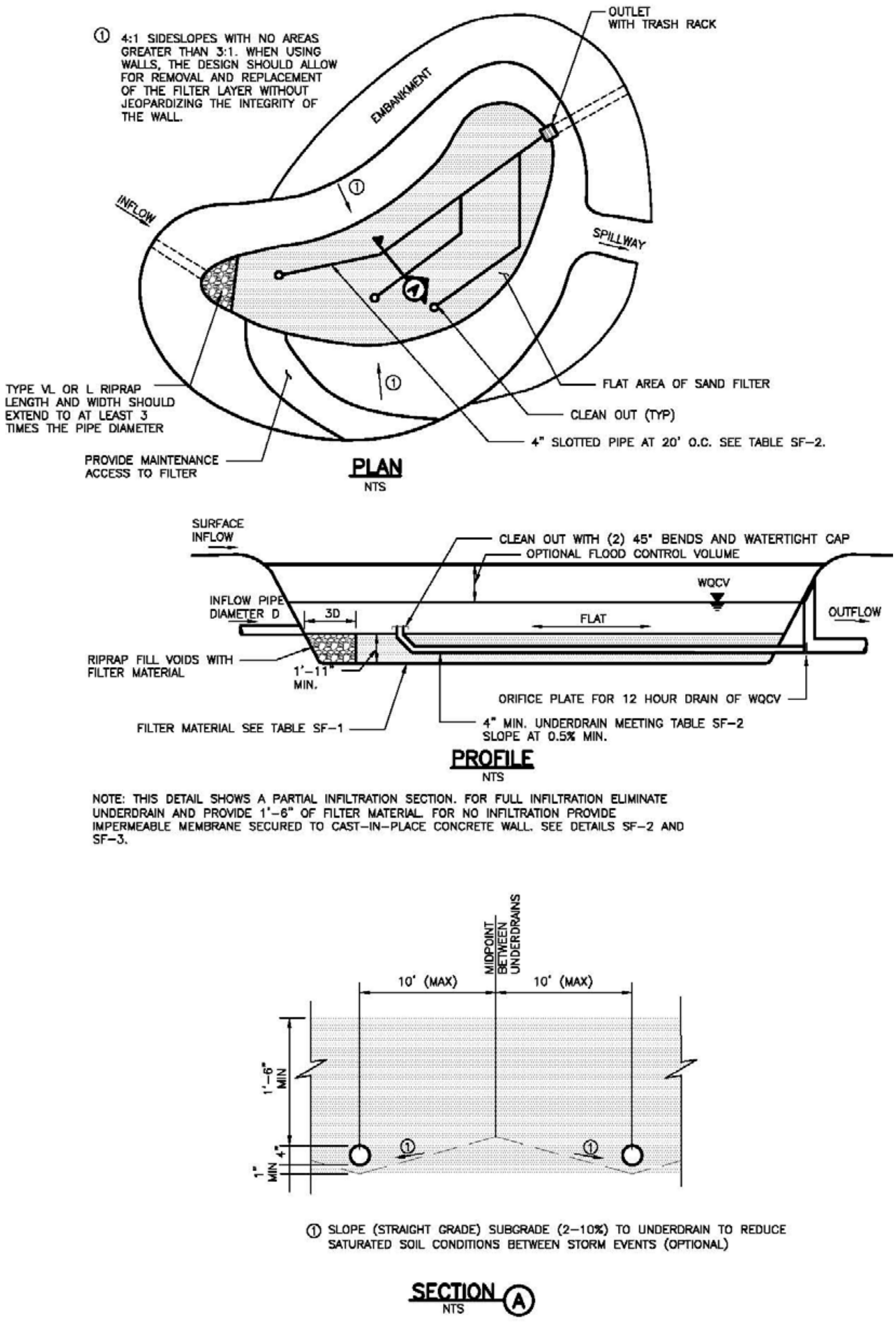


Figure SF-1. Sand Filter Plan and Sections

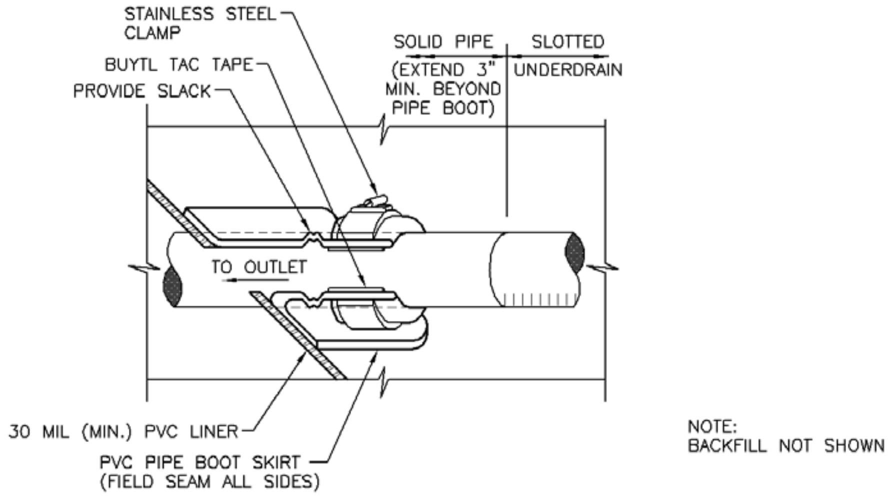


Figure SF-2. Geomembrane Liner/Underdrain Penetration Detail

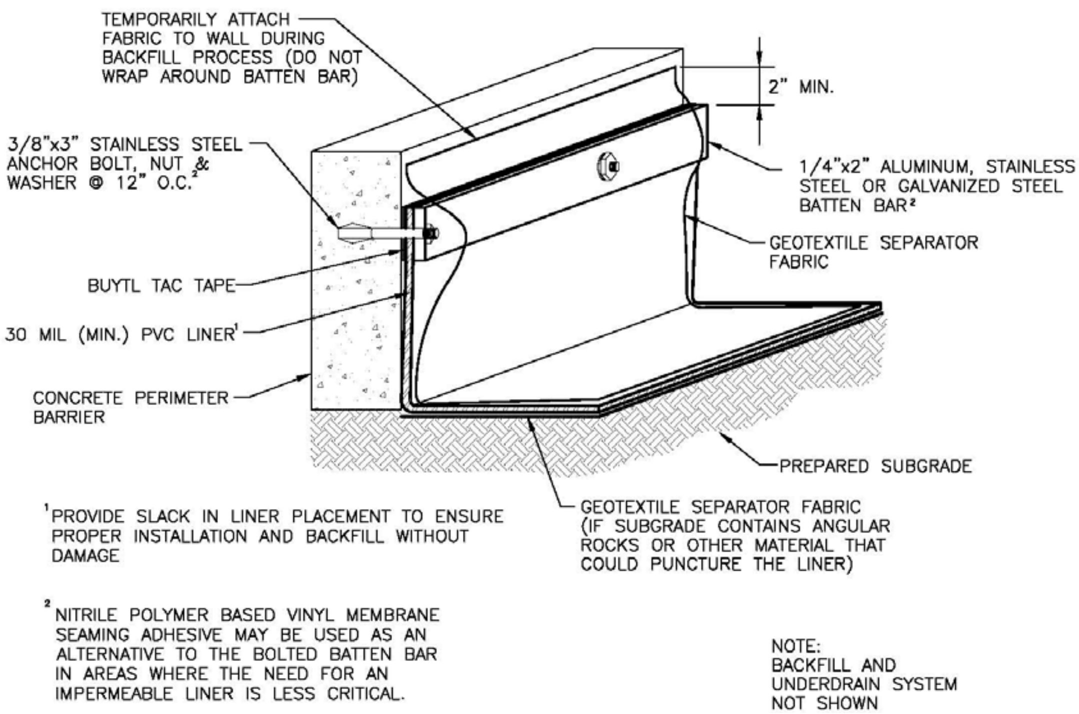


Figure SF-3. Geomembrane Liner/Concrete Connection Detail

Design Examples

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Sand Filter (SF)

Sheet 1 of 2

Designer:	**T. Chio**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Shops at 67th**
Location:	**SE Corner of 67th Ave. and 104th St.**

1. Basin Storage Volume	
A) Effective Imperviousness of Tributary Area, I_a (100% if all paved and roofed areas upstream of sand filter)	I_a = 75.0 %
B) Tributary Area's Imperviousness Ratio ($i = I_a/100$)	i = 0.750
C) Water Quality Capture Volume (WQCV) Based on 24-hour Drain Time WOCV= $0.9 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i)$	WQCV = 0.27 watershed inches
D) Contributing Watershed Area (including sand filter area)	Area = 217,800 sq ft
E) Water Quality Capture Volume (WQCV) Design Volume V_{WOCV} = WQCV / 12 * Area	V_{WQCV} = 4,893 cu ft
F) For Watersheds Outside of the Denver Region, Depth of Average Runoff Producing Storm	d_6 = ______ in
G) For Watersheds Outside of the Denver Region, Water Quality Capture Volume (WQCV) Design Volume	$V_{WQCV\ OTHER}$ = ______ cu ft
H) User Input of Water Quality Capture Volume (WQCV) Design Volume (Only if a different WQCV Design Volume is desired)	$V_{WQCV\ USER}$ = ______ cu ft
2. Basin Geometry	
A) WQCV Depth	D_{WQCV} = 3.2 ft
B) Sand Filter Side Slopes (Horizontal distance per unit vertical, 4:1 or flatter preferred). Use "0" if sand filter has vertical walls.	Z = 4.00 ft / ft
C) Mimimum Filter Area (Flat Surface Area)	A_{Min} = 1087 sq ft
D) Actual Filter Area	A_{Actual} = 1625 sq ft
E) Volume Provided	V_T = 4893 cu ft
3. Filter Material	Choose One ◉ 18" CDOT Class C Filter Material ○ Other (Explain):
4. Underdrain System	
A) Are underdrains provided?	Choose One ◉ YES ○ NO
B) Underdrain system orifice diameter for 12 hour drain time	
i) Distance From Lowest Elevation of the Storage Volume to the Center of the Orifice	y = 2.8 ft
ii) Volume to Drain in 12 Hours	Vol_{12} = 4,893 cu ft
iii) Orifice Diameter, 3/8" Minimum	D_O = 1.51 in

Design Procedure Form: Sand Filter (SF)

Sheet 2 of 2

Designer:	**T. Chio**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Shops at 67th**
Location:	**SE Corner of 67th Ave. and 104th St.**

5. Impermeable Geomembrane Liner and Geotextile Separator Fabric A) Is an impermeable liner provided due to proximity of structures or groundwater contamination?	Choose One ○ YES ◉ NO
6-7. Inlet / Outlet Works A) Describe the type of energy dissipation at inlet points and means of conveying flows in excess of the WQCV through the outlet	At grade type VL riprap pad at both inlet locations.

Notes:

Description

Photograph RP-1. Retention ponds treat stormwater though sedimentation and biological processes including uptake.

A retention pond, sometimes called a "wet pond," has a permanent pool of water with capacity above the permanent pool designed to capture and slowly release the water quality capture volume (WQCV) over 12 hours. The permanent pool is replaced, in part, with stormwater during each runoff event so stormwater runoff mixes with the permanent pool water. This allows for a reduced residence time compared to that of the extended detention basin (EDB). The 12-hour drain time helps to both better replicate pre-development flows for frequent events and reduce the potential for short circuiting treatment in smaller ponds. Retention ponds can be very effective in removing suspended solids, organic matter and metals through sedimentation, as well as removing soluble pollutants like dissolved metals and nutrients through biological processes.

Retention ponds can also be designed to provide Full Spectrum Detention. Widespread use of full spectrum detention is anticipated to reduce impacts on major drainageways by reducing post-development peak discharges to better resemble pre-development peaks.

Retention	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Moderate
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis is based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

Retention ponds require groundwater or a dry-weather base flow if the permanent pool elevation is to be maintained year-round. They also require legal and physical use of water. In Colorado, the availability of this BMP can be limited due to water rights issues.

The designer should consider the overall water budget to ensure that the baseflow will exceed evaporation, evapotranspiration, and seepage losses (unless the pond is lined). High exfiltration rates can initially make it difficult to maintain a permanent pool in a new pond, but the bottom can eventually seal with fine sediment and become relatively impermeable over time. However, it is best to seal the bottom and the sides of a permanent pool if the pool is located on permeable soils and to leave the areas above the permanent pool unsealed to promote infiltration of the stormwater detained in the surcharge WQCV.

Studies show that retention ponds can cause an increase in temperature from influent to effluent. Retention ponds are discouraged upstream of receiving waters that are sensitive to increases in temperature (e.g., fish spawning or hatchery areas).

Use caution when placing this BMP in a basin where development will not be completed for an extended period, or where the potential for a chemical spill is higher than typical. When these conditions exists, it is critical to provide adequate containment and/or pretreatment of flows. In developing watersheds, frequent maintenance of the forebay may be necessary.

Benefits

- Creates wildlife and aquatic habitat.
- Provides recreation, aesthetics, and open space opportunities.
- Can increase adjacent property values.
- Cost-effective BMP for larger tributary watersheds.

Limitations

- Safety concerns associated with open water.
- Requires both physical supply of water and a legal availability (in Colorado) to impound water.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.
- Ponds can attract water fowl which can add to the nutrients and bacteria leaving the pond.
- Ponds increase water temperature.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term.

- Provide pretreatment upstream of the permanent pool.
- Provide maintenance access to the outlet structure as well as the forebay.
- Exceed the minimum criterion for the permanent pool volume. Greater depth will help deter algae growth by reducing temperature and the area of the pond bottom that receives sunlight.

Design Procedure and Criteria

The following steps outline the retention pond design procedure and criteria, and Figure RP-1 shows a typical configuration.

1. **Baseflow**: Unless the permanent pool is establish by groundwater, a perennial baseflow that exceeds losses must be physically and legally available. Net influx calculations should be conservative to account for significant annual variations in hydrologic conditions. Low inflow in relation to the pond volume can result in poor water quality. Losses include evaporation, evapotranspiration, and seepage. Evaporation can be estimated from existing local studies or from the National Weather Service (NWS) Climate Prediction website. Data collected from Chatfield Reservoir from 1990 to 1997 show an average annual evaporation of 37 inches, while the NWS shows approximately 40 inches of evaporation per year in the Denver metropolitan area. Potential evapotranspiration (which occurs when water supply to both plant and soil surface is unlimited) is approximately equal to the evaporation from a large, free-water surface such as a lake (Bedient and Huber, 1992). When retention ponds are placed above the groundwater elevation, a pond liner is recommended unless evaluation by a geotechnical engineer determines this to be unnecessary.

2. **Surcharge Volume**: Provide a surcharge volume based on a 12-hour drain time.

   - Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).

   - Find the required storage volume. Determine the required WQCV or EURV (watershed inches of runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 (for EURV).

   - Calculate the design volume (surcharge volume above the permanent pool) as follows:

     For WQCV:

$$V = \left[\frac{\text{WQCV}}{12}\right]A \qquad \text{Equation RP-1}$$

     For EURV:

$$V = \left[\frac{\text{EURV}}{12}\right]A \qquad \text{Equation RP-2}$$

     Where:

     V = design volume (acre ft)

     A = tributary catchment drainage area (acres)

3. **Basin Shape:** Always maximize the distance between the inlet and the outlet. A basin length to width ratio between 2:1 and 3:1 is recommended to avoid short-circuiting. It may be necessary to modify the inlet and outlet locations through the use of pipes, swales, or channels to accomplish this.

4. **Permanent Pool**: The permanent pool provides stormwater quality enhancement between storm runoff events through biochemical processes and continuing sedimentation.

   - Volume of the permanent pool:

$$V_p \geq 1.2\left[\frac{\text{WQCV}}{12}\right]A \qquad \text{Equation RP-3}$$

     Where:

     V_p = permanent pool volume (acre ft)

     A = tributary catchment drainage area (acres)

- Depth Zones: The permanent pool should have two zones:
  - Safety Wetland Bench: This area should be located along the perimeter of the pond, 6 to 12 inches deep and a minimum of 4 feet wide. Aquatic plant growth along the perimeter of the permanent pool can help strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake. The safety wetland bench is also constructed as a safety precaution. It provides a shallow area that allows people or animals who inadvertently enter the open water to gain footing to get out of the pond.
  - Open Water Zone: The remaining pond area should be open, providing a volume to promote sedimentation and nutrient uptake by phytoplankton. To avoid anoxic conditions, the maximum depth in the pool should not exceed 12 feet.

5. **Side Slopes**: Side slopes should be stable and sufficiently gentle to limit rill erosion and to facilitate maintenance. Side slopes above the safety wetland bench should be no steeper than 4:1, preferably flatter. The safety wetland bench should be relatively flat with the depth between 6 to 12 inches. The side slope below this bench should be 3:1 (or flatter when access is required or when the surface could be slippery). The steeper 3:1 slope below the safety wetland bench can be beneficial to deterring algae growth as it will reduce the shallow area of the pond, thus reducing the amount of sunlight that penetrates the pond bottom.

6. **Inlet**: Dissipate energy at the inlet to limit erosion and to diffuse the inflow plume. Inlets should be designed in accordance with the *Hydraulic Structures* chapter of Volume 2. This chapter includes design of impact basins and drop structures.

7. **Forebay**: Forebays provide an opportunity for larger particles to settle out, which will reduce the required frequency of sediment removal in the permanent pool. Install a solid driving surface on the bottom and sides below the permanent water line to facilitate sediment removal. A soil riprap berm should be constructed to contain the forebay opposite of the inlet. This should have a minimum top width of 8 feet and side slopes no steeper than 4:1. The forebay volume within the permanent pool should be sized for anticipated sediment loads from the watershed and should be at least 3% of the WQCV. If the contributing basin is not fully developed, additional measures should be taken to maintain a relatively clean forebay. This includes more frequent maintenance of the forebay and/or providing and maintaining temporary erosion control.

8. **Outlet:** The outlet should be designed to release the WQCV over a 12-hour period. This can be done through an orifice place as detailed in BMP Fact Sheet T-12. Use reservoir routing calculations as discussed in the *Storage* chapter of Volume 2 or use equation RP-4, a simplified orifice sizing equation (see Technical Memorandum dated July 13, 2010 available at www.udfcd.org).

$$A_O = \frac{201V^{\left(0.95/H^{0.085}\right)}}{T_D H^{0.164}} \qquad \text{Equation RP-4}$$

Where:

A_O = area per row of orifices spaced on 4-inch centers (in^2)

V = design volume (WQCV or EURV) (acre ft)

T_D = time to drain the prescribed volume (hrs) (i.e., 12 for WQCV or 72 for EURV)

H = depth of surcharge volume (ft)

Refer to BMP Fact Sheet T-12 for schematics pertaining to structure geometry, grates, trash racks, orifice plate, and all other necessary components.

9. **Trash Rack**: Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Similar to the trash rack design for the extended detention basin, extend the water quality trash rack into the permanent pool a minimum of 28 inches. The benefit of this is documented in Fact Sheet T-5. BMP Fact Sheet T-12 provides additional guidance on trash rack design including standard tables for most designs.

10. **Overflow Embankment**: Design the embankment not to fail during the 100-year storm. If the embankment falls under the jurisdiction of the State Engineer's Office, it should be designed to meet the requirements of the State Engineer's Office. Embankment slopes should be no steeper than 4:1, preferably flatter, and planted with turf grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to 95% of maximum dry density for ASTM D698 (Standard Proctor) or 90% for ASTM D1557 (Modified Proctor). Spillway structures and overflows should be designed in accordance with local drainage criteria and should consider the use of stabilizing materials such as buried soil riprap or reinforced turf mats installed per manufacturer's recommendations.

11. **Maintenance Considerations:** The design should include a means of draining the pond to permit drying out of the pond when it has to be "mucked out" to restore volume lost due to sediment deposition. A means to drain the pond or a portion of the pond by gravity is preferred but not always practicable. Some level of pumping is typically required. Past versions of this manual included an underdrain at the perimeter of the pond with a valved connection to the outlet structure for this purpose. This remains an acceptable method for draining the pond. Additional alternatives include providing a drywell with a piped connection to the outlet structure or to a downstream conveyance element or connecting a valved pipe directly to the outlet structure. The pipe should include a valve that will only be opened for maintenance.

12. **Vegetation:** Vegetation provides erosion control and enhances site stability. Berms and side-sloping areas should be planted with native grasses or irrigated turf, depending on the local setting and proposed uses for the pond area. The safety wetland bench should be vegetated with aquatic species. This vegetation around the perimeter of an open water body can discourage frequent use of the pond by geese.

Providing a buffer of tall native grasses around a retention pond provides treatment through filtering (straining) and helps discourage frequent use of the pond by geese.

Photograph RP-2. This retention pond outlet structure is both accessible and functional while not interfering with the natural aesthetic.

13. **Access:** All weather stable access to the bottom, forebay, and outlet works area should be provided for maintenance vehicles. Grades should not exceed 10% for haul road surfaces and should not exceed 20% for skid-loader and backhoe access. Provide a solid driving surface such as gravel, concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement. The recommended cross slope is 2%.

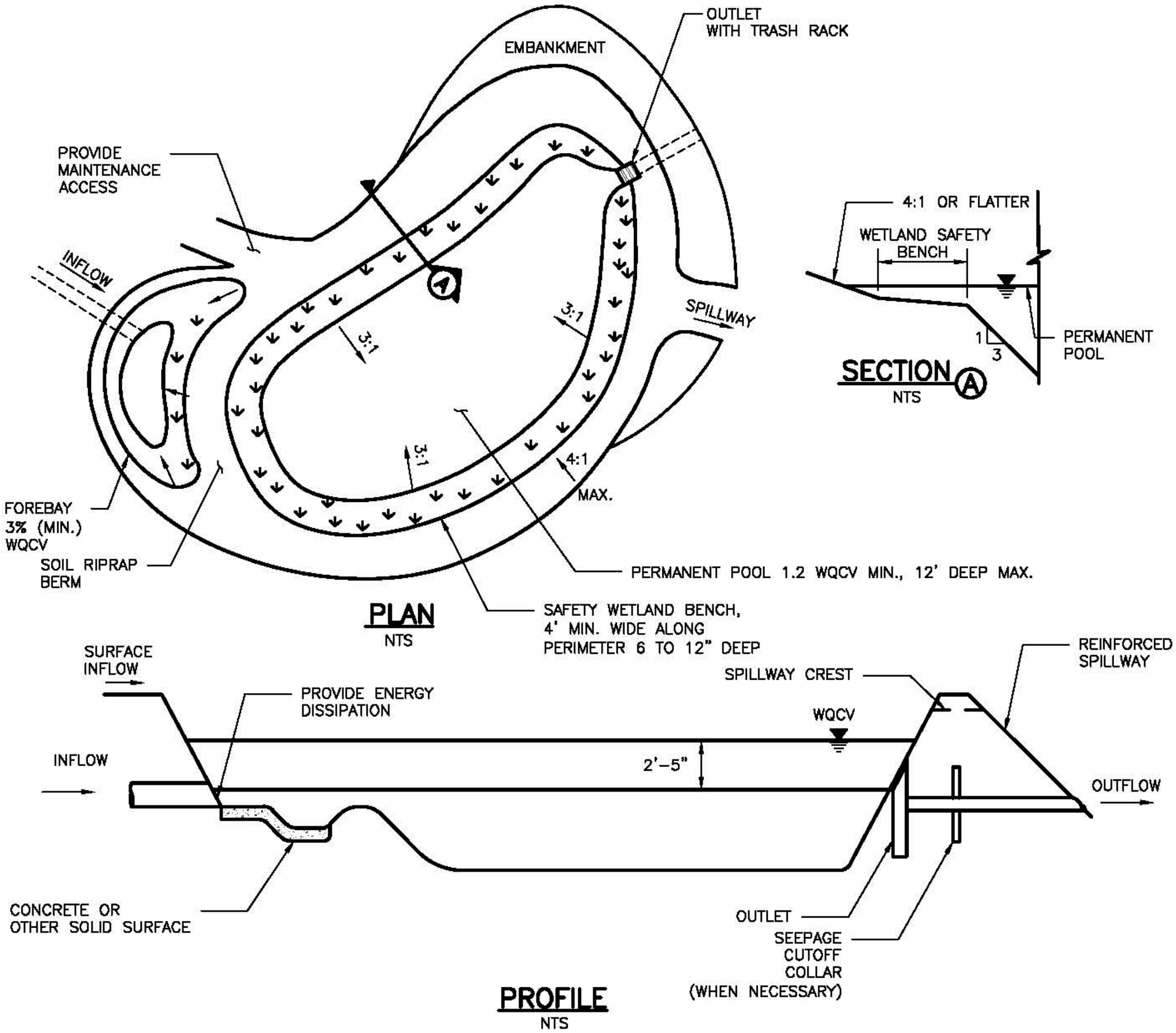


Figure RP-1. Retention Pond Plan and Sections

Aesthetic Design

Since all land owners and managers wish to use land in the most efficient manner possible, it is important that retention basins become part of a multi-use system. This encourages the design of retention ponds as an aesthetic part of a naturalized environment or to be expanded to include passive and/or active open space. Within each scenario, the retention basin can begin to define itself as more than just a drainage facility. When this happens, the basin becomes a public amenity. This combination of public amenity and drainage facility is of much greater value to a landowner. Softened and varied slopes, interspersed irrigated fields, planting areas and wetlands can all be part of a retention pond.

The design should be aesthetic whether it is considered to be an architectural or naturalized basin. Architectural basins incorporate design borrowed or reflective of the surrounding architecture or urban forms. An architectural basin is intended to appear as part of the built environment, rather than hiding the cues that identify it as a stormwater structure. A naturalized basin is designed to appear as though it is a natural part of the landscape. This section provides suggestions for designing a naturalized basin. The built environment, in contrast to the natural environment, does not typically contain the randomness of form inherent in nature. Constructed slopes typically remain consistent, as do slope transitions. Even dissipation structures are usually a hard form and have edges seldom seen in nature. If the retention pond is to appear as though it is a natural part of the landscape, it is important to minimize shapes that provide visual cues indicating the presence of a drainage structure. For example, the pond sides in the area of the surcharge volume should be shaped more naturally and with varying slopes for a naturalized pond. See Figure RP-2 for an example.

Suggested Methods for Creating the Look of a Naturalized Pond:

- Create a flowing overall form that looks like it was shaped by water. This includes the banks of the retention pond, which should have an undulating outline rather than a straight line.
- One side of the pond can be higher than the other side. This may require a berm.
- The shape of the permanent pool should vary from the shape of the surcharge volume.
- The slopes on at least three sides of the pond (above the permanent pool) should be varied and gentle. To achieve this, one or more sides of the basin may have to be stabilized by a retaining structure, i.e., stacked boulders and walls.
- Vary slope transitions.

Photograph RP-3. (altered photo) When incorporating rock into a structure, use other matching, functional rock to prevent the structure from looking out of context. Photo courtesy of Design Concepts.

- Any use of rock for energy dissipation or for erosion control should graduate away from the area of hard edge into the surrounding landscape. Other functional matching rock should occur in other areas of the pond to prevent the energy dissipation structure from appearing out of context. Photo RP-3 serves as an example of this.

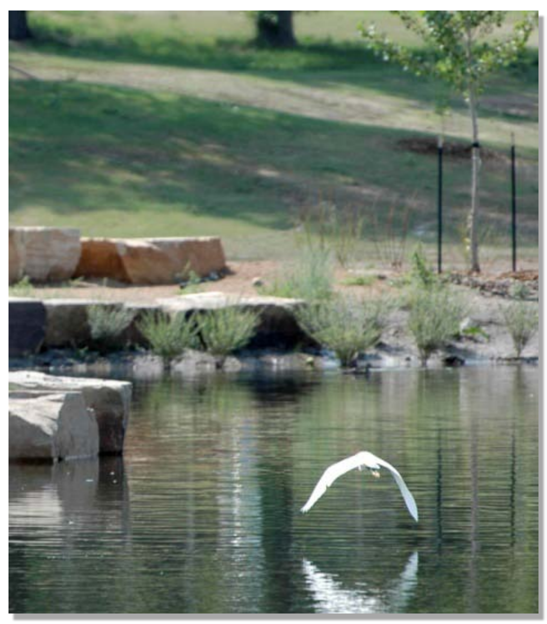
- If concrete is required in the basin, colored concrete matching the rocks or other site features of the surrounding landscape can be used to prevent the structure from appearing out of context. Colored concrete, form liners and veneers for construction walls are preferred for outlet structures.

Photograph RP-4. (altered photo) Variations in slope and texture around the pond are brought together by mass groupings of local stone boulders. The boulders are placed intermittently around the pond in groups and interspersed with plantings. Photo courtesy of Design Concepts. Note: A minimum 4-foot vegetated buffer (littoral zone) is recommended to strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake.

- Adjust the vegetation to the different uses of the pond surrounding.

- Ground cover should reflect the type of water regime expected for the location within the basin. For example, riparian plants would be placed around the edge of the retention pond, groups of trees and shrubs would be placed in more manicured areas that have no retention or detention function.

Photograph RP-5. A curving stream with vegetated edges provides habitat for wildlife. Photo courtesy of Design Concepts.



Photograph RP-6. Landscape elements such as vegetation and stone highlight the irregularly-shaped pond edge, making it appear more natural. Photo courtesy of Design Concepts.

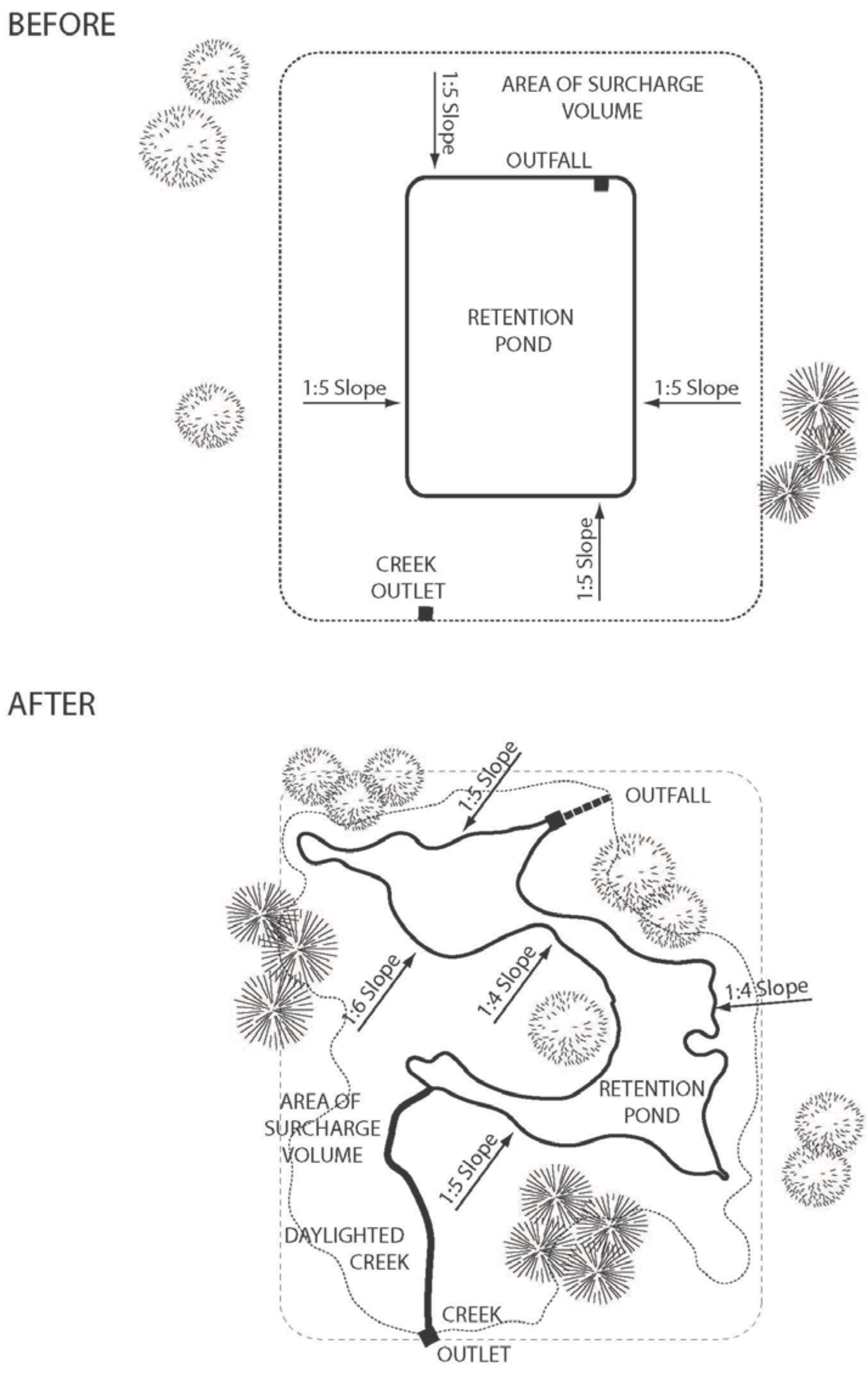


Figure RP-2. Example of a Naturalized Retention Pond

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Retention Pond (RP)

Sheet 1 of 3

Designer:	**L. Gibson**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivision B**
Location:	**NE Corner of 67th Ave. and 88th St.**

1. Baseflow A) Is the permanent pool established by groundwater?	Choose One (●) YES ( ) NO
2. Surcharge Volume	
A) Effective Imperviousness of Tributary Area, I_a	I_a = 80.0 %
B) Tributary Area's Imperviousness Ratio ($i = I_a / 100$)	i = 0.800
C) Contributing Watershed Area	Area = 50.000 ac
D) For Watersheds Outside of the Denver Region, Depth of Average Runoff Producing Storm	d_6 = ______ in
E) Design Concept (Select EURV when also designing for flood control)	Choose One ( ) Water Quality Capture Volume (WQCV) (●) Excess Urban Runoff Volume (EURV)
F) Water Quality Capture Volume (WQCV) Based on 12-hour Drain Time ($V_{WQCV} = (0.8 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i) / 12 * Area)$	V_{WQCV}= 1.094 ac-ft
G) For Watersheds Outside of the Denver Region, Water Quality Capture Volume (WQCV) ($V_{WQCV\ OTHER} = (d_6*(V_{WQCV}/0.43))$	$V_{WQCV\ OTHER}$= ______ ac-ft
H) User Input of Water Quality Capture Volume (WQCV) (Only if a different WQCV Design Volume is desired)	$V_{WQCV\ USER}$= ______ ac-ft
I) Predominant Watershed NRCS Soil Group	Choose One ( ) A ( ) B (●) C / D
J) Excess Urban Runoff Volume (EURV) Design Volume For HSG A: $EURV_A = (0.1878i - 0.0104)*Area$ For HSG B: $EURV_B = (0.1178i - 0.0042)*Area$ For HSG C/D: $EURV_{C/D} = (0.1043i - 0.0031)*Area$	EURV = 4.017 ac-f t
3. Basin Shape (It is recommended to have a basin length to width ratio between 2:1 and 3:1)	L : W = 3.0 : 1
4. Permanent Pool	
A) Minimum Permanent Pool Volume	V_{POOL} = 1.313 ac-ft
B) Depth of the Safety Wetland Bench (Recommended to be 6 to 12 inches deep)	D_{LZ} = 6 in
C) Depth of the Open Water Zone (Maximum depth of 12 feet)	D_{OWZ} = 12.0 ft
5. Side Slopes	
A) Maximum Side Slopes Above the Safety Wetland Bench (Horiz. dist. per unit vertical, should be no steeper than 4:1)	Z_{PP} = 5.00 ft / ft
B) Maximum Side Slopes Below the Safety Wetland Bench (Horiz. dist. per unit vertical, should be no steeper than 3:1)	Z_{OWZ} = 3.00 ft / ft
6. Inlet A) Describe means of providing energy dissipation at concentrated inflow locations:	Adequate tailwater during events exceeding the WQCV.

Design Procedure Form: Retention Pond (RP)

Sheet 2 of 3

Designer:	**L. Gibson**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivision B**
Location:	**NE Corner of 67th Ave. and 88th St.**

7. Forebay

A) Minimum Forebay Volume (V_{FMIN} = 3% of the WQCV) — V_{FMIN} = 0.033 ac-ft

B) Actual Forebay Volume — V_F = 0.037 ac-ft

8. Outlet

A) Outlet Type

Choose One
- (●) Orifice Plate
- ( ) Other (Describe):

B) Depth of Surcharge Volume (Depth of WQCV or EURV depending on design concept) — H = 3.0 feet

C) Volume to Drain Over Prescribed Time — EURV = 4.017 ac-ft

D) Drain Time (Min T_D for WQCV= 12 hours; Max T_D for EURV= 72 hours) — T_D = 72 hours

E) Recommended Outlet Area per Row, (A_o) — A_o = 7.77 square inches

F) Orifice Dimensions:
- i) Circular Orifice Diameter or — $D_{orifice}$ = ______ inches
- ii) Width of 2" High Rectangular Orifice — $W_{orifice}$ = 3.88 inches

G) Number of Columns — nc = 1 number

H) Actual Design Outlet Area per Row (A_o) — A_o = 7.8 square inches

I) Number of Rows (nr) — nr = 9 number

J) Total Outlet Area (A_{ot}) — A_{ot} = 69.8 square inches

K) Depth of WQCV (H_{WQCV}) (Estimate using actual stage-area-volume relationship and V_{WQCV}) — H_{WQCV} = ______ feet

L) Ensure Minimum 12 Hour Drain Time for WQCV — $T_{D\ WQCV}$ = ______ hours

9. Trash Rack

A) Type of Outlet Opening

Choose One
- ( ) Circular (up to 2" diameter)
- (●) Rectangular (2" high)

B) Trash Rack Open Area: $A_t = 0.5 * 77(e^{-0.124D})*A_{ot}$ — A_t = 2,224 square inches

C) For 2", or Smaller, Circular **Opening** (Reference figure in Fact Sheet T-12):

- i) Depth of Trash Rack below Permanent Pool WS (28 inch min.) — $D_{inundation}$ = ______ inches
- ii) Width of Trash Rack and Concrete Opening ($W_{opening}$) — $W_{opening}$ = ______ inches
- iii) Height of Trash Rack Screen (H_{TR}) — H_{TR} = ______ inches
- iv) Type of Screen, Describe if "Other"

Choose One
- ( ) S.S. Well Screen with 60% Open Area*
- ( ) Other (Describe):

Design Procedure Form: Retention Pond (RP)

Sheet 3 of 3

Designer:	**L. Gibson**
Company:	**BMP, Inc.**
Date:	**November 29, 2010**
Project:	**Subdivision B**
Location:	**NE Corner of 67th Ave. and 88th St.**

D) For 2" High **Rectangular Opening** (See Fact Sheet T-12):	
i) Depth of Trash Rack below Permanent Pool WS (28 inch min.)	$D_{inundation}$ = 28.0 inches
ii) Width of Rectangular Opening ($W_{orifice}$)	W = 3.88 inches
iii) Width of Trash Rack Opening ($W_{opening}$)	$W_{opening}$ = 4.1 feet
iv) Height of Trash Rack Screen (H_{TR})	H_{TR} = 5.3 feet
v) Type of Screen, (Describe if "Other")	Choose One (●) Aluminum Amico-Klemp SR Series (or equal) ( ) Other (Describe):
vi) Cross-bar Spacing	**2.00**
vii) Minimum Bearing Bar Size	**1-1/4 in x 3/16 in**
10. Overflow Embankment	
A) Describe embankment protection for 100-year and greater overtopping:	soil riprap
B) Maximum Embankment Side Slopes (Horiz. dist. per unit vertical, should be no steeper than 4:1)	Z_E = 4.00 ft / ft
11. Maintenance Considerations	
A) Describe Means of Draining the Pond	The pond can be partially gravity drained with the valve located in the outlet structure. Remaining water must be pumped.
12. Vegetation	Choose One ( ) Irrigated (●) Not Irrigated
13. Access	
A) Describe Sediment Removal Procedures	Sediment may be removed from the forebay via the maintenance access located on the maintenance plan.

Notes:

References

Bedient, Philip B. and Wayne C. Huber. 1992. *Hydrology and Floodplain Analysis (Second Edition).* Addison-Wesley Publishing Company.

United States Environmental Protection Agency (EPA). 1999. *Storm Water Technology Fact Sheet: Wet Detention Ponds.*

Description

Photograph CWP-1. This constructed wetland pond, located downstream of an extended detention basin, is part of a BMP "treatment train."

A constructed wetlands pond is a shallow retention pond designed to permit the growth of wetland plants such as rushes, willows, and cattails. Constructed wetlands slow runoff and allow time for sedimentation, filtering, and biological uptake.

Constructed wetlands ponds differ from "natural" wetlands, as they are artificial and are built to enhance stormwater quality. Do not use existing or natural wetlands to treat stormwater runoff. Stormwater should be treated prior to entering natural or existing wetlands and other environmentally sensitive areas. Allowing untreated stormwater to flow into existing wetlands will overload and degrade the quality of the wetland. Sometimes, small wetlands that exist along ephemeral drainageways on Colorado's high plains can be enlarged and incorporated into the constructed wetland system. Such actions, however, require the approval of federal and state regulators.

Regulations intended to protect natural wetlands recognize a separate classification of wetlands, constructed for water quality treatment. Such wetlands generally are not allowed to be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality enhancement is separate from the disturbance of a natural wetland. Nevertheless, any activity that disturbs a constructed wetland should be cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

Constructed Wetland Basin	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis is based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

A constructed wetland pond requires a positive net influx of water to maintain vegetation and microorganisms. This can be supplied by groundwater or a perennial stream. An ephemeral stream will not provide adequate water to support this BMP.

A constructed wetland pond is best used as a follow-up BMP in a watershed, although it can serve as a stand-alone facility. Algae blooms may be reduced when BMPs that are effective in removing nutrients are placed upstream. Constructed wetland ponds can also be designed for flood control in addition to capture and treatment of the water quality capture volume (WQCV).

Although this BMP can provide an aesthetic onsite amenity, constructed wetland ponds designed to treat stormwater can also become large algae producers. The owner should maintain realistic expectations.

Benefits

- Creates wildlife and aquatic habitat.
- Provides open space opportunities.
- Cost effective BMP for larger tributary watersheds.

Limitations

- Requires both physical supply of water and a legal availability (in Colorado) to impound water.
- Ponding depth can pose safety concerns requiring additional considerations for public safety during design and construction.
- Sediment, floating litter, and algae blooms can be difficult to remove or control.
- Ponds can attract water fowl which can add to the nutrients leaving the pond.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design consider the sediment removal process, including access and equipment for the pond. As sedimentation occurs and depth becomes limited, removal of sediment from the pond bottom will be required to support beneficial habitat.

Be aware, nutrient rich inflow will produce algae blooms in this BMP. Source control BMPs, such as reduced fertilizer use, should be implemented to reduce regular maintenance.

Design Procedure and Criteria

The following steps outline the design procedure for a constructed wetland pond:

1. **Baseflow**: Unless the permanent pool is establish by groundwater, a perennial baseflow that exceeds losses must be physically and legally available. Net influx calculations should be conservative to account for significant annual variations in hydrologic conditions. Low inflow in relation to the pond volume can result in poor water quality. Losses include evaporation, evapotranspiration, and seepage. Evaporation can be estimated from existing local studies or from the National Weather Service (NWS) Climate Prediction website. Data collected from Chatfield Reservoir from 1990 to 1997 show an average annual evaporation of 37 inches, while the NWS shows approximately 40 inches of evaporation per year in the Denver metropolitan area. Potential evapotranspiration (which occurs when water supply to both plant and soil surface is unlimited) is approximately equal to the evaporation from a large, free-water surface such as a lake (Bedient and Huber, 1992). When constructed wetland ponds are placed above the groundwater elevation, a pond liner is recommended unless evaluation by a geotechnical engineer determines this to be unnecessary.

2. **Surcharge Volume**: Provide a surcharge storage volume based on a 24-hour drain time.

   - Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).

   - Find the required storage volume: Determine the required WQCV/EURV (watershed inches of runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the *Storage* chapter of Volume 2 of the USDCM (for EURV).

- Calculate the design volume (surcharge volume above the permanent pool) as follows:

  For WQCV:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation CWP-1}$$

  For EURV:

$$V = \left[\frac{\text{EURV}}{12}\right] A \qquad \text{Equation CWP-2}$$

  Where:

  V = design volume (acre ft)

  A = watershed tributary to the constructed wetland pond (acre)

3. **Depth of Surcharge WQCV**: In order to maintain healthy wetland growth, the surcharge depth for WQCV above the permanent water surface should not exceed 2 feet.

4. **Basin Shape**: Always maximize the distance between the inlet and the outlet. Shape the pond with a gradual expansion from the inlet and a gradual contraction to the outlet to limit short-circuiting. Try to achieve a basin length to width ratio between 2:1 to 4:1. It may be necessary to modify the inlet and outlet point through the use of pipes, swales, or channels to accomplish this.

5. **Permanent Pool**: The permanent pool provides stormwater quality enhancement between storm runoff events through biochemical processes and sedimentation. This requires a minimum volume as provided in Equation CWP-3.

$$V_p \geq 0.75 \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation CWP-3}$$

   Where:

   V_p = permanent pool volume (acre ft)

   A = watershed tributary to the constructed wetland pond (acre)

   Proper distribution of wetland habitat within and surrounding the permanent pool is needed to establish a diverse ecology. Distribute pond area in accordance with Table CWP-1.

Table CWP-1.

Pond Components	Permanent Pool Surface Area	Water Design Depth
Forebay, outlet and open water surface areas	30% to 50%	2 to 4 feet deep
Wetland zones with emergent vegetation	50% to 70%	6 to 12 inches deep[1]
[1] One-third to one-half of this zone should be 6 inches deep.		

6. **Side slopes:** Side slopes should be stable and sufficiently gentle to limit rill erosion and to facilitate maintenance. They should provide a safety wetland bench along the perimeter of the pond. This area should be 6 to 12 inches deep and a minimum of 4 feet wide. Aquatic plant growth along the perimeter of the permanent pool can help strain surface flow into the pond, protect the banks by stabilizing the soil at the edge of the pond, and provide biological uptake. The safety wetland bench is also constructed as a safety precaution. It provides a shallow area that allows people or animals who inadvertently enter the open water to gain footing to get out of the pond. Side slopes above the safety wetland bench should be no steeper than 4:1, preferably flatter. The safety wetland bench surrounding the perimeter of the pond should be relatively flat with the depth between 6 to 12 inches.

7. **Inlet**: Provide energy dissipation for flows entering the basin to limit sediment resuspension. Inlet designs should correspond to UDFCD drop-structure criteria, impact basin pipe outlet structure standards, or other energy dissipating and flow diffusing structure designs.

8. **Forebay**: Forebays provide an opportunity for larger particles to settle out, which will reduce the required frequency of sediment removal in the permanent pool. Install a solid driving surface on the bottom and sides below the permanent water line to facilitate sediment removal. A soil riprap berm should be constructed to contain the forebay opposite of the inlet. This should have a minimum top width of 8 feet and side slopes no steeper than 4:1. The forebay volume within the permanent pool should be sized for anticipated sediment loads from the watershed and should be at least 3% of the WQCV. If the contributing basin is not fully developed, additional measures should be taken to maintain a relatively clean forebay. This includes more frequent maintenance of the forebay and/or providing and maintaining temporary erosion control.

9. **Outlet**: The outlet should be designed to release the WQCV over a 24-hour period. This can be done through an orifice plate as detailed in BMP Fact Sheet T-12. Use reservoir routing calculations as discussed in the *Storage* Chapter of Volume 2 or use equation CWP-4, a simplified orifice sizing equation (see Technical Memorandum dated July 13, 2010 available at www.udfcd.org).

$$A_O = \frac{201V^{\left(0.95/H^{0.085}\right)}}{T_D H^{0.164}} \qquad \text{Equation CWP-4}$$

Where:

A_O = area per row of orifices spaced on 4" centers (in^2)

V = volume of stormwater to be drained (WQCV or EURV) (acre ft)

T_D = time to drain the prescribed volume (i.e., 24 for WQCV or 72 for EURV) (hrs)

H = depth of surcharge volume (ft)

Refer to BMP Fact Sheet T-12 for schematics pertaining to structure geometry, grates, trash racks, orifice plate, and all other necessary components.

10. **Trash Rack**: Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Similar to the trash rack design for the extended detention basin, extend the water quality trash rack into the permanent pool a minimum of 28 inches. The benefit of this is documented in Fact Sheet T-5. BMP Fact Sheet T-12 provides additional guidance on trash rack design including details and standard tables and for most designs.

11. **Overflow Embankment**: Design the embankment not to fail during the 100-year storm. If the embankment falls under the jurisdiction of the State Engineer's Office, it should be designed to meet the requirements of the State Engineer's Office. Embankment slopes should be no steeper than 4:1, preferably flatter, and planted with turf grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to 95 percent of maximum dry density for ASTM D698 (Standard Proctor) or 90 percent for ASTM D1557 (Modified Proctor). Spillway structures and overflows should be designed in accordance with local drainage criteria and should consider the use of stabilizing materials such as buried soil riprap or reinforced turf mats installed per manufacturer's recommendations.

12. **Maintenance Considerations:** The design should include a means of draining the pond to facilitate drying out of the pond when it has to be "mucked out" to restore volume lost due to sediment deposition. Past versions of this manual included an underdrain at the perimeter of the pond with a valved connection to the outlet structure for this purpose. This remains an acceptable method for draining the pond. Additional alternatives include providing a drywell with a piped connection to the outlet structure or a downstream conveyance element, or connecting a valved pipe directly to the outlet structure. The pipe should include a valve that will only be opened for maintenance.

13. **Vegetation**: Vegetation provides erosion control and enhances site stability. Berms and side-sloping areas should be planted with native bunch or turf-forming grasses. The safety wetland bench at the perimeter of the pond should be vegetated with aquatic species. Aquatic species should be planted in the wetland bottom. Initial establishment of the wetlands requires control of the water depth. After planting wetland species, the permanent pool should be kept at 3 to 4 inches deep at the plant zones to allow growth and to help establish the plants, after which the pool should be raised to its final operating level.

14. **Access:** All-weather stable access to the bottom, forebay, and outlet works area should be provided for maintenance vehicles. Grades should not exceed 10% for haul road surfaces and should not exceed 20% for skid-loader and backhoe access. Provide a solid driving surface such as gravel, concrete, articulated concrete block, concrete grid pavement, or reinforced grass pavement. The recommended cross slope is 2%.

Diverse wetlands make healthy wetlands. Create zones with different depths and plant a variety of vegetation.

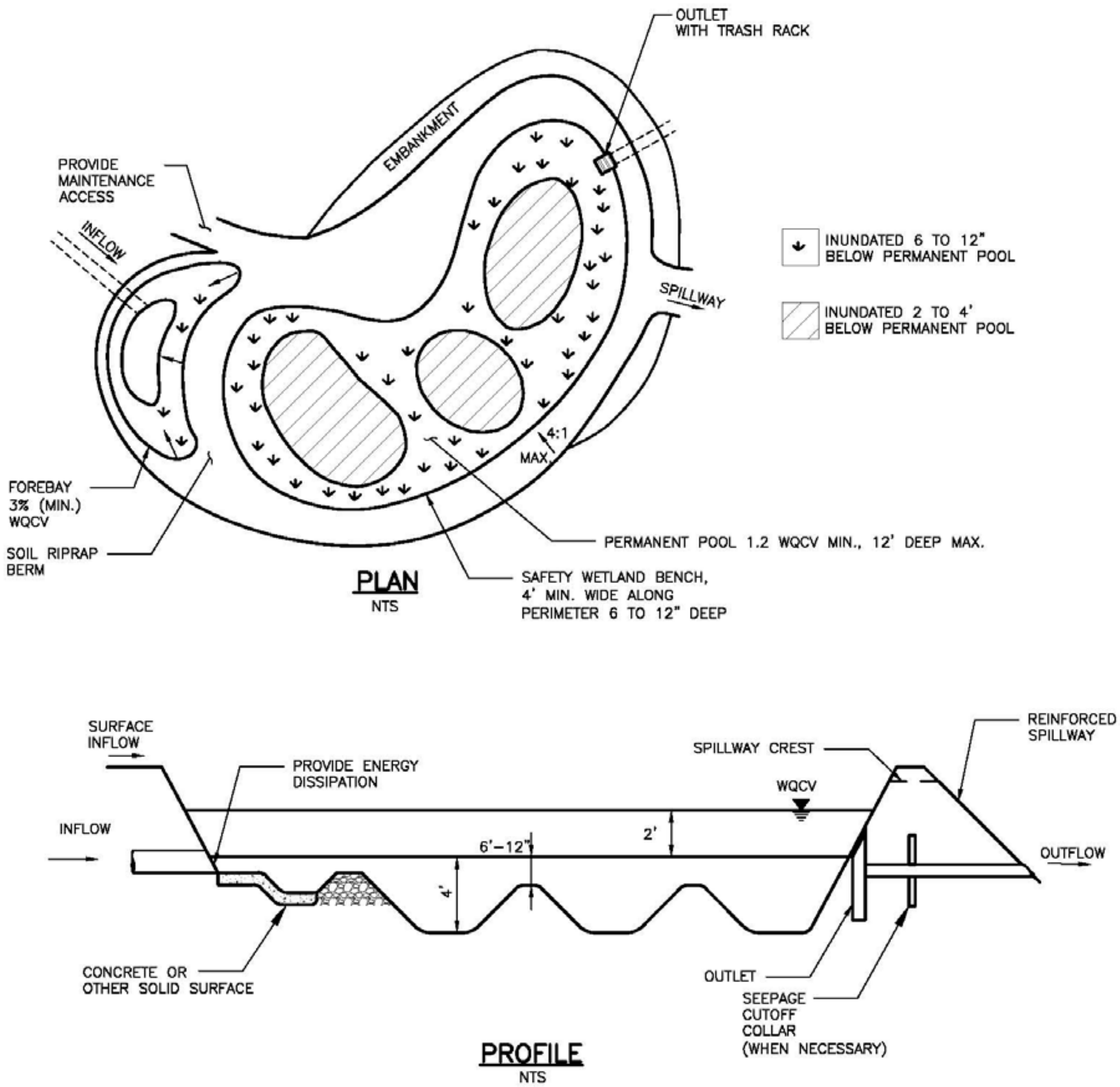


Figure CWP-1 – Constructed Wetland Pond – Plan and Cross-Section

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Constructed Wetland Pond (CWP)

Sheet 1 of 3

Designer:	N. Calisoff
Company:	BMP Inc.
Date:	November 29, 2010
Project:	Industrial Park
Location:	SW corner of 105th Ave. and 93rd St.

1. Baseflow A) Is the permanent pool established by groundwater?	Choose One (•) YES ( ) NO
2. Surcharge Volume	
A) Effective Imperviousness of Tributary Area, I_a	I_a = 60.0 %
B) Tributary Area's Imperviousness Ratio ($i = I_a / 100$)	i = 0.600
C) Contributing Watershed Area	Area = 10.000 ac
D) For Watersheds Outside of the Denver Region, Depth of Average Runoff Producing Storm	d_6 = ____ in
E) Design Concept (Select EURV when also designing for flood control)	Choose One ( ) Water Quality Capture Volume (WQCV) (•) Excess Urban Runoff Volume (EURV)
F) Water Quality Capture Volume (WQCV) Design Volume Based on 24-hour Drain Time ($V_{WQCV} = (0.9 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i) / 12 * Area)$)	V_{WQCV}= 0.177 ac-ft
G) For Watersheds Outside of the Denver Region, Water Quality Capture Volume (WQCV) Design Volume ($V_{WQCV\ OTHER} = (d_6*(V_{WQCV}/0.43))$)	$V_{WQCV\ OTHER}$= ____ ac-ft
H) User Input of Water Quality Capture Volume (WQCV) Design Volume (Only if a different WQCV Design Volume is desired)	$V_{WQCV\ USER}$= ____ ac-ft
I) Predominant Watershed NRCS Soil Group	Choose One ( ) A ( ) B (•) C / D
J) Excess Urban Runoff Volume (EURV) Design Volume For HSG A: $EURV_A = (0.1878i - 0.0104)*Area$ For HSG B: $EURV_B = (0.1178i - 0.0042)*Area$ For HSG C/D: $EURV_{C/D} = (0.1043i - 0.0031)*Area$	EURV = 0.595 ac-f t
3. Depth of Surcharge WQCV (Should not exceed 2 feet, required even if EURV is chosen)	D_{WQCV} = 2.0 ft
4. Basin Shape (It is recommended to have a basin length to width ratio between 2:1 and 4:1)	L : W = 4.0 : 1
5. Permanent Pool A) Minimum Permanent Pool Volume	V_{POOL} = 0.133 ac-ft
6. Side Slopes A) Maximum Side Slope Above the Safety Wetland Bench (Horiz. dist. per unit vertical, should be no steeper than 4:1)	Z = 4.00 ft / ft
7. Inlet A) Describe means of providing energy dissipation at concentrated inflow locations:	Adequate tailwater during events exceeding the WQCV.

Design Procedure Form: Constructed Wetland Pond (CWP)

Sheet 2 of 3

Designer:	**N. Calisoff**
Company:	**BMP Inc.**
Date:	**November 29, 2010**
Project:	**Industrial Park**
Location:	**SW corner of 105th Ave. and 93rd St.**

8. Forebay	
A) Minimum Forebay Volume (V_{FMIN} = 3% of the WQCV)	V_{FMIN} = 0.005 ac-ft
B) Actual Forebay Volume	V_F = 0.006 ac-ft
9. Outlet	
A) Outlet Type	Choose One (●) Orifice Plate ( ) Other (Describe):
B) Depth of Surcharge Volume (Depth of WQCV or EURV depending on design concept)	H = 2.0 feet
C) Volume to Drain Over Prescribed Time	EURV = 0.595 ac-ft
D) Drain Time (Min T_D for WQCV= 24 hours; Max T_D for EURV= 72 hours)	T_D = 72.0 hours
E) Recommended Outlet Area per Row, (A_o)	A_o = 1.56 square inches
F) Orifice Dimensions: i) Circular Orifice Diameter or ii) Width of 2" High Rectangular Orifices	$D_{orifice}$ = 1 - 3 / 8 inch inches $W_{orifice}$ = inches
G) Number of Columns	nc = 1 number
H) Actual Design Outlet Area per Row (A_o)	A_o = 3.25 square inches
I) Number of Rows (nr)	nr = 6 number
J) Total Outlet Area (A_{ot})	A_{ot} = 19.5 square inches
K) Depth of WQCV (H_{WQCV}) (Estimate using actual stage-area-volume relationship and V_{WQCV})	H_{WQCV} = 2.0 feet
L) Ensure Minimum 24 Hour Drain Time for WQCV	$T_{D\ WQCV}$ = 24.3 hours
10. Trash Rack	
A) Type of Outlet Opening	Choose One (●) Circular (up to 2" diameter) ( ) Rectangular (2" high)
B) Trash Rack Open Area: $A_t = 0.5 * 77(e^{-0.124D})*A_{ot}$)	A_t = 655 square inches
C) For 2", or Smaller, **<u>Circular Opening</u>** (See Fact Sheet T-12):	
i) Depth of Trash Rack below Permanent Pool WS (28 inch min.)	$D_{inundation}$ = 28 inches
ii) Width of Trash Rack and Concrete Opening ($W_{opening}$)	$W_{opening}$ = 21 inches
iii) Height of Trash Rack Screen (H_{TR})	H_{TR} = 52 inches
iv) Type of Screen	Choose One (●) S.S. Well Screen with 60% Open Area* ( ) Other (Describe):

Design Procedure Form: Constructed Wetland Pond (CWP)

Sheet 3 of 3

Designer:	**N. Calisoff**
Company:	**BMP Inc.**
Date:	**November 29, 2010**
Project:	**Industrial Park**
Location:	**SW corner of 105th Ave. and 93rd St.**

D) For 2" High Rectangular Opening (See Fact Sheet T-12):	
i) Depth of Trash Rack below Permanent Pool WS (28 inch min.)	$D_{inundation}$ = ______ inches
ii) Width of Rectangular Opening ($W_{orifice}$)	W = ______ inches
iii) Width of Trashrack Opening ($W_{opening}$) from Fact Sheet T-12	$W_{opening}$ = ______ feet
iv) Height of Trash Rack Screen (H_{TR})	H_{TR} = ______ feet
v) Type of Screen (based on depth H) (Describe if "Other")	Choose One ○ Aluminum Amico-Klemp SR Series (or equal) ○ Other (Describe):
vii) Minimum Bearing Bar Size	
11. Overflow Embankment	
A) Describe embankment protection for 100-year and greater overtopping:	buried soil riprap
B) Slope of Overflow Embankment (Horiz. dist. per unit vertical, should not be steeper than 4:1)	Z_E = 5.00 ft / ft
12. Maintenance Considerations	
A) Describe Means of Draining the Pond	pumping
13. Vegetation	Choose One ○ Irrigated ◉ Not Irrigated
14. Access	
A) Describe Sediment Removal Procedures	Gravel trail on north side of pond allows access to forebay. The remainder of the pond will need to be at least partially drained. Layout of the pond is such that excavation can be performed from the maintenance trail.

Notes:

References

Bedient, Philip B. and Wayne C. Huber. 1992. *Hydrology and Floodplain Analysis (Second Edition).* Addison-Wesley Publishing Company.

Description

Photograph CWC-1: Constructed wetland channels treat stormwater through straining, settling, and biological processes.

A constructed wetland channel is a conveyance BMP that is built, in part, to enhance stormwater quality. Constructed wetland channels use dense vegetation to slow down runoff and allow time for both biological uptake and settling of sediment.

Constructed wetlands differ from natural wetlands, as they are artificial and are built to enhance stormwater quality. Do not use existing or natural wetlands to treat stormwater runoff. Stormwater should be treated prior to entering natural or existing wetlands and other environmentally sensitive areas. Allowing untreated stormwater to flow into existing wetlands will overload and degrade the quality of the wetland. Sometimes, small wetlands that exist along ephemeral drainageways on Colorado's high plains may be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

Regulations intended to protect natural wetlands recognize a separate classification of wetlands constructed for water quality treatment. Such wetlands generally are not allowed to be used to mitigate the loss of natural wetlands but are allowed to be disturbed by maintenance activities. Therefore, the legal and regulatory status of maintaining a wetland constructed for the primary purpose of water quality enhancement is separate from the disturbance of a natural wetland. Nevertheless, any activity that disturbs a constructed wetland should be first cleared through the U.S. Army Corps of Engineers to ensure it is covered by some form of an individual, general, or nationwide 404 permit.

Constructed Wetland Channel	
Functions	
LID/Volume Red.	Somewhat
WQCV Capture	No
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	Unknown
Nutrients	Unknown
Total Metals	Unknown
Bacteria	Moderate
Other Considerations	
Life-cycle Costs[4]	Moderate

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

Constructed wetland channels provide conveyance of stormwater similar to a grass swale; however, this BMP is appropriate when a baseflow can be anticipated. A constructed wetland channel requires a net influx of water to maintain vegetation and microorganisms. This can be supplied by groundwater or a perennial stream. An ephemeral stream may not provide adequate water. In addition to water supply, loamy soils are needed in the wetland bottom to permit plants to take root. Wetland channels also require a near-zero longitudinal slope; drop structures can be used to create and maintain a flat grade.

A constructed wetland channel can be used in the following two ways:

- It can be established in a completely man-made channel providing conveyance and water quality enhancement.
- It can be located in a treatment train configuration, downstream of a stormwater detention facility (water quality and/or flood control) where a large portion of the sediment load has been removed upstream. This allows the wetland channel to benefit from the long duration of outlet flow and reduced maintenance requirements associated with pretreatment.

Benefits

- Wetland channels provide natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal.
- Provides effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles

Limitations

- Requires a continuous baseflow.
- Without proper design, salts and scum can accumulate and be flushed out during larger storms.
- Safety concerns associated with open water.

Designing for Maintenance

Recommended maintenance practices for all BMPs are provided in the BMP Maintenance chapter of this manual. As with many BMPs, poor maintenance of this BMP can result in reduced effectiveness (see inset). During design, the following should be considered to ensure ease of maintenance over the long-term:

- Ensure a continuous dry-weather baseflow. Without adequate water supply, salts and algae can concentrate in the water column and can be released into the receiving water in higher levels.
- Provide pretreatment when appropriate. If the influent concentrations are high, this BMP should be used in a treatment train approach. High levels of nutrients will overload the BMP causing algae growth. High solids will reduce capacity and increase maintenance requirements.

Design Procedure and Criteria

The criteria for a wetland channel presented in the following section differ somewhat from the criteria presented in the *Major Drainage* chapter of Volume 1. This is because of the water quality focus of this BMP. Before selecting this BMP, assess the water budget required so that the inflow of water throughout the year is sufficient to meet all the projected losses (such as evaporation, evapotranspiration, and seepage). An insufficient baseflow could cause the wetland vegetation to dry out and die.

The following steps outline the constructed wetland channel design procedure. Refer to Figure CWC-1 for its design components.

1. **Design Discharge**: Calculate the 2-year peak flow rate in the wetland channel using methods discussed in the *Runoff* chapter of Volume 1. Unless higher flows are diverted from the wetland channel, also calculate the 100-year peak flow rate.

2. **Channel Geometry**: Design the mature channel geometry to pass the design 2-year flow rate at 2.0 feet per second or less with a channel depth between 1.5 to 3.0 feet. The channel cross-section should be trapezoidal with stabilized side slopes of 2.5:1 (Horizontal:Vertical) or flatter. The bottom width should be no less than 3.0 feet. Unless higher flows are diverted from the wetland channel, ensure the

100-year peak flow rate can also be safely conveyed in the channel. See the *Major Drainage* chapter in Volume 1.

3. **Longitudinal Slope**: Set the longitudinal slope to meet channel geometry criteria using Manning's equation and a Manning's roughness coefficient of n=0.035 for the 2-year flow. If necessary due to the existing terrain, include grade control checks or small drop structures. Tie grade control structures into the bank a minimum of 0.50 feet above the 2-year water surface elevation. Design drop structures to satisfy the drop structure criteria of the *Major Drainage* chapter in Volume *1*.

4. **Channel Capacity**: Calculate the mature channel capacity during a 2-year event using a Manning's roughness coefficient based on the method for composite channels presented in the *Major Drainage* chapter of Volume 1. The channel should also provide enough capacity to contain the flow during a 100-year event while maintaining one foot of free-board. Increase the bottom width of the channel when additional capacity is needed.

5. **Grade Control Structures:** Grade control structures are frequently required to meet longitudinal slope and velocity recommendations. The structures should extend into the bank and at least 0.5 feet above the 2-year water surface elevation.

6. **Toe Protection**: Provide bank toe protection using type VL soil riprap or other stabilization methods as discussed in the *Major Drainage* chapter of Volume 1. Channel stabilization should include protection of the side slopes extending up to the 2-year water surface elevation. Carry this protection down 3 feet below the channel invert or place soil riprap in channel invert.

7. **Vegetation**: Vegetate the channel bottom and side slopes to provide solids entrapment and biological nutrient uptake. Cover the channel bottom with loamy soils to enable establishment of sedges and reeds. Side slopes should be planted with grasses.

8. **Maintenance Access**: Provide access for maintenance along the channel length. Maximum grades for maintenance vehicles should be 10% and provide a solid driving surface.

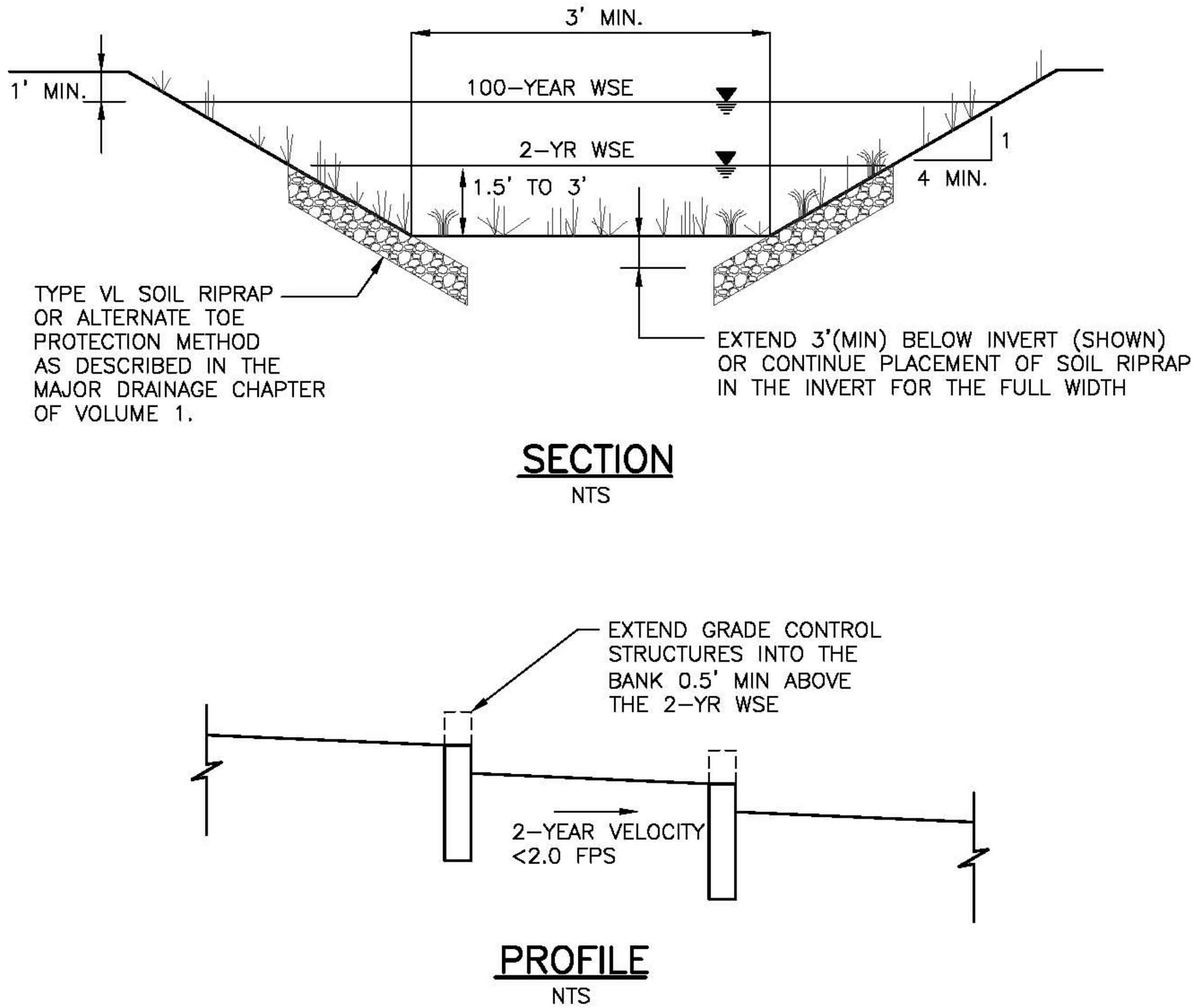


Figure CWC-1. Constructed Wetland Channel Plan and Section

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Constructed Wetland Channel (CWC)

Sheet 1 of 1

Designer: G. Damato
Company: BMP, Inc.
Date: November 29, 2010
Project: Subdivison F
Location: NW corner of 90th Ave. and 57th St.

1. Design Discharge

A) 2-Year Design Discharge — Q_2 = 15.00 cfs

B) 100-Year Design Discharge — Q_{100} = 48.00 cfs

2. Channel Geometry (New Channel - No Wetland Veg. in Bottom)
Channel Side Slopes (Z = 2.5 min., horiz. distance per unit vertical) — Z = 2.50 (H:V)

3. Longitudinal Slope (Based on Manning's *n* for the mature channel so as not to exceed the maximum given velocity) — S = 0.005 feet/feet

4. Channel Capacity
(Based on Manning's n = 0.0018 * D2 ^ 2 - 0.0206 * D2 + 0.099 for D ≤ 5, and Manning's n = 0.0001 * Y ^ 2 - 0.0025 * Y + 0.05 for D > 5)

A) Calculated channel geometry required to maintain the design discharge during a 2-year event with newly established and mature vegetation. Calculated resulting flow velocities for mature condition should be kept to 2 fps or less for the 2-year flow.

	New 2-Yr. Channel		Mature 2-Yr. Channel	
D_2 =	1.10	feet	1.55	feet
B_2 =	3.0	feet	3.0	feet
T_2 =	8.5	feet	10.7	feet
V_2 =	2.39	fps	1.42	fps
n_2 =	0.035		0.071	
$Froude_2$ =	0.35		0.25	

B) Geometry and velocity to use for the 100-year discharge:
Suggest the design for a 100-year capacity channel follow the guidance contained in the Major Drainage Chapter of Volume One. of the USDCM, or through the use of the UD-CHANNELS workbook.

100-Year depth with 1-foot freeboard is 3.4 feet.
100-Year top width with 1-foot freeboard is 20.1 feet.

	New 100-Yr. Channel		Mature 100-Yr. Channel	
D_{100} =	1.91	feet	2.43	feet
B_{100} =	3.0	feet	3.0	feet
T_{100} =	12.5	feet	15.1	feet
V_{100} =	3.24	fps	2.18	fps
n_{100} =	0.035		0.060	
$Froude_{100}$ =	0.47		0.32	

5. Grade Control Structures: Number required — 5 number

6. Toe Protection
Due to narrow channel bottom, provide soil riprap across width. — 1.75 soil riprap thickness (feet)

7. Vegetation

- [x] Wetland Seeding
- [ ] Wetland Plugs
- [x] Willow Stakes
- [ ] Other (Describe):

8. Maintenance Access: Describe access along channel. — reinforced grass maintenance trail parallel to channel

Notes:

Photograph PPS-1. The reservoir layer of a permeable pavement provides storage volume for the WQCV. Photo courtesy of Muller Engineering and Jefferson County Open Space.

Description

The term *Permeable Pavement System*, as used in this manual, is a general term to describe any one of several pavements that allow movement of water into the layers below the pavement surface. Depending on the design, permeable pavements can be used to promote volume reduction, provide treatment and slow release of the water quality capture volume (WQCV), and reduce effective imperviousness. Use of permeable pavements is a common Low Impact Development (LID) practice and is often used in combination with other BMPs to provide full treatment and slow release of the WQCV. A number of installations within the UDFCD boundary have also been designed with an increased depth of aggregate material in order to provide storage for storm events in excess of the water quality (80th percentile) storm event. This requires some additional design considerations, which are discussed within this BMP Fact Sheet.

Permeable Pavement	
Functions	
LID/Volume Red.	Yes
WQCV	Yes
WQCV+Flood Control	Yes
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Good
Total Metals	Good
Bacteria	Unknown
Other Considerations	
Life-cycle Costs[4]	High[2]

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

[2] Does not consider the life cycle cost of the conventional pavement that it replaces.

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

Site Selection

This infiltrating BMP requires consultation with a geotechnical engineer when proposed near a structure. In addition to providing the pavement design, a geotechnical engineer can assist with evaluating the suitability of soils, identifying potential impacts, and establishing minimum distances between the BMP and structures.

Permeable pavement systems provide an alternative to conventional pavement in pedestrian areas and lower-speed vehicle areas. They are not appropriate where sediment-laden runoff could clog the system (e.g., near loose material storage areas).

This BMP is not appropriate when erosive conditions such as steep slopes and/or sparse vegetation drain to the permeable pavement. The sequence of construction is also important to preserve pavement infiltration. Construction of the pavement should take place only after construction in the watershed is complete.

For sites where land uses or activities can cause infiltrating stormwater to contaminate groundwater, special design requirements are required to ensure no-infiltration from the pavement section.

Permeable pavements and other BMPs used for infiltration that are located adjacent to buildings, hardscape or conventional pavement areas can adversely impact those structures if protection measures are not provided. Wetting of subgrade soil underlying those structures can cause the structures to settle or result in other moisture-related problems. Wetting of potentially expansive soils or bedrock can cause those materials to swell, resulting in structure movements. In general, a geotechnical engineer should evaluate the potential impact of the BMP on adjacent structures based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. In addition, the following minimum requirements should be met:

- In locations where subgrade soils do not allow infiltration, the growing medium should be underlain by an underdrain system.
- Where infiltration can adversely impact adjacent structures, the filter layer should be underlain by an underdrain system designed to divert water away from the structure.
- In locations where potentially expansive soils or bedrock exist, placement of a rain garden adjacent to structures and pavement should only be considered if the BMP includes an underdrain designed to divert water away from the structure and is lined with an essentially impermeable geomembrane liner designed to restrict seepage.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in the BMP Maintenance chapter of this manual. During design and construction, the following should be considered to ensure ease of maintenance over the long-term:

- Hold a pre-construction meeting to ensure that the contactor has an understanding of how the pavement is intended to function. Discuss the contractor's proposed sequence of construction and look for activities that may require protection of the permeable pavement system.
- Ensure that the permeable pavement is protected from construction activities following pavement construction (e.g., landscaping operations). This could include covering areas of the pavement, providing alternative construction vehicle access, and providing education to all parties working on-site.
- Include an observation well to monitor the drain time of the pavement system over time. This will assist with determining the required maintenance needs. See Figure PPS-8.

Benefits

- Permeable pavement systems provide water quality treatment in an area that serves more than one purpose. The depth of the pavement system can also be increased to provide flood control.
- Permeable pavements can be used to reduce effective imperviousness or alleviate nuisance drainage problems.
- Permeable pavements benefit tree health by providing additional air and water to nearby roots.
- Permeable pavements are less likely to form ice on the surface than conventional pavements.
- Some permeable pavements can be used to achieve LEED credits.

Limitations

- Additional design and construction steps are required for placement of any ponding or infiltration area near or upgradient from a building foundation, particularly when potentially expansive soils exist. This is discussed in the design procedure section.
- In developing or otherwise erosive watersheds, high sediment loads can clog the facility.

- Call for construction fence on the plans around pervious areas where infiltration rates need to be preserved and could be reduced by compaction from construction traffic or storage of materials.

Example Construction Drawing Notes

- Excavation of subgrade shall not commence until after the pre-construction meeting.
- Subgrade shall be excavated using low ground pressure (LGP) track equipment to minimize over compaction of the subgrade. [1]
- Grading and compaction equipment used in the area of the permeable pavement should be approved by the engineer prior to use.
- Loose materials shall not be stored on the permeable pavement area.
- The contractor shall, at all times during and after system installation, prevent sediment, debris, and dirt from any source from entering the permeable pavement system.
- Placement of the wearing course shall be performed after fine grading and landscaping in adjacent areas is complete. If the wearing course becomes clogged due to construction activities, clean the surface with a vacuum machine to restore the infiltration rate after construction is complete.

[1] For partial and full infiltration sections only.

Design Procedure and Criteria

Note: This manual includes a variety of specific pavements, which are discussed and distinguished in supplemental BMP Fact Sheets T-10.1, T-10.2, etc. This BMP Fact Sheet outlines the design procedure and other design components and considerations that are common to all of the systems. Review of the supplemental Fact Sheets is recommended to determine the appropriate pavement for a specific site or use.

1. **Subsurface Exploration and Determination of a No-Infiltration, Partial Infiltration, or Full Infiltration Section**: Permeable pavements can be designed with three basic types of sections. The appropriate section will depend on land use and activities, proximity to adjacent structures and soil characteristics. Sections of each installation type are shown in Figure PPS-1.

    - **No-Infiltration Section**: This section includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils. Consider using this section when any of the following conditions exist:

        - Land use or activities could contaminate groundwater if stormwater is allowed to infiltrate.
        - Permeable pavement is located over potentially expansive soils or bedrock that could swell due to infiltration and potentially damage the permeable pavement system or adjacent structures (e.g., building foundation or conventional pavement).

- **Partial Infiltration Section**: This section does not include an impermeable liner, and allows some infiltration. Stormwater that does not infiltrate is collected and removed by an underdrain system.

- **Full Infiltration Section**: This section is designed to infiltrate the water stored in the voids of the pavement into the subgrade below. UDFCD recommends a minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours.

Subsurface Exploration and Testing for all Sections: A geotechnical engineer should scope and perform a subsurface study. Typical geotechnical investigation needed to select and design the pavement system for handling anticipated traffic loads includes:

- Prior to exploration review geologic and geotechnical information to assess near-surface soil, bedrock and groundwater conditions that may be encountered and anticipated ranges of infiltration rate for those materials. For example, if the site is located in a general area of known shallow, potentially expansive bedrock, a no-infiltration section will likely be required. It is also possible that this BMP may be infeasible, even with a liner, if there is a significant potential for damage to the pavement system or adjacent structures (e.g., areas of dipping bedrock).

- Drill exploratory borings or exploratory pits to characterize subsurface conditions beneath the subgrade and develop requirements for subgrade preparation. Drill at least one boring or pit for every 40,000 ft^2, and at least two borings or pits for sites between 10,000 ft^2 and 40,000 ft^2. The boring or pit should extend at least 5 feet below the bottom of the base, and at least 20 feet in areas where there is a potential of encountering potentially expansive soils or bedrock. More borings or pits at various depths may be required by the geotechnical engineer in areas where soil types may change, in low-lying areas where subsurface drainage may collect, or where the water table is likely within 8 feet below the planned bottom of the base or top of subgrade. Installation of temporary monitoring wells in selected borings or pits for monitoring groundwater levels over time should be considered where shallow groundwater that could impact the pavement system area is encountered.

- Perform laboratory tests on samples obtained from the borings or pits to initially characterize the subgrade, evaluate the possible section type, and to assess subgrade conditions for supporting traffic loads. Consider the following tests: moisture content (ASTM D 2216); dry density (ASTM D 2936); Atterberg limits (ASTM D 4318); gradation (ASTM D 6913); swell-consolidation (ASTM D 4546); subgrade support testing (R-value, CBR or unconfined compressive strength); and hydraulic conductivity. A geotechnical engineer should determine the appropriate test method based on the soil type.

- For sites where a full infiltration section may be feasible, perform on-site infiltration tests using a double-ring infiltrometer (ASTM D 3385). Perform at least one test for every 160,000 ft^2 and at least two tests for sites between 40,000 ft^2 and 160,000 ft^2. The tests should be located near completed borings or pits so the test results and subsurface conditions encountered in the borings can be compared, and at least one test should be located near the boring or pit showing the most unfavorable infiltration condition. The test should be performed at the planned top of subgrade underlying the permeable pavement system, and that subgrade should be prepared similar to that required for support of the permeable pavement system.

- Be aware that actual infiltration rates are highly variable dependent on soil type, density and moisture content and degree of compaction as well as other environmental and construction influences. Actual rates can differ an order of magnitude or more from those indicated by infiltration or permeability testing. Selection of the section type should be based on careful assessment of the subsurface exploration and testing data.

2. **Required Storage Volume**: Provide the WQCV based on a 12-hour drain time.

- Find the required WQCV (watershed inches of runoff). Using the effective impervious area of the watershed area, use Figure 3-2 located in Chapter 3 to determine the WQCV based on a 12-hour drain time. The maximum recommended ratio for tributary impervious area to permeable pavement area is 2.0. Higher loading is not recommended, as it may increase the required maintenance interval.

- Calculate the design volume as follows:

$$V = \left[\frac{\mathrm{WQCV}}{12}\right] A$$ Equation PPS-1

Where:

A = watershed area tributary to the permeable pavement (ft^2)

V = design volume (ft^3)

- Add flood control volume if desired. When designing for flood control volumes, provide an overflow that will convey runoff in excess of the WQCV directly into the reservoir. A gravel strip or inlet that is connected to the reservoir can provide this overflow.

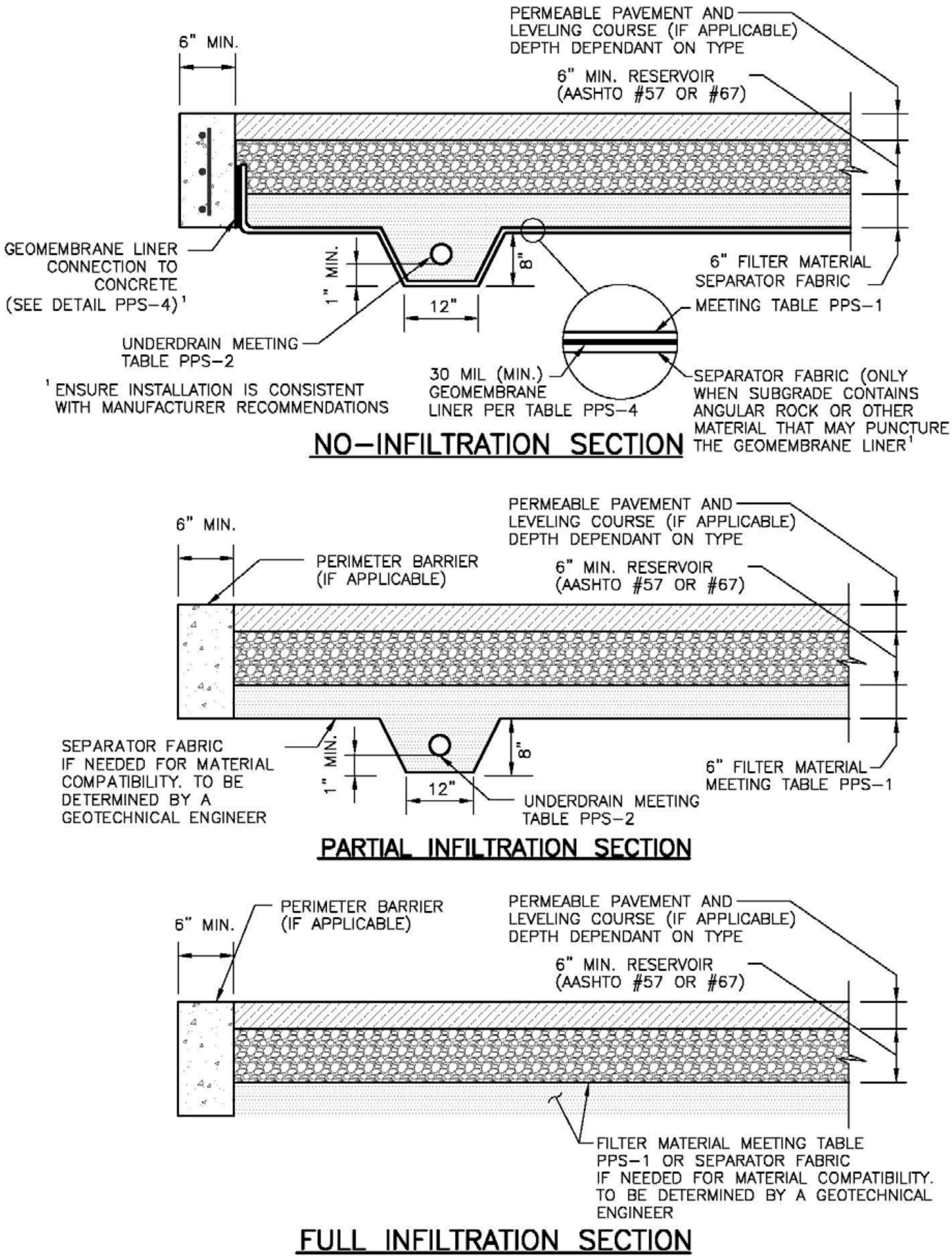


Figure PPS-1. Permeable Pavement Sections

3. **Depth of Reservoir**: The minimum recommended depth of AASHTO No. 57 or No. 67 coarse aggregate is 6 inches. Additional depth may be required to support anticipated loads or to provide additional storage, (i.e., for flood control). This material should have all fractured faces. UDFCD recommends that void storage be calculated only for the reservoir, assuming the aggregate filter layer is saturated. With the exception of porous gravel pavement, use a porosity of 40% or less for both No. 57 and No. 67 coarse aggregate. For porous gravel pavement use a porosity of 30% or less to account for reduced volume due to sediment. Porous gravel pavements typically allow greater sediment volumes to enter the pavement. See Figures PPS-2 and PPS-3 for alternative pavement profiles. Calculate available storage using equation PPS-2 for a flat subgrade installation, and PPS-3 for a sloped subgrade installation. These equations allow for one inch of freeboard. Flat installations are preferred as the design spreads infiltration evenly over the subgrade. For sloped subgrade installations, the increased storage depth located upstream of the lateral barrier (see step 7) can increase lateral movement (parallel to the flow barrier) of water into areas adjacent to the pavement section.

   When used for vehicular traffic, a pavement design should be performed by a qualified engineer experienced in the design of permeable pavements and conventional asphalt and concrete pavements. The permeable pavement should be adequately supported by a properly prepared subgrade, properly compacted filter material and reservoir material.

   Reservoir aggregate should have all fractured faces. Place the aggregate in 6-inch (maximum) lifts, compacting each lift by using a 10-ton, or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.

   - For flat or stepped installations (0% slope at the reservoir/subgrade interface):

   $$V = P\left[\frac{D-1}{12}\right]A \qquad \text{Equation PPS-2}$$

   Where:

   V = volume available in the reservoir (ft^3)

   P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

   D = depth of reservoir (in)

   A = area of the permeable pavement (ft^2)

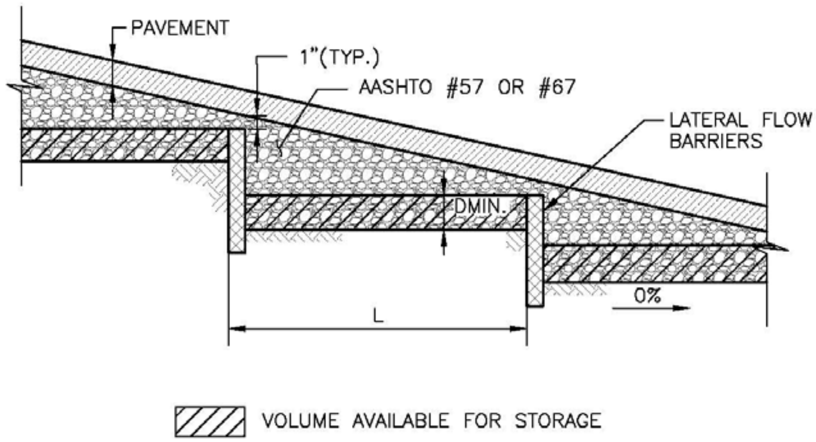


Figure PPS-2. Permeable Pavement Profile, Stepped Installation

- For sloped installations (slope of the reservoir/subgrade interface > 0%):

$$V = P\left[\frac{D - 6sL - 1}{12}\right]A$$ Equation PPS-3a

While:

$$L < \frac{2\ \text{WQCV}}{sAP}$$ Equation PPS-3b

Where:

V = volume available in the reservoir (ft^3)

P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

s = slope of the reservoir/subgrade interface (ft/ft)

D = depth of the reservoir (in)

L = length between lateral flow barriers (see step 4) (ft)

A = area of the permeable pavement (ft^2)

WQCV = water quality capture volume (ft^3)

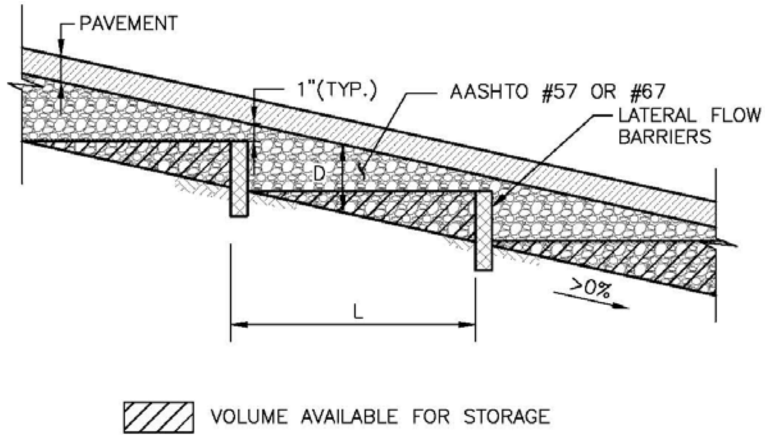


Figure PPS-3. Permeable Pavement Profile, Sloped Installation.

4. **Lateral Flow Barriers:** Construct lateral flow cutoff barriers using concrete walls or a 30 mil (minimum) PVC geomembrane. Lateral flow barriers should be placed parallel to contours (normal to flow). This will preserve the volume available for storage and ensure that stormwater will not resurface, washing out infill material. See Figure PPS-6 and Table PPS-4 when using a PVC geomembrane for this purpose. Also include a separator fabric, per Table PPS-3, between the geomembrane and all aggregate materials. Lateral flow barriers should be installed in all permeable pavement installations that have a reservoir/subgrade interface greater than 0%. Lateral flow barriers should be spaced, as necessary, to satisfy equations PPS-3a and PPS-3b. One exception is reinforced grass pavement. Infill washout is not a concern with reinforced grass pavement.

5. **Perimeter Barrier:** For all no-infiltration sections, provide a reinforced concrete barrier on all sides of the pavement system. Perimeter barriers may also be recommended for other permeable pavement installations depending on the type or use of the pavement. For PICP and concrete grid pavement, a barrier is required to restrain movement of the pavers or grids. Precast, cast-in-place concrete or cut stone barriers are required for commercial vehicular areas. For residential use and commercial pedestrian use, a metal or plastic edge spiked with 3/8-inch-diameter, 10-inch-long nails provides a less expensive alternative for edge restraint.

   For all pavements, consider the section beyond the permeable pavement when evaluating the perimeter design. The perimeter barrier helps force water into the underdrain and reduces lateral flow of water. Lateral flow can negatively impact the adjacent conventional pavement section, structure, or embankment (especially when the subgrade is sloped). Also consider material separation. Consider construction of the interface between the permeable pavement and the adjacent materials and how the design will prevent adjacent materials from entering the permeable pavement section. Depending on the soils, depth of pavement, and other factors, this may be achieved with fabric or may require a more formalized barrier.

   When a permeable pavement section is adjacent to conventional pavement, a vertical liner may be required to separate the reservoir of the permeable pavement system from dense-graded aggregates and soils within the conventional pavement. An impermeable linear can be used to provide this vertical barrier and separate these two pavement systems.

   <u>No-Infiltration Section:</u> For this type of section, the perimeter barrier also serves to attach the impermeable membrane. The membrane should extend up to the top of the filter layer and be firmly

attached to the concrete perimeter barrier using batten bars to provide a leak-proof seal. A nitrile-based vinyl adhesive can be used when the need for an impermeable liner is less critical. See Figures PPS-4 and PPS-5 for installation details. For ease of construction, including the placement of geotextiles, it is suggested that the barrier extend to the bottom of the filter layer.

Partial and Full Infiltration Section: The perimeter barrier for these sections also restricts lateral flow to adjacent areas of conventional pavement or other structures where excessive moisture and/or hydrostatic pressure can cause damage. When this is of particular concern, the perimeter barrier should be extended to a depth 12 inches or more below the underdrain. Otherwise, extend the barrier to the bottom of the filter layer.

6. **Filter Material and Underdrain System**: An aggregate filter layer and underdrain are required for all partial and no-infiltration sections. Without this filter layer, the section will not provide adequate pollutant removal. This is based on research performed by UDFCD monitoring sites with and without this component. A filter or separator fabric may also be necessary under the reservoir in a full infiltration section if the subgrade is not filter compatible with the reservoir material such that finer subgrade soils could enter into the voids of the reservoir.

   In previous versions of the USDCM, UDFCD recommended that the underdrain be placed in an aggregate drainage layer and that a geotextile separator fabric be placed between this drainage and the filter layer. This version of the USDCM replaces that fabric, which could more easily plug or be damaged during construction, with aggregate filter material that is filter-compatible with the reservoir, and a drainpipe with perforations that are filter-compatible with the filter material. This eliminates the need for a separator fabric between the reservoir and the underdrain layer. The filter material provided below should only be used with the underdrain pipe specified within this section.

   The underdrain should be placed below a 6-inch-thick layer of CDOT Class C filter material meeting the gradation in Table PPS-1. Extend the filter material around and below the underdrain as shown in Figure PPS-1.

   Provide clean-outs to allow inspection (by camera) of the drainpipe system during and after construction to ensure that the pipe was not crushed or disconnected during construction and to allow for maintenance of the underdrain.

   Use of Class C Filter material with a slotted PVC pipe that meets the slot dimensions provided in Table PPS-2 will eliminate the need for an aggregate layer wrapped geotextile fabric.

Design Opportunity

Pollutant removal occurs in the filter material layer of the section. The basic permeable pavement section may be considered with other wearing courses to provide water quality as long as:

- the filter layer is included in the section,
- the wearing course provides adequate permeability, and
- the new section does not introduce new pollutants to the runoff.

Table PPS-1. Gradation Specifications for Class C Filter Material (Source: CDOT Table 703-7)

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

Table PPS-2. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4"	1-1/16"	0.032"	0.413"	1.90 in^2
6"	1-3/8"	0.032"	0.516"	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

Compact the filter layer using a vibratory drum roller or plate. The top of each layer below the leveling course must be uniform and should not deviate more than a ½ inch when a 10-foot straight edge is laid on its surface. The top of the leveling course should not deviate more than 3/8 inch in 10 feet.

7. **Impermeable Geomembrane Liner and Geotextile Separator Fabric:** For no-infiltration sections, install a 30 mil (minimum) PVC geomembrane liner, per Table PPS-4, on the bottom and sides of the basin, extending up at least to the top of the filter layer. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to the wall to protect the membrane from UV deterioration. The geomembrane should be field-seamed using a dual track welder, which allows for non-destructive testing of almost all field seams. A small amount of single track and/or adhesive seaming should be allowed in limited areas to seam around pipe perforations, to patch seams removed for destructive seam testing, and for limited repairs. The liner should be installed with slack to prevent tearing due to backfill, compaction, and settling. Place CDOT Class B geotextile separator fabric, per Table PPS-3, above the geomembrane to protect it from being punctured during the placement of the filter material above the liner. If the subgrade contains angular rocks or other material that could puncture the geomembrane, smooth-roll the surface to create a suitable surface. If smooth-rolling the surface does not provide a suitable surface, also place the separator fabric between the geomembrane and the underlying subgrade. This should only be done when necessary because fabric placed under the geomembrane can increases seepage losses through pinholes or other geomembrane defects. Connect the geomembrane to perimeter concrete walls around the basin perimeter, creating a watertight seal between the geomembrane and the walls using a continuous batten bar and anchor connection (see Figure PPS-5). Where the need for the impermeable

membrane is not as critical, the membrane can be attached with a nitrile-based vinyl adhesive. Use watertight PVC boots for underdrain pipe penetrations through the liner (see Figure PPS-4).

Table PPS-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction
[2] As measured in accordance with ASTM D 4632

Table PPS-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m^2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

8. **Outlet**: The portion of the WQCV in each cell should be slowly released to drain in approximately 12 hours. An orifice at the outlet of the underdrain can be used for each cell to provide detention and slow release of the WQCV to offset hydromodification. Use a minimum orifice size of 3/8 inch to avoid clogging. If lateral walls are required, each cell should be considered a separate system and be

controlled independently. See Figure PPS-6 for underdrain system layout and outlet details showing a multi-cell configuration. Equations PPS-4 and PPS-5 can be used to determine the depth of the WQCV within the pavement section (based either on the stepped/flat installation shown in Figure PPS-2 or the sloped installation shown in Figure PPS-3) and Equation PPS-6 can be used to size the WQCV orifice. If the design includes multiple cells, these calculations should be performed for each cell substituting WQCV and V_{Total} with the volumes provided in each cell. The UD-BMP workbook available at www.udfcd.org can be used when multiple cells are similar in area. The workbook assumes that the WQCV is distributed evenly between each cell.

For calculating depth of the WQCV using a flat/stepped installation, see Figure PPS-2:

$$d = \frac{12\ \mathrm{WQCV}}{PA}$$ Equation PPS-4

Where:

d = depth of WQCV storage in the reservoir (in)

P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

A = area of permeable pavement system (ft^2)

WQCV = water quality capture volume (ft^3)

For calculating depth of the WQCV using a sloped installation, see Figure PPS-3:

$$d = 6\left[\frac{2\ \mathrm{WQCV}}{P\mathrm{A}}\right] + \mathrm{sL}$$ Equation PPS-5

Where:

d = depth of WQCV storage in the reservoir (in)

A = area of permeable pavement system (ft^2)

s = slope of the reservoir/subgrade interface (ft/ft)

L = length between lateral flow barriers (see step 4) (ft)

For calculating the diameter of the orifice for a 12-hour drain time (Use a minimum orifice size of 3/8 inch to avoid clogging.):

$$D_{12\ \text{hour drain time}} = \sqrt{\frac{V}{1414\ y^{0.41}}} \qquad \text{Equation PPS-6}$$

Where:

D = diameter of the orifice to drain a volume in 12 hours (in)

Y = distance from the lowest elevation of the storage volume (i.e. the bottom of the reservoir) to the center of the orifice (ft)

V = volume (WQCV or the portion of the WQCV in the cell) to drain in 12 hours (ft^3)

Additional Design Considerations

Subgrade Preparation

Partial Infiltration and Full Infiltration Installations: The subgrade should be stripped of topsoil or other organics and either excavated or filled to the final subgrade level. Unnecessary compaction or over-compaction will reduce the subgrade infiltration rate. However, a soft or loosely compacted subgrade will settle, adversely impacting the performance of the entire permeable pavement system. The following recommendations for subgrade preparation are intended to strike a balance between those competing objectives:

- For sites, or portions thereof, requiring excavation to the final subgrade level, compaction of the subgrade may not be needed, provided that loose materials are removed from the excavation, and a firm subgrade is provided for the support of the pavement system. A geotechnical engineer should observe the prepared subgrade. Local soft areas should be excavated and replaced with properly compacted fill. As an alternative to excavating and replacing material, stabilization consisting of geogrid and compacted granular fill material can be used to bridge over the soft area. Fill material should be free draining and have a hydraulic conductivity significantly higher than the subgrade soil. Fill is typically compacted to a level equivalent to 95% Standard Proctor compaction (ASTM D 698). The designer should specify the level of compaction required to support the pavement system.

- For sites (or portions thereof), requiring placement of fill above the existing subgrade to reach the final subgrade level, the fill should be properly compacted. Specify the hydraulic conductivity for the material that is to be placed. This should be at least one order of magnitude higher than the native material. If the type or level of compaction of fill material available for construction is different than that considered in design, additional testing should be performed to substantiate that the design infiltration rate can be met. However, additional infiltrometer testing may not be necessary, provided that it can be demonstrated by other means that the compacted fill material is more permeable than that considered for design.

- Low ground pressure (LGP) track equipment should be used within the pavement area to limit over-compacting the subgrade. Wheel loads should not be allowed.

No-Infiltration Sections: Unless otherwise indicated by the geotechnical engineer, the subgrade for this section should be scarified and properly compacted to support the liner and pavement system. A level of compaction equivalent to 95% of the Standard Proctor density (ASTM D 698) is typically used. The designer should specify the level of compaction. No-infiltration sections should be smooth rolled with a roller compactor, and the prepared subgrade surface should be free of sharp objects that could puncture the liner. Both the designer and the liner installer should inspect the subgrade for acceptance prior to liner placement.

Filter and Reservoir Layer Compaction

Filter material placed above the prepared subgrade should be compacted to a relative density between 70% and 75% (ASTM D4253 and ASTM D4254) using a walk-behind vibratory roller, vibratory plate compactor or other light compaction equipment. Do not over-compact; this will limit unnecessary infiltration into the underlying subgrade. The reservoir layer may not be testable for compaction using a method based on specified density (e.g., nuclear density testing). The designer should consider a method specification (e.g., number of passes of a specified vibratory compactor) for those materials. The number of passes appropriate is dependent on the type of equipment and depth of the layer.

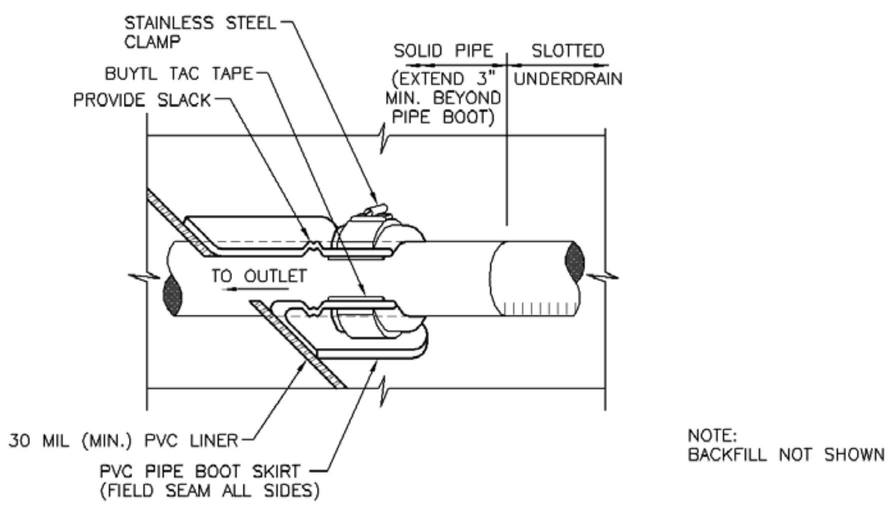


Figure PPS-4. Geomembrane Liner/Underdrain Penetration Detail

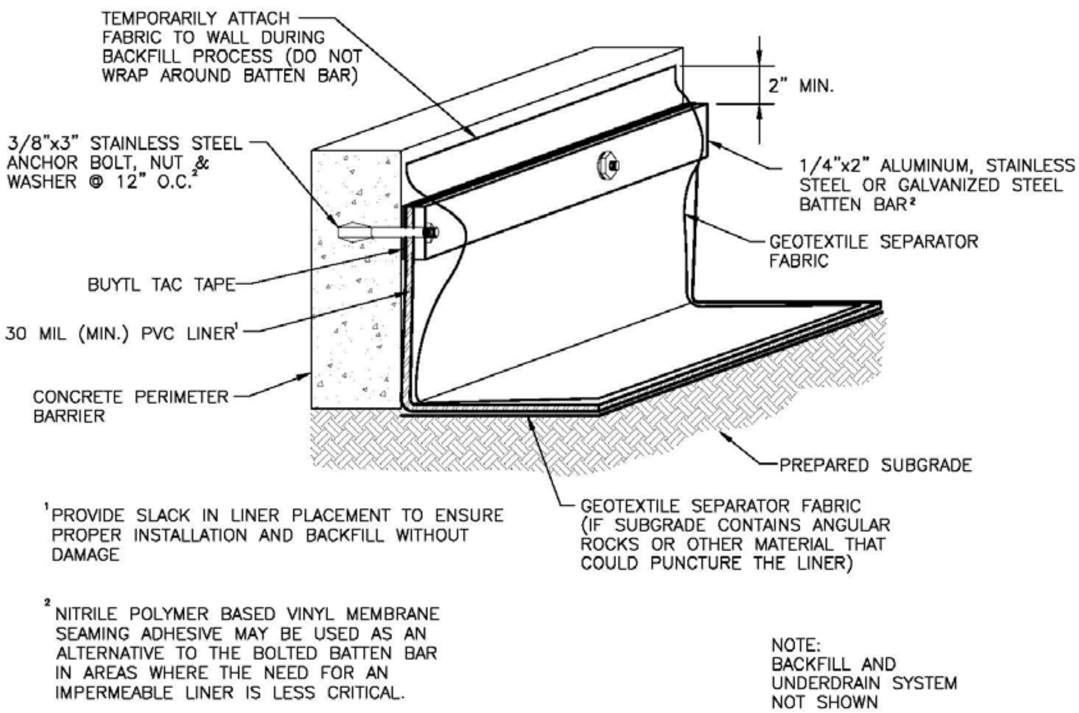


Figure PPS-5. Geomembrane Liner/Concrete Connection Detail

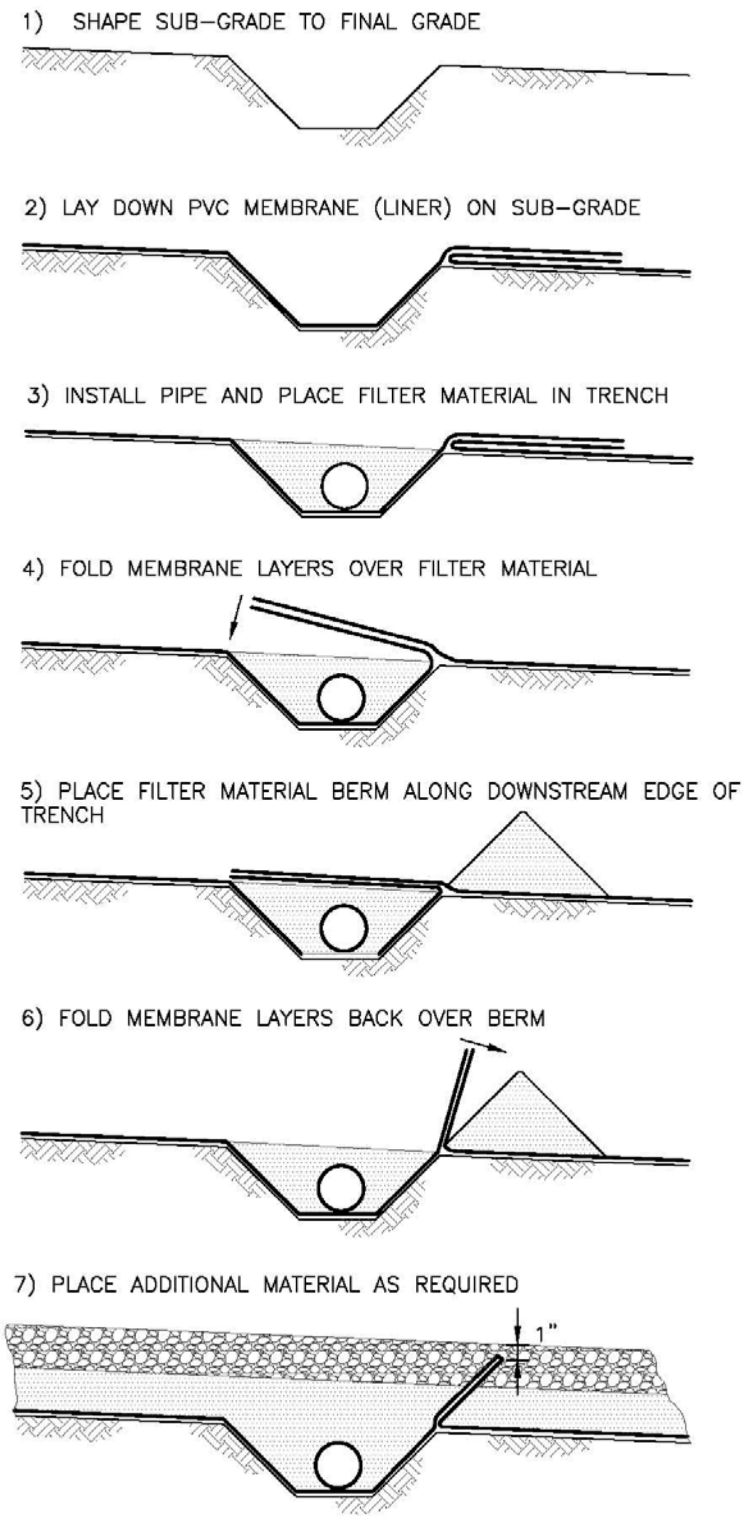


Figure PPS-6. Lateral Barrier Installation

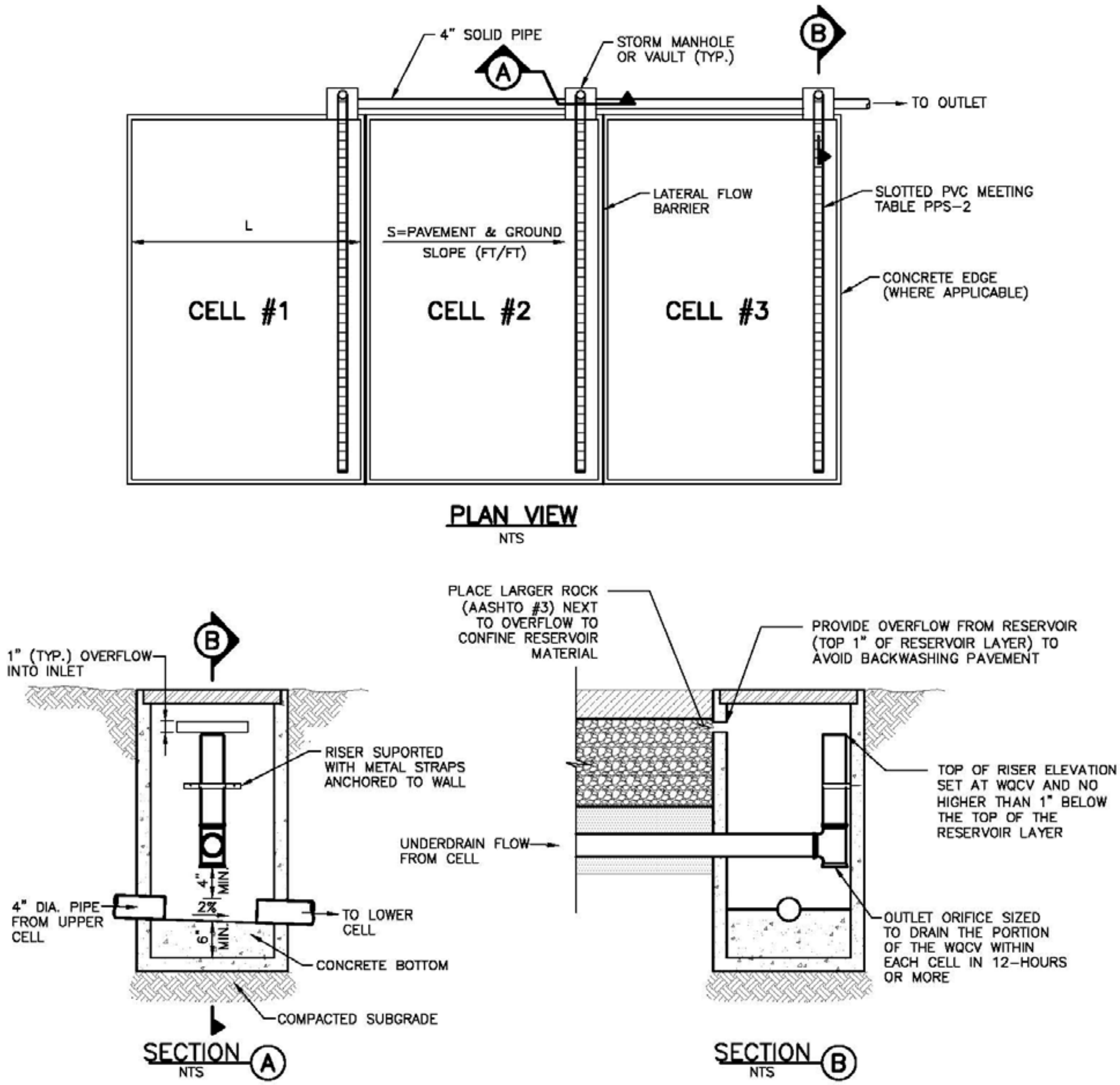


Figure PPS-7. Underdrain System Layout and Outlet Details

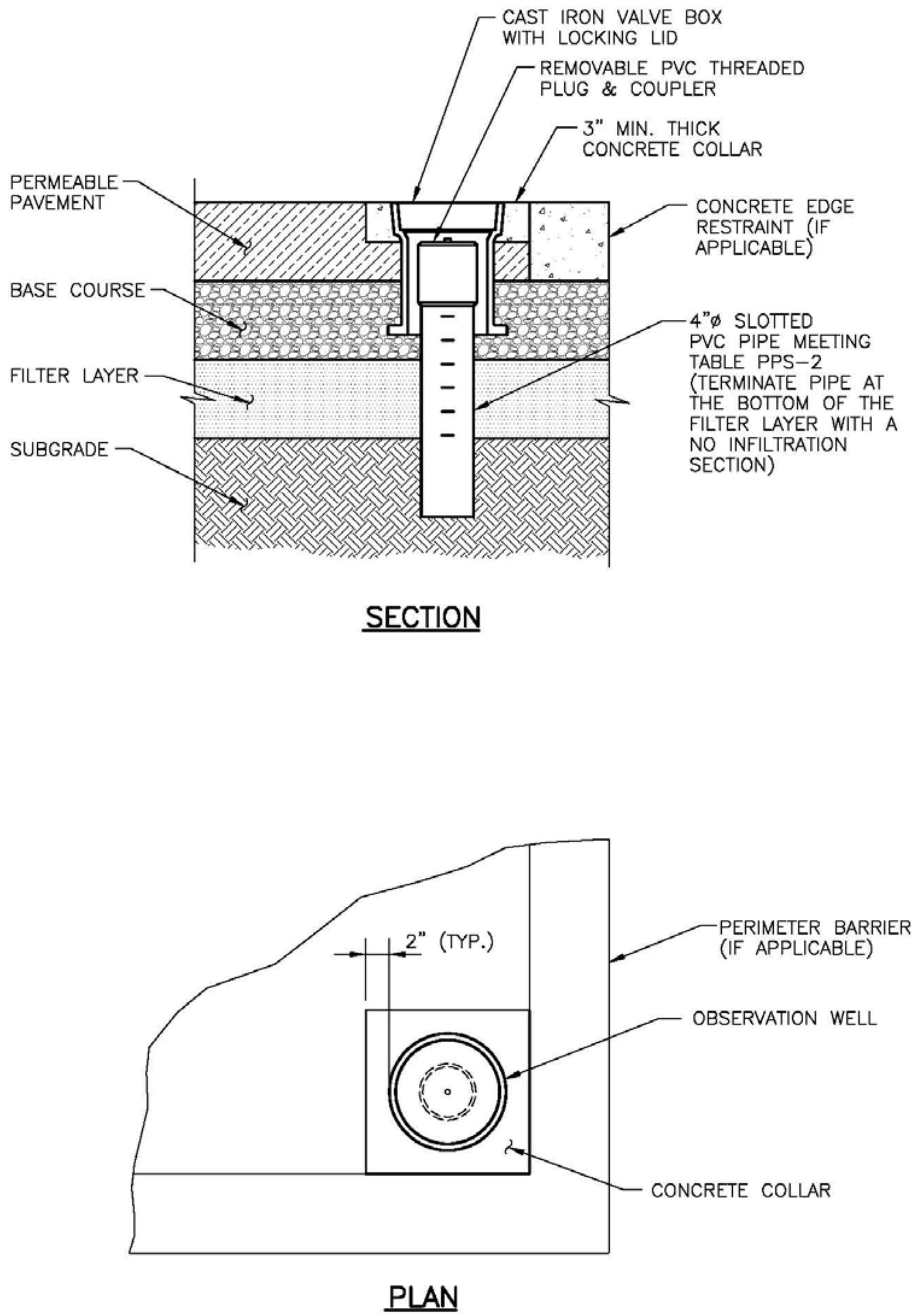


Figure PPS-8. Observation Well

Construction Considerations

Proper construction of permeable pavement systems requires measures to preserve natural infiltration rates (for full and partial infiltration sections) prior to placement of the pavement, as well as measures to protect the system from the time that pavement construction is complete to the end of site construction. Supplemental Fact Sheets on the specific pavements provide additional construction considerations. The following recommendations apply to all permeable pavement systems:

- When using an impermeable liner, ensure enough slack in the liner to allow for backfill, compaction, and settling without tearing the liner.
- Provide necessary quality assurance and quality control (QA/QC) when constructing an impermeable geomembrane liner system, including, but not limited to fabrication testing, destructive and non-destructive testing of field seams, observation of geomembrane material for tears or other defects, and air lace testing for leaks in all field seams and penetrations. QA/QC should be overseen by a professional engineer. Consider requiring field reports or other documentation from the engineer.
- Keep mud and sediment-laden runoff away from the pavement area.
- Temporarily divert runoff or install sediment control measures as necessary to reduce the amount of sediment run-on to the pavement.
- Cover surfaces with a heavy impermeable membrane when construction activities threaten to deposit sediment onto the pavement area.

Design Example

The *UD-BMP* workbook, designed as a tool for both designer and reviewing agency is available at www.udfcd.org. This section provides a completed design form from this workbook as an example.

Design Procedure Form: Permeable Pavement Systems (PPS)

Sheet 1 of 2

Designer:	**G. Frazer**
Company:	**BMP Inc.**
Date:	**November 29, 2010**
Project:	**Shops at 56th Ave.**
Location:	**SE corner of 56th Ave. and 83rd St.**

1. Type of Permeable Pavement Section A) What type of section of permeable pavement is used? (Based on the land use and activities, proximity to adjacent structures and soil characteristics.) B) What type of wearing course?	Choose One ○ No Infiltration ● Partial Infiltration Section ○ Full Infiltration Section Choose One ● PICP ○ Concrete Grid Pavement ○ Pervious Concrete ○ Porous Gravel
2. Required Storage Volume A) Effective Imperviousness of Area Tributary to Permeable Pavement, I_a B) Tributary Area's Imperviousness Ratio ($I = I_a / 100$) C) Tributary Watershed Area (including area of permeable pavement system) D) Area of Permeable Pavement System (Minimum recommended permeable pavement area = 13491 sq ft) E) Impervious Tributary Ratio (Contributing Imperviuos Area / Permeable Pavement Ratio) F) Water Quality Capture Volume (WQCV) Based on 12-hour Drain Time ($WQCV = (0.8 * (0.91 * i^3 - 1.19 * i^2 + 0.78 * i) / 12) * Area$) G) Is flood control volume being added? H) Total Volume Needed	I_a = 65.0 % i = 0.650 A_{Total} = 55,000 sq ft A_{PPS} = 15,000 sq ft R_T = 1.7 WQCV = 932 cu ft Choose One ● YES ○ NO **Provide overflow to carry runoff directly into the reservoir layer to ensure use of flood control volume regardless of infiltration rates.** V_{Total} = 6,340 cu ft
3. Depth of Reservoir A) Minimum Depth of Reservoir (Minimum recommended depth is 6 inches) B) Is the slope of the reservoir/subgrade interface equal to 0%? C) Porosity (Porous Gravel Pavement ≤ 0.3, Others ≤ 0.40) D) Slope of the Base Course/Subgrade Interface E) Length Between Lateral Flow Barriers F) Volume Provided Based on Depth of Base Course Flat or Stepped: $V = P * ((D_{min-1})/12) * Area$ Sloped: $V = P * [(D_{min} - (D_{min} - 6*SL-1)) / 12] * Area$	D_{min} = 18.0 inches Choose One ● YES- Flat or Stepped Installation ○ NO- Sloped Installation P = 0.40 S = ____ ft / ft L = ____ ft V = 8,500 cu ft
4. Lateral Flow Barriers A) Type of Lateral Flow Barriers B) Number of Permeable Pavement Cells	Choose One ○ Concrete Walls ○ PVC geomembrane installed normal to flow ● N/A- Flat installation ○ Other (Describe): Cells = 1
5. Perimeter Barrier A) Is a perimeter barrier provided on all sides of the pavement system? (Recommeded for PICP, concrete grid pavement, or for any no-infiltration section.)	Choose One ● YES ○ NO

Design Procedure Form: Permeable Pavement Systems (PPS)

Sheet 2 of 2

Designer: G. Frazer
Company: BMP Inc.
Date: November 29, 2010
Project: Shops at 56th Ave.
Location: SE corner of 56th Ave. and 83rd St.

6. Filter Material and Underdrain System	
A) Is the underdrain placed below a 6-inch thick layer of CDOT Class C filter material?	Choose One ◉ YES ○ NO ○ N/A
B) Diameter of Slotted Pipe (slot dimensions per Table PPs-2)	Choose One ◉ 4-inch ○ 6-inch
C) Distance from the Lowest Elevation of the Storage Volume (i.e. the bottom of the base course to the center of the orifice)	y = 3.8 ft
7. Impermeable Geomembrane Liner and Geotextile Separator Fabric	
A) Is there a minimum 30 mil thick impermeable PVC geomembrane liner on the bottom and sides of the basin, extending up to the top of the base course?	Choose One ○ YES ◉ NO
B) CDOT Class B Separator Fabric	Choose One ○ Placed above the liner ○ Placed above and below the liner
8. Outlet (Assumes each cell has similar area, subgrade slope, and length between lateral barriers (unless subgrade is flat). Calculate cells individually where this varies.)	
A) Depth of WQCV in the Reservoir (Elevation of the Flood Control Outlet)	D_{WQCV} = 1.86 inches
B) Diameter of Orifice for 12-hour Drain Time (Use a minimum orifice diameter of 3/8-inches)	$D_{Orifice}$ = 0.62 inches

Notes:

Permeable Interlocking Concrete Pavement T-10.1

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Permeable Interlocking Concrete Pavement (PICP) is one of several different types of permeable pavement systems contained within Volume 3. In previous versions of this manual, PICP was referred to as *cobblestone block pavement*. The PICP wearing course consists of concrete blocks that, when placed together, create spaces between the blocks where runoff can enter the pavement. Typically, the blocks contain ridges along the sides that both create these spaces and help ensure that the blocks are installed correctly. The spaces between the blocks are filled with aggregate. Depending on the manufacturer, these spaces should provide an open surface that is between 5 and 15% of the pavement surface. Figure PICP-1 provides a pavement section.

Photograph PICP-1. PICP in downtown Ft. Morgan, CO. Photo courtesy of SEH and the City of Ft. Morgan.

Site Selection

PICP is appropriate for areas with low to high traffic volume and lower vehicle speeds. Applications include:

- Intersections,
- Parking lots,
- Residential streets,
- Sidewalks/pedestrian areas,
- Emergency vehicle and fire access lanes, and
- Equipment storage areas.

See additional details on Fact Sheet T-10.

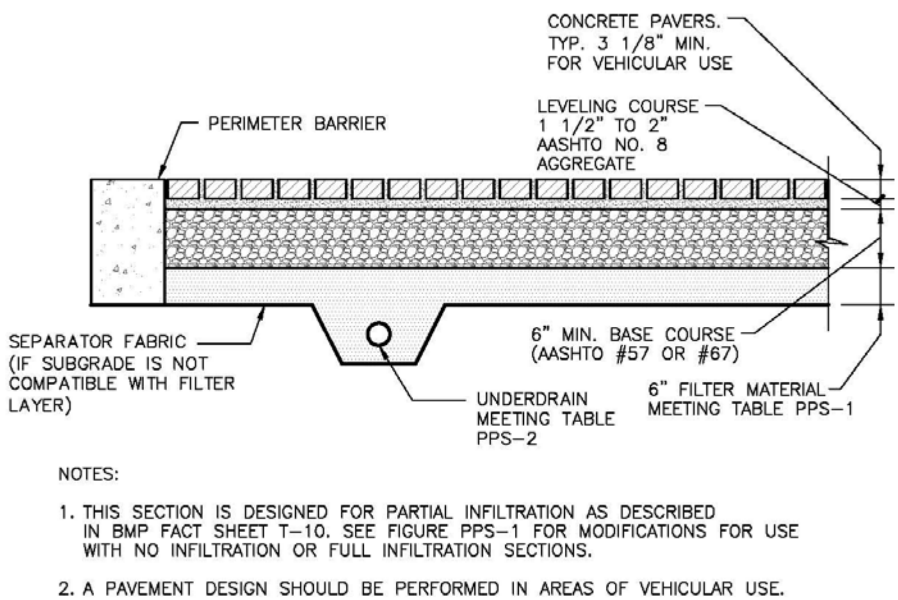


Figure PICP-1. PICP Pavement Section

T-10.1 Permeable Interlocking Concrete Pavement

Use the herring bone pattern shown in Photo PICP-1 and units with an overall length to thickness (aspect) ratio of three or less for vehicular applications. When ADA accessibility is needed, select units with a maximum opening of 0.5 inches.

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- The outer edge of any vehicular PICP area should be bordered by concrete. This can be a concrete ribbon or curb and gutter. Additionally, provide a line of uncut blocks adjacent to the concrete border. This will ensure that cut edges are not placed directly against the concrete border, which could cause damage to the paver at the interface with the concrete. This is often accomplished by specifying a sailor course (see photo PICP-1) or soldier course (see photo PICP-2) adjacent to the concrete edge.

- Specify that all cut pavers used must be at least 40% of its full, uncut size when subject to vehicular use. This criterion can be easily met, although it occasionally requires a slight modification to the paver pattern in construction. See photo PICP-2.

- Use units with an overall length to thickness (aspect) ratio of three or less for vehicular applications. Units with aspect ratios between three and four may be used in pedestrian areas or in areas with limited automobile use (e.g., residential driveways) (ICPI Tech Spec No. 10).

- Specify a herringbone pattern for areas intended for vehicular traffic. This provides greater structural support.

Benefits

- Provides traffic calming benefits.
- Can be placed back if utility cuts or other patches are required.
- Maintains infiltration rates well.
- Provides flexibility in design options such as color and patterns.
- Can be ADA compliant.

Limitations

- Capital costs are generally more expensive than some other permeable pavement systems.

Photograph PICP-2. The very small cut paver shown in this photo could have been eliminated by rotating the paver above it 90 degrees

Paver Placement

Where cutting pavers can be avoided, there is often a savings of time and cost. Additionally, the integrity of the paver is preserved. Photos PICP-3, 4, and 5 show good examples for incorporating markings into the pavement with and without cutting paver blocks.

Photograph PICP-3. Parking spaces can be clearly delineated without cutting the pavers. Photo courtesy of Bill Wenk.

Photograph PICP-4. The pattern used allows both parking spaces and the crosswalk to be delineated with minimal cutting of pavers. Photo courtesy SEH and the City of Ft. Morgan.

Photograph PICP-5. Pavers can also be painted just like conventional pavement. Photo courtesy of SEH and the City of Ft. Morgan.

Photograph PICP-6. Mechanical placement in larger areas can reduce the unit cost of the pavement. Photo courtesy of Muller Engineering and Jefferson County Open Space**.**

Local Installation

The City of Greenwood Village decided to replace their concrete patio at the employee entrance of City Hall with PICP citing the following issues with the former concrete patio:

- The patio had little positive drainage.
- Roof drains discharged directly onto the patio.
- Snowmelt caused icing and a safety issue.
- Freeze/thaw cycles were rapidly deteriorating the existing concrete creating tripping hazards.

The patio has been in place since November 2008. To date, the City lists the following benefits:

- The patio dries quickly with no ponding or refreezing.
- Water moves quickly through the pavement rather than sheet flowing over the entire length of the walkway.
- City staff describe maintenance of the patio as "minimal." Discussions with building maintenance staff were held to get assistance with debris removal and to ensure that sanding for ice control was eliminated.

Photograph PICP-7. City staff demonstrate the infiltration capacity of PICP at the Greenwood Village City Hall.

Photograph PICP-8. The limits of wetting remain the same after multiple demonstrations.

References

Interlocking Concrete Pavement Institute (ICPI), Contractor Focus PICP Construction Tips. *Interlocking Concrete Pavement Magazine* vol. 17, no. 2, pp. 16-22, May 2010.

Interlocking Concrete Pavement Institute (ICPI). 2008. *Permeable Interlocking Concrete Pavement: A Comparison Guide to Porous Asphalt and Pervious Concrete.* www.icpi.org

Interlocking Concrete Pavement Institute (ICPI). 2007. *Permeable Interlocking Concrete Pavements: Selection, Design, Construction, Maintenance*. www.icpi.org

Interlocking Concrete Pavement Institute (ICPI). 2004. *ICPI Tech Spec No. 10.* www.icpi.org

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Concrete grid pavement is one of several different types of permeable pavement systems described in Volume 3. Previous versions of the manual referred to this pavement as *modular block pavement*. This pavement consists of concrete block units with large openings (at least 20% of the total surface area) that are filled with free draining material. Figure CGP-1 provides a pavement section.

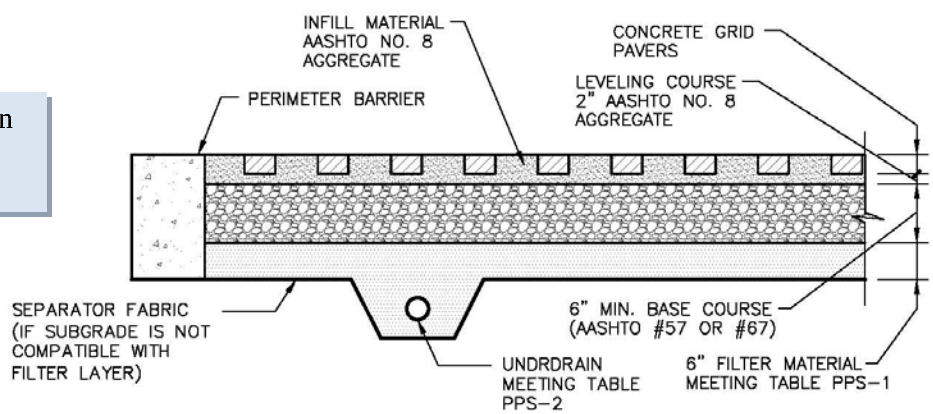
Photograph CGP-1. Concrete grid pavement installation in a parking area. The concrete segments along the perimeter of this installation showed wear that could have been mitigated with a concrete perimeter barrier.

Site Selection

Concrete grid pavement is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Overflow parking areas,
- Access/maintenance roads,
- Emergency vehicle and fire access lanes, and
- Equipment storage areas.

See additional details on Fact Sheet T-10.



NOTES:

1. THIS SECTION IS DESIGNED FOR PARTIAL INFILTRATION AS DESCRIBED IN BMP FACT SHEET T-10. SEE FIGURE PPS-1 FOR MODIFICATIONS FOR USE WITH NO INFILTRATION OR FULL INFILTRATION SECTIONS.
2. A PAVEMENT DESIGN SHOULD BE PERFORMED IN AREAS OF VEHICULAR USE.

Figure CGP-1. Concrete Grid Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- A concrete perimeter is recommended for this pavement. This will reduce movement and grinding between blocks.

Local Installation

The concrete grid pavement parking site was one of UDFCD's first stormwater monitoring sites. This site was constructed in 1994 and monitored with and without a layer of ASTM C-33 sand to provide filtration. Through our work at this site and the data collected, UDFCD learned the following:

- A filter layer (such as ASTM C-33 sand or CDOT Class C filter material) is required to achieve adequate pollutant removal.
- A concrete perimeter barrier will increase the lifespan of the concrete blocks.
- Concrete blocks can be removed and reused.

Benefits

- Concrete blocks can be removed and replaced back if utility cuts or other patches are required.
- Concrete grid pavement maintains infiltration rates well.

Limitations

- Concrete Grid Pavement does not meet ADA requirements for accessible paths.

Photograph CGP-2. The Lakewood concrete grid pavement installation was one the first permeable pavement stormwater monitoring sites constructed by UDFCD. This photo was taken following construction in 1994.

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Pervious concrete is one of several different types of permeable pavement systems contained within Volume 3. Carefully controlled amounts of water and cementitious materials are used to create a paste that forms a coating around aggregate particles. The pervious concrete mixture contains very little sand allowing for a significant voids and infiltration rates on the order of 480 in./hr. Figure PC-1 provides a pavement section.

Photograph PC-1. Construction of pervious concrete at the UDFCD stormwater monitoring site in Lakewood, CO, in 2004.

Site Selection

Pervious concrete is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Parking lots,
- Low-volume streets or alleys,
- Sidewalks/pedestrian areas, and
- Tennis courts.

See additional details on Fact Sheet T-10.

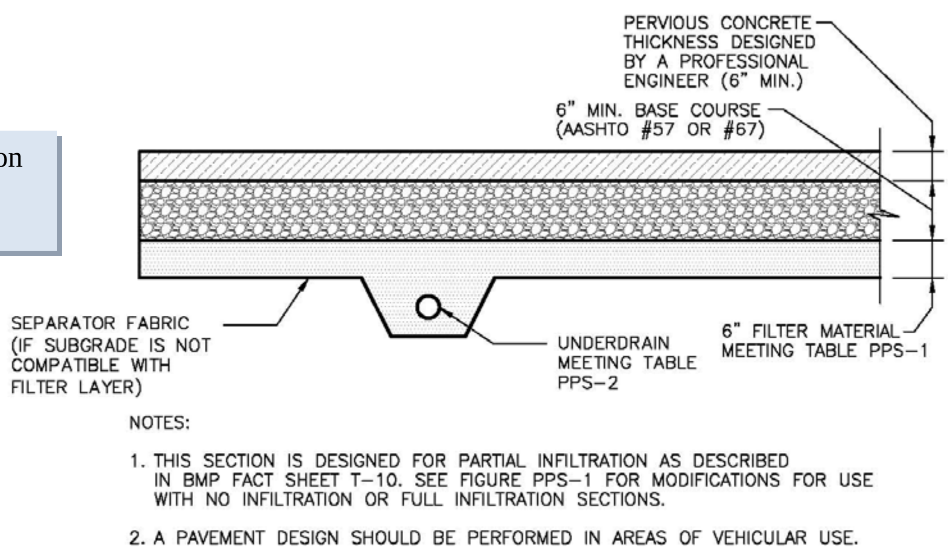


Figure PC-1. Pervious Concrete Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of the USDCM, Volume 3. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- Provide adequate joints including isolation joints with expansion joint material to allow for expansion and contraction. Provide this information in the plans and/or specifications. Joint spacing should not exceed 20 feet.

Benefits

- Meets ADA requirements.
- Maintains high infiltration rates.

Limitations

- When the pavement starts to ravel, a patch is needed quickly to limit the area of the damage.
- Limited success in Colorado to date.
- Shorter life span than conventional concrete as well as other permeable pavements in this manual.
- Quality control during installation is critical to the success of the pavement.
- A long cure time limits use of the area following construction.

Construction Considerations

This BMP Fact Sheet highlights important components of a successful installation. The design engineer, contractor, and any other individual responsible for construction inspection or observation should become familiar with the *Specifier's Guide for Pervious Concrete Pavement Design*, prepared by the Colorado Ready Mix Concrete Association (CRMCA). That document specifically addresses Colorado's freeze-thaw cycles, seasonal temperature variations and extremely low humidity. At a minimum, those involved with selecting, designing or constructing this BMP should understand the following:

- Selection of a contractor with prior experience in successful pervious concrete installation is highly recommended. The National Ready Mixed Concrete Association (NRMCA) has a certification program administered through the CRMCA. It is recommended that at least one out of three workers in the crew performing the work be certified.
- Mixing and transportation of pervious concrete should be completed and discharged within one hour of the introduction of mixture water to the cement. Alternatively, concrete could be mixed on site. Hydration stabilizer may also be added.
- Compaction of pervious concrete is achieved by rolling, using special equipment as shown in Photo PC-1. Do not over-compact or over-work the concrete. Cross rolling should be performed using the minimum number of passes required to achieve an acceptable surface. Overworking the surface will close voids and limit porosity.
- Joints should be rolled using a "pizza cutter roller." Joints should never be cut. Sawcutting introduces clogging material and increases the probability of raveling. Provide expansion material at all isolation/construction joints.
- Weather restrictions dictate that pervious concrete should only be placed between April 1 and November 1 and when the ambient temperature is between 40° and 90° Fahrenheit.

- Mixture water quantity is critical. The correct quantity has been achieved when the concrete has a wet metallic sheen. Using too much water may form an impervious bottom layer in the pavement and poor bonding at the top. Using too little water will result in poor bond strength.

- Air entrainment has been shown to increase freeze-thaw durability.

- Curing procedures begin immediately, but no later than 20 minutes from the time pervious concrete is discharged from the truck. The pavement surface must be covered with a 6-mil-thick polyethylene sheet. **The sheet should remain secure and in place until the concrete has reached a maturity equivalent to 14 days of curing at 70° Fahrenheit at 95% relative humidity. No vehicular traffic should be permitted during this time.**

- Fogging**,** using a fogging nozzle is required to raise the relative humidity of the ambient air over the slab and to reduce evaporation from the concrete. Fogging should begin once the concrete has been placed and should continue until the polyethylene curing cover is secured.

References

Colorado Ready Mixed Concrete Association (CRMCA). *Specifier's Guide for Pervious Concrete Pavement Design Version 1.2*. www.crmca.org

Tennis, Paul D, Michael L. Leming and David J. Akers. 2004. *Pervious Concrete Pavements.* Portland Cement Association (PCA). www.cement.org

Note: This BMP Fact Sheet is a supplement to Fact Sheet T-10, Permeable Pavement Systems. It is not intended to be a standalone document.

Description

Porous gravel is one of several different types of permeable pavement systems contained within Volume 3. This BMP can be used in place of conventional gravel paving and is well suited for industrial applications that do not pose contamination risks to groundwater. Figure PG-1 provides a typical pavement section of porous gravel.

Photograph PG-1. This Denver installation of porous gravel provides volumetric treatment of the WQCV as well as a material storage area.

Site Selection

Porous gravel is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Parking lots,
- Driveways,
- Storage yards, and
- Maintenance roads.

See additional details on Fact Sheet T-10.

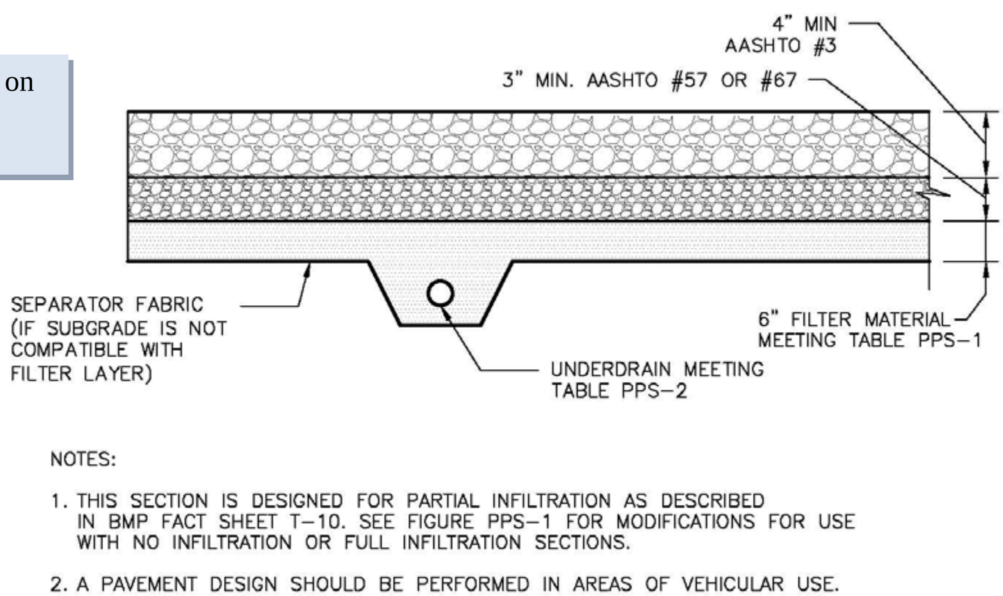


Figure PG-1. Porous Gravel Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6 of this manual. During design, consider the items provided on BMP Fact Sheet T-10 as well as the following:

- The surface of porous gravel pavement may rut more than desired. If this is a concern, consider an interlocking plastic cellular paving product (or similar product) to better stabilize the wearing course. Discussion on this product is provided in BMP Fact Sheet T-10.5 (Reinforced Grass).

Benefits

- Low cost compared to other permeable pavements.

Limitations

- Not ADA compliant.
- Ruts without stabilization.

Note: This permeable pavement system differs from others discussed in this manual. Rather than a pavement system designed to capture the WQCV, it is offered for the uses discribed within this Fact Sheet. Unlike Fact Sheets T-10.1 through T-10.4, this document is intended as a standalone document.

Description

Reinforced grass is one of several different types of permeable pavement systems contained within Volume 3. Reinforced grass is designed to have the appearance of grass turf while providing the stability of pavement. There are a number of reinforced grass products available. Different products provide varied levels of turf protection as well as pavement stability and can vary significantly in price. This BMP is frequently used to provide emergency vehicle access. It can also be used to stabilize an area adjacent to a roadway. Figure RG-1 provides a non-proprietary section for reinforced grass pavement.

Site Selection

Reinforced grass is appropriate for areas with low traffic volume and lower vehicle speeds. Applications include:

- Roadway shoulder,
- Maintenance roads including BMP access ramps,
- Emergency vehicle access roads, and
- Infrequently used parking areas.

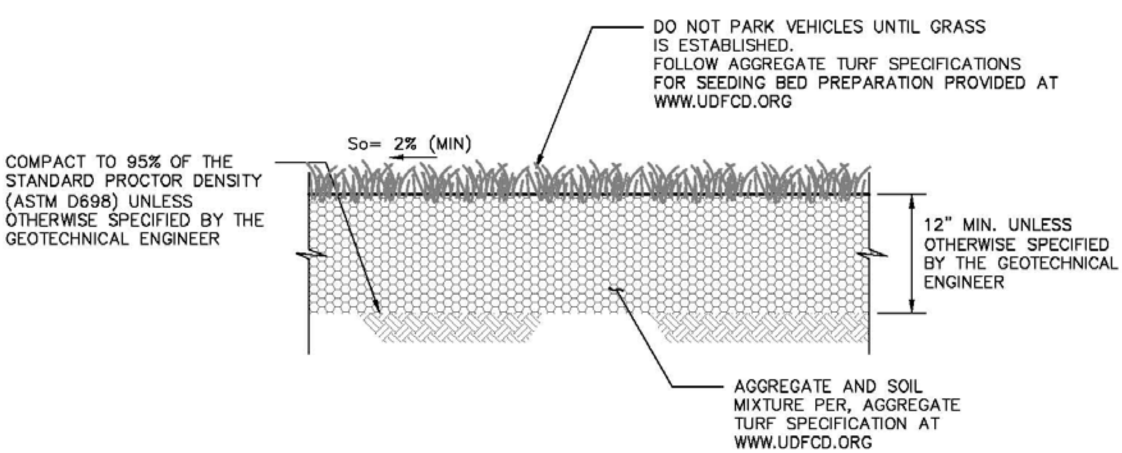


Figure RG-1. Aggregate Turf Pavement Section

Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6. During design, the following should be considered to ensure ease of maintenance over the long-term. These items are in addition to the items provided on BMP Fact Sheet T-10:

- For parking lot installations, consider a conventional pavement section in the drive aisles. These areas experience a higher volume of traffic.
- Irrigation requirements increase with frequency of use.

Benefits

- Reduces the heat island effect.

Limitations

- Requires irrigation.
- Not recommended when frequency of use exceeds two to three uses per space (for parking stalls) per week.

Selection Considerations

Figure RG-1 is adapted from the Federal Aviation Administration (FAA) section for *aggregate turf pavement*. In addition to this non-proprietary section, there are a number of products available under the name of *reinforced grass* or *turf pavement systems*. The most commonly used systems include:

- **Plastic Cellular Paving**: This category includes interlocking plastic pavers typically designed to be filled with turf or aggregate. This system allows for a high percentage of grass surface within the pavement area.
- **Concrete Cellular Paving**: This type of pavement consists either of interlocking pavers that have openings for the placement of grass or a similar cast-in-place system. Some systems include a reinforcement system that ties the pavers together providing greater protection from over-compaction and greater resistance to differential movement. Although some systems confine the grass area to the opening in the concrete, others are designed to provide the appearance of a fully vegetated landscape.

Consider the following variables when selecting a reinforced grass system:

- **Frequency of Use**: For more frequently used areas, it is important to select a system that protects the root system of the turf from compaction.
- **Appearance**: Concrete systems look different than plastic systems.
- **Vehicle Loading**: Emergency vehicle access roads may need to be designed for high loads but will be used infrequently.
- **Irrigation Expectations**: Some pavements rely, in part, on the turf for stability.
- **Optimum Drainage Capability**: Where soils allow for infiltration, select a product that will bridge the subgrade providing better protection from over-compaction.

Description

Photograph UG-1. Installation of an underground BMP (Photo courtesy of Robert Pitt).

Underground stormwater BMPs include proprietary and non-proprietary devices installed below ground that provide stormwater quality treatment via sedimentation, screening, filtration, hydrodynamic separation, and other physical and chemical processes. Conceptually, underground BMPs can be categorized based on their fundamental treatment approach and dominant unit processes as shown in Figure UG-1. Some underground BMPs combine multiple unit processes to act as a treatment train.

Historically, underground stormwater quality treatment devices have not been recommended based on UDFCD policies and criteria. This is due to several factors including problems with unmaintained or poorly maintained devices, remobilization by wash-out (scour) of accumulated pollutants during larger events, lack of performance data for underground devices in the region, and other issues discussed in this Fact Sheet. While underground flood-control detention is still discouraged, UDFCD has added this Fact Sheet to Volume 3 to provide criteria for determining when the use of underground BMPs may be considered for water quality. When surface BMPs are found to be infeasible, underground BMPs may be the only available strategy for satisfying regulatory water quality requirements, especially in highly built-up urban areas where water quality measures must be implemented as a part of a retrofit to meet regulatory requirements.

Underground BMPs should not be considered for standalone treatment when surface-based BMPs are practicable. For most areas of new urban development or significant redevelopment, it is feasible and desirable to provide the required WQCV on the surface. It is incumbent on the design engineer to demonstrate that surface-based BMPs such as permeable pavements, rain gardens, extended detention basins and others have been thoroughly evaluated and found to be infeasible before an underground system is proposed. Surface-based BMPs provide numerous environmental benefits including infiltration, evapotranspiration, groundwater recharge, aquatic habitat, mitigation of "heat island effect", and other benefits associated with vegetation for those that are planted. Be aware that some local governments prohibit the use of underground BMPs or impose requirements that go beyond this Fact Sheet.

Underground BMPs	
Functions	
LID/Volume Red.	Variable
WQCV Capture	Variable
WQCV+Flood Control	Variable
Fact Sheet Includes EURV Guidance	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Variable
Nutrients	Variable
Total Metals	Variable
Bacteria	Variable
Other Considerations	
Life-cycle Costs[4]	Moderate

[3] Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

[4] Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).

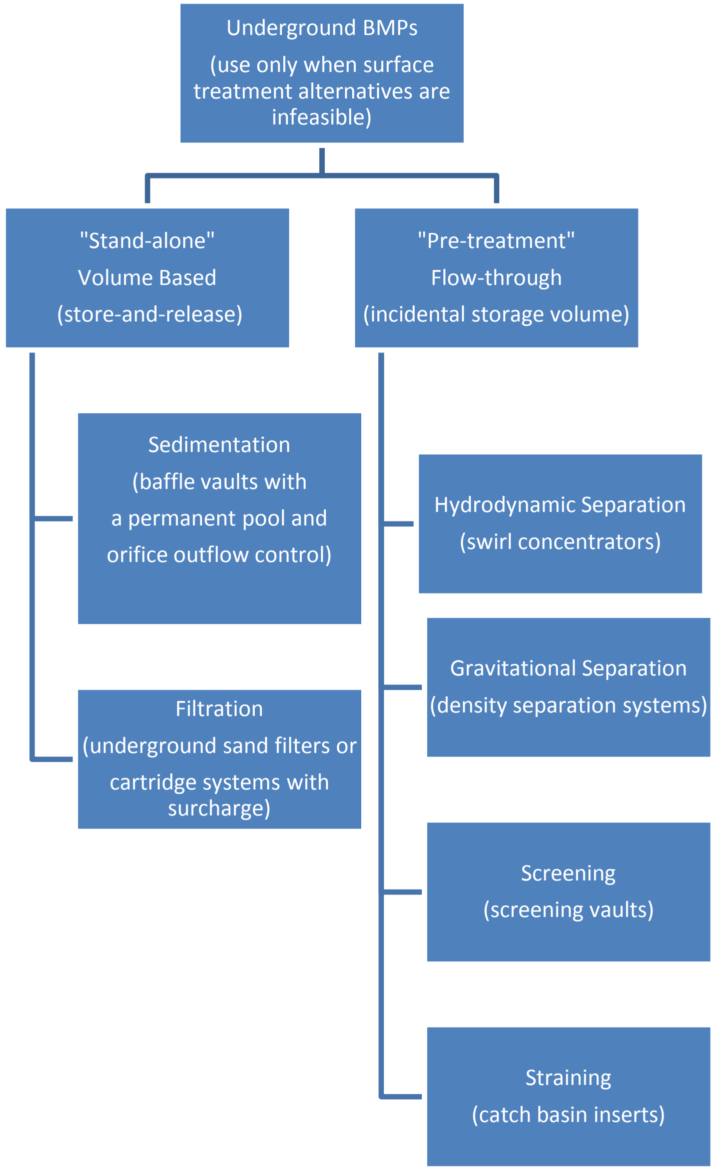


Figure UG-1. Classification of Underground BMPs

Site Selection

The most common sites for underground BMPs are "ultra urban" environments with significant space constraints. These could include downtown lot-line-to-lot-line development projects, transportation corridors, or small (less than 0.5 acre) redevelopment sites in urban areas. Important site features that must be considered include the following:

- **Depth to Groundwater**: Due to the potentially large displacement caused by an underground vault, if there is seasonally high groundwater, buoyancy can be a problem. Vaults can be sealed to prevent infiltration of groundwater into the underground system and these systems can be anchored to resist uplift. If seasonally high groundwater is expected near the bottom of an underground system, the engineer should evaluate the potential for infiltration of groundwater and uplift forces and adjust the design accordingly.

- **Proximity to Public Spaces**: As material accumulates in an underground system, there is potential for anoxic conditions and associated odor problems.

- **Gravity versus Pumped Discharge**: The ability to drain to the receiving storm sewer system via gravity is an important consideration. In some cases it may be necessary to pump discharge from an underground system; however, a gravity outfall is always reccomended if possible and some communities may not allow pumped systems. If a pumped system must be used, there should be redundancy in pumps, as well as a contingency plan in the event that a power outage disables pumps. Additionally, maintenance of the pump system should be identified as part of the water quality BMP in the maintenance plan. When BMP maintenance records are required by the MS4 permit holder, pump system maintenance records should also be included.

- **Access**: Equipment must be able to access all portions of the underground BMP, typically at multiple locations, to perform maintenance. As the size of the underground system increases, so must the number of access points.

Benefits

- Underground BMPs may be designed to provide pre-treatment and/or WQCV in space-constrained situations.
- There are many alternative configurations for proprietary and non-proprietary devices.
- Treatment train applications can be designed using different unit processes in series.
- Some underground BMPs, designed specifically for certain target pollutants, can be used to address a TMDL.
- Many underground devices can be effective for settling of particulates in stormwater runoff and gross solids removal.

Limitations

- Performance data for underground BMPs in the Denver area are limited.
- Maintenance is essential and must be performed frequently.
- Inspection and maintenance can require traffic control, confined space entry, and specialized equipment.
- Devices that do not provide WQCV do not qualify for standalone treatment.
- Gravity outfall may not be feasible in some situations.
- Many do not provide volume reduction benefits.
- Potential for anoxic conditions and odor problems.
- Not recommended when surface alternatives are feasible.

- **Traffic Loading**: Due to space constraints, in some situations, underground BMPs may be located in a right-of-way or other location where there may be traffic loadings. Many underground BMPs are or can be constructed for HS-20 traffic loading. Take additional measures when necessary to ensure that the BMP is designed for the anticipated loading.

- **Potential for Flooding of Adjacent Structures or Property**: For underground BMPs, it is important that the hydraulic grade line be analyzed to evaluate the potential for backwater in the storm sewer system. In addition, some types of underground BMPs, such as catch basin inserts, have the potential to clog and cause flooding if not frequently maintained.

Designing for Maintenance

All underground BMPs must be sized so that routine maintenance is not required more than once per year. The only exception to this is inlet inserts which may need to be cleaned as frequently as following each runoff producing event. **Because underground BMPs are generally less visible and more difficult to access than surface-based BMPs, regular maintenance and early detection of performance issues can be a challenge.**

When developing a design for an underground BMP, the engineer should ensure that all portions of the underground facility can be accessed with maintenance equipment. For multi-chambered systems, access should be provided to each chamber, and openings should be of sufficient size to accommodate the equipment recommended by the manufacturer or designer for maintenance.

Photograph UG-2. Maintenance access to all chambers of an underground BMP is an important design consideration. Photo courtesy of Robert Pitt.

Underground BMPs are generally considered confined spaces and OSHA confined space training typically will be required if a person must enter the underground BMP to perform maintenance. In all cases, a maintenance plan should be developed at the time that the underground BMP is designed.

The maintenance plan should specify, at a minimum, quarterly inspections with maintenance performed as needed based on inspections. The required inspection frequency may be reduced to biannually if, after two or more years, the quarterly regimen demonstrates that this will provide adequate maintenance. Local governments may consider requiring owners of underground BMPs to provide written inspection and maintenance documentation to better assure that required inspection and maintenance activities are taking place. When the BMP includes a pump system, pump inspection and maintenance records should also be included.

Questions to Ask When Considering an Underground BMP

Feasibility

- Are surface-based BMPs truly infeasible?
- Does the device help mitigate the adverse hydrologic impact of development?
- What are the pollutants of interest and are the treatment processes associated with the BMP expected to be effective for these pollutants?
- What is the whole life cycle cost of the BMP?

Location

- If applicable, is the device equipped for HS-20 traffic loading?
- Will the device be placed so that parked vehicles have potential to block access?

Performance

- Is stormwater monitoring required to demonstrate effectiveness of the BMP?
- Where else has a similar BMP been applied in the region? How effective was the application?
- Have independent, third-party data been collected to support performance claims?

Design

- Is pretreatment required?
- Should the device serve as a step in a treatment train instead of a standalone BMP?
- Are there mechanisms to minimize mobilization of accumulated pollutants?
- Is there a maximum drainage area recommended for the device?
- Is the device sized properly for the contributing drainage area and imperviousness?
- What is the head loss through the device for the full range of flow conditions?
- What are design water quality flow rates?
- How does the bypass operate when flow rates are greater than those for the water quality event?
- Have hydraulic grade lines been prepared for the device to evaluate potential surcharging and flooding?

Installation and Maintenance

- What support does the manufacturer provide for design, installation and/or maintenance?
- Who will be on-site during and after construction to ensure that the BMP has been installed correctly?
- What are the maintenance requirements, including access? Is the overall site plan compatible with assured long-term maintenance? Will the underground BMP be located in an easement to assure long-term access?
- What is the recommended maintenance frequency, and what is the cost and method of disposal for removed material?
- What parts of the BMP will need to be maintained and/or replaced (filter media, absorbent pillows, etc.) and what are the associated costs?
- What monitoring will occur?
- Are access openings large enough to accommodate the equipment that will be used to maintain the BMP?
- Who is responsible for inspection and maintenance?
- What proof of maintenance will be required of the owner to show that inspections and routine maintenance is performed?
- What level of effort is required to determine if the BMP is being maintained? Can this be done visually?
- Is there a contingency plan for failure of essential components (pumps, screens, obstructions in flow paths, etc.)?

Design Procedure and Criteria

Two primary options are available for underground BMPs:

1. **Underground BMPs Based on a Surface BMP design**: BMPs that satisfy the requirements for capture and slow release of the WQCV and that are based on and designed in substantial conformance with the criteria for surface-based BMPs described in this manual.

2. **Underground Proprietary BMPs**: Proprietary BMPs that satisfy the requirements for capture and slow release of the WQCV and provide a level of treatment for targeted pollutants that is comparable to that of the surface-based BMPs provided in this manual.

Underground BMPs Based on a Surface BMP Design

This class of underground BMP includes sand filter basins and retention facilities designed for below grade installation. The design must provide the WQCV and empty it over a time period of 12 hours or more. Not all of the surface-based BMPs that provide the WQCV can be adapted for underground use. For example, the vegetative components of a constructed wetland pond render it inadaptable to underground use. Underground extended detention basins are also problematic due to historical problems with remobilization of collected sediment and the difficulty of creating an effective underground micropool.

The most commonly used underground BMP to date in the UDFCD area is the underground sand filter. In addition to the criteria for an above ground sand filter, underground sand filters should meet the following criteria:

1. A pretreatment chamber for removal of coarse sediments with a volume equivalent to 0.10 times the WQCV should be provided. The pretreatment chamber must be separated from the sand filter chamber by baffles, and serves as the sediment forebay to reduce the frequency of maintenance required in the sand filter. Also consider incorporating a vertical baffle to trap oil and grease. This can be easily incorporated into the forebay and should be included where oil and grease are target constituents. Absorbent mats or booms could also be used for this purpose.

2. Where discharges from the BMP will be pumped, a separate outlet chamber is required from which the water passing through the filter layer can be pumped. The outlet pump must be sized to discharge at a rate such that the WQCV is released in no less than 12 hours.

3. For flows in excess of the water quality design event, a diversion must be sized so that excess flows bypass the sand filter chamber and the underground sand filter is not surcharged (in terms of depth or hydraulic grade line) beyond the WQCV maximum elevation.

4. Maintenance access must be provided to each chamber. Access must be sufficient to allow complete removal and replacement of the filter material. Allow for at least 6 feet of headroom (from the surface of the filter) to facilitate maintenance.

Underground Proprietary BMPs

There are numerous proprietary BMPs with wide variability in performance, design flow rates, unit processes, and volume of storage provided (if any). Sizing methodologies for proprietary devices vary from device to device—some are flow based, some are volume based, some consider surface/filter hydraulic loading, etc. As a result, this manual does not seek to provide a one-size-fits-all sizing methodology for proprietary BMPs. Instead, this manual provides a performance-based set of criteria for determining whether a proprietary BMP is acceptable for use.

To evaluate performance of an underground proprietary BMP, data should be provided to the local jurisdiction to demonstrate that anticipated BMP performance will be comparable to that of surface-based BMPs such as extended detention basins, constructed wetland basins, sand filter basins, or retention ponds. Underground BMPs approved for standalone treatment should be capable, on an annual basis, of producing effluent quality with a median TSS concentration of no more than 30 mg/L. This level of treatment is comparable to the long-term effluent median concentrations from the International Stormwater BMP Database for surface-based BMPs.

Data collected to substantiate performance of proprietary BMPs should meet the following criteria:

1. Testing must consist of field data (not laboratory data) collected in compliance with the criteria in Table UG-1. Laboratory studies and/or vendor-supplied studies without third party involvement or verification should not be considered. The Technology Acceptance Reciprocity Partnership (TARP) Protocol for Stormwater Best Management Practice Demonstrations may provide additional useful information on development of a monitoring program for evaluation of underground BMPs. Information on the TARP program can be found in several locations on the internet, including http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/. Forthcoming field testing guidelines from the American Society of Civil Engineers Urban Water Resources Research Council (ASCE UWRRC) Task Committee developing Guidelines for Certification of Manufactured Stormwater BMPs (Sansalone et al. 2009) may also be applicable in the future.

2. Data collected in environments similar to the Colorado Front Range (i.e., semi-arid with freezing and thawing in the winter) are preferable. This is particularly important for flow based devices where differences in rainfall intensity and duration may affect performance.

3. Data should be collected and analyzed in accordance with the guidance provided in *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE 2009; available online at www.bmpdatabase.org). When reviewing performance data, it is important to recognize that the use of percent removal may be more reflective of how "dirty" the influent water is rather than how well the BMP is actually performing (Jones et. al. 2008). Instead, look at effluent concentrations for a range of influent concentrations. **The device should have performance data that demonstrates the ability to meet a median TSS effluent concentration of approximately 30 mg/L or lower on an annual basis**.

4. Data should be collected or verified by independent third parties in accordance with good Quality Assurance/Quality Control (QA/QC) procedures.

Many studies have been conducted over the past decade to document the performance of underground BMPs. Sources of data that may be used to support using a proprietary BMP include the following:

- New Jersey Corporation for Advanced Technology (NJCAT) Technology Verification Program. (http://www.njcat.o0rg/verification/protocol.cfm).

- Washington State Department of Ecology (2002). Guidance for Evaluating Emerging Stormwater Treatment Technologies, Technology Assessment Protocol – Ecology (TAPE), October 2002 (Revised June 2004), Publication Number 02-10-037. (http://www.ecy.wa.gov/biblio/0210037.html).

- International Stormwater BMP Database (www.bmpdatabase.org).

- University of Massachusetts Amherst Stormwater Technologies Clearinghouse (www.mastep.net).

- Wisconsin Department of Commerce & Wisconsin Department of Natural Resources (2007). Method for Predicting the Efficiency of Proprietary Storm Water Sedimentation Devices (1006), http://www.socwisconsin.org/pdf/Broad%20Review/Proprietary%20Stormwater%20Devices%20Std.-Draft6.pdf

- U.S. Environmental Protection Agency Environmental Technology Verification (ETV) Program http://www.epa.gov/etv/

Other data sources may also be acceptable, provided they meet the documentation criteria above.

Table UG-1. Field Monitoring Criteria for Evaluation of Proprietary Underground BMPs

Monitoring Plan Element	Criteria
Number of storm events	▪ Minimum of 10 with "complete" data sets (inflow and outflow quality and quantity data).
Parameters	▪ Inflow(s), Outflow(s) (volume and rate), Precipitation, TSS, TP, COD, Particle Size Distribution (minimum of 3 out of 10 events).
Quality Assurance/Quality Control (QA/QC)—monitoring plan	▪ Monitoring plan shall be developed in accordance with guidance from TARP or *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE 2009) and shall satisfy USEPA requirements for a Quality Assurance Project Plan (QAPP).
QA/QC—laboratory analyses	▪ All analyses shall be performed by a qualified laboratory using USEPA standard analytical procedures.
Representativeness —sampling method	▪ Flow-weighted composite samples for event mean concentrations.
Representativeness—storm characteristics	▪ Aliquots from event shall bracket at least 2/3 of the volume of runoff and the peak of the hydrograph for each monitoring station.
Representativeness—precipitation depth	▪ All events monitored shall have a depth of at least 0.2 inches. ▪ At least 6 of the 10 events shall have total depths between 0.2 and 0.6 inches (targeted water quality storms). ▪ At least 2 of the 10 events shall have total depths > 0.6 inches—bypass quantity and quality shall be quantified and reported.
Representativeness—antecedent dry period	▪ For a storm to qualify as one of the 10 required events, the storm should be preceded by an antecedent dry period of at least 72 hours.
Data Analysis	▪ Data analysis shall follow procedures in *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE 2009) or other established protocols such as TARP or the ASCE UWRRC Task Committee Guidelines for Certification of Manufactured Stormwater BMPs (Sansalone et al. 2009).

Depending on long-term median effluent concentrations from monitoring and whether or not the BMP provides the WQCV, a proprietary underground BMP will fall into one of three categories:

1. **Not recommended:** This category is for underground BMPs that have not demonstrated the ability to achieve an effluent median concentration for TSS of 30 mg/L or less over the long term. This category also may apply to BMPs that have a limited number of data points or studies that were not conducted in accordance with the criteria described above. Even if performance data are favorable, an underground BMP may be deemed unacceptable if a community determines that it is more difficult and/or expensive to maintain compared to a surface BMP alternative.
2. **Pretreatment:** This category is for underground BMPs that generally demonstrate performance capable of meeting the 30 mg/L TSS median effluent benchmark but provide little, if any, surcharge storage/WQCV. BMPs in this category may be useful as an initial step in a treatment train approach to water quality. A BMP meeting these criteria could be used in conjunction with a downstream BMP that provides slow release of the WQCV.
3. **Standalone:** This category is for underground BMPs that demonstrate the ability to produce effluent with a median concentration of 30 mg/L TSS or less over the long term and provide the WQCV in accordance with UDFCD criteria. "Standalone" devices should be designed to provide release of the WQCV in no less than 12 hours. Furthermore, this category of BMP should only be used where it is determined that surface BMPs are not feasible.

Stand-alone Treatment

Underground BMPs should meet three basic criteria when considered for stand-alone treatment:

- Capture and treat the WQCV.
- Drain the WQCV over approximately 12 hours.
- Demonstrate performance capable of meeting a median effluent concentration for TSS of 30 mg/L or less.

See Figure UG-1 for typical types of underground BMPs that may fall into each category. UDFCD does not maintain a list of specific devices that fall into each of these categories. It is the responsibility of the designer to present relevant data, demonstrate that the criteria for data collection above have been satisfied, and identify the appropriate category for the BMP based on those data. Local governments should reserve the right to disallow underground BMPs, proprietary or not, at their discretion. In addition, a local government may require collection of additional monitoring data to demonstrate BMP performance, especially in situations where data from other geographic regions have been presented to justify use of the underground BMP. Finally, local governments may require agreements that run in perpetuity attached to the property served by the BMP, assuring that it will be inspected and maintained by the owner as required by the local government (or recommended by manufacturer) with a provision for taking over the inspection and maintenance if needed and back charging the owner.

Construction Considerations

Improper installation will cause poor performance of proprietary underground BMPs. This problem has been noted not only by manufacturers, but also by Colorado municipalities who have observed that the "as built" BMPs often vary significantly from the design. Most underground BMPs already face hydraulic challenges due to limited vertical fall and because of head losses, so they may be sensitive to slight changes in elevation. In addition, many of the proprietary underground BMPs require assembly of special baffling or patented inserts that may not be familiar to contractors.

For these reasons, it is important to discuss the installation of the underground BMP with the manufacturer prior to selecting a contractor so that the installation requirements are clearly understood. Construction observation by the design engineer, and, if possible, a manufacturer's representative is essential for proper installation. At a minimum, the installation should be inspected by the manufacturer's representative once completed. Any deficiencies of the installation identified by the manufacturer's inspection should be corrected immediately.

Description

Photograph OS-1. Although each site is different, most sedimentation BMPs have similar outlet structures. Each structure should include a partially submerged orifice plate with a screen (or grate) protecting the orifice plate from clogging, and an overflow weir for flows exceeding the WQCV or excess urban runoff volume (EURV), when full spectrum detention is used.

This section provides guidance and details for outlet structures for use primarily with BMPs utilizing sedimentation, (i.e., extended detention basins (EDBs), retention ponds, and constructed wetland ponds). The information provided in this section includes guidance for different size watersheds as well as for incorporating Full Spectrum Detention as described in the *Storage* chapter of Volume 2.

The details contained in this Fact Sheet are intended to provide a starting point for design. UDFCD recommends that design details for outlet structures be specific for each site with structural details drawn to scale. The details provided in this Fact Sheet are not intended to be used without modification or additional detail.

Outlet Design

Large Watershed Considerations

UDFCD recommends that water quality treatment be provided close to the pollutant source. This is a fundamental concept of Low Impact Development (LID). Although flood control facilities, including Full Spectrum Detention facilities, have been shown to be very effective for watersheds exceeding one square mile, this is not the case for water quality facilities. One reason for this is that the baseflow associated with a larger watershed will vary and can be difficult to estimate. The orifice plate should be designed to pass the baseflow while detaining the water quality capture volume (WQCV) for approximately 40 hours. When the baseflow is overestimated, the WQCV is not detained for the recommended time, passing through without treatment. When the baseflow is underestimated, the elevation of the permanent pool will be higher than designed, causing maintenance issues as well as reducing the volume available for detention of the WQCV, which also allows for a portion of this volume to pass through without treatment. For this reason, UDFCD recommends that facilities designed for both water quality and flood control be limited, where possible, to watersheds without a baseflow. The maximum recommended watershed for combined facilities is one square mile. Additional discussion on designing for baseflows is provided in the EDB BMP Fact Sheet (T-5).

Designing for Maintenance

Rather than using the minimum criteria, consider maximizing the width of the trash rack to the geometry of the outlet. This will reduce clogging and frequency of maintenance. Reduced clogging in EDB outlet structures will preserve the initial surcharge volume thus reducing frequency of inundation in the bottom of the basin. This will benefit the grasses and reduce long-term EDB maintenance requirements (including sediment removal in the grassed area) and may reduce the life-cycle cost of the BMP.

Orifice Plates and Trash Racks

An orifice plate is used to release the WQCV slowly over 40 hours. For Full Spectrum Detention, the orifice plate is extended to drain a larger volume, the EURV, over approximately 72 hours. The figures and tables in this section provide recommendations for orifice configurations and trash rack type and size. Guidance is provided for plates using both circular and rectangular orifices.

Orifice Sizing

Follow the design steps included in the BMP Fact Sheet for the appropriate BMP. The UD-BMP workbook, available at www.udfcd.org, can also be used to calculate the required orifice area per row. This is the first step in detailing the outlet structure for sedimentation BMPs. It is good practice to maximize the area of each orifice to avoid clogging. The *UD-BMP* workbook will allow up to two columns of circular orifices before recommending a single rectangular orifice. A rectangular orifice is recommended when the required open area per row is equal to approximately 4 square inches or greater. Details showing orifice configurations are provided in Figure OS-4. Table OS-1 can be used to determine orifice shape and number of columns based on the required area per row.

Photograph OS-2. This trash rack could not be properly attached due to its inadequate flange width.

Photograph OS-3. Trash rack after repair.

Trash Rack Sizing

Once the size of the orifice has been determined, this information, along with the total orifice area in the water quality plate, is used to determine the total open area of the grate (see Figure OS-1). The trash rack should be sized using this figure. This Fact Sheet also includes standard tables that can be used when the outlet is designed per UDFCD criteria, including inundation of trash rack into the permanent pool for a depth of approximately 2.5 feet. The standard tables assume the use of the specified stainless steel screen with circular orifices and the specified aluminum bar grate for use with rectangular orifices. Use Figure OS-1 when using a different track rack material or when the geometry of the structure does not fit within the assumptions of the tables. Use Tables OS-2a and OS-2b for circular orifices and Tables OS-3a and OS-3b for rectangular orifices. Be aware, these tables provide the minimum width clear for the trash rack frame. It is also important to provide adequate width for attachment to the outlet structure (see Photos OS-2 and OS-3). Also, consider maximizing the width of the trash rack to the geometry of the outlet. This will reduce clogging and maintenance requirements associated with cleaning the trash rack.

Table OS-1. Orifice Sizing

Hole Dia. (in) [1]	Hole Dia. (in)	Area per Row (in^2)	
		n = 1	n = 2
1/4	0.250	0.05	-
5/16	0.313	0.08	-
3/8	0.375	0.11	-
7/16	0.438	0.15	-
1/2	0.500	0.2	-
9/16	0.563	0.25	-
5/8	0.625	0.31	-
11/16	0.688	0.37	-
3/4	0.750	0.44	-
13/16	0.813	0.52	-
7/8	0.875	0.6	-
15/16	0.938	0.69	-
1	1.000	0.79	-
1-1/16	1.063	0.89	-
1-1/8	1.125	0.99	-
1-3/16	1.188	1.11	-
1-1/4	1.250	1.23	-
1-5/16	1.313	1.35	-
1-3/8	1.375	1.48	-
1-7/16	1.438	1.62	3.24
1-1/2	1.500	1.77	3.54
1-9/16	1.563	1.92	3.84
1-5/8	1.625	2.07	-
1-11/16	1.688	2.24	-
1-3/4	1.750	2.41	-
1-13/16	1.813	2.58	-
1-7/8	1.875	2.76	-
1-15/16	1.938	2.95	-
2	2.000	3.14	-
n = Number of Columns of Orifices			
Steel Thickness (Min.)		1/4”	5/16”
[1] If desired, interpolate to the nearest 32" to better match the needed area.			

Use one column of rectangular orifices when the needed area exceeds 3.84 in^2

Rectangular Height (in) = 2
Rectangular Width (in) = Required Area / 2 in

Rectangular Width (in)	Steel Thickness (in)
≤6	≥1/4
≤8	≥5/16
≤10	≥3/8
>10	≥1/2

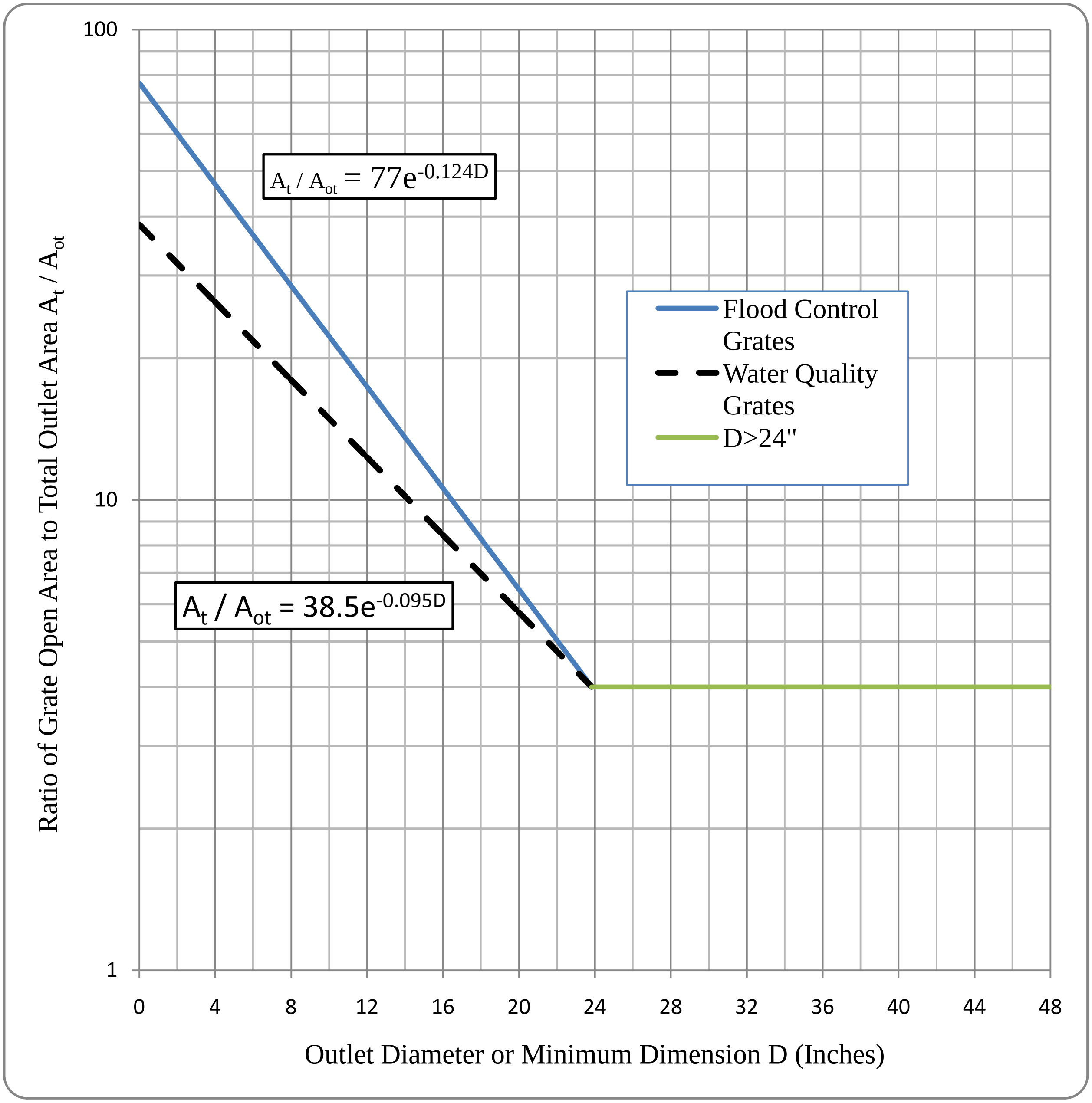


Figure OS-1. Trash Rack Sizing

Table OS-2a. Trash Rack Sizing for Circular Orifices[1,3]

Number of Columns	Diameter of Circular Orifice (in)	Width of Trash Rack Opening ($W_{opening}$) as a Function of Water Depth H Above Lowest Perforation				
		H=2.0’	H=3.0’	H=4.0’	H=5.0’	H=6.0’
1	≤ 1-1/4	12"[2]	12"[2]	12"[2]	12"	13"
1	≤ 1-1/2	12"[2]	14"	16"	17"	18"
1	≤ 1-3/4	15"	18"	21"	22"	24"
1	≤ 2	19"	23"	26"	28"	30"
2	1-7/16	21"	26"	29"	31"	33"
2	1-1/2	23"	28"	31"	34"	35"
2	1-9/16	24"	30"	34"	36"	38"

[1] For use with Johnson VEE WireTM Stainless Steel Screen1 (or equivalent screen with 60% open area). Assumes inundation of well screen into the permanent pool 2'4".

[2] Represents the minimum recommended width of 12 inches, otherwise width is calculated based on Figure OS-1.

[3] This table provides the minimum opening in the concrete, not the minimum width of the well screen. Ensure the well screen is wide enough to properly attach to the structure.

Table OS-2b. Trash Rack Specifications for Circular Orifice Plates

Max. Width of Trash Rack Opening (in)	Screen #93 VEE Wire Slot Opening (in)	Support Rod Type	Support Rod, On Center, Spacing	Total Screen Thickness	Carbon Steel Frame Type
≤9	0.139	#156 VEE	¾"	0.31"	3/8"x1.0" flat bar
≤18	0.139	TE 0.074"x0.50"	1"	0.655"	¾" x 1.0 angle
≤24	0.139	TE 0.074"x0.75"	1"	1.03"	1.0" x 1½" angle
≤27	0.139	TE 0.074"x0.75"	1"	1.03"	1.0" x 1½" angle
≤30	0.139	TE 0.074"x1.0"	1"	1.155”	1 1/4"x 1½" angle
≤36	0.139	TE 0.074"x1.0"	1"	1.155”	1 1/4"x 1½" angle
≤42	0.139	TE 0.105"x1.0"	1"	1.155”	1 1/4"x 1½" angle

[1] Johnson Screens, St. Paul, Minnesota, USA (1-800-833-9473)

Table OS-3a. Trash Rack Sizing for 2" High Rectangular Orifices

Width (W) of 2” Rectangular Orifice (in)	Minimum Width of Trash Rack Opening ($W_{opening}$) as a Function of Water Depth H Above Lowest Perforation					
	H≤2.0 ft.	H≤3.0 ft.	H≤4.0 ft.	H≤5.0 ft.	H≤6.0 ft.	Spacing of Bearing Bars, Cross Rods
2	1.7'	2.1'	2.4'	2.5'	2.7'	1-3/16”, 2”
≤ 2.5	2.2'	2.6'	3'	3.2'	3.4'	1-3/16”, 2”
≤ 3.0	2.6'	3.2'	3.5'	3.8'	4.0'	1-3/16”, 2”
≤ 3.5	3.0'	3.7'	4.1'	4.5'	4.7'	1-3/16”, 2”
≤ 4.0	3.4'	4.2'	4.7'	5.1'	5.4'	1-3/16”, 2”
≤ 4.5	3.6'	4.4'	4.9'	5.3'	5.6'	1-3/16”, 4”
≤ 5.0	4.0'	4.8'	5.4'	5.9'	6.2'	1-3/16”, 4”
≤ 5.5	4.4'	5.3'	6.0'	6.5'	6.8'	1-3/16”, 4”
≤ 6.0	4.8'	5.8'	6.5'	7.0'	7.4'	1-3/16”, 4”
≤ 6.5	5.2'	6.3'	7.1'	7.6'	8.1'	1-3/16”, 4”
≤ 7.0	5.6'	6.8'	7.6'	8.2'	8.7'	1-3/16”, 4”
≤ 7.5	6.0'	7.3'	8.2'	8.8'	9.3'	1-3/16”, 4”
≤ 8.0	6.4'	7.8'	8.7'	9.4'	9.9'	1-3/16”, 4”
≤ 8.5	6.8'	8.2'	9.2'	10'	*	1-3/16”, 4”
≤ 9.0	7.2'	8.7'	9.8'	*	*	1-3/16”, 4”
≤ 9.5	7.6'	9.2'	*	*	*	1-3/16”, 4”
≤ 10.0	8.0'	9.7'	*	*	*	1-3/16”, 4”
≤ 10.5	8.3'	*	*	*	*	1-3/16”, 4”
≤ 11.0	8.7'	*	*	*	*	1-3/16”, 4”
≤ 11.5	9.1'	*	*	*	*	1-3/16”, 4”
≤ 12.0	9.5'	*	*	*	*	1-3/16”, 4”

* Size trash rack per Figure OS-1. Use 4-inch high staggered rectangular orifices to limit size of the structure.

Notes:

1. Width shown based on Figure OS-1 assuming inundation of trash rack into the permanent pool 2'4".
2. This table provides the minimum opening in the concrete, not the minimum width of the trash rack. Ensure the trash rack is wide enough to properly attach to the structure.

Table OS-3b. Trash Rack Specifications for 2” High Rectangular Orifices

Water Depth Above Lowest Opening, H (ft)	Minimum Bearing Bar Size, Bearing Bars Aligned Vertically (in)
2.0'	1” x 3/16”
3.0'	1-1/4” x 3/16”
4.0'	1-3/4” x 3/16”
5.0'	2” x 3/16”
6.0'	2-1/4” x 3/16”

Outlet Geometry

Outlets for small watersheds will typically be sized for maintenance operations while the geometry of outlets for larger watersheds may be determined based on the required size of the trash rack. For all watershed sizes, the outlet should be set back into the embankment of the pond to better allow access to the structure. This also provides a more attractive BMP. For larger watersheds, this will require wing walls. Wing walls are frequently cast-in-place concrete, although other materials, such as grouted boulders, may be used where appropriate. Consider safety, aesthetics, and maintenance when selecting materials and determining the geometry. A safety rail should be included for vertical drops of 3 feet or more. Depending on the location of the structure in relation to pedestrian trails, safety rails may also be required for lesser drops. Stepped grouted boulders can be used to reduce the height of vertical drops.

Photograph OS-4. Maintenance access to the water quality trash rack was compromised by the location of a secondary trash rack on this outlet. This may have been included as a safety rack or as additional protection from clogging. The owner modified the structure for better access. A safety rail would have been a better solution.

As shown in Figures EDB-1 and EDB-2 provided in BMP Fact Sheet T-5, wing walls can be flared or parallel. There are advantages to both configurations. Parallel wing walls may be more aesthetic; however, depending on the geometry of the pond, may limit accessibility to the trash rack. Flared wing walls can call attention to the structure but provide better accessibility and sometimes a vertical barrier from the micropool of an EDB, which can increase safety of the structure. Parallel walls can also be used with a second trash rack that is secured flush with the top of the wall as shown in Photo OS-4. This eliminates the need for a safety rail and may provide additional protection from clogging; however, it creates a maintenance issue by restricting access to the water quality screen. The rack shown in Photo OS-4 was modified after construction due to this problem.

Photograph OS-5. Interruptions in the horizontal members of this trash rack and the spacing of the vertical members allow easier access to clean the water quality grate. A raking tool can be used to scrape the water quality trash rack.

Micropools within the Outlet Structure

The micropool of an EDB may be placed inside the structure when desired. This is becoming increasingly common for smaller watersheds and near airfields where large bird populations can be problematic. When designing this type of structure, consider maintenance of the water quality trash rack. The secondary trash rack should be designed to allow maintenance of the water quality trash rack similar to that shown in Photo OS-5. This concept can easily be incorporated into smaller outlet structures (see Figures OS-7 and OS-8 for details).

Outlet Structure Details

A number of details are presented in this section to assist designers with detailing outlet structures. Table OS-2 provides a list of details available at www.udfcd.org. These details are not intended to be used in construction plans without proper modifications as indicated in Table OS-4.

Table OS-4. Summary of Outlet Structure Details and Use

Figure	Detail	Use of Detail
OS-2	Typical Outlet Structure for Full Spectrum Detention	Conceptual.
OS-3	Typical Outlet Structure for WQCV Treatment and Attenuation	Conceptual.
OS-4	Orifice Plate and Trash Rack	Outlet section. Modify per true structure geometry and concrete reinforcement. Modify notes per actual design.
OS-5	Typical Outlet Structure with Circular Orifice Plate	Outlet sections. Modify per true structure geometry and concrete reinforcement. Add additional sections and detailing as necessary. Modify notes per actual design.
OS-6	Typical Outlet Structure with Rectangular Orifice Plate	Outlet sections. Modify per true structure geometry and concrete reinforcement. Add additional sections and detailing as necessary. Modify notes per actual design.
OS-7	Full Spectrum Detention Outlet Structure for 5-acre Impervious Area or Less	Outlet profile and section. Modify per true EURV elevation and concrete reinforcement. Add additional sections and detailing as necessary.
OS-8	WQCV Outlet Structure for 5-acre Impervious Area or Less	Outlet sections. Modify per true WQCV elevation and concrete reinforcement. Add additional sections and detailing as necessary.

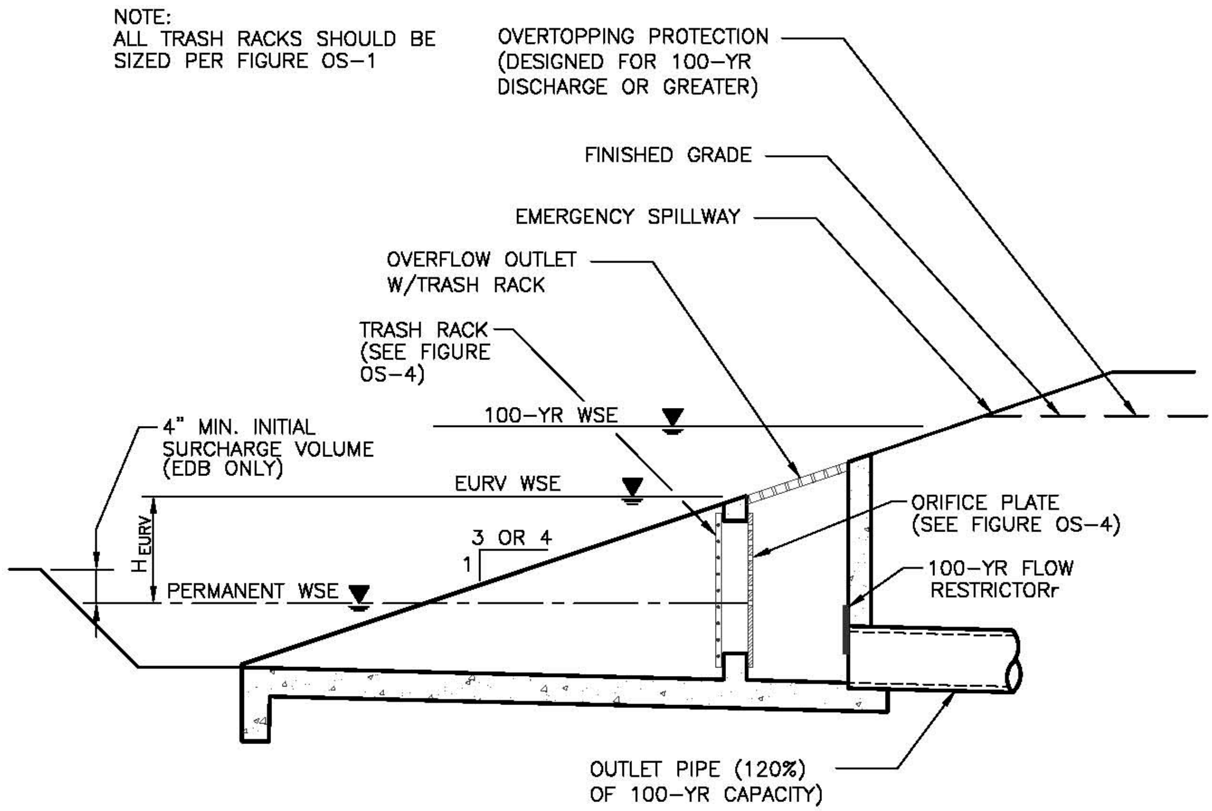


Figure OS-2. Typical Outlet Structure for Full Spectrum Detention

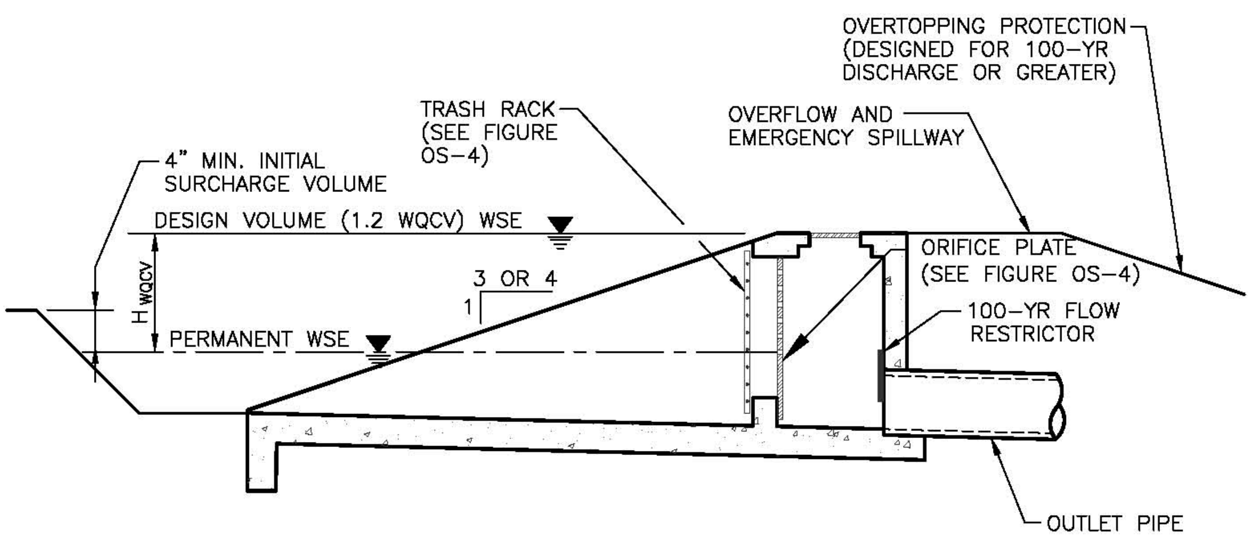
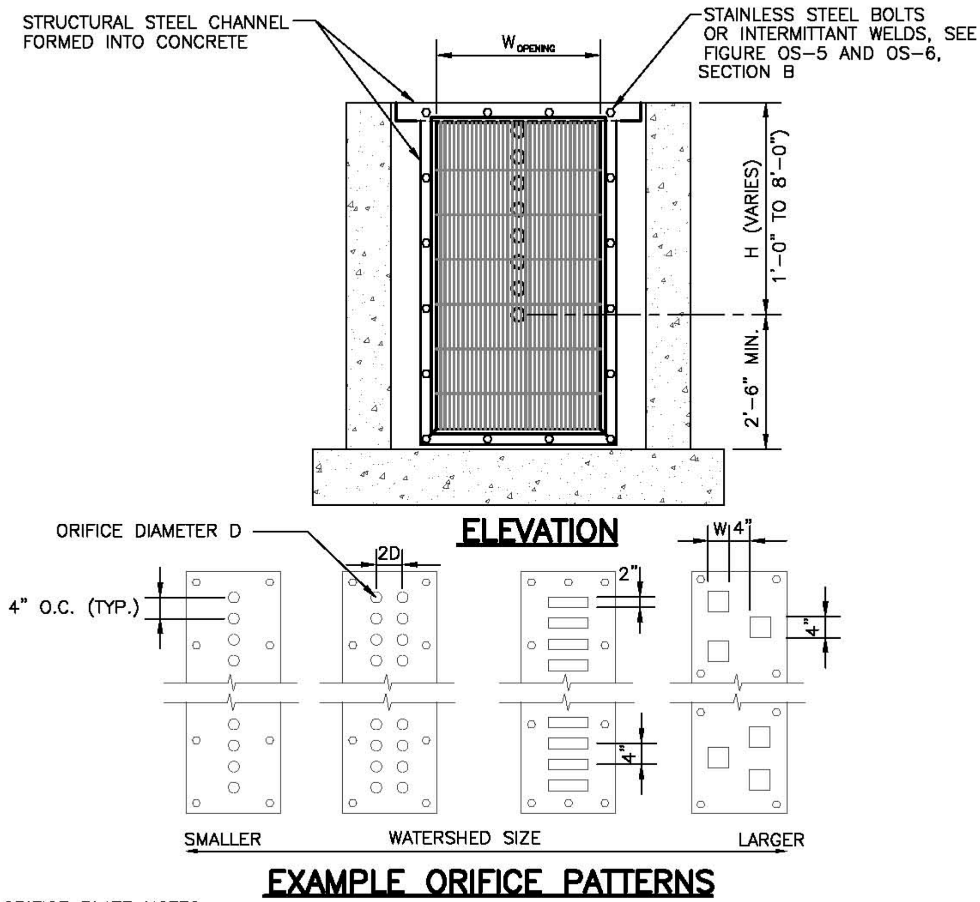


Figure OS-3. Typical Outlet Structure for WQCV Treatment and Attenuation



ORIFICE PLATE NOTES:

1. MINIMIZE THE NUMBER OF COLUMNS.
2. PROVIDE GASKET MATERIAL BETWEEN THE ORIFICE PLATE AND CONCRETE.
3. BOLT PLATE TO CONCRETE 12" MAX. ON CENTER.

EURV AND WQCV TRASH RACKS:

1. WELL-SCREEN TRASH RACKS (FOR CIRCULAR ORIFICES) SHALL BE STAINLESS STEEL AND SHALL BE ATTACHED BY INTERMITTENT WELDS ALONG THE EDGE OF THE MOUNTING FRAME.
2. BAR GRATE TRASH RACKS (FOR RECTANGULAR ORIFICES) SHALL BE ALUMINUM AND SHALL BE BOLTED USING STAINLESS STEEL HARDWARE.
3. TRASH RACK WIDTHS PROVIDED IN TABLE OS-2A AND OS-3A ARE FOR SPECIFIED TRASH RACK MATERIAL AND NEED TO BE ADJUSTED FOR MATERIALS HAVING A DIFFERENT OPEN AREA/GROSS AREA RATIO (R VALUE)
4. STRUCTURAL DESIGN OF TRASH RACKS SHALL BE BASED ON FULL HYDROSTATIC HEAD WITH ZERO HEAD DOWNSTREAM OF THE RACK.

OVERFLOW TRASH RACKS:

1. ALL TRASH RACKS SHALL BE MOUNTED USING STAINLESS STEEL HARDWARE AND PROVIDED WITH HINGED AND LOCKABLE OR BOLTABLE ACCESS PANELS.
2. TRASH RACKS SHALL BE STAINLESS STEEL, ALUMINUM, OR STEEL. STEEL TRASH RACKS SHALL BE HOT DIP GALVANIZED AND MAY BE HOT POWDER COATED AFTER GALVANIZING.
3. TRASH RACKS SHALL BE DESIGNED SUCH THAT THE DIAGONAL DIMENSION OF EACH OPENING IS SMALLER THAN THE DIAMETER OF THE OUTLET PIPE.
4. STRUCTURAL DESIGN OF TRASH RACKS SHALL BE BASED ON FULL HYDROSTATIC HEAD WITH ZERO HEAD DOWNSTREAM OF THE RACK.

Figure OS-4. Orifice Plate and Trash Rack

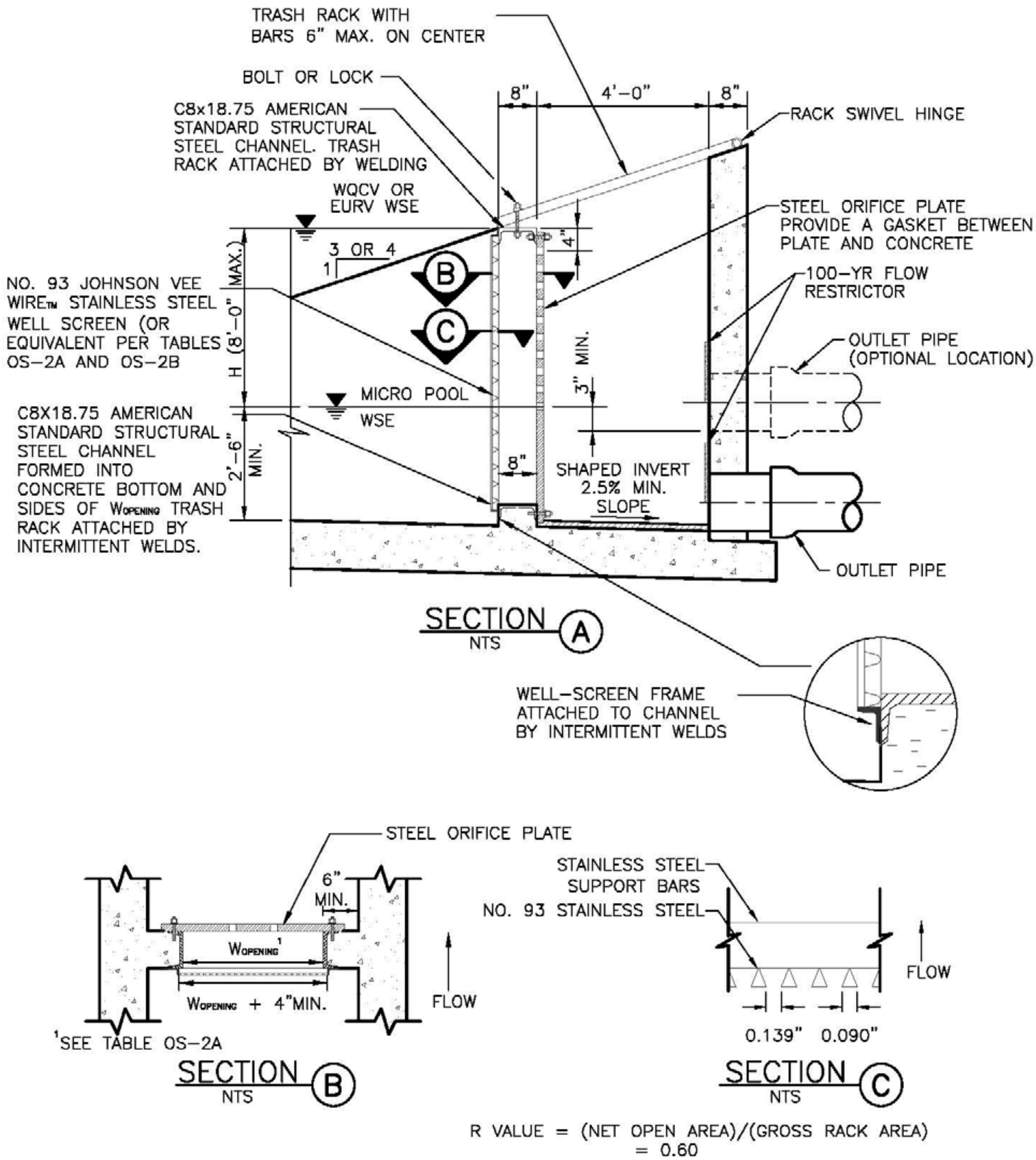


Figure OS-5. Typical Outlet Structure with Circular Orifice Plate

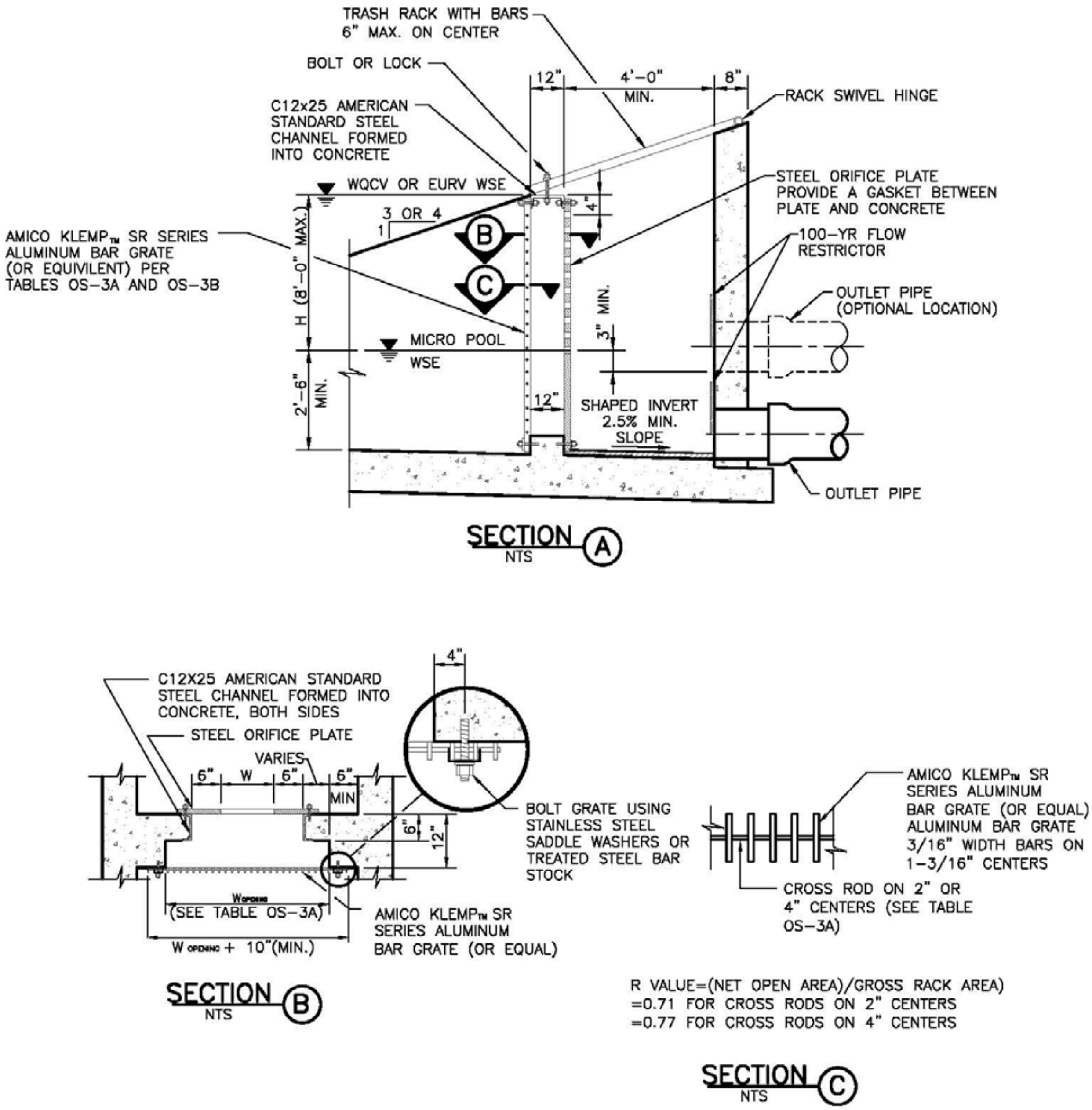


Figure OS-6. Typical Outlet Structure with Rectangular Orifice Plate

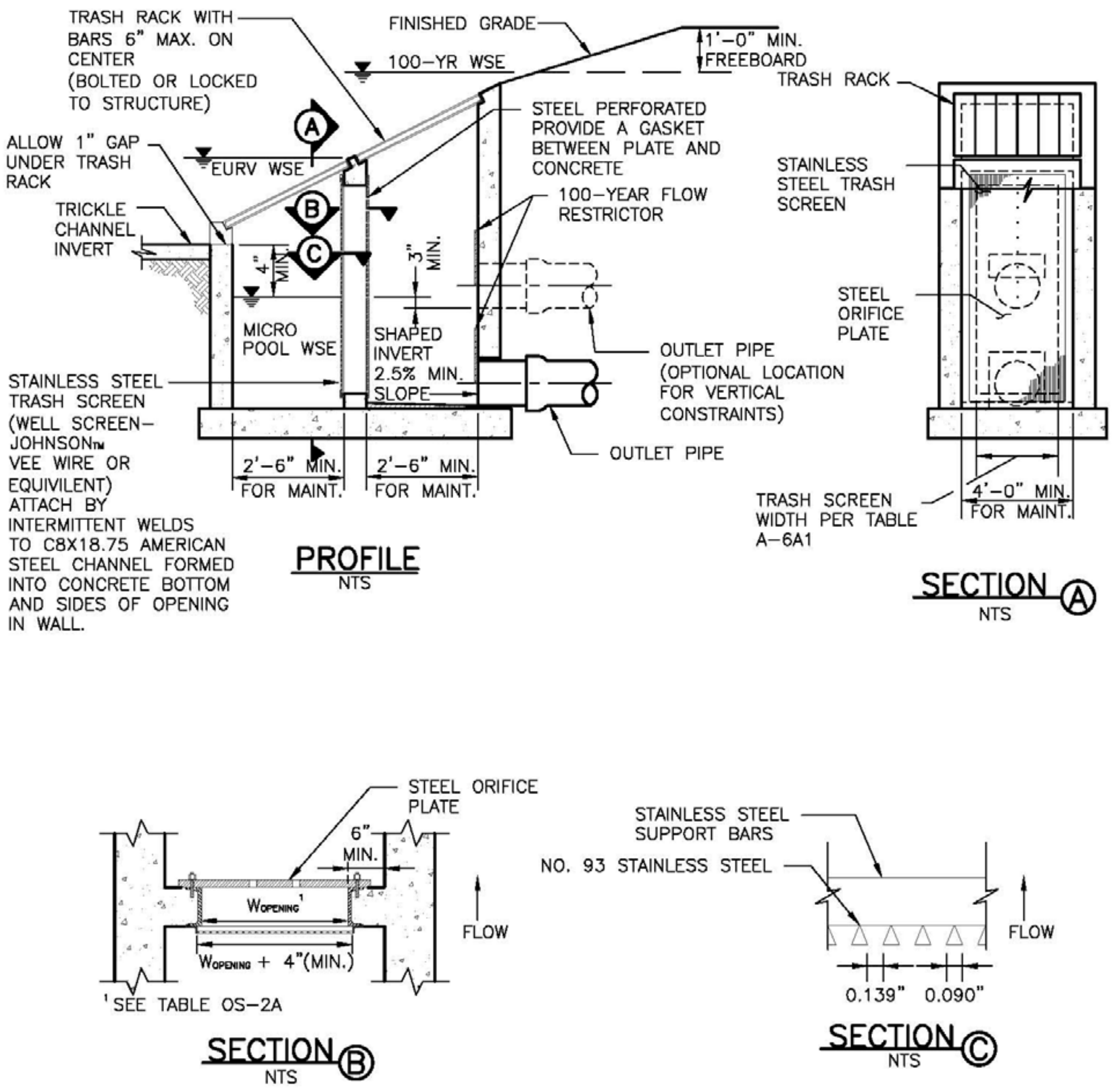


Figure OS-7. Full Spectrum Detention Outlet Structure for 5-acre Impervious Area or Less

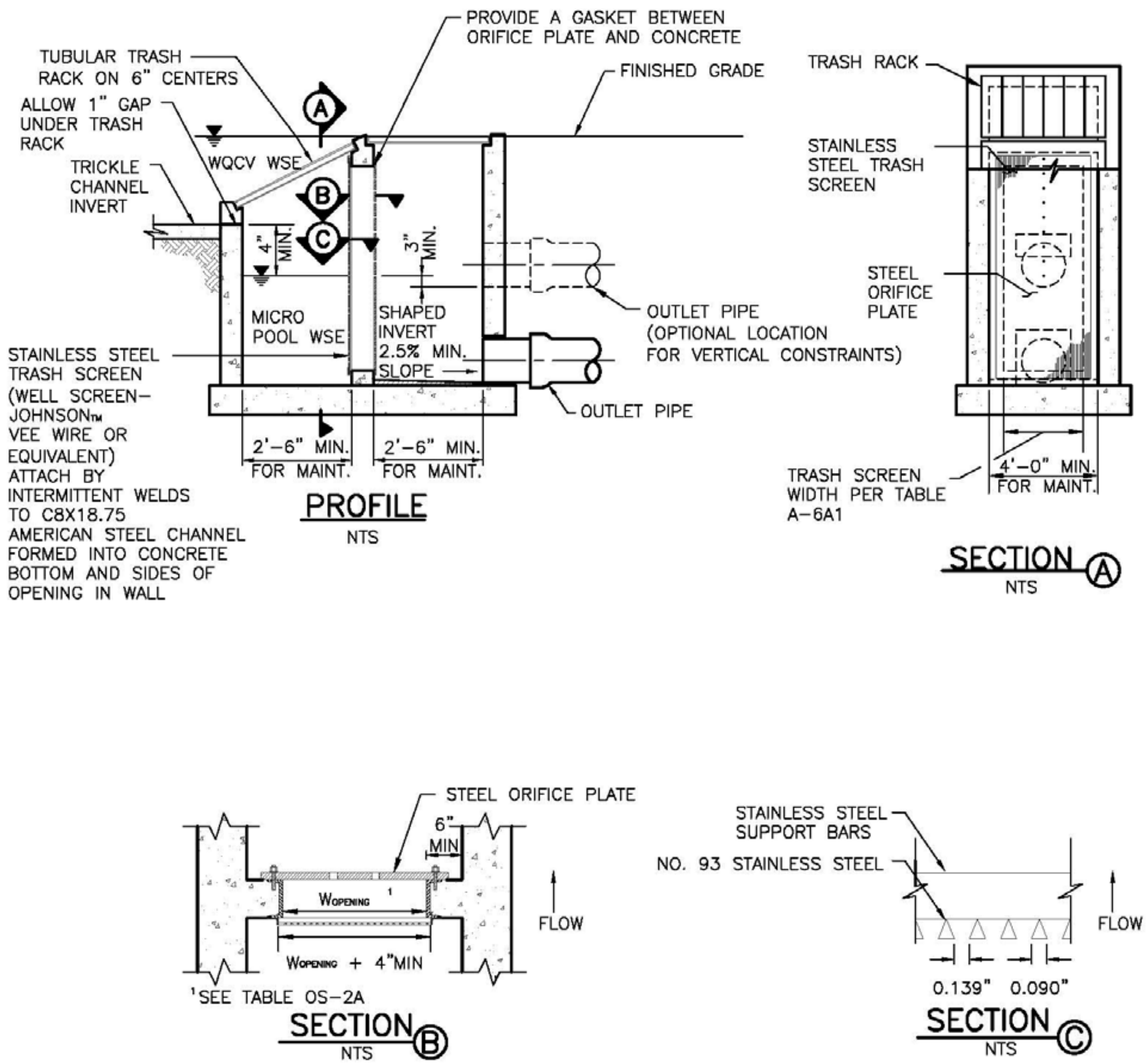


Figure OS-8. WQCV Outlet Structure for 5-acre Impervious Area or Less