CHAPTER 8

STORMWATER BEST MANAGEMENT PRACTICES

27 January 2014

Chapter Eight - Stormwater Best Management Practices

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8.1 Overview

8.1.1 Purpose

Chapter 8 of the Drainage Criteria Manual is designed to provide guidance for engineers, planners, landscape architects, developers, and Municipal Separate Storm Sewer System (MS4) permit holders in selecting, designing, maintaining, constructing and installing Best Management Practices (BMPs) to manage water quality and quantity impacts from stormwater runoff. This chapter focuses on smaller, more frequently occurring precipitation events that have the greatest overall impact on the quality of receiving waters.

The purpose of this chapter is to provide criteria to prevent and manage stormwater pollution and to diminish adverse impacts to health, safety, property and the general welfare of the citizens of the City of Lincoln.

8.1.2 Clean Water Act Requirements

The Federal Water Pollution Control Act of 1972, as amended (33 U.S.C. 1251 et seq.) is commonly known as the Clean Water Act and establishes minimum stormwater management requirements for urbanized areas in the United States. At the federal level, the EPA is responsible for administering and enforcing the requirements of the Clean Water Act. Section 402(p) of the Clean Water Act requires urban and industrial stormwater be controlled through the National Pollutant Discharge Elimination System (NPDES) permit program. Requirements affect both construction and post-construction phases of development. As a result, urban areas must meet requirements of MS4 permits, and many industries and institutions must also meet NPDES stormwater permit requirements. MS4 permittees are required to develop a Stormwater Management Program that includes measurable goals and to implement needed stormwater management controls (i.e. BMPs). MS4 permittees are also required to assess controls and the effectiveness of their stormwater programs and to reduce the discharge of pollutants to the “maximum extent practicable”.

Although it is not the case for every state, the EPA has delegated Clean Water Act authority to the State of Nebraska. The State must meet the minimum requirements of the federal program. The state rules and regulations are promulgated under the Nebraska Environmental Protection Act, as amended (Neb. Rev. Stat. §81-1501 et seq).

8.1.3 Introduction

The physical and chemical characteristics of stormwater runoff change as urbanization occurs, requiring comprehensive planning and management to reduce adverse effects on receiving waters. As stormwater flows across roads, rooftops, and other hard surfaces, pollutants are picked up and then discharged to streams and lakes. Additionally, the increased frequency, flow rate, duration, and volume of stormwater discharges due to urbanization can result in the scouring of rivers and streams, degrading the physical integrity of aquatic habitats, stream function, and overall water quality (EPA 2009). This chapter provides information fundamental to effective stormwater quality management and planning, including:
- An overview of the potential adverse impacts of urban stormwater runoff
- A summary of key regulatory requirements for stormwater management in Lincoln. These regulations set the minimum requirements for stormwater quality management. It is essential that

those involved with stormwater management understand the requirements that shape stormwater management decisions at the construction and post-construction stages of development and redevelopment.

It is highly recommended that engineers and planners begin the development process with a clear understanding of the seriousness of stormwater quality management from regulatory and environmental perspectives, and implement a holistic planning process that incorporates water quality upfront in the overall site development process.

8.1.4 Urban Stormwater Characteristics

Numerous studies conducted since the late 1970s show stormwater runoff from urban and industrial areas can be a significant source of pollution. Stormwater impacts can occur during both the construction and post-construction phases of development. As a result, federal, state, and local regulations have been promulgated to address stormwater quality. Although historical focus of stormwater management was either flooding or chemical water quality, more recently, the hydrologic and hydraulic (physical) changes in watersheds associated with urbanization are recognized as significant contributors to receiving water degradation. Whereas only a few runoff events per year may occur prior to development, many runoff events per year may occur after urbanization. In the absence of controls, runoff peaks and volumes increase due to urbanization. This increased runoff is environmentally harmful, causing erosion in receiving streams and generating greater pollutant loading downstream. Urban characteristics (e.g. imperviousness, BMPs, drainage infrastructure, time of concentration) and Watershed characteristics (drainage network, geology, slope, soils, climate) are some of the physical factors associated with stormwater runoff and the subsequent response of receiving waters (e.g. pollutant loads, channel morphology changes, riparian and aquatic conditions, connectivity, flooding).

With regard to chemical water quality, Table 8.1 identifies a variety of pollutant types and sources often found in urban settings such as solids, nutrients, pathogens, dissolved oxygen demands, metals, and oils. Several national data sources are available characterizing the chemical quality of urban runoff.

Table 8.1

Pollution Source	Source Explanation	Pollutants						
		Solids	Nutrients	Pathogens	Dissolved Oxygen Demands	Metals	Oils	Synthetic Organics
Wildlife and Pet Waste	Pet waste (typically from dogs and cats) may contribute significantly if waste is not properly disposed. Bird droppings into the streams and creeks often occur at bridges and other structures where birds nest and perch. Other wildlife (such as raccoons, squirrels, etc.) live in most watersheds and their waste is a source of pollution.	X	X	X	X			
Fertilizers	Improper storage and disposal of fertilizers, over application, or incidental application to impervious surfaces (e.g. driveways and sidewalks) can lead to excess nutrients in stormwater runoff. Excess nutrients often contribute to algal blooms.		X	X	X			
Soil Erosion and Construction Site Runoff	Sediment entering a stream through natural processes or erosion from construction sites can decrease the biological function of the water and be detrimental to aquatic habitat. In addition, sediment can 'pick up' nutrients such as nitrogen and phosphorus, and carry them downstream in the waterbody. This can create an incubation zone for bacteria growth.	X	X		X	X		
Gravel/Sand	Gravel and sand, primarily applied in the winter to provide better traction on urban streets, typically gets flushed off parking areas and streets after rain events if it is not removed manually by a sweeper truck or other method.	X						
Vehicle fuel and fluids	Pollution from vehicles includes oil, grease, metals and fuel. Maintenance facilities, streets and parking lots typically drain directly to urban storm sewer system where pollutants drain to streams.	X			X	X	X	X
Industrial Processes and Household Chemicals Sources	Industrial processes can intentionally or unintentionally contribute point source pollution to waterbodies. Household chemicals, including paint and preservatives can also contribute to the degradation of water quality. In some cases heavy metals or other pollutants can come from unkown sources such as contaminated soil.	X	X		X	X	X	X

As part of the Clean Water Act - Section 303, the EPA and subsequently the Nebraska Department of Environmental Quality (NDEQ) are charged with reporting on the quality of water in its jurisdiction. NDEQ summarizes the water quality information for the streams, rivers and lakes within the State. For each water body, the water is sampled and compared against corresponding water quality standards based on the intended use. The Clean Water Act requires that a stream, river, or lake be placed on the 303(d) impaired waters list if it fails to meet the water quality criteria. In Lincoln, most of the major urbanized streams and channels have been declared impaired, meaning the water does not meet the thresholds established for their intended use (e.g. recreation, aquatic life).

For purposes of this manual, the most recent local data is from the July 2012 Antelope Creek Watershed Basin Management Plan. Antelope Creek from Holmes Lake to its confluence at Salt Creek, near Bob Devaney Sports Center, is one of the 303(d) impaired waters listed in Lincoln mainly due to the high levels of Escherichia coli (E. coli) measured in the creek. In 2007, NDEQ calculated the TMDL of E. coli and set a reduction goal as 113 colony forming units per 100 milliliters (cfu/100mL). The sampling and research completed for the Plan in 2010-2011 indicated the concentration of E. coli at the confluence with Salt Creek was 1,511 cfu/100mL, therefore a 93% reduction in the E. coli pollutant load is needed to meet the level set by NDEQ.

The sources of pollution can be 'point' sources such as an industrial plant discharging into a creek, or 'non-point' sources such as pet waste, fertilizers, pesticides, etc. Pollution sources often contain, carry, or create, a variety of specific pollutants. As sources contribute pollutants to the streams and lakes, water bodies can become impaired. The primary pollutants of concern for Lincoln are Total Suspended Solids (TSS), E. Coli and nutrients such as phosphorous (typically from fertilizers). Other pollutants and causes for impairments include heavy metals, pesticides, oil, high pH, and temperature.

8.1.5 Structural and Nonstructural Best Management Practices (BMPs)

To reduce the concentrations and the loads of pollutants reaching receiving waters, a system of stormwater BMPs must be implemented. BMPs are defined as measures that function to either keep pollutants from entering stormwater or remove pollutants from stormwater. Various BMPs have been implemented throughout the United States. In general, they can be categorized as either structural or nonstructural. Structural BMPs can be thought of as constructed facilities designed to reduce runoff and/or passively treat urban stormwater runoff before it enters the receiving waters. Nonstructural BMPs consist of pollution prevention BMPs and source control BMPs.

The selection of the most appropriate BMPs for a given site or basin is largely dependent on whether development is in place or has yet to occur. In areas with existing development, nonstructural BMPs are the most cost-effective because retrofitting structural controls in a developed area can be costly. Structural controls are more appropriate for new development and significant redevelopment, where they have been integrated into the planning of the infrastructure.

Because non-point source pollution is varied in nature and impact, no individual BMP may fit all situations. It must be tailored to fit the needs of particular sources and circumstances. An effective strategy for minimizing stormwater pollution loads is to use multiple BMPs (structural, nonstructural, and source controls). Multiple BMPs and combining BMPs in series can provide complementary water quality enhancement that minimizes pollutant loads being transported to the receiving waters.

8.1.6 General Planning and Design Guidelines

The following general planning and design guidelines for structural and nonstructural controls are recommended when developing a water quality control strategy:

- Promote natural infiltration of urban runoff by minimizing onsite impervious areas and preserving natural, broad drainageways.

- Minimize directly connected impervious areas by providing grassed buffer zones between impervious surfaces. Divert runoff from impervious areas to pervious surfaces before the flows enter surface drainageways.
- Locate structural BMPs in areas that avoid creating a nuisance and the need for increased maintenance.
- Provide multiple accesses to facilities to improve maintenance capabilities.
- Revegetate and/or stabilize all areas disturbed by construction activities and all drainageways created as a part of a development.
- Ensure the plantings (e.g. grass) are established before the initial owner's obligation is released and maintenance efforts begin.
- Select the appropriate option for the control objectives, specific conditions at the site, proper implementation and maintenance for the most successful Best Management Practice.

8.1.7 Ownership and Maintenance of Best Management Practices

BMP facilities proposed in a development or redevelopment, along with all inlet and outlet structures and/or channels, are to be owned and maintained by the developer or a property-owners' association unless a different ownership/maintenance arrangement has been approved by the Director of Public Works and Utilities. Structural BMPs are a critical part of the storm drainage system and shall remain functional as Structural BMP facilities permanently. Provisions shall be made in the approval of developments or redevelopments by the Planning Commission and City Council for the permanence of the Structural BMP facilities and ongoing maintenance of Structural BMP facilities.

8.1.8 References

Some of the information contained in Chapter 8 is referenced from Denver's Urban Storm Drainage Criteria Manual, Volume 3 with the latest revision date of June 2012. Specific performance data can be found at the International Stormwater BMP Database website at www.bmpdatabase.org.

8.2 Design Criteria

8.2.1 General Criteria

Management of frequent rainfall events for water quality may be concentrated in a single facility or distributed throughout an entire development or redevelopment project. However flows must be managed at every discharge point from a development or redevelopment project. The usefulness and effectiveness of any water quality facility depends on the amount of storage, its location within the system and its operational characteristics. An analysis of such water quality facilities shall include designing the facilities to manage the Water Quality Control Volume at each discharge point from the contributing drainage area. In addition to the Water Quality Control Volume, flows in excess of the Water Quality Control Volume design flow that might be expected to pass through the water quality facility shall be included in the analysis. The design criteria for water quality facilities shall include the following list:

- Water Quality Control Volume
- Release rate
- Storage volume
- Infiltration
- Grading and depth requirements
- Safety considerations and landscaping
- Outlet works and location
- Downstream impact
- Operations and maintenance guidelines

8.2.2 New Development Standard Criteria

For new development sites that are one acre or greater, at a minimum, the Water Quality Control Volume shall be based on the percentile rainfall event specified in the Lincoln Municipal Code (Section 28.03) measured at every discharge point within the development. The Water Quality Control Volume shall be calculated by the use of Equation 8.1 and the corresponding rainfall amount from Table 8.2. Methods other than Equation 8.1 may be used if approved by the Director of Public Works and Utilities.

8.2.3 Redevelopment Standard Criteria

For redevelopment sites that are one acre or greater, at a minimum, the Water Quality Control Volume shall be based on the percentile rainfall event specified in the Lincoln Municipal Code (Section 28.03) measured at every discharge point within the development. The Water Quality Control Volume shall be calculated by the use of Equation 8.1 and the corresponding rainfall amount from Table 8.2. Methods other than Equation 8.1 may be used if approved by the Director of Public Works and Utilities.

Table 8.2

Percentile	Rainfall, inches
70%	0.62
75%	0.70
80%	0.83
85%	0.97
90%	1.25
95%	1.65

The Water Quality Control Volume (WQCV) shall be expressed as:

$$\mathbf{WQCV = P \times (0.05 + 0.009 \times I) \times A \times 1/12} \qquad \mathbf{(8.1)}$$

Where: WQCV = Water Quality Control Volume in acre feet
P = relevant storm event in inches
I = percent impervious of contributing drainage area (note: some standard average percent impervious areas can be found in Table 2-8 from Chapter 2 of the Drainage Criteria Manual)
A= contributing drainage area in acres

Example 1: The Water Quality Control Volume for a 100 acre residential new development with 38 percent impervious area would be calculated as follows:

WQCV = 1.25 inches x (0.05 + 0.009 x 38) x 100 acres x 1 ft/12 inches = 4.08 acre feet

Example 2: The Water Quality Control Volume for a 10 acre commercial redevelopment with 85 percent impervious area would be calculated as follows:

WQCV = 0.83 inches x (0.05 + 0.009 x 85) x 10 acres x 1 ft/12 inches = 0.56 acre feet

8.2.4 Release Rates

The Water Quality Control Volume is to be temporarily held and then released over a 24 to 40 hour period. For facilities that combine water quality control with flood control, the runoff from the design storms for the flood control criteria shall be 'stacked' on top of the Water Quality Control Volume. These types of facilities may be required to have multi stage control structures to control runoff from the Water Quality Control Volume as well as the flood control design storms.

For Structural BMPs that are designed for subsurface storage (e.g. pervious pavements, bioretention, rain gardens, etc) the subsurface storage must hold the Water Quality Control Volume and infiltrate into the underlying soil as is practical.

8.2.5 Water Quality Control Volume Form

The Water Quality Control Volume form must be completed to verify the Structural BMP is able to detain the Water Quality Control Volume with the proper release rate. Appendix 8.1 provides a copy of the form.

8.2.6 Storage Volume

Storage volume of Structural BMP facilities shall be adequate to hold the Water Quality Control Volume. Proper implementation of site erosion and sediment measures is necessary to prevent clogging and failure of Structural BMPs. Phasing is also critical as Structural BMPs should typically be the last infrastructure constructed. For facilities that combine water quality control with flood control or that are not subsurface, both the flood control volume and water quality volume shall all be drained from the facility within 72 hours. For facilities that function just for water quality control and are not subsurface the Water Quality Control Volume will be stored for a duration between 24 and 40 hours (for retention ponds and subsurface Structural BMPs the Water Quality Control Volume will be stored for a duration between 12 and 40 hours).

8.2.7 Infiltration

The construction of Structural BMP facilities that require infiltration will have adequate infiltration to drain the Structural BMP within the specified time periods (e.g. 12 to 24 hours for subsurface type Structural BMPs). Most soils in the Lincoln, NE consist of 'D' soils that are clayey and have relative low infiltration rates in the order of less than 0.6 inches/hour. Also in Lincoln there are some more silty loam type 'B' soils that have higher infiltration rates in the order of 0.6 to 2.0 inches/hour. Infiltration tests shall be ran to determine the local infiltration rates if infiltration is a critical part of the Structural BMP facility. An underdrain is needed for subsurface type Structural BMPs if the infiltration rate is inadequate of if infiltration is not desired.

8.2.8 Grading and Depth Requirements

The construction of Structural BMP facilities can require excavation to obtain sufficient storage volume. Non-subsurface storage embankments must be vegetated, have side slopes no steeper than 4:1 (horizontal to vertical), an embankment top width no narrower than 14 feet, and a traversable vehicular access for maintenance purposes that shall be provided from public right-of-way.

Other considerations when setting depths include flood elevation requirements, public safety, land availability, land value, present and future land use, water table fluctuations, soil characteristics, maintenance requirements and required freeboard. BMPs for new developments shall be designed so the lowest opening of adjacent new buildings is a minimum of one foot above the calculated 100-year flood elevation. Aesthetically pleasing features are also important in urbanizing areas.

The bottoms of non-subsurface Structural BMP facilities shall have a slope with a minimum of 2% everywhere towards the outlet to allow drainage and to prevent standing water. Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff.

If water is retained permanently as part of the design of the Structural BMP facility then the facility shall be conducive to establishment of wetland and open water habitats. Site-specific criteria relating to such things as depth, habitat, and bottom and shoreline geometry shall be selected to encourage establishment of desired habitat. Where wetland habitat is desired, vegetative and geometric conditions shall be provided to minimize the propagation of undesired vegetation. Plant and wildlife experts should be contacted for site specific guidance. If the facility provides open water conditions, a depth sufficient to discourage growth of vegetation, except along the shoreline, (without creating undue potential for anaerobic bottom conditions) shall be provided. A depth of 5 to 10 feet is generally reasonable unless fishery requirements dictate otherwise. Aeration may be required in permanent pools to prevent anaerobic conditions. The maximum depth of permanent storage facilities will be determined by site conditions, design constraints, safety, and environmental needs.

8.2.9 Outlet Works

Outlet works selected for Structural BMP facilities must be able to accomplish the design functions of the facility unless adequate supporting documentation is provided to the satisfaction of the Public Works Department. Discharge must be released in a non-erosive manner. Outlet works can be combinations of drop inlets, pipes, weirs, orifices, chutes, and channels. Slotted riser pipes are discouraged because of clogging problems. Outlet works must function without requiring attendance.

8.2.10 Location and Downstream Analysis

Structural BMP facilities shall be located and designed to not cause flooding and nuisance impacts to downstream properties. An analysis is required for the downstream receiving stream or waterbody to ensure that there is a proper outlet to the Structural BMP.

8.3 Structural Best Management Practice Descriptions

This Section provides information regarding the applicability, pollutant removal efficiencies, advantages, disadvantages, maintenance considerations and design considerations that can be used in the City's jurisdiction. Other structural BMPs not listed may be applicable for use also in the City's jurisdiction. Some of the information presented for the listed structural BMPs is from Denver's Urban Drainage Criteria Manual, which is a useful reference for further information. Pollutant Removal Effectiveness is based on data from the International Stormwater BMP Database.

The structural BMPs covered in this chapter include:

- Bioretention (rain garden, biocell, bioswale, etc)
- Constructed Wetland
- Extended Detention Basin
- Green Roof
- Permeable Pavement (Permeable Interlocking Concrete Pavement, Concrete Grid Pavement, Porous Concrete, Pervious Gravel, Reinforced Grass Pavement).
- Retention Pond
- Underground BMP

8.3.1 Bioretention (also Rain garden, Porous Landscape Detention)

8.3.1.1 Description

A BMP that utilizes bioretention is an engineered, depressed landscape area designed to capture and filter or infiltrate the Water Quality Control Volume. BMPs that utilize bioretention are frequently referred to as rain gardens, biocells, bioswale, etc. 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*.

Bioretention BMPs require 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.

8.3.1.2 Pollutant Removal Effectiveness

Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Moderate

8.3.1.3 Benefits

- Bioretention uses multiple treatment processes to remove pollutants, including sedimentation, filtering, adsorption, evapotranspiration, and biological uptake of constituents.

- 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.

8.3.1.4 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.
- In developing, or otherwise erosive, watersheds, high sediment loads can clog the facility.
- Pre treatment is required for drainage areas with high sediment yields.

8.3.1.5 Site Selection

Bioretention can be provided in a variety of areas within new developments, or as a retrofit within an existing site. Bioretention allows the Water Quality Control Volume to be treated within areas designated for landscape. 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 lots, street medians, landscape areas between the road and sidewalk, planter boxes that collect roof drains or within residential lots.

Bioretention requires a stable watershed. Retrofit applications are typically successful for this reason. If the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils, then consider another BMP or provide pretreatment before runoff from these areas reaches the rain garden. The bottom 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 many 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 is lined with an essentially impermeable geomembrane liner designed to restrict seepage and includes an underdrain designed to divert water away from adjacent structures.

8.3.1.6 Designing for Maintenance

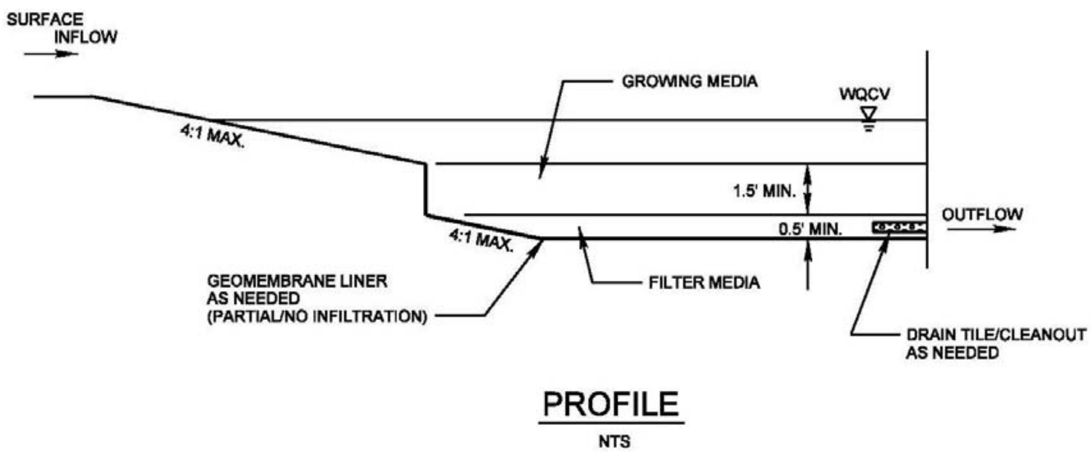
Recommended maintenance practices for all BMPs are described in Section 8.4 of this chapter. During a rain garden design, the following should be considered to ensure ease of maintenance over the long-term:

- 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. Wood mulch should be double shredded hardwood mulch as it is less likely to float. Depending upon the type of mulch used and the configuration of the outlet there may be some floating of wood mulch, which may settle unevenly or be transported downstream.
- 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 drainage area to the site is larger than two impervious acres, prone to debris or the use of sand for ice control, consider a small forebay to capture debris and sand.
- 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.

8.3.1.7 Design Procedure and Criteria

The following steps outline the design procedure and criteria, with Figure 8.1 providing a corresponding typical cross-section.

FIGURE 8.1 BIORETENTION



Bioretention - Cross Section

1. Basin Storage Volume: Provide a storage volume

Find the required Water Quality Control Volume. Using the percent imperviousness and area of the tributary area, use Equation 8.1 to determine the Water Quality Control Volume in acre feet.

Calculate the design volume as follows:

V = WQCV x 43,560 square feet/Acre **(8.2)**

Where: V = Design Volume in cubic feet
WQCV = Water Quality Control Volume in acre feet (see Equation 8.1)

2. Basin Geometry: The bottom surface of the rain garden should be flat. Sediment will reside on the bottom surface of the rain garden; therefore, if the bottom area is too small, it may clog prematurely. Increasing the bottom surface area will reduce clogging and decrease the frequency of maintenance. Use side slopes of the basin as necessary to achieve the required volume. Sideslopes should be no steeper than 4:1 (horizontal:vertical).

3. Growing Medium: Provide a minimum of 18 inches of growing medium to enable establishment of the roots of vegetation. Growing medium shall be well mixed and uncompacted 50% sand and 50% compost. 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. 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, or especially clayey soils.

4. Underdrain System: Underdrains are often necessary and should be provided if infiltration tests show percolation drawdown rates slower than the rate needed to drain the Water Quality Control Volume within 40 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.

When using an underdrain system, provide a control orifice sized to drain the design volume in 24 hours (preferable) to 40 hours (see Equations 8-3 and 8-4). Use a minimum orifice size of 3/8 inch to avoid clogging. This will provide detention and slow release of the Water Quality Control Volume, 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 ensure that the pipe was not crushed or disconnected during construction.

Calculate the diameter of the orifice for a 24-hour drain time using Equations 8-3 and 8-4. Methods other than Equations 8.3 and 8.4 may be used if approved by the Director of Public Works and Utilities. Equation 8.3 is a derivation of the orifice equation ($Q = \text{Coef} \times A \times (2gh)^{0.5}$)

$$\mathbf{A = (V/86{,}400)/(0.6 \times (64.4 \times H/2)^{0.5})} \qquad \textbf{(8.3)}$$

Where: A = Area of orifice in square feet
V = Design Volume in cubic feet (see Equation 8.2)
86,400 = seconds in 24 hours*
64.4 = 2 times the acceleration of gravity (32.2 ft/sec^2)
H = Head from orifice in feet, measured from the center of orifice to the maximum water surface. In cases where the tailwater is higher than the center of the opening, the head is calculated as the difference in water surface elevations.

* Note: As the maximum drain time is 40 hours, Equation 8.3 can be revised using 144,000 seconds for a maximum drain time of 40 hours instead of 86,400 seconds (24 hour drain time)

$$\mathbf{D = 24 \times (A/\pi)^{0.5}} \qquad \textbf{(8.4)}$$

Where D = Diameter of Orifice in inches
A = Area of orifice in square feet (see Equation 8.3)

The underdrain system should be placed within a 6-inch-thick section of filter material meeting the gradation in Table 8.3. Use slotted pipe that meets the slot dimensions provided in Table 8.4.

Table 8.3

Sieve Size	Mass percent passing square mesh sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 um (No. 50)	10-30

150 um (No. 100)	0 – 10
75um (No. 200)	0-3

Table 8.4*

Pipe Diameter	Slot Length	Maximum Slot Width	Slot Centers	Open Area (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

* Note: Some variation of these values is acceptable and is expected from various pipe manufacturers. Increased slot length and decreased slot centers will increase outflow hydraulics but be detrimental to the structural integrity of the pipe.

5. Impermeable Geomembrane Liner and Geotextile Separator Fabric: For bottom surfaces or side slopes where no infiltration is desired, install a 30 mil (minimum) PVC geomembrane liner. Provide at least 9 inches (12 inches if possible) of cover over the membrane where it is attached to a 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 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. 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.

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. Equations 8-3 and 8-4 are simplified equations for sizing an orifice plate for a 24-hour drain time.

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 Water Quality Control Volume. 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.

7. Vegetation: It is recommended that the filter area be vegetated with drought tolerant species that thrive in sandy soils. It is suggested to use a seed mix that will not need to be irrigated after the vegetation 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. 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.

8. Irrigation**:** Provide spray irrigation at or above the Water Quality Control Volume 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 can be damaged during maintenance operations.

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

8.3.1.8 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 a minimum grade of 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).

5. Provide the Water Quality Control Volume in rain gardens that direct excess flow to a landscaped area designed to receive 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 significant flooding events and the Water Quality Control Volume. (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.

8.3.1.9 Design Aesthetics

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 (reflective design) or become distinct features within their surroundings. Guidelines for each approach are provided below:

- 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.
- 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 "fit" 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 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.

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 creates 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.

8.3.1.10 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, can be 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 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. Quality Assurance/Quality Control 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.

8.3.2 Constructed Wetland Pond

8.3.2.1 Description

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.

Regulations intended to protect natural wetlands may 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.

8.3.2.2 Pollutant Removal Effectiveness

Sediment/Solids	Very Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor

8.3.2.3 Benefits

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

8.3.2.4 Limitations

- Requires a dependable supply of water and a legal availability 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 in the water leaving the pond.

8.3.2.5 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 Control Volume. 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.

8.3.2.6 Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 8.4 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.

8.3.2.7 Design Procedure and Criteria

The following steps outline the design procedure for a constructed wetland pond (see Figure 8.2):

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. 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. When constructed

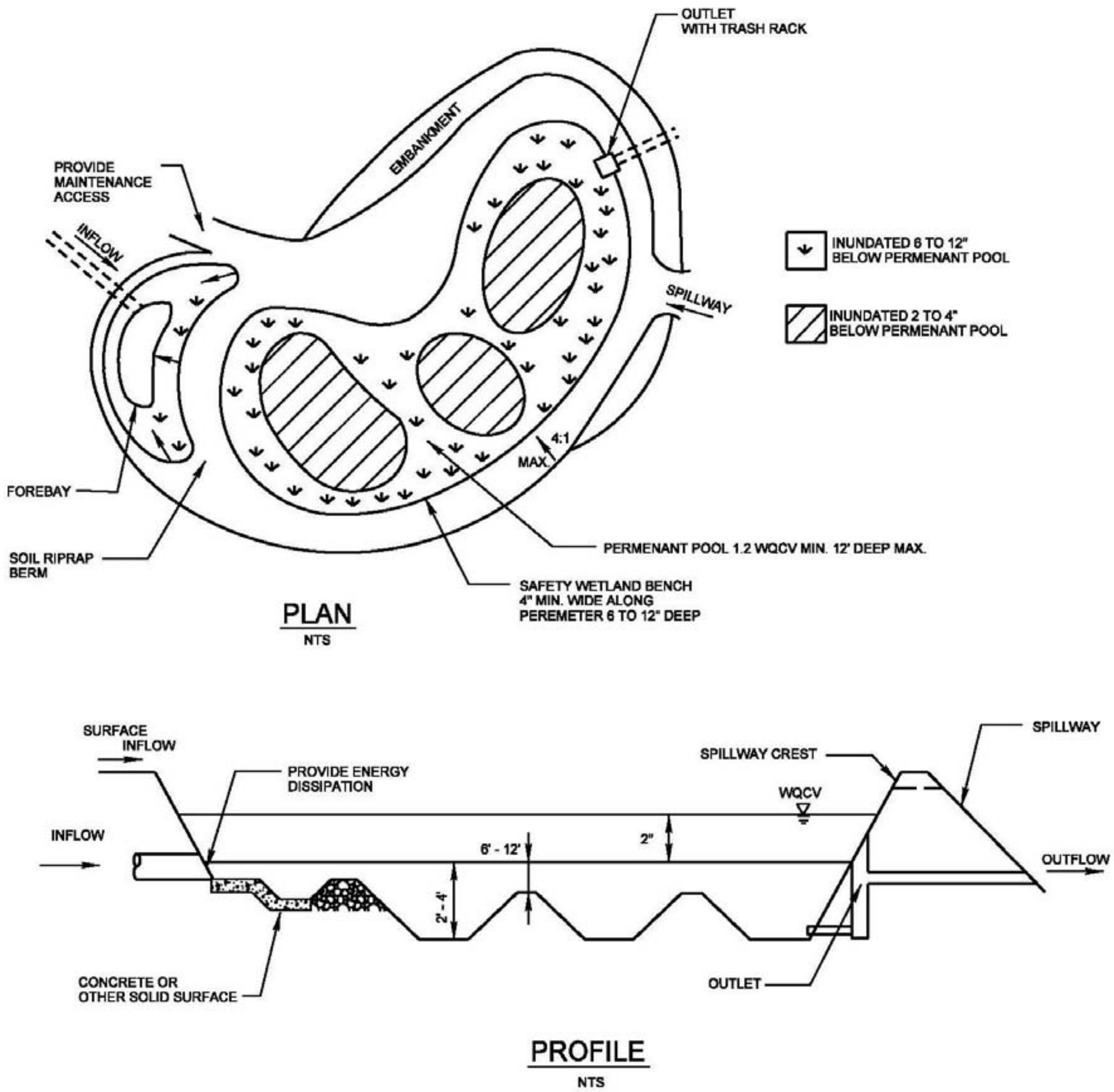
wetland ponds are placed above the groundwater elevation, a pond liner is recommended unless evaluation by a geotechnical engineer determines this to be unnecessary.

2. Surcharge Volume: Provide a surcharge storage volume based on a 24-hour to 40 hour drain time
- Determine the imperviousness of the watershed (or effective imperviousness where LID elements are used upstream).
- Find the required storage volume:
- Calculate the design volume (surcharge volume above the permanent pool) using Equation 8.2.

3. Depth of Surcharge*:* 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 of 3:1 or over. It may be necessary to modify the inlet and outlet point through the use of pipes, swales, or channels to accomplish this.

FIGURE 8.2 CONSTRUCTED WETLAND



Constructed Wetland - Plan and Cross Section

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 shown below:

Volume of the permanent pool:

$$\mathbf{V_p \geq 1.2 \times (WQCV)} \qquad \textbf{(8.5)}$$

Where: V_p = permanent pool volume (acre feet)
WQCV = Water Quality Control Volume in acre/feet

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

- 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 (a third to a half of this zone should be 6 inches deep)
- See Item 13 below for permanent pool levels during vegetation establishment

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..

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 to 48 hour period. Use Equations 8.3 and 8.4 for sizing the outlet.

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.

11. Overflow Embankment: Design the embankment not to fail during the 100-year storm. If the embankment falls under the jurisdiction of the Nebraska Department of Natural Resources, it should be designed to meet their requirements. 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. An underdrain at the perimeter of the pond with a valved connection to the outlet structure is 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%.

8.3.3 Extended Detention Basin

8.3.3.1 Description

An extended detention basin 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 extended detention basin uses a much smaller outlet that extends the emptying time of the more frequently occurring runoff events to facilitate pollutant removal. The extended detention basin’s 24 to 40-hour drain time for the Water Quality Control Volume is recommended to remove a significant portion of total suspended solids. 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 detention for more major storm events. In this case, the extended detention basin is sized also for major storm events (2, 10 and 100-year) peak flow reduction. The major storm events drain time is designed to be drained within 72 hours (see Section 6.4.3 of the Drainage Criteria Manual). Widespread use of detention ponds for both the Water Quality Control Volume and major storm events is anticipated to reduce impacts on major drainage ways by reducing post-development peak discharges to better resemble pre-development peaks. Refer to the Chapter 6 – Storage Facilities of the Drainage Criteria Manual for additional information on detaining major storm events.

8.3.3.2 Pollutant Removal Effectiveness

Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Moderate
Bacteria	Poor

8.3.3.3 Benefits

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

8.3.3.4 Limitations

- Ponding time and depths may generate safety concerns.
- Best suited for tributary areas of 5 impervious acres or more. Extended detetention basins 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.

8.3.3.5 Site Selection

Extended detention basins 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.
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.

8.3.3.6 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 for extended detention basins:

- Provide a micropool.
- Provide a design slope of at least 2% 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.
- Provide adequate initial surcharge volume for frequent inundation.
- 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 extended detention basin 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 outlet control. 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 Water Quality Control Volume over approximately 24 hours. Measuring the actual baseflow can be helpful in determining if and when the orifice place should be replaced.

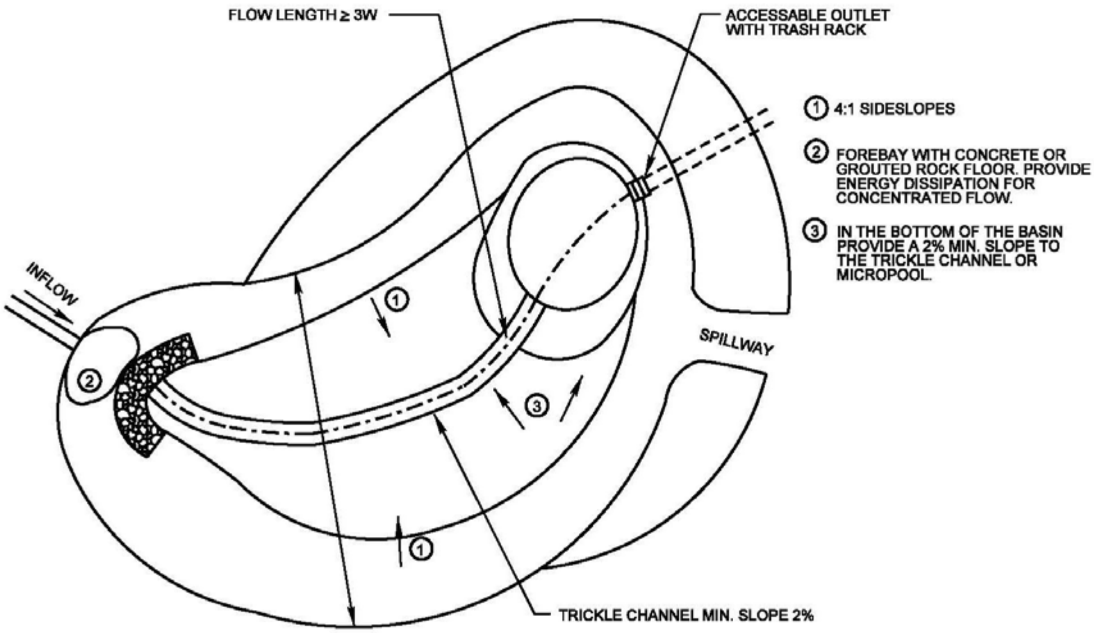
Note: Extended detention basins providing combined water quality and flood control functions can serve multiple uses such as playing fields or picnic areas. These uses are best located at higher elevation within the basin, above the Water Quality Control Volume pool level.

8.3.3.7 Design Procedure and Criteria

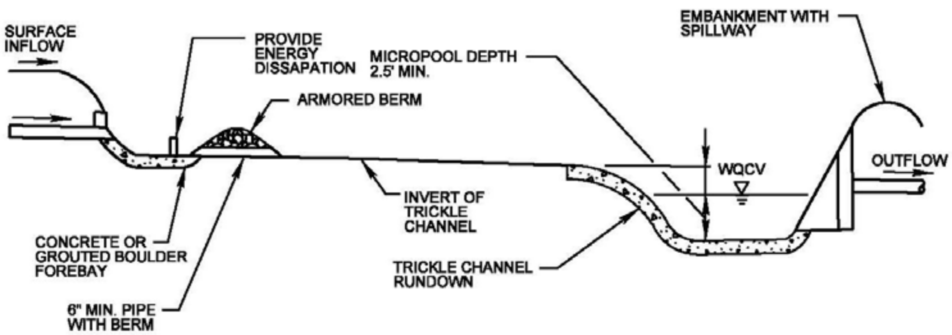
The following steps outline the design procedure and criteria for an extended detention basin with Figure 8.3 providing a corresponding plan view and cross-section:

1. Basin Storage Volume:
- Determine the imperviousness of the watershed.
- Find the required Water Quality Control Volume. Using the imperviousness of the tributary area, use Equation 8.1 to determine the Water Quality Control Volume in acre feet.
- Calculate the design volume using Equation 8.2.

FIGURE 8.3 EXTENDED DETENTION BASIN



PLAN
NTS



PROFILE
NTS

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 3:1. A longer flow path from inlet to outlet will minimize short circuiting and improve reduction of total suspended solids. 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. 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 using 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 Water Quality Control Volume. 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. Design the forebay with a volume of 3% of the Water Quality Control Volume. Also 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 (soil combined with 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 extended detention basin. 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: Concrete trickle channels are not recommended but if used can 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.
- Non Concrete 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. It is recommended that soft bottom trickle channels be designed with a consistent longitudinal slope from forebay to

micropool and that they not meander with a minimum slope of 2%. 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.

Note: Riprap and soil riprap lined trickle channels are not recommended.

7. Micropool and Outlet Structure: Locate the outlet structure in the embankment of the extended detention basin 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).

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. 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. The outlet should be designed to release the Water Quality Control Volume over a 24 to 40-hour period. This can be done through an orifice plate as detailed in Section 8.3.1.7 (Item 4). Also can use reservoir routing calculations as discussed in the Chapter 6 of the Drainage Criteria Manual or other methods if approved by the Director of Public Works and Utilities.

8. Additional Guidelines for Incorporating Flood Control: When designing for flood control for the major storm events as well as the Water Quality Control Volume, the outlet is typically designed to drain in 72 hours. However, the designer may want to modify the design (reduce the 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 Water Quality Control Volume over a period of at least 24 hours.

The velocity of flows into the outlet 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:

$$\mathbf{Vel = Q_{100}/A \leq 2} \qquad \textbf{(8.6)}$$

Where: Vel = 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. Either configuration should be recessed into the embankment to minimize its profile. Additionally, the trash rack should be sloped with the basin side-slopes.

9. 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).

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 Water Quality Control Volume. The initial surcharge volume is considered a part of the water Quality Control Volume and does not need to be provided in addition to the Water Quality Control Volume. It is recommended that this area be shown on the grading plan or in a profile for the extended detention basin. When baseflows are anticipated, it is recommended that the initial surcharge volume be increased.

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

- 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 extended detention basin. This will reduce baseflows and help preserve storage for the Water Quality Control Volume.
- 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.

11. 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 Chapter 6.15 of the Drainage Criteria Manual for information on trash rack design guidance.

12. Overflow Embankment: Design the embankment to withstand the 100-year storm at a minimum. If the embankment falls under the jurisdiction of the Nebraska Department of Natural Resources, it must be designed to meet the State's requirements. 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 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 Chapter 6 of the Drainage Criteria Manual. Buried soil riprap or reinforced

turf mats installed per manufacturer's recommendations can provide an attractive and less expensive alternative to concrete.

13. 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 extended detention basin can become buried with sediment over time.

14. 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. Grades 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%.

8.3.3.8 Aesthetic Design

Since all land owners and managers wish to use land in the most efficient manner possible, it is important that extended detention basins become part of a multi-use system. This encourages the design of extended detention basins as an aesthetic part of a naturalized environment or to include passive and/or active open space. Within each scenario, the extended detention 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 an extended detention basin.

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 extended detention basin 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 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 non concrete trickle channel as appropriate.

- 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.

8.3.4 Green Roof

8.3.4.1 Description

Green Roofs can 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.

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.

The design of a green roof involves many disciplines in addition to stormwater engineers, including structural engineers, architects, landscape architects, horticulturists, and others. This Section is intended only to provide an overview of green roof information relative to stormwater quality and quantity management that is applicable to Lincoln.

As Low Impact Development 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. There are some green roofs in Nebraska and research is on-going regarding the best design approach. Plant selection, growing medium, and supplemental irrigation requirements are key considerations for which design criteria continue to evolve.

8.3.4.2 Pollutant Removal Effectiveness

Unknown at this time

8.3.4.3 Benefits

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

8.3.4.4 Limitations

- Limited experience in Nebraska.
- Initial installation costs are typically 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.

8.3.4.5 Site Selection

Green roofs can be installed on commercial or residential buildings as well as on underground structures such as a parking garage. 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.

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.

8.3.4.6 Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Section 8.4 of this Chapter. 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 medium, 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.

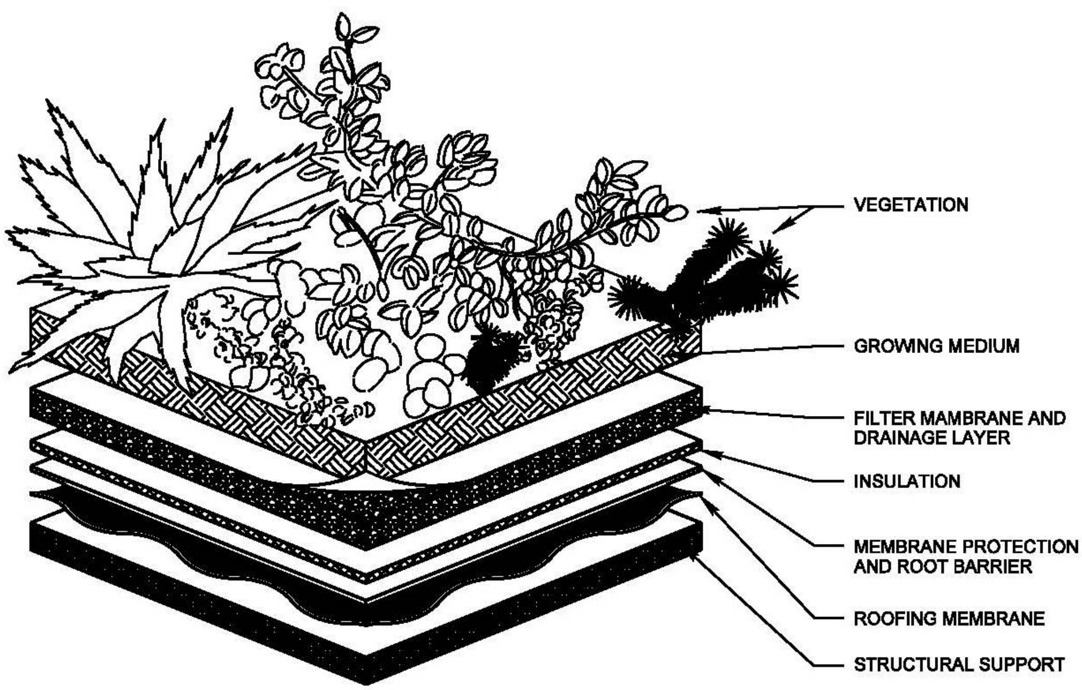
8.3.4.7 Design Procedure and Criteria

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 8.4, 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 may require supplemental irrigation.

FIGURE 8.4 PERMEABLE PAVEMENT SYSTEMS



Typical Green Roof Cross Section

1. Providing Stormwater Treatment and Slow Release: Green roof vegetation benefits from stormwater detained in the growing medium and the volume the system detains should be recognized when designing for the Water Quality Control Volume.

From research it appears the green roof retains and evapotranspires a significant portion of relative small rain events 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, green roofs are recognized as being able to capture the Water Quality Control Volume for the area of the green roof, without constructing a controlled release at the outlet. This is for roofs that meet or exceed modular systems using trays that allow for 4 inches of growing medium. An intensive roof should also be considered to capture the Water Quality Control Volume.

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 Water Quality Control Volume for an area in excess of the area of the green roof.

Calculate the design volume using Equation 8.2.

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 (see Section 8.3.1.7, Item 4). 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.

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.

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." Some extensive green roof substrates are made up of significant lightweight aggregate. However, lightweight aggregates have some limitations. These materials typically drain very quickly and leave little water or nutrients available to plants.. 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 can range from rolled sedum mats to hand-planted buffalograss plugs.

7. Plant Selection: 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). Note: CAM is common in sedums (stonecrops) where plant stomata are closed during the day to conserve water.

8. Irrigation: Irrigation is needed for successful green roofs. 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. Non-succulents appear to 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.

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

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.

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.

8.3.4.8 Additional Design Guidance

Until more experience is gained in Nebraska with regard to green roofs, the following design guidance documents may provide additional assistance; with the understanding that the guidelines may need adjustment for Lincoln'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 Nebraksa.
- 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.

Other codes:

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. 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.

8.3.4.9 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.

8.3.5 Permeable Pavement

8.3.5.1 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 Control Volume, 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 Water Quality Control Volume.

8.3.5.2 Pollutant Removal Effectiveness

Sediments/Solids	Very Good
Nutrients	Good
Total Metals	Good
Bacteria	Unknown

8.3.5.3 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.

8.3.5.4 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.
- Runoff flow into permeable pavement can cause clogging.

8.3.5.5 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 necessary to ensure infiltration from the pavement section does not enter the groundwater..

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 pavement 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 permeable pavement adjacent to structures and conventional 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.

8.3.5.6 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 contractor 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 onsite.
- Include an observation well to monitor the drain time of the pavement system over time. This will assist with determining the required maintenance needs.
- Call for a 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.

8.3.5.7 Design Procedures and Criteria

Note: This manual includes a variety of specific pavements, which are discussed and distinguished in supplemental Sections (Sections 8.3.5.11 to 8.3.5.15). This Section outlines the design procedure and other design components and considerations that are common to all of the systems. Review of the supplemental Sections 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. A cross-section of a typical permeable pavement is shown in Figure 8.5.

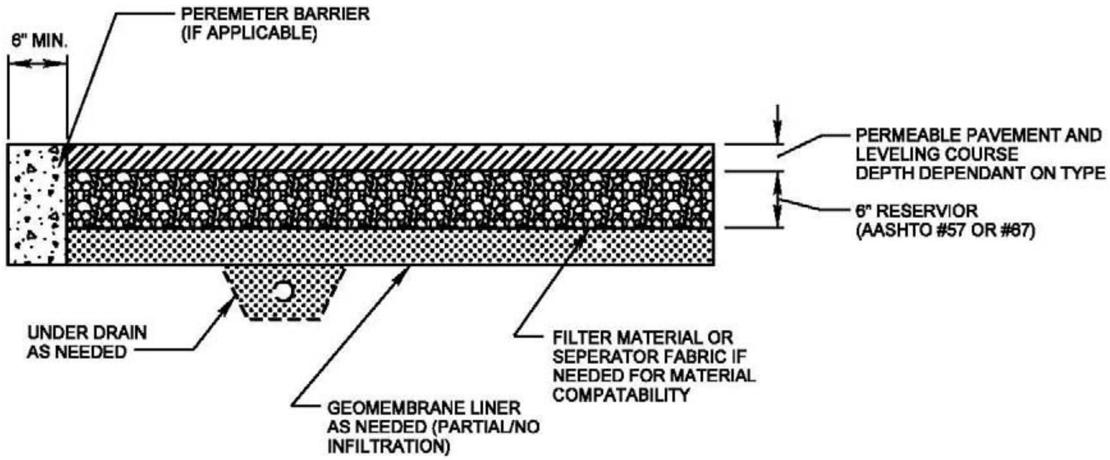
No-Infiltration Section: This section includes an underdrain and an impermeable liner that prevents infiltration of stormwater into the subgrade soils. Consider using this section when any of the following conditions exist:

- 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. It is recommended that the minimum infiltration rate of the subgrade by two times the rate needed to drain the Water Quality Control Volume over 24 hours.

FIGURE 8.5 PERMEABLE PAVEMENT SYSTEMS



Permeable Pavement Section

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 for large sites, 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); swellconsolidation (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 for large sites 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 Water Quality Control Volume based on a 24-hour drain time.
- Find the required Water Quality Control Volume (watershed inches of runoff).

- Calculate the design volume using Equation 8.2.

Add flood control volume if desired. When designing for flood control volumes, provide an overflow that will convey runoff in excess of the Water Quality Control Volume directly into the area designed for the flood control volume (i.e. reservoir). A gravel strip or inlet that is connected to the reservoir can provide this overflow.

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. Calculate available storage using Equation 8.7 for a flat subgrade installation. This equation allows for one inch of freeboard. Flat installations are preferred as the design spreads infiltration evenly over the subgrade.

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):

$$\mathbf{Vr = Por \times ((D-1)/12) \times Ap} \qquad \mathbf{(8.7)}$$

Where: Vr = volume available in the reservoir (cubic feet)
Por = porosity, 0.3 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 (inches)
Ap = area of the permeable pavement (square feet)

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. Also include a separator fabric between the geomembrane and all aggregate materials. 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 Permeable Interlocking Concrete Pavement 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.

No-Infiltration Section: 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 based. Vinyl adhesive can be used when the need for an impermeable liner is less critical. 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. 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.

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.

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 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 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 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. 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.

8. Outlet: The portion of the Water Quality Control Volume in each cell should be slowly released to drain in approximately 24 hours. An orifice at the outlet of the underdrain can be used for each cell to provide detention and slow release of the Water Quality Control Volume 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.

For calculating the diameter of the orifice for a 24-hour drain time (Use a minimum orifice size of 3/8 inch to avoid clogging) use Equations 8.3 and 8.4.

8.3.5.8 Additional Design Considerations

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 overcompaction 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 overcompacting 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.

8.3.5.9 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.

8.3.5.10 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 Sections 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 nondestructive 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.

8.3.5.11 Permeable Interlocking Concrete Pavement

Use a herring bone pattern 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.

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.

Designing for Maintenance
Recommended ongoing maintenance practices for all BMPs are provided in Chapter 8.4 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term.

- The outer edge of any vehicular Permeable Interlocking Concrete Pavement 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 or soldier course 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.
- 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).
- Specify a herringbone pattern for areas intended for vehicular traffic. This provides greater structural support.

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. Markings can be incorporated into the pavement without cutting paver blocks.

8.3.5.12 Concrete Grid Pavement

Description
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.

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.

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.

Designing for Maintenance
Recommended ongoing maintenance practices for all BMPs are provided in Chapter 8.4 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term:
- A concrete perimeter is recommended for this pavement. This will reduce movement and grinding between blocks.

8.3.5.13 Porous Concrete

Description
Pervious concrete is one of several different types of permeable pavement systems contained within this Chapter. 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 significant voids and infiltration rates on the order of 100 inches per hour or more.

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.
- Quality control during installation is critical to the success of the pavement.

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.

Designing for Maintenance
Recommended ongoing maintenance practices for all BMPs are provided in Chapter 8.4 of this manual. During design, the following should be considered to ensure ease of maintenance over the long-term.

- 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.

Construction Considerations
This Section highlights important components of a successful installation. 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.
- 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. 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 cut into cured concrete to allow for expansion. Care must be taken to vacuum saw slurry and fill the joints with the appropriate product. Provide expansion material at all isolation/construction joints.
- Weather restrictions dictate that pervious concrete should only be placed between April 1 and November 1 or 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 may be 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.

8.3.5.14 Porous Gravel

Description
Porous gravel is one of several different types of permeable pavement systems contained within this chapter. 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.

Benefits
Low cost compared to other permeable pavements

Limitations
- Not ADA compliant
- Ruts without stabilization

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.

Designing for Maintenance
Recommended ongoing maintenance practices for all BMPs are provided in Chapter 8.4 of this manual.

- 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.

8.3.5.15 Reinforced Grass

Note: This permeable pavement system differs from others discussed in this manual. Rather than a pavement system designed to capture the Water Quality Control Volume, it is offered for the uses described within this Section.

Description
Reinforced grass is one of several different types of permeable pavement systems contained within this chapter. 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.

Benefits
Reduces the heat island effect.

Limitations

- May require irrigation
- Not recommended when frequency of use exceeds two to three uses per parking stall per week

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.

Designing for Maintenance
Recommended ongoing maintenance practices for all BMPs are provided in Chapter 8.4. During design, the following should be considered to ensure ease of maintenance over the long-term.

- 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.

Selection Considerations
The most common 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.

8.3.6. Retention Pond

8.3.6.1 Description

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 Control Volume 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. 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 for both the Water Quality Control Volume and the flood control volume.

8.3.6.2 Pollutant Removal Efficiency

Sediments/Solids	Very Good
Nutrients	Moderate
Total Metals	Moderate
Bacteria	Moderate

8.3.6.3 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.

8.3.6.4 Limitations

- Safety concerns associated with open water.
- Requires both physical supply of water and availability 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 can increase water temperature.

8.3.6.5 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. 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 Water Quality Control Volume.

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.

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.

8.3.6.6 Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Section 8.4 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.

8.3.6.7 Design Procedure and Criteria

The following steps outline the retention pond design procedure and criteria, and Figure 8.6 shows a typical configuration.

1. Baseflow: Unless the permanent pool is established 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. 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. 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.
- Calculate the design volume using Equation 8.2.

3. Basin Shape: Always maximize the distance between the inlet and the outlet. A basin length to width ratio of 3:1 or greater 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 sedimentation.

Volume of the permanent pool:

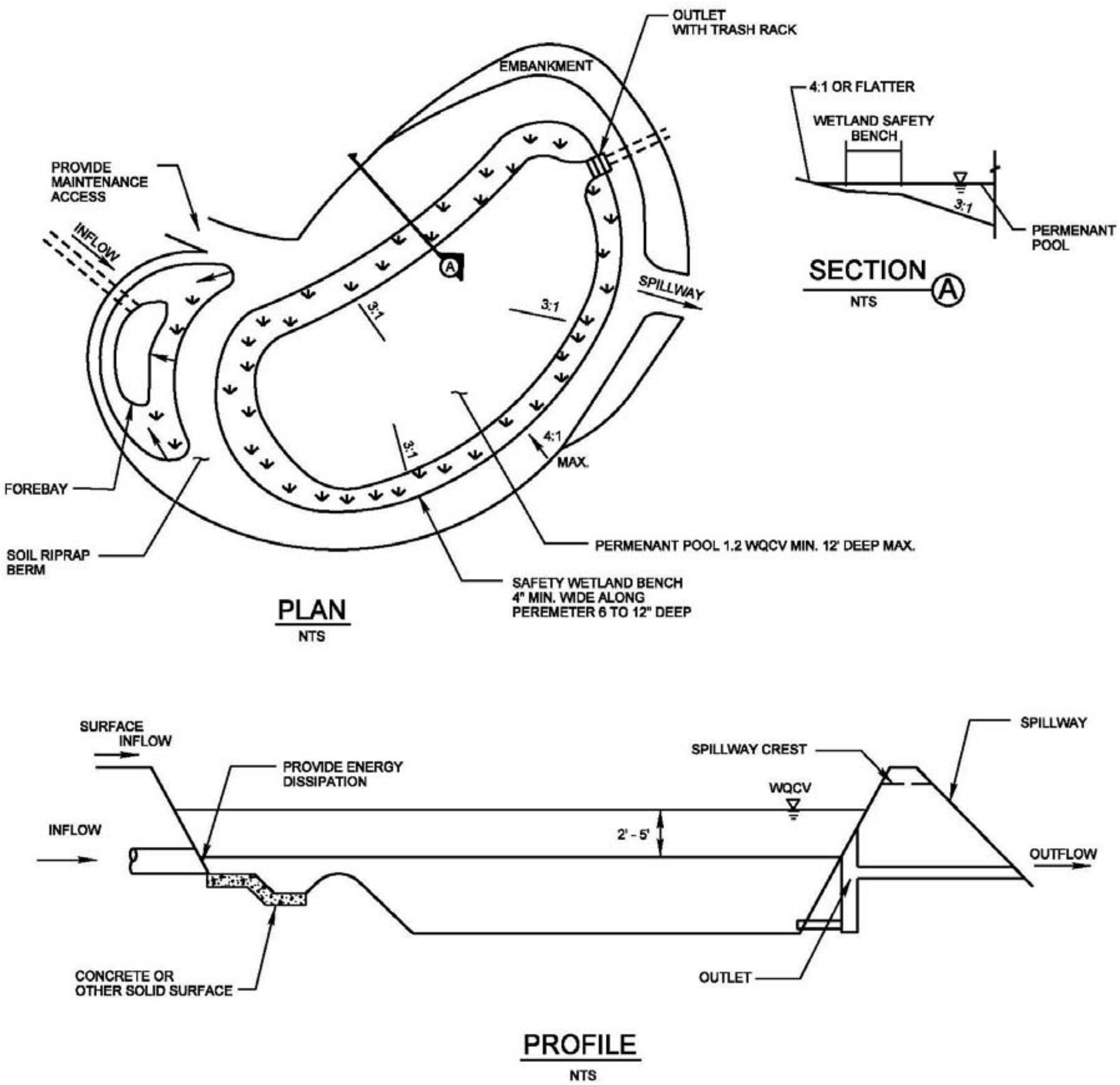
$$\mathbf{V_p \geq 1.2 \ x\ (WQCV)} \qquad \mathbf{(8.8)}$$

Where: V_p = permanent pool volume (acre feet)
WQCV = Water Quality Control Volume (acre feet)

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 of nutrients. 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.

FIGURE 8.6 RETENTION POND



Retention Pond - Plan and Cross Section

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 reaches the pond bottom.

6. Inlet: Dissipate energy at the inlet to limit erosion and to diffuse the inflow plume per Chapter 7 of the Drainage Criteria Manual.

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 Water Quality Control Volume. 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 orifice should be designed to release the Water Quality Control Volume over a 12-hour period using Equations 8.9 and 8.10.

$$\mathbf{A = (V/43{,}200)/(0.6 \times (64.4{*}H/2)^{0.5})} \qquad \textbf{(8.9)}$$

Where: A = Area of orifice in square feet
V = Design Volume in cubic feet (see Equation 8.2)
43,200 = seconds in 12 hours
64.4 = 2 times the acceleration of gravity (32.2 ft/sec^2)
H = Head from orifice in feet, measured from the center of orifice to the maximum water surface. In cases where the tailwater is higher than the center of the opening, the head is calculated as the difference in water surface elevations.

$$\mathbf{D = 24 \times (A/\pi)^{0.5}} \qquad \textbf{(8.10)}$$

Where D = Diameter of Orifice in inches
A = Area of orifice in square feet (see Equation 8.9)

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.

10. Overflow Embankment: Design the embankment not to fail during the 100-year storm. If the embankment falls under the jurisdiction of the Nebraska Department of Natural Resources, it shall be designed to meet their requirements. 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. Stable access to the bottom, forebay, and outlet works area should be provided 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. Vegetation around the perimeter of an open water body can discourage frequent use of the pond by geese.

13. Access: 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%.

8.3.6.8 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.

8.3.6.9 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.
- 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.
- 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.
- 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.

8.3.7 Underground BMPs

8.3.7.1 Description

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. Some underground BMPs combine multiple unit processes to act as a treatment train.

This Section has been added 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 Water Quality Control Volume 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.

8.3.7.2 Pollutant Removal Efficiency

Sediments/Solids	Variable
Nutrients	Variable
Total Metals	Variable
Bacteria	Variable

8.3.7.3 Benefits

- Underground BMPs may be designed to provide pre-treatment and/or Water Quality Control Volume 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.
- Underground BMPs can be combined with rain harvesting for reuse of stormwater.

8.3.7.4 Limitations

- Inspection and maintenance may require traffic control, confined space entry, and specialized equipment.
- Devices that do not provide Water Quality Control Volume do not qualify for stand alone 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.

8.3.7.5 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 in the maintenance plan as part of the water quality BMP. When BMP maintenance records are required by the MS4 permit holder, pump system maintenance records should also be included.

- Access: Access for maintenance equipment must be provided to the site to perform maintenance. As the size of the underground system increases, so must the number of access points.

- 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. 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. Some types of underground BMPs, such as catch basin inserts, have the potential to clog and cause flooding if not frequently maintained.

8.3.7.6 Designing for Maintenance

All underground BMPs must be sized so that routine maintenance is minimal. Inlet inserts 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.

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. The maintenance plan should identify all confined spaces 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 are to be included as part of the maintenance plan.

8.3.7.7 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, treatment and slow release of the Water Quality Control Volume 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 Water Quality Control Volume 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 Water Quality Control Volume and empty it over a time period of 12 to 24 hours. Not all of the surface-based BMPs that provide the Water Quality Control Volume 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.

A common underground BMP in the midwest 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 should be provided with a volume equivalent to 10% of the Water Quality Control Volume. 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 can 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 Water Quality Control Volume 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 Water Quality Control Volume 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.

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 stand alone 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 BMPs.

8.3.7.8 Construction Considerations

Improper installation will cause poor performance of proprietary underground BMPs. 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.

8.4 BMP Maintenance

8.4.1 Introduction

In order for stormwater BMPs to be effective, proper maintenance is essential. Maintenance includes both routinely scheduled activities, as well as non-routine repairs that may be required after large storms, or as a result of other unforeseen problems. BMP maintenance is the responsibility of the entity owning the BMP; however, the City per the National Pollutant Discharge Elimination System Permit (i.e. stormwater permit) is responsible for ensuring the maintenance of privately owned BMPs

BMPs should be designed with maintenance as a key design consideration. Planning-level design guidance pertaining to maintenance is included in the individual BMP information contained within this manual. This chapter focuses on maintenance of in-service BMPs and provides recommendations for private BMP owners, as well as City responsibilities for ensuring proper maintenance for both public and private facilities.

8.4.2 Defining Maintenance responsibility for Public and Private Facilities

Identifying who is responsible for maintenance of BMPs and ensuring that an adequate budget is allocated for maintenance is critical to the long-term success of BMPs. Maintenance responsibility may be assigned in different ways:

- Publicly owned BMPs are maintained by the City.
- Privately owned BMPs typically are maintained by the property owner, homeowner’s association, property manager or private company hired by them.
- Privately owned BMPs may be maintained by the City under a written agreement with the owner, with appropriate fees a maintenance permit.

For public facilities, one of the key issues is ensuring that adequate staff and budget are provided to the department responsible for maintenance. Ponds, lakes, and wetland BMPs should be built only if assurances are provided that adequate maintenance staff and resources are identified in advance.

For private facilities, such as those owned and maintained by homeowners' associations, there can be a lack of understanding of maintenance required for BMPs. Maintenance plans should be prepared and submitted as part of the development review/approval process and be provided to the owner(s) upon sale of the development. It is also important to educate the general public on the purpose and function of stormwater BMPs. This is critical in cases where Low Impact Development (LID) or landscape-based BMPs are distributed throughout multiple parcels in developments. In addition to legally binding maintenance agreements, it is also helpful to have easy-to-understand informational brochures and signage that describe the functions and maintenance requirements for these facilities.

Privately owned BMPs may be maintained by the City through a maintenance permit. Appendix 8.2 provides an example maintenance permit. Typical annual costs for a maintenance permit are approximately $150/year for City inspection plus approximately 5% of the construction cost annually for maintenance.

8.4.3 Developing a Maintenance Plan

A maintenance plan can be prepared as a stand-alone document, or be made part of a construction plan set. An example maintenance plan is attached in Appendix 8.3. The following outlines key components of a maintenance plan:

1. A simple drawing or construction plan of the site development showing the locations of all stormwater quality BMPs at the site and key components such as forebays, inlets, outlets, low flow channels or other components that require inspections or maintenance. The drawing should be kept on-site at the property or the property management office. Any changes to the facility over time should be noted on the drawing.

2. A brief description of the maintenance requirements and expected frequency of actions, which can be obtained from discussion within this chapter. Include instruction on how to access each component of each BMP and with what equipment. It is important to identify all maintenance requirements related directly to the water quality functions of the BMP and provide information concerning future site work that could potentially impact the integrity of the BMP. This is particularly true for landscaped BMPs.

Additionally, the maintenance plans should identify constraints and considerations for future work that have the potential to affect the performance of the BMP.

3. An inspection form or checklist specific to the facilitie(s) in place at the site. A log of inspection forms should be kept onsite or at the property management office to demonstrate that routine inspections and maintenance are occurring.

Appendices 8.2 through 8.8 provide maintenance inspection forms for each of the BMPs in this Chapter.

4. Contact information for the entity responsible for maintenance of the facility. For example, this could be a homeowner's association, municipality, or other entity.

5. Copies of legally binding agreements associated with the facility that show that the facility owner is aware of, and will abide by, their maintenance responsibilities.

6. Other items as appropriate for specific conditions, which may include any of the following:

- A permanent control point and other critical elevations for ponds, (i.e. bottom of pond, 100-year Water Surface Elevation, overflow, etc).
- The estimated baseflow used for the design and other hydrologic information for larger watersheds.
- Information pertaining to materials testing for any contaminant testing requirements for removed sediment.
- Post-maintenance considerations, (e.g. restoration of flow paths).
- Long-term monitoring requirements, (e.g. 404 permit reports).

It is also important to note that the guidelines included in this manual should always be combined with common sense and good judgment based on field observations and practical experience. Often, there will be maintenance requirements that are specific to a given site in addition to the general maintenance guidance provided in this manual.

On a general note with regard to BMPs that have a vegetation component or involve weed and pest control, it is strongly advocated to use Integrated Pest Management (IPM) practices that help to reduce the level of chemical applications.

Although water quality monitoring is not typically required as part of maintenance agreements, it is encouraged as an effective tool for determining if the BMP is functioning effectively. Stormwater quality monitoring guidelines can be downloaded from the International Stormwater BMP Database website (www.bmpdatabase.org).

8.4.4 Bioretention Maintenance

The primary maintenance objective for bioretention, also known as porous landscape detention, is to keep vegetation healthy, remove sediment and trash, and ensure that the facility is draining properly. The growing medium may need to be replaced eventually to maintain performance. This Section summarizes key maintenance considerations for bioretention.

Inspection
Inspect the infiltrating surface at least annually and following major precipitation events to determine if the bioretention area is providing acceptable infiltration. Bioretention facilities are designed with a maximum depth for the Water Quality Control Volume of one foot and soils that will typically drain the Water Quality Control Volume over approximately 24 hours. If standing water persists for more than 40 hours after runoff has ceased, clogging should be further investigated and remedied. Additionally, check for erosion and repair as necessary (See Appendix 8.4 for sample Inspection Form).

Debris and Litter Removal
Remove debris and litter from the infiltrating surface to minimize clogging of the media. Remove debris and litter from the overflow structure.

Mowing and Plant Care
- All vegetation: Maintain healthy, weed-free vegetation. Weeds should be removed before they flower. The frequency of weeding will depend on the planting scheme and cover. When the growing media is covered with mulch or densely vegetated, less frequent weeding will be required.

- Grasses: When started from seed, allow time for germination and establishment of grass prior to mowing. If mowing is required during this period for weed control, it should be accomplished with hand-held string trimmers to minimize disturbance to the seedbed. After vegetation is established, mow as desired or as needed for weed control. Remove cut vegetation from the BMP and dispose of properly. Following this period, mowing of native/drought tolerant grasses may stop or be reduced to maintain a length of no less than 6 inches. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter. See Section 4.4 for additional guidance on mowing.

Irrigation Scheduling and Maintenance
Adjust irrigation throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, while more irrigation is needed during the peak summer months. Native grasses and other drought tolerant plantings should not typically require routine irrigation after establishment, except during prolonged dry periods.

Check for broken sprinkler heads and repair them, as needed. Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

Replacement of Wood Mulch
Replace wood mulch only when needed to maintain a mulch depth of up to approximately 3 inches. Excess mulch will reduce the volume available for storage of stormwater.

Sediment Removal and Growing Media Replacement
If ponded water is observed in a bioretention cell more than 40 hours after the end of a runoff event, check underdrain outfall locations and clean-outs for blockages. Maintenance activities to restore infiltration capacity of bioretention facilities will vary with the degree and nature of the clogging. If clogging is primarily related to sediment accumulation on the filter surface, infiltration may be improved by removing excess accumulated sediment and scarifying the surface of the filter with a rake. If the clogging is due to migration of sediments deeper into the pore spaces of the media, removal and replacement of all or a portion of the media may be required. The frequency of media replacement will depend on site-specific pollutant loading characteristics. Although surface clogging of the media is expected over time, established root systems promote infiltration. This means that mature vegetation that covers the filter surface should increase the life span of the growing media, serving to promote infiltration even as the media surface clogs.

8.4.5 Constructed Wetland Maintenance

Inspection
Inspect the pond at least annually. Note the amount of sediment in any forebays and look for debris at the outlet structure (See Appendix 8.5 for sample Inspection Form).

Debris and Litter Removal
Remove debris and litter from the pond as needed. This includes floating debris that could clog the outlet or overflow structure.

Aquatic Plant Harvesting
Harvesting entire plants including roots will permanently remove nutrients from the system although removal of vegetation can also resuspend sediment and leave areas susceptible to erosion. For this reason, it is not recommend to harvest vegetation as a routine maintenance item. However, aquatic plant harvesting can be performed if desired to maintain volume or eliminate nuisances related to overgrowth of vegetation. When this is the case, perform this activity during the dry season (November to February). This can be performed manually or with specialized machinery.

If a reduction in cattails is desired, harvest them annually, especially in areas of new growth. Cut them at the base of the plant just below the waterline, or slowly pull the shoot out from the base. Cattail removal should be done during late summer to deprive the roots of food and reduce their ability to survive winter.

Mosquito Control
Mosquito control may be necessary if mosquitoes are found to be breeding in the BMP. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections and treatment can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. The use of larvicidal briquettes or "dunks" is not recommended for ponds due to their relative large size and configuration.

Sediment Removal from the Forebay
Remove sediment from the forebay before it becomes a significant source of pollutants for the remainder of the pond. More frequent removal will benefit long-term maintenance practices. For dry forebays, sediment removal should occur once a year. Sediment removal in wet forebays should occur approximately once every four years or when build up of sediment results in excessive algae growth or mosquito production. Ensure that the sediment is disposed of properly and not placed elsewhere in the pond.

Sediment Removal from the Pond Bottom
Removal of sediment from the bottom of the pond may be required every 10 to 20 years to maintain volume and deter algae growth. This typically requires heavy equipment, designated corridors, and considerable expense. Harvesting of vegetation may also be desirable for nutrient removal. When removing vegetation from the pond, take care not to create or leave areas of disturbed soil susceptible to erosion. If removal of vegetation results in disturbed soils, implement proper erosion and sediment control BMPs until vegetative cover is reestablished.

For constructed wetland ponds, reestablish growth zone depths and replant if necessary.

8.4.6 Extended Detention Basin Maintenance

Extended Detention Basins have low to moderate maintenance requirements on a routine basis, but may require significant maintenance once every 15 to 25 years. Maintenance frequency depends on the amount of construction activity within the tributary watershed, the erosion control measures implemented, the size of the watershed, and the design of the facility.

Inspection
Inspect the Extended Detention Basin at least annually, observing the amount of sediment in the forebay and checking for debris at the outlet structure (See Appendix 8.6 for sample Inspection Form).

Debris and Litter Removal
Remove debris and litter from the detention area as required to minimize clogging of the outlet.

Mowing and Plant Care
When starting from seed, mow native/drought tolerant grasses only when required to deter weeds during the first three years. Following this period, mowing of native/drought tolerant grass may stop or be reduced to maintain a height of no less than 6 inches (higher mowing heights are associated with deeper roots and greater drought tolerance). In general, mowing should be done as needed to maintain appropriate height and control weeds. Mowing of manicured grasses may vary from as frequently as weekly during the summer, to no mowing during the winter.

Aeration
For Extended Detention Basins with manicured grass, aeration will supply the soil and roots with air and increase infiltration. It reduces soil compaction and helps control thatch while helping water move into the root zone. Aeration is done by punching holes in the ground using an aerator with hollow punches that pull the soil cores or "plugs" from the ground. Holes should be at least 2 inches deep and no more than 4 inches apart.

Aeration should be performed at least once per year when the ground is not frozen. Water the turf thoroughly prior to aeration. Mark sprinkler heads and shallow utilities such as irrigation lines and cable TV lines to ensure those lines will not be damaged. Avoid aerating in extremely hot and dry conditions. Heavy traffic areas may require aeration more frequently.

Mosquito Control
Although the design provided in this manual implements practices specifically developed to deter mosquito breeding, some level of mosquito control may be necessary. The most effective mosquito control programs include weekly inspection for signs of mosquito breeding with treatment provided when breeding is found. These inspections can be performed by a mosquito control service and typically start in mid-May and extend to mid-September. Treatment should be targeted toward mosquito larvae. Mosquitoes are more difficult to control when they are adults. This typically requires neighborhood fogging with an insecticide.

The use of larvicidal briquettes or "dunks" may be appropriate. These are typically effective for about one month and perform best when the basin has a hard bottom (e.g., concrete lined micropool).

Irrigation Scheduling and Maintenance
Adjust irrigation throughout the growing season to provide the proper irrigation application rate to maintain healthy vegetation. Less irrigation is typically needed in early summer and fall, with more irrigation needed during July and August. Native grass and other drought tolerant plantings should not require irrigation after establishment.

Check for broken sprinkler heads and repair them, as needed. Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

Sediment Removal from Forebay, Trickle Channel and Micropool
Remove sediment from the forebay and trickle channel annually. If portions of the watershed are not developed or if roadway or landscaping projects are taking place in the watershed, the required frequency of sediment removal in the forebay may be as often as after each storm event. The forebay should be maintained in such a way that it does not provide a significant source of resuspended sediment in the stormwater runoff.

Sediment removal from the micropool is required about once every one to four years, and should occur when the depth of the pool has been reduced to approximately 18 inches. Small micropools may be vacuumed and larger pools may need to be pumped in order to remove all sediment from the micropool bottom. Removing sediment from the micropool will benefit mosquito control. Ensure that the sediment is disposed of properly and not placed elsewhere in the basin.

Sediment Removal from the Basin Bottom
Remove sediment from the bottom of the basin when accumulated sediment occupies about 20% of the water quality design volume or when sediment accumulation results in poor drainage within the basin. The required frequency may be every 15 to 25 years or more frequently in basins where construction activities are occurring.

Erosion and Structural Repairs
Repair basin inlets, outlets, trickle channels, and all other structural components required for the basin to operate as intended. Repair and vegetate eroded areas as needed following inspection.

8.4.7 Green Roof Maintenance

A five-year maintenance plan should be established prior to the completion of all new green roofs. Both plant maintenance and inspection of various roof structural elements will be required regularly. Additionally, green roof plants require regular attention and care including irrigation, weeding, fertilizing, pruning, and replanting. While the first several years following green roof construction are critical for establishing vegetation, controlling weeds, and detecting problems such as leaks, a long-term maintenance plan will also be necessary. During the first five years, the maintenance plan should be refined and adjusted based on experience to develop an effective long-term plan.

Inspection
Green roof inspection should be conducted at least three times per year (See Appendix 8.7 for sample Inspection Form).. At a minimum, the following areas require inspection:

- Inspect joints, borders or other features that pass through the roof to remove roots and identify damage that could lead to leaks. For example, inspect abutting vertical walls, roof vent pipes, outlets, air conditioning units, and perimeter areas. Joints with facades must provide open access for inspection, maintenance, and upkeep.
- A vegetation-free zone of approximately one foot should be maintained at the border of roof edges and at drain openings on the roof. Vegetation-free zones should be lined with pavers, stones, or gravel. Drains must remain free of vegetation and foreign objects. In order to allow for regular inspections and maintenance, drains on a green roof must remain permanently accessible.
- Because of the severe consequences of drain backups, inspection of drainage flow paths is crucial. Remove the inlet cover and visually inspect drainage pipes for roots or other material that could impede the flow of water.

- Plants are susceptible to poor drainage in the soil. If too much water is present and unable to drain, the plants will drown or rot. Routine inspections of drains should take place approximately three times per year as well as after precipitation events of 0.6 inches or more.
- Inspect the irrigation system for leaks or malfunctions. Uneven vegetative growth or dying plants should serve as indicators of potential irrigation system problems.

Plant Care and Media Replacement

As with any garden, plant replacement will be required periodically throughout the life of a green roof. For green roofs serving stormwater functions, heat-tolerant plants with shallow, spreading and fibrous root systems are recommended. Plant selection is crucial on roofs with intense wind and light such as roofs of skyscrapers or roofs that receive reflected solar radiation from other structures. Additionally, certain portions of the roof may experience more intense sunlight and or reflected heat, requiring additional care or irrigation system adjustments.

Care of the plants on a green roof will require the most attention during the critical establishment phase. A horticultural professional should work with individuals caring for the new roof to organize schedules and routines for hand weeding, thinning, pruning, fertilizing, irrigation system scheduling and adjustments, and plant replacement. Watering and weeding are particularly important for the first two years of the green roof. For overall health of the green roof, weeds should be identified and removed early and often.

If the growing medium needs to be replaced, it should be replaced in accordance with the original design specifications, unless these specifications have been identified as a cause of poor plant growth or green roof performance. Any substitutions or adjustments to the original green roof media must be balanced carefully to meet loading limits, drainage requirements, and characteristics conducive to healthy plant growth.

When caring for plants or adjusting growing media, care should be taken to avoid use of materials likely to result in nutrient export from the green roof. For example, growing media and compost should have a low phosphorus index (P index). Appropriate plants with low fertilization requirements should be chosen. If used, fertilizer application should be minimized to levels necessary only for plant health.

Irrigation Scheduling and Maintenance

Green roofs should be equipped with irrigation systems, even if the ultimate goal is for the plants to rely primarily on natural precipitation. Irrigation schedules should be based on the evapotranspiration requirements of the plants, the type of irrigation system used (e.g., drip or spray), and changing evapotranspiration over the growing season. Irrigation systems equipped with advanced irrigation controllers based on soil moisture can help facilitate watering according to the changing water needs of the plants. If advanced systems are not used, irrigation should be manually adjusted during the growing season to replace water lost through evapotranspiration. During the first two years of plant establishment, regular irrigation will likely be needed. After plant establishment, it may be possible to reduce supplemental irrigation during non-drought conditions.

Completely drain the irrigation system before the first winter freeze each year. Upon reactivation of the irrigation system in the spring, inspect all components and replace damaged parts, as needed.

8.4.8 Permeable Pavement Maintenance

The key maintenance objective for any permeable pavement system is to know when runoff is no longer rapidly infiltrating into the surface, which is typically due to void spaces becoming clogged and requiring sediment removal. This Section identifies key maintenance considerations for various types of permeable pavement BMPs.

Inspection
Inspect pavement condition and observe infiltration at least annually, either during a rain event or with a garden hose to ensure that water infiltrates into the surface (See Appendix 8.8 for sample Inspection Form).. Video, photographs, or notes can be helpful in measuring loss of infiltration over time. Systematic measurement of surface infiltration of pervious concrete, Permeable Interlocking Concrete Pavers, concrete grid pavement, and porous asphalt can be accomplished using ASTM C1701 Standard Test Method for Infiltration Rate of In Place Pervious Concrete.

Debris Removal, Sweeping and Vacuuming
- All Pavements: Debris should be removed, routinely, as a source control measure. Typically, sites that require frequent sweeping already plan for this activity as part of their ongoing maintenance program. For example, a grocery store may sweep weekly or monthly. Although this type of sweeper can be effective at removing solids and debris from the surface, it will not remove solids from the void space of a permeable pavement. Use a vacuum or regenerative air sweeper to help maintain or restore infiltration. If the pavement has not been properly maintained, a vacuum sweeper will likely be needed.

- Permeable Interlocking Concrete Pavers, Concrete Grid Pavements (with aggregate infill), Pervious Concrete, and Porous Asphalt: Use a regenerative air or vacuum sweeper after any significant site work (e.g., landscaping) and approximately twice per year to maintain infiltration rates. This should be done on a warm dry day for best results. Do not use water with the sweeper. The frequency is site specific and inspections of the pavement may show that biannual vacuuming is more frequent than necessary. After vacuuming Permeable Interlocking Concrete Pavers and Concrete Grid Pavers, replace infill aggregate as needed.

Snow Removal
In general, permeable pavements do not form ice to the same extent as conventional pavements. Additionally, conventional liquid treatments (deicers) will not stay at the surface of a permeable pavement as needed for the treatment to be effective. Sand should not be applied to a permeable pavement as it can reduce infiltration. Plowing is the recommended snow removal process. Conventional plowing operations should not cause damage to the pavements.
- Permeable Interlocking Concrete Pavers and Concrete Grid: Deicers may be used on Permeable Interlocking Concrete Pavers and grid pavers; however, it may not be effective for the reason stated above. Sand should not be used. If sand is accidentally used, use a vacuum sweeper to remove the sand. Mechanical snow and ice removal should be used.
- Pervious Concrete: Do not use liquid or solid deicers or sand on pervious concrete. Deicers can damage the concrete and sand will reduce infiltration. Mechanical snow and ice removal should be used.
- Porous Asphalt: Use liquid or solid deicers sparingly; mechanical snow and ice removal is preferred. Do not apply sand to porous asphalt.

Full and Partial Replacement of the Pavement or Infill Material
- Permeable Interlocking Concrete Pavers and Concrete Grid: Concrete pavers, when installed correctly, should have a long service life. If a repair is required, it is frequently due to poor

placement of the paver blocks. Follow industry guidelines for installation and replacement after underground repairs.

If surface is completely clogged and rendering a minimal surface infiltration rate, restoration of surface infiltration can be achieved by removing the first ½ to 1 inch of soiled aggregate infill material with a vacuum sweeper. After cleaning, the openings in the Permeable Interlocking Concrete Pavers will need to be refilled with clean aggregate infill materials. Replacement of the infill is best accomplished with push brooms.

- Porous Gravel: Remove and replace areas of excessive wear or reduced infiltration as needed. The frequency is dependent on site characteristics including site uses, vegetation, and materials.
- Pervious Concrete: Partial replacement of pervious concrete should be avoided. If clogged, power washing or power blowing should be attempted prior to partial replacement. Any patches should extend to existing isolated joints. Conventional concrete may be used in patches, provided that 90 percent of the original pervious surface is maintained.
- Reinforced Grass: Remove and replace the sod cover as needed to maintain a healthy vegetative cover or when the sod layer accumulates significant amount of sediment (i.e., >1.5 inches). Maintenance and routine repairs should be performed annually, with sod replacement approximately every 10 to 25 years. When replacing sod, use a high infiltration variety such as sod grown in sandy loam.

8.4.9 Retention Pond Maintenance

- See Constructed Wetland Ponds Section 8.4.5. For sample Inspection Form see Appendix 8.9.

8.4.10 Underground BMP Maintenance

Maintenance requirements of underground BMPs can vary greatly depending on the type of BMP. Frequent inspections (approximately every three months) are recommended in the first two years in order to determine the appropriate interval of maintenance for a given BMP. This Section provides general recommendations for assorted underground BMPs. For proprietary devices, the manufacturer should provide detailed maintenance requirements specific for the BMP (See Appendix 8.10 for sample Inspection Form).

Inspection
- All Underground BMPs: Inspect underground BMPs at least quarterly for the first two years of operation and then twice a year for the life of the BMP, if a reduced inspection schedule is warranted based on the initial two years. Specifically look for debris that could cause the structure to bypass water quality flows. Strong odors may also indicate that the facility is not draining properly. Inspection should be performed by a person who is familiar with the operation and configuration of the BMP.
- Inlet Inserts: Inspect inlet inserts frequently; at a minimum, inspect after every storm event exceeding 0.6 inches. Removal of flow blocking debris is critical for flood control.

Debris Removal, Cartridge Replacement and Vacuuming
- All Underground BMPs: Follow the manufacturer's recommended maintenance requirements and remove any flow blocking debris as soon as possible following inspection.

- Replacement of filter cartridges is anticipated on an annual basis. Depending on site characteristics, the replacement frequency may be extended to no less than once every three

years. However, semi-annual inspection should continue to ensure that proper function of the system is maintained. Maintenance is required when any of the following conditions exist:
- If there is more than 4 inches of accumulated sediment on the vault floor.
- If there is more than ¼ inch of accumulation on the top of the cartridge.
- If there is more than 4 inches of standing water in the cartridge bay for more than 24 hours after the end of a rain event.
- If the pore space between media granules is full.
- If inspection is conducted during an average rainfall event and the system remains in bypass condition (water over the internal outlet baffle wall or submerged cartridges).
- If hazardous material release (automotive fluids or other) is reported.
- If pronounced scum line (≥ 1/4" thick) is present above top cap.
- If system has not been maintained for three years.
- Hydrodynamic Separators: Vacuum sediment and debris from units at least once annually and more frequently as needed, based on inspections.

8.5 Waivers/Credits

8.5.1 Watershed Based Criteria

The City has federal requirements to address impaired waters. Each impaired creek or lake in Lincoln typically has different pollutants of concern unique to that waterbody. As such, it is necessary that any credits be located within the same watershed of the proposed development or re-development project seeking credits (preferably near the proposed development).

8.5.2 Waivers

Waivers for Best Management Practice requirements may be granted based on the Director's discretion. Waivers are generally based on:

- Unplanned emergency work or repairs necessary to health, safety and the general welfare of the public.
- Structural Best Management Practices on previously developed property within the same watershed that have been retro-fitted to provide the same level of stormwater quality or more.
- Previously constructed private Structural Best Management Practices within the same watershed that were constructed to be above the standards and for which the City has approved credits above and beyond the standards.
- Previously constructed public Structural Best Management Practices within the same watershed, that are above the standards for which the City has established credits above and beyond the standards.
- Circumstances where the project cost of implementing the proposed standards would be so disproportionate, that completing the project would not be practical.

8.5.3 Credit Policy

The credit policy is based on a volume (acre feet) of stormwater being treated for development and re-development projects that obtain a waiver. In summary the treatment of stormwater above the required rainfall standards for developments or re-developments would obtain a credit for the extra volume of stormwater treated up to an amount of 1.65 inches (95th percentile rainfall event). The volume of credit would be the extra volume obtained by treating more than the required amount, i.e. subtracting the volume of stormwater required to be treated from the actual volume of stormwater treated.

Also as an incentive, credits could be obtained by treatment of stormwater through alternative Best Management Practices that use subsurface storage such as porous pavements, bioswales, rain gardens, etc with infiltration practices and no drain down to the municipal storm drainage system. These credits would be based on a volume basis of 0.01 acre feet per acre treated basis.

Examples of determining credit amounts are as follows:

1. A 20 acre residential development site (with 30% impervious area) would be required to treat 0.83 inches or 0.44 acre feet of stormwater runoff. This is 20 acres multiplied by 0.32 (Impervious Area Factor) multiplied by 0.83 inches divided by 12 inches/foot. If the 20 acre development site was designed to treat 1.65 inches (95th percentile rainfall event) it would treat 0.88 acre feet. This would provide a credit of 0.44 acre feet (i.e. 0.88 acre feet minus 0.44 acre feet) of credits that could potentially be used elsewhere in the watershed. This 0.44 acre feet credit would be enough to satisfy the recommendations for a similar sized residential development site in the same watershed if it obtained approval for the credit.

2. A 20 acre development site that uses applicable alternate Best Management Practices will obtain a credit of 0.20 acre feet (0.01 acre feet/acre multiplied by 20 acres). Similar to the other type of credit this could be used elsewhere in the watershed for a project that had obtained approval for using a credit.

Appendix 8.1 Water Quality Control Form

For Owner Use

Site Name:

Location:

Owner:

Owner Contact Information:
(Name, Address, Phone #, Email)

Person responsible for Maintenance:
(Name, Company name, Address, Phone #, Email)

Development/Redevelopment Project:

Water Quality Control Volume:
- Relevant Storm Event:
- Percent Impervious Area:
- Contributing Drainage Area:
- Design Volume:
- Ac ft of Credits Requested (if applicable):
    - Owner of Credits:

Volume of treatment for Structural BMP:

Structural BMP Type:

Attach Plans:

Attach Maintenance Plan and other relevant information (e.g. non structural BMP activities/descriptions if applicable):

For Staff Use

- Date Received:
- Reviewer and date reviewed:
- Planning/Building and Safety number:
- Instrument Number of owner agreement:
- Plans and Maintenance Plan Attached (Y/N):
- Ac ft of Credits Approved (if any):

Appendix 8.2 Example Maintenance Permit

This Agreement is made and entered into as of this ____ day of _____, by and between the City of Lincoln, a municipal corporation ("City"), and ________ (XX).

WHEREAS, XX is responsible under the dedication in the Plat for the inspections and maintenance of the Best Management Practices identified in the Plat; and

WHEREAS, XX is aware of inspection and maintenance needs for the Best Management Practices; and

WHEREAS, XX desires that the City inspect and maintain the Best Management Practices; and

WHEREAS, XX and the City desire to enter into this Agreement for a Maintenance Permit that outlines responsibilities for inspections and maintenance of the Best Management Practices for the specified period of time.

NOW THEREFORE, in consideration of the above, and the covenants and conditions contained herein, the parties agree as follows:

1. Best Management Practices. The parties agree the following Best Management Practices shall be inspected and maintained by the City:

    a. {Description of Best Management Practice(s), include location graphic in Attachment A}

2. Inspection of Best Management Practices. The City will annually inspect the Best Management Practices using the Inspection Form shown in {Attachment B}. The completed Inspection Form will be submitted to the designated representative for XX annually in _________ of each year.

3. Maintenance of Best Management Practices. The City will maintain the Best Management Practices using the below frequencies and standards of maintenance. A report will be completed at the end of each inspection and submitted to the designated representative for XX within one month of the inspection.
    a. {List frequency and standards of maintenance for Best Management Practices, Report to be submitted using the form supplied in Attachment C}

4. XX will provide the City a designated representative as the point of contact between the City and XX prior to the start of any inspections or maintenance activities.

5. Funding. XX will submit $________ in costs to the City for the City inspecting and maintaining the Best Management Practices prior to any inspections or maintenance activities.

6. Time Frame: This maintenance permit will commence upon the approval of this agreement and end on _________.

7. Ownership of the Best Management Practices. Before, during and upon completion of the Maintenance Permit, the Best Management Practices continue to be owned by XX. In addition, by the execution of this Agreement, the Associations hereby authorizes the City, its representatives, designees, contracts, and subcontractors, without any further notice or authorization, to access the Best Management Practices properties for the purposes of inspection and maintenance.

   It is agreed that City shall not be liable for trespass or any other damages or taking of any kind arising out of entering onto the Best Management Practice properties for the purposes provided herein. XX shall not allow others to use the Best Management Practices in such manner that might interfere with the inspections and maintenance of the City during the term of this Agreement. In the event interference, damage, or tampering occurs on the Best Management Practices during the term of the Agreement, the party with notice shall inform the other party within five (5) business days.

8. Indemnification: To the fullest extent permitted by law, XX shall release, waive, indemnify, defend and hold harmless City, its officers, agents, contractors, and employees from and against claims, damages, losses and expenses, including but not limited to, attorney's fees, arising out of or resulting from the performance of this Agreement that results in any claim for damage, including without limitation, any bodily injury, sickness, disease, death, or damage to tangible or intangible property, including any loss of use resulting therefrom that is caused in whole or in part by the acts or omission of XX, its employees, agents, contractors or other duly authorized representatives or designees. City does not waive its governmental immunity by entering into this Agreement and fully retains all immunities and defenses provided by law with regard to any activities authorized by this Agreement. This section survives termination of this Agreement.

9. Binding Effect. This Agreement shall be binding upon and inure to the benefit of the parties hereto, and their respective heirs, devisees, personal representatives, successors and assigns. Each party hereby certifies, represents and warrants to the other party that the execution of this Agreement is duly authorized and constitutes a legal, valid and binding obligation of said party.

10. Amendment: This Agreement may only be amended or modified in writing signed by the parties to this Agreement.

11. Further Assurances. Each party will use its best and reasonable efforts to successfully carry out and complete each task, covenant, and obligation as stated herein. Each of the parties shall cooperate in good faith with the other and shall do any and all acts and execute, acknowledge, and deliver any and all documents so requested in order to satisfy the conditions set forth herein and carry out the intent and purposes of this Agreement.

12. Execution in Counterparts. This Agreement may be executed on two or more counterparts, each of which shall be an original, but all of which shall constitute one and the same instrument.

13. Governing law. All aspects of this Agreement shall be governed by the laws of the State of Nebraska. The invalidity of any portion of this Agreement shall not invalidate the remaining provisions.

14. Interpretations. Any uncertainty or ambiguity existing herein shall not be interpreted against any party because such party prepared any portion of this Agreement, but shall be interpreted according the application of rules and interpretations of contracts generally. This Agreement represents the entire agreement between the parties and all prior negotiations and representations are hereby expressly excluded from this Agreement. The failure of either party to enforce any provision of this Agreement shall not be construed as a waiver or limitation of that party's right to subsequently enforce and compel strict compliance with every provision of this Agreement.

15. Relationship of Parties. Neither the method of computation of funding nor any other provisions contained in this Agreement nor any acts of any party shall be deemed or construed by the City, or by and third person to create the relationship of partnership or of joint venture or any association between the parties, other than contractual relationships stated in this Agreement.

16. Assignment. In the case of the assignment of this Agreement to other parties, prompt written notice shall be given to the other party, who shall at the time of such notice be furnished with a duplicate of such assignment by such assignor. Any such assignment shall not terminate the liability of the assignor to perform its obligations hereunder, unless a specific release in writing is given and signed by the other party to this Agreement.

IN WITNESS WHEREOF, the parties have executed this Agreement as of the date written above.

{Add City signature block, XX signature block and notaries}

Appendix 8.3 Example Maintenance Form

Reference Section 8.4.3
Following is an example maintenance plan from a water quality project at 27th and 'F' that is maintained by Parking Services, a Division of the Urban Development Department, City of Lincoln.

1. Drawing. See Figure 8.3-1 for overall schematic diagram

2. Descriptions as follows

3. Inspection Form as follows

4. Contact information is Parking Services, Parking Manager (402-441- 6097)

5. Legal documents: City of Lincoln is property owner

Description:
The 27th and 'F' water quality project was constructed in the mid -2000's. All maintenance of the features is the responsibility of Parking Services, a Division of the Urban Development Department, City of Lincoln.

The project consists of pervious concrete with an underdrain to a rain garden. Any overflow (if any) from the pervious concrete area also drains to the rain garden. See Figure 8.3-1 for an overall schematic diagram of the project. An overflow is located in the rain garden that drains to the urban drainage system along S. 27th Street.

The pervious pavement is underlain by a layer of gravel for infiltrating to the ground as well as an underdrain system. The rain garden consists of native plantings and engineered soils consisting of a 50/50 mixture of sand and compost.

Appendix 8.3 Example Maintenance Form

INSPECTION FORM

Site Name: 27th and ‘F’ public parking area

Location: 27th and ‘F’

Owner: City of Lincoln, Parking Services

Contact Information: Parking Services, Parking Manager (402-441-6097)

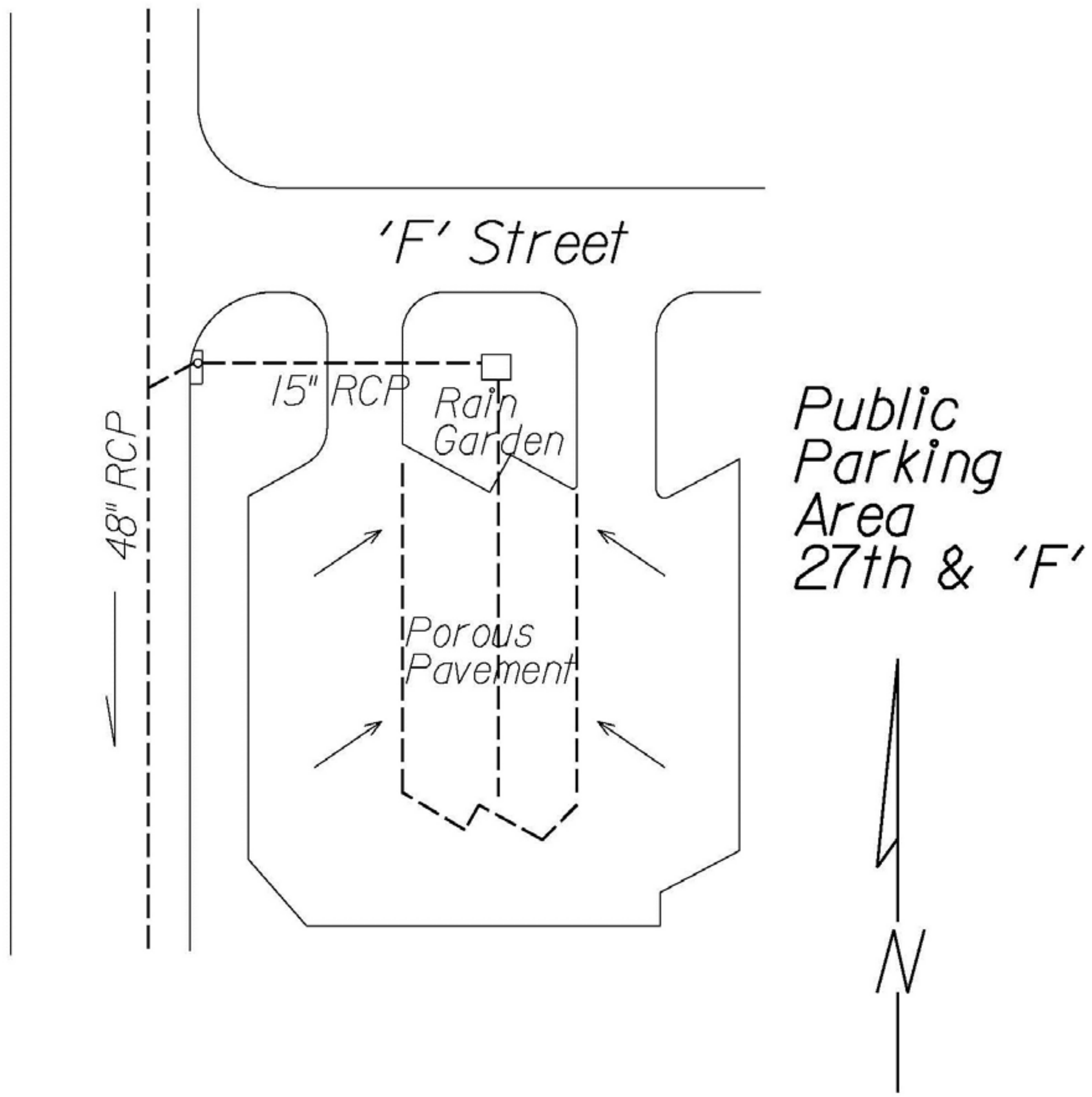
Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity*	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control weeds and remove debris monthly in the Rain Garden			
Cut back plants as needed each Fall in the Rain Garden			
Replace mulch as needed each Spring in the Rain Garden			
Check for standing water, excess sediment, clogged pipes, and remove debris after major storm events			
Sweep, vacuum and or high pressure hose pervious pavement annually. Check permeability			
Check for damage on the permeable pavement annually and replace as needed			

Appendix 8.3 Example Maintenance Form

Figure 8.3 – 1



Appendix 8.4 Bioretention Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity*	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control Weeds (remove manually by hand or mowing)			
Remove debris			
Check any outlet pipe for clogging			
Ensure any cleanout pipes remain water tight			
Cut back plants as appropriate and replace plants as needed			
Check for standing water issues (< 40 hrs after rainfall event)			
Replace mulch as needed (2 to 3 inches)			
Check for accumulated sediment, remove as needed			
If irrigated, check for any necessary repairs (drain irrigation line in Fall)			

* Some activities such as weed control will need to be done more frequently during the first few years of establishment

Appendix 8.5 Constructed Wetland Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity*	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control Weeds (remove manually by hand or mowing)			
Remove debris, including floating debris			
Check outlet for clogging			
Check sediment accumulation in forebay, remove when half full			
Replace plants as needed			
Check for signs of mosquito breeding			
Check sediment in bottom of pond			

* Some activities such as weed control will need to be done more frequently during the first few years of establishment

Appendix 8.6 Extended Detention Basin Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity*	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control Weeds (remove manually by hand or mowing)			
Remove debris, including any floating debris			
Check inlets and outlet for clogging and repair needs			
Check sediment accumulation in forebay, trickle channel and micropool			
Replace vegetation as needed			
Mow and check for excessive erosion			
Check sediment in bottom of pond			
Check for mosquito breeding			
If irrigated, check for any necessary repairs (drain irrigation line in Fall)			

* Some activities such as weed control will need to be done more frequently during the first few years of establishment

Appendix 8.7   Green Roof Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity*	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control Weeds (remove manually by hand or mowing)			
Remove debris			
Inspect joints, borders, outlets, and other features for damage			
Check all drainage paths including inlet covers			
Replace vegetation as needed			
Thin, prune, fertilize as needed			
Check growing media for any needed replacement			
If irrigated, check for any necessary repairs (drain irrigation line in Fall)			

* Some activities such as weed control will need to be done more frequently during the first few years of establishment

Appendix 8.8 Permeable Pavement Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control Weeds (remove manually by hand or mowing)			
Remove debris			
Sweep and vacuum			
Check permeability (during a rain event or by using a garden hose)			
Replace any vegetation as needed			
Remove snow as needed			
Check for damage and replace as needed			

Appendix 8.9 Retention Pond Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity*	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Control Weeds (remove manually by hand or mowing)			
Remove debris, including floating debris			
Check outlet for clogging			
Check sediment accumulation in forebay, remove when half full			
Replace plants as needed			
Check for signs of mosquito breeding			
Check sediment in bottom of pond			

* Some activities such as weed control will need to be done more frequently during the first few years of establishment

Appendix 8.10 Underground BMPs Maintenance Inspection Form

Site Name:

Location:

Owner:

Contact Information:
(Name, Address, Phone #, Email)

Inspection Date: Inspection By:

Site Conditions: Date of Previous Inspection:

Inspection Activity	Maintenance Needed	Description of Required Maintenance Activity	Date Maintenance Completed
Follow manufacturer instructions for maintenance			
Remove debris			
Vacuum out debris as appropriate			
Replace filter material as appropriate			