Appendix A - Best Management Practices
OVERVIEW

This appendix briefly discusses the different BMPs that can be utilized once a site has been selected. These descriptions are not intended as design guidance and are limited to basic descriptions and selection considerations. For additional information on design criteria, design considerations for safety and maintenance, and construction-phase considerations, the appropriate storm drainage design criteria manual should be consulted. Possible sources include the City of Lincoln Drainage Criteria Manual (Revised in May 2004) and the Urban Storm Drainage Criteria Manual, Volume 3 (www.udfcd.org). The Urban Drainage and Flood Control District (UDFCD) has established design criteria, procedures, and details for a number of BMPs providing treatment of post-construction urban runoff. Information contained in this appendix has been adapted from the UDFCD (updated November 2010) prepared by the Urban Drainage and Flood Control District, Denver, Colorado.

BMPs provide treatment through a variety of hydrologic, physical, biological, and chemical processes. The functions provided by BMPs are summarized into three main functions: volume reduction, water quality capture volume (WQCV) capture, and WQCV including flood control. The WQCV represents the runoff volume from frequent storm events. Volume reduction is generally achieved by the slow release of stormwater runoff, encouraging infiltration, plant uptake and evapotranspiration. BMPs can be sized to capture and slowly release the water quality capture volume (WQCV). This size allows the BMP to treat and infiltrate stormwater runoff. Flood control can be incorporated by increasing the size of the BMP to capture more stormwater runoff. Ideally, site designs will include a variety of source control and treatment BMPs combined in a "treatment train" that controls pollutants at their sources, reduces runoff volumes, and treats pollutants in runoff. The BMPs discussed in this appendix are listed below:

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

Each BMP includes a basic description, identifies site selection factors, as well as general benefits and limitations. A table is also included for each that summarizes their function, typical effectiveness for targeted pollutants, and other considerations.
GRASS BUFFER

DESCRIPTION
Grass buffers are densely vegetated strips of grass designed to accept sheet flow from upgradient development. Properly designed grass buffers play a key role by enabling infiltration, slowing runoff, and providing filtration (straining) of sediment. Buffers differ from swales in that they are designed to accommodate overland sheet flow rather than concentrated or channelized flow. Over time, sediment must be removed, and replanting in areas might be needed.

SITE SELECTION
Grass buffers can be incorporated into a wide range of development settings. Runoff can be directly accepted from a parking lot, roadway, or the roof of a structure, provided the flow is distributed in a uniform manner over the width of the buffer. This can be achieved through the use of flush curbs, slotted curbs, or level spreaders where needed. Grass buffers are often used in conjunction with grass swales. They are well suited for use in riparian zones to assist in stabilizing channel banks adjacent to major drainage ways and receiving waters. These areas can also sometimes serve multiple functions such as recreation. Hydrologic Soil Groups A and B provide the best infiltration capacity for grass buffers. For Type C and D soils, buffers still serve to provide filtration (straining) although infiltration rates are lower.

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

LIMITATIONS
- A thick vegetative cover is needed for grass buffers to be effective,
- Nutrient removal in grass buffers is typically low,
- High loadings of coarse solids, trash, and debris require pretreatment,
- Space for grass buffers may not be available in high intensity urban areas (lot-line-to-lot-line),
- Tend to accumulate sediment if not properly maintained.

Grass buffer located at 25th and Randolph St.

Grass Swale

<table>
<thead>
<tr>
<th>Functions</th>
<th>LID/Volume Red.</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>WQCV Capture</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Typical Effectiveness for Targeted Pollutants

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Sediment/Solids</th>
<th>Nutrients</th>
<th>Total Metals</th>
<th>Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Moderate</td>
<td>Good</td>
<td>Poor</td>
<td></td>
</tr>
</tbody>
</table>

Other Considerations

| Life-cycle Costs | Low |

1 Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org)
GRASS SWALE

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

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

BENEFITS
- Removal of sediment and associated constituents through filtering (straining),
- Reduces length of storm drainage pipes in the upper portions of a watershed,
- Provides a less expensive and more attractive conveyance element than a typical pipe system,
- Reduces directly connected impervious area and can help reduce runoff volumes.

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

<table>
<thead>
<tr>
<th>Grass Swale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions</td>
</tr>
<tr>
<td>LID/Volume Red.</td>
</tr>
<tr>
<td>WQCV Capture</td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
</tr>
<tr>
<td>Typical Effectiveness for Targeted Pollutants^3</td>
</tr>
<tr>
<td>Sediment/Solids</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Total Metals</td>
</tr>
<tr>
<td>Bacteria</td>
</tr>
<tr>
<td>Other Considerations</td>
</tr>
<tr>
<td>Life-cycle Costs</td>
</tr>
</tbody>
</table>

^3 Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org)
BIORETENTION (RAIN GARDEN)

DESCRIPTION
A BMP that utilizes bioretention is an engineered, depressed landscape area designed to capture and filter or infiltrate the WQCV. 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.

Use of this infiltrating BMP near a structure requires evaluating the suitability of soils, identifying potential impacts, and establishing minimum distances between the BMP and structures.

SITE SELECTION
Bioretention can be provided in a variety of areas within new developments, or as a retrofit within an existing site. This BMP allows the WQCV to be treated within areas designated for landscape. 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 base flow is anticipated. They are typically small and installed in locations such as:
- Parking lot islands,
- Street medians,
- Landscape areas between the road and a detached walk,
- Areas that collect roof drains.

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

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 analysis may be needed to 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:
- Rain garden should have an underdrain system in locations where subgrade soils do not allow infiltration,
- An underdrain system should be used to divert water away from the structure where infiltration can adversely impact adjacent structures,
In locations where potentially expansive soils or bedrock exist, placement of a rain garden adjacent to structures and pavement should only be considered if the BMP includes an underdrain designed to divert water away from the structure and is lined with an essentially impermeable geomembrane liner designed to restrict seepage.

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

**LIMITATIONS**
- Additional design and construction steps are required for placement of any ponding or infiltration area near or upgradient from a building foundation and/or when expansive (low to high swell) soils exist.
- In developing or otherwise erosive watersheds, high sediment loads can require frequent sediment removal from the rain garden.
GREEN ROOF

DESCRIPTION
Green roofs could be defined as “contained” vegetated living systems on top of buildings.

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

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

As LID strategies have been emphasized increasingly throughout the U.S., green roofs have been implemented in some parts of the country, most frequently in areas with humid climates and relatively high annual rainfall. Although there are some green roofs in Lincoln (Pioneers Park Nature Center, Assurity office building, The Arbor Day Foundation on P Street), they have not been widely installed, and research is in progress regarding the best design approach and plant list for Lincoln’s climate. Plant selection, growing medium, and supplemental irrigation requirements are generally key considerations when designing a green roof. It should be noted that the U.S. Green Building Council LEED rating system recognizes a second kind of green roof that includes reflective, high albedo roof materials that are not designed for stormwater purposes.

SITE SELECTION
Green roofs can be installed on commercial or residential buildings as well as on underground structures such as parking garages. 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. The Assurity Life building in Lincoln anticipates growing vegetables within their green roof plant selection for the building inhabitants.

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.
BENEFITS

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

LIMITATIONS

- Limited experience in Lincoln,
- Initial installation costs are greater than conventional roof (although lifecycle costs may be less),
- Supplemental irrigation may be required,
- Maintenance during vegetation establishment (first two years) may be significant.
EXTENDED DETENTION BASIN (EDB)

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

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

SITE SELECTION
EDBs are well suited for watersheds of 5 to 640 impervious acres. Smaller watersheds can result in an orifice size small enough to increase the potential for clogging. Larger watersheds and watersheds with base flows can complicate the design and reduce the level of treatment provided. EDBs are also well suited where flood detention is incorporated into the same basin. 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.

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

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

<table>
<thead>
<tr>
<th>Extended Detention Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functions</strong></td>
</tr>
<tr>
<td>LID/Volume Red.</td>
</tr>
<tr>
<td>WQCV Capture</td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
</tr>
<tr>
<td><strong>Typical Effectiveness for Targeted Pollutants&lt;sup&gt;3&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>Sediment/Solids</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Total Metals</td>
</tr>
<tr>
<td>Bacteria</td>
</tr>
<tr>
<td><strong>Other Considerations</strong></td>
</tr>
<tr>
<td>Life-cycle Costs&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>3</sup> Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

<sup>4</sup> Based primarily on BMP-REALCOST available at www.udfccd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).
**SAND FILTER**

*Source: Platte River Recovery Implementation Program*

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

<table>
<thead>
<tr>
<th>Sand/Media Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functions</strong></td>
</tr>
<tr>
<td>LID/Volume Red.</td>
</tr>
<tr>
<td>WQCV Capture</td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
</tr>
<tr>
<td><strong>Typical Effectiveness for Targeted Pollutants</strong></td>
</tr>
<tr>
<td>Sediment/Solids</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Total Metals</td>
</tr>
<tr>
<td>Bacteria</td>
</tr>
<tr>
<td><strong>Other Considerations</strong></td>
</tr>
<tr>
<td>Life-cycle Costs&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

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

**SITE SELECTION**
Sand filters require a stable watershed. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes in sandy soils, consider another BMP or provide pretreatment before runoff from these areas reach the sand filter. When sand filters (and other BMPs used for infiltration) are located adjacent to buildings or pavement areas, protective measures should be implemented to avoid adverse impacts to these structures. Oversaturated subgrade soil underlying a structure can cause the structure to settle or result in moisture related problems. Wetting of expansive soils or bedrock can cause swelling, resulting in structural movements. The potential impact of the BMP on adjacent structures should be considered based on an evaluation of the subgrade soil, groundwater, and bedrock conditions at the site. Additional minimum...
requirements include:

- An underdrain system should be used in locations where subgrade soils do not allow infiltration,
- An underdrain system should be used in locations where infiltration can adversely impact adjacent structures,

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

**BENEFITS**

- Provide pollutant removal through settling and filtering,
- Reduces stormwater runoff by providing and area of increased infiltration,
- Recharges groundwater table.

**LIMITATIONS**

- This BMP may require frequent maintenance if a moderate to high level of silts and clays are allowed to flow into the facility,
- This BMP should not be located within 10 feet of a building foundation without an impermeable membrane. See Bioretention description for additional information,
- The sand filter should not be put into operation while construction or major landscaping activities are taking place in the watershed.
**RETENTION POND**

*Pond within Wyuka Cemetery*

**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 WQCV over 12 hours. The permanent pool is replaced, in part, with stormwater during each runoff event so stormwater runoff mixes with the permanent pool water. This allows for a reduced residence time compared to that of the EDB. The 12-hour drain time helps to both better replicate pre-development flows for frequent events and reduce the potential for short circuiting treatment in smaller ponds. Retention ponds can be very effective in removing suspended solids, organic matter and metals through sedimentation, as well as removing soluble pollutants like dissolved metals and nutrients through biological processes. Retention ponds can also be designed to provide Full Spectrum Detention. Widespread use of full spectrum detention is anticipated to reduce impacts on major drainage ways by reducing post-development peak discharges to better resemble predevelopment peaks.

**SITE SELECTION**
Retention ponds require groundwater or a dry-weather base flow if the permanent pool elevation is to be maintained year-round. The designer should consider the overall water budget to ensure that the base flow will exceed evaporation, evapotranspiration, and seepage losses (unless the pond is lined). High exfiltration rates can initially make it difficult to maintain a permanent pool in a new pond, but the bottom can eventually seal with fine sediment and become relatively impermeable over time. However, it is best to seal the bottom and the sides of a permanent pool if the pool is located on permeable soils and to leave the areas above the permanent pool unsealed to promote infiltration of the stormwater detained in the surcharge WQCV.

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

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

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

**LIMITATIONS**
- Safety concerns associated with open water,
- Requires physical supply of water,
- Sediment, floating litter, and algae blooms can be difficult to remove or control,
- Ponds can attract water fowl which can add to the nutrients and bacteria leaving the pond,
- Ponds increase water temperature.
CONSTRUCTED WETLAND POND

DESCRIPTION
A constructed wetland pond is a shallow retention pond designed to permit the growth of wetland plants such as rushes, willows, and cattails. Constructed wetlands slow runoff and allow time for sedimentation, filtering, and biological uptake. Constructed wetlands ponds differ from "natural" wetlands, as they are artificial and are built to enhance stormwater quality. Do not use existing or natural wetlands to treat stormwater runoff. Stormwater should be treated prior to entering natural or existing wetlands and other environmentally sensitive areas. Allowing untreated stormwater to flow into existing wetlands will overload and degrade the quality of the wetland. Sometimes, small wetlands that exist along ephemeral drainage ways can be enlarged and incorporated into the constructed wetland system. Such actions, however, require the approval of federal and state regulators.

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

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

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

LIMITATIONS
- Requires physical supply of water to be impounded,
- 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 waterfowl which can add to the nutrients leaving the pond.
CONSTRUCTED WETLAND CHANNEL

DESCRIPTION
A constructed wetland channel is a conveyance BMP that is built, in part, to enhance stormwater quality. Constructed wetland channels use dense vegetation to slow down runoff and allow time for both biological uptake and settling of sediment. Constructed wetlands differ from natural wetlands, as they are artificial and are built to enhance stormwater quality. Do not use existing or natural wetlands to treat stormwater runoff. Stormwater should be treated prior to entering natural or existing wetlands and other environmentally sensitive areas. Allowing untreated stormwater to flow into existing wetlands will overload and degrade the quality of the wetland. Sometimes, small wetlands that exist along ephemeral drainage ways may be enlarged and incorporated into the constructed wetland system. Such action, however, requires the approval of federal and state regulators.

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

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

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

BENEFITS

<table>
<thead>
<tr>
<th>Constructed Wetland Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions</td>
</tr>
<tr>
<td>LID/Volume Red.</td>
</tr>
<tr>
<td>WQCV Capture</td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
</tr>
<tr>
<td>Typical Effectiveness for Targeted Pollutants</td>
</tr>
<tr>
<td>Sediment/Solids</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Total Metals</td>
</tr>
<tr>
<td>Bacteria</td>
</tr>
<tr>
<td>Other Considerations</td>
</tr>
<tr>
<td>Life-cycle Costs(^4)</td>
</tr>
</tbody>
</table>

\(^4\) Based primarily on BMP-REALCOST available at [www.udfio.org](http://www.udfio.org). Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).
• Wetland channels provide natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal,
• Provides effective follow-up treatment to onsite and source control BMPs that rely upon settling of larger sediment particles.

LIMITATIONS
• Requires a continuous base flow,
• Without proper design, salts and other floatables can accumulate and be flushed out during larger storms,
• Safety concerns associated with open water.
PERMEABLE PAVEMENT SYSTEMS

DESCRIPTION

The term Permeable Pavement System, as used in this appendix, 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 WQCV, and reduce effective imperviousness. Use of permeable pavements is a common LID practice and is often used in combination with other BMPs to provide full treatment and slow release of the WQCV. Installations can be designed with an increased depth of aggregate material in order to provide storage for storm events in excess of the water quality (80th percentile) storm event.

SITE SELECTION

This infiltrating BMP may require a geotechnical analysis when proposed near a structure.

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

This BMP is not appropriate when erosive conditions such as steep slopes and/or sparse vegetation drain to the permeable pavement. The sequence of construction is also important to preserve pavement infiltration. Construction of the pavement should take place only after construction in the watershed is complete. For sites where land uses or activities can cause infiltrating stormwater to contaminate groundwater, special design requirements are required to ensure no-infiltration from the pavement section.

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

- Pavement should be underlain by an underdrain system in locations where subgrade soils do not allow infiltration,
- The filter layer should be underlain by an underdrain system designed to divert water away from the structure where infiltration can adversely impact adjacent structures,

<table>
<thead>
<tr>
<th>Permeable Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functions</strong></td>
</tr>
<tr>
<td>LID/Volume Red.</td>
</tr>
<tr>
<td>WQCV</td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Typical Effectiveness for Targeted Pollutants</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment/Solids</td>
</tr>
<tr>
<td>Nutrients</td>
</tr>
<tr>
<td>Total Metals</td>
</tr>
<tr>
<td>Bacteria</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Other Considerations</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Life-cycle Costs&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

<sup>2</sup> Does not consider the life cycle cost of the conventional pavement that it replaces.

<sup>3</sup> Based primarily on data from the International Stormwater BMP Database (www.bmpdatabase.org).

<sup>4</sup> Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).
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 is lined with an impermeable geomembrane liner designed to restrict seepage and includes an underdrain designed to divert water away from the structure.

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

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

**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. While performance data for underground flood-control detention is lacking, this description provides general knowledge of the BMP 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 measurements must be implemented as a part of a retrofit to meet regulatory requirements. Underground BMPs should not be considered for standalone treatment when surface-based BMPs are practicable. For most areas of new urban development or significant redevelopment, it is feasible and desirable to provide the required WQCV on the surface. It is incumbent on the design engineer to demonstrate that surface-based BMPs such as permeable pavements, rain gardens, extended detention basins and others have been thoroughly evaluated and found to be infeasible before an underground system is proposed. Surface-based BMPs provide numerous environmental benefits including infiltration, evapotranspiration, groundwater recharge, aquatic habitat, mitigation of "heat island effect", and other benefits associated with vegetation for those that are planted.

**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

---

**Underground BMPs**

<table>
<thead>
<tr>
<th>Functions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LID/Volume Red.</td>
<td>Variable</td>
</tr>
<tr>
<td>WQCV Capture</td>
<td>Variable</td>
</tr>
<tr>
<td>WQCV+Flood Control</td>
<td>Variable</td>
</tr>
</tbody>
</table>

**Typical Effectiveness for Targeted Pollutants**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment/Solids</td>
<td>Variable</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Variable</td>
</tr>
<tr>
<td>Total Metals</td>
<td>Variable</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Variable</td>
</tr>
</tbody>
</table>

**Other Considerations**

<table>
<thead>
<tr>
<th>Life-cycle Costs</th>
<th>Moderate</th>
</tr>
</thead>
</table>

---

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

4 Based primarily on BMP-REALCOST available at www.udfcd.org. Analysis based on a single installation (not based on the maximum recommended watershed tributary to each BMP).
Receiving storm drainage 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 recommended if possible and some communities may not allow pumped systems. If a pumped system must be used, there should be redundancy in pumps, as well as a contingency plan in the event that a power outage disables pumps. Additionally, maintenance of the pump system should be identified as part of the water quality BMP in the maintenance plan. When BMP maintenance records are required by the MS4 permit holder, pump system maintenance records should also be included.

- **Access**: Equipment must be able to access all portions of the underground BMP, typically at multiple locations, to perform maintenance. As the size of the underground system increases, so must the number of access points.
- **Traffic Loading**: Due to space constraints, in some situations, underground BMPs may be located in a right-of-way or other location where there may be traffic loadings. Many underground BMPs are or can be constructed for HS-20 traffic loading. Take additional measures when necessary to ensure that the BMP is designed for the anticipated loading.
- **Potential for Flooding of Adjacent Structures or Property**: For underground BMPs, it is important that the hydraulic grade line be analyzed to evaluate the potential for backwater in the storm drainage system. In addition, some types of underground BMPs, such as catch basin inserts, have the potential to clog and cause flooding if not frequently maintained.

**BENEFITS**

- Underground BMPs may be designed to provide pre-treatment and/or WQCV in space-constrained situations,
- There are many alternative configurations for proprietary and nonproprietary devices,
- Treatment train applications can be designed using different unit processes in series,
- Some underground BMPs, designed specifically for certain target pollutants, can be used to address a TMDL,
- Many underground devices can be effective for settling of particulates in stormwater runoff and gross solids removal.

**LIMITATIONS**

- Performance data for underground BMPs in the Lincoln area are limited,
- Maintenance is essential and must be performed frequently,
- Inspection and maintenance can require traffic control, confined space entry, or specialized equipment,
- Devices that do not provide WQCV do not qualify for standalone treatment,
- Gravity outfall may not be feasible in some situations,
- Many do not provide volume reduction benefits,
- Potential for anoxic conditions and odor problems,
- Not recommended when surface alternatives are feasible.