CHAPTER 9. WATER QUALITY

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1.0 INTRODUCTION

The purpose of this chapter is to provide guidance for selecting, designing, and maintaining stormwater BMPs to minimize potential adverse impacts on stormwater quality caused by urbanization in the City of Bella Vista. The City, along with many communities around the United States, encourages the widespread use of stormwater BMPs on all development sites.

To comply with the *Federal Clean Water Act*, the Arkansas Department of Environmental Quality (ADEQ) issued Arkansas State Operating Permit ARR040041 to the City of Bella Vista to authorize discharges from the City's Municipal Separate Storm Sewer System (MS4) to waters of the State. In accordance with the MS4 permit, the City is required to develop and implement a comprehensive Stormwater Management Program that includes controls to identify illicit discharges and reduce the discharge of pollutants from the MS4 to the Maximum Extent Practicable. The design tools provided in this chapter are intended to improve the quality of stormwater runoff from development sites in the City.

1.1 Nature of Pollutants in Stormwater Runoff

Urban stormwater runoff can contain a variety of pollutants that can adversely impact water bodies. The Nationwide Urban Runoff Program (USEPA 1983) and other studies widely document the types and concentrations of pollutants associated with various land use types. Urban runoff may contain contaminants such as metals; lubricants; solvents; pesticides; herbicides; fertilizers; sanitary wastes of animals and humans; litter; and suspended sediments.

1.2 Historic Engineering Approaches for Stormwater Management

Traditional engineering approaches for stormwater management historically focused on moving water away from people, structures, and transportation systems as quickly and efficiently as feasible. This was accomplished by creating conveyance networks of impervious storm sewers, roof drains, and lined channels, which concentrated runoff discharges to receiving waters.

While the historical focus on stormwater was not on water quality, the potential adverse effects of urban runoff on the physical, chemical, and biological characteristics of receiving waters have been widely documented (e.g., WEF/ASCE 1992, 1998; Debo and Reese 2002; Horner, et al. 1994; Schueler and Holland 2000). Potential water quality implications of the traditional approach to drainage design include the following:

- Introduction of new pollutant sources and types (e.g. sediment from streets and parking lots).
- Increased runoff temperature.

- Habitat damage and ecosystem disruption associated with increased runoff from impervious surfaces, resulting in streambed and bank erosion and associated sediment and pollutant transport.
- Channel widening and instability.
- Destruction of both aquatic and terrestrial physical habitats.
- Increased contaminant transport, leading to increased water quality degradation that often may result in regulatory consequences such as stream segments being listed as impaired on the State 303(d) list and requirements for Total Maximum Daily Load (TMDL) allocations for dischargers to the stream.
- Production of potentially toxic concentrations of contaminants in receiving waters and long-term accumulation of contaminants.

1.3 New Approach and Requirements for Stormwater Management

To comply with the NPDES requirements and to minimize the potential adverse impacts of urbanization on water quality with many communities around the United States encourage the widespread use of stormwater BMPs on all new development as well as redeveloping sites. The purpose of this chapter is to provide guidance for selecting, designing, and maintaining BMPs that address water quality. This section is primarily targeted at protecting water quality in conjunction with development and redevelopment of residential and commercial areas. However, BMPs for light industrial areas and other types of land uses are also addressed.

Structural BMPs are constructed facilities designed to passively treat urban stormwater runoff, including practices such as detention basins (both dry basins and wet ponds); wetlands; porous pavement; and designed vegetated zones; and others. Structural BMPs can be designed to treat small volumes of stormwater on development sites or to serve larger regional drainage areas.

Non-structural BMPs are practices and procedures that 1) minimize or prevent pollution and/or 2) control it at its source. Examples of non-structural BMPs include proper handling and storage of materials; minimizing directly connected impervious areas to reduce the transport of pollutants in runoff; and implementing public education programs to protect stormwater quality.

The design guidelines in this chapter represent current BMP technology. These guidelines are anticipated to evolve as BMP technology is evaluated and refined; new BMPs are developed; or as new standards are promulgated by the federal or state governments. This chapter significantly draws from the Denver Urban Drainage and Flood Control District (UDFCD) *Urban Storm Drainage Criteria Manual (UDFCM), Volume 3, Best Management Practices*, first published in 1992 and regularly updated since then. Volume 3 updates and other information are available from the UDFCD website (www.udfcd.org).

Design requirements are presented for both structural and non-structural water quality BMPs. General BMP descriptions, design considerations and criteria, maintenance considerations, design forms and completed examples are provided for each structural BMP. The discussion in this section is limited to permanent, post-development BMPs.

2.0 APPLICABILITY

The water quality requirements outlined in this chapter are not a requirement of all developments at this time. The City encourages their use on all developments and may require that BMPs be implemented if a project is suspected that it will negatively impact the quality of receiving waters. Furthermore, these guidelines will apply when another agency such as the US Fish & Wildlife; ADEQ; or the US Army Corps of Engineers require best management practices to be employed as a condition of permitting a project within the limits of Bella Vista.

3.0 WATER QUALITY DESIGN OBJECTIVES

The primary objectives of the City's stormwater quality requirements are to:

- Protect drinking water supplies.
- Protect public health and safety related to water resources.
- Maximize the quality of water resources to enhance the quality of life.
- Enable recreational opportunities where feasible and beneficial.
- Meet federal NPDES program requirements.

To achieve these objectives, the City requires that new and revisions to existing developments incorporate specific design features to improve the quality of stormwater runoff. Specifically, new development must implement one or more of the water quality design principles summarized in Section 3.1 as a means to achieve the specific WQCV design requirement(s) for the site, as discussed in Section 3.2.

3.1 Water Quality Design Principles

To achieve the stormwater quality design objectives for a new development, designs shall incorporate one or more of the following principles:

1. **Minimize the amount of runoff.** The total quantity of pollutants transported to receiving waters can be minimized most effectively by minimizing the amount of runoff. Both the quantity of runoff and the amount of pollutant wash-off can be reduced by minimizing the DCIA at a site. Impervious areas are considered connected when runoff travels directly from

roofs, driveways, pavement, and other impervious areas to street gutters, closed storm drains, and concrete or other impervious lined channels. Impervious areas are considered disconnected when runoff travels as sheet flow over grass and other pervious areas or through properly designed BMPs prior to discharge from the site.

Minimizing DCIA is a land development design philosophy that seeks to reduce paved areas and direct stormwater runoff to landscaped areas; grass buffer strips; and grass-lined swales to slow down the rate of runoff; reduce runoff volumes; attenuate peak flows; and facilitate the infiltration and filtering of stormwater. This approach increases the time of concentration for runoff in contrast to the historic stormwater engineering approach that resulted in drainage systems with a relatively rapid, large peak runoff rate and increased runoff volumes, even for relatively small storms.

A design approach that minimizes DCIA can be integrated into the landscape and drainage planning for any development. Drainage from rooftop collection systems, sidewalks, and driveways can be directed to landscaped areas; infiltration areas such as porous landscape detention; porous pavement; grassed buffer strips; or grass swales. Instead of using traditional solid curbing, curbing can be eliminated in some areas or slotted curbing can be used along with stabilized grass shoulders and swales. Residential driveways can use porous pavement or their runoff can be redirected to the lawn rather than the street. Large parking lots can minimize DCIA by using porous pavement to encourage local infiltration or storage. Green roofs may also be used as a tool to minimize DCIA.

2. **Maximize contact with grass and vegetated soil.** The opportunity for pollutants to settle can be maximized by providing maximum contact with grass and vegetated soil. Directing runoff over vegetative filter strips and grass swales enhances settling of pollutants as the velocity of flow is reduced.

3. **Maximize holding and settling time.** The most effective runoff quality controls reduce both the runoff peak and volume. By reducing the rate of outflow and increasing the time of detention storage, the infiltration of runoff and the settling of pollutants are maximized.

4. **Design for small, frequent storms.** Drainage stormwater systems for flood control are typically designed for large, infrequent storm events. In contrast, water quality controls shall be designed for small, frequent storm events. In Bella Vista, approximately 90% of all rainfall events total 1 inch or less. Studies indicate that many pollutants are frequently washed off in the “first flush,” typically considered the first ½-inch of runoff from directly connected impervious areas.

5. **Utilize BMPs in series where feasible.** Performance monitoring of BMPs throughout the country has shown that the combined effect of several BMPs in series can be more effective

in reducing the level of pollutants than just providing a single BMP at the point of discharge. For example, impervious areas should be directed first to vegetative filter strips, then to grass swales or channels, and then to extended detention basins, etc.

6. **Incorporate both flood control and stormwater quality objectives in designs, where practical.** Incorporating both flood control and water quality enhancement into a single stormwater management facility is encouraged whenever practical. Combining several objectives, such as water quality enhancement and flood control, maximizes the cost-effectiveness of stormwater management facilities.
7. **Provide special care for runoff from fueling areas and other areas having higher probabilities of concentration of pollutants.** Runoff from areas that pose a specific high hazard to the water quality of the runoff must be directed to a properly designed BMP that provides filtration; sedimentation; and/or treatment prior to discharge to receiving waters.

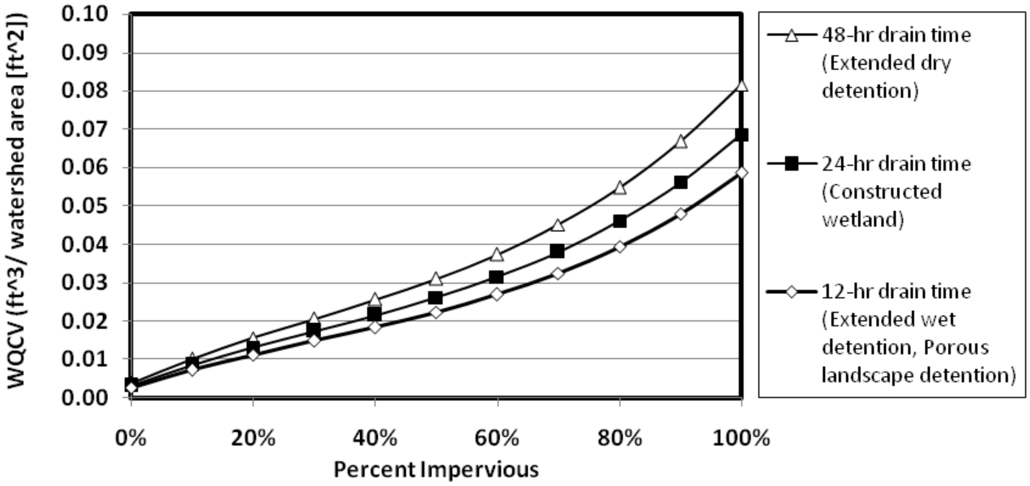
3.2 Water Quality Capture Volume

Studies indicate that small, frequently occurring storm events account for the majority of the stormwater runoff from urban drainage basins. Consequently, these frequent storms also account for a significant portion of the annual pollutant loads. Capture and treatment of stormwater from these smaller storms is the recommended design approach for water quality enhancement instead of designing for flood control facilities that focus on larger, less frequent storm events. Incorporation of both sets of criteria (i.e. small, frequent storms for water quality purposes versus larger storms for flood control) into a single stormwater management facility is encouraged, where practical.

For sites where water quality requirements apply, water quality BMPs shall be designed to capture and treat the WQCV of the site. The required WQCV (measured in cubic feet) is a function of the total area tributary to the storage facility and the impervious percentage of the tributary area. The WQCV curves in Figure WQ-1 are calculated for the City of Bella Vista and are based on approximately the 85th percentile runoff event (i.e. the top 85% of storm events in Bella Vista that generate runoff) (WEF and ASCE, 1998). The three curves represent the required WQCV for drain times of 12, 24, and 48 hours. Different drain times are dependent on the type of BMP and their relative effectiveness. Storage and treatment of the WQCV can be achieved through the use of the 4 BMPs described in Section 4.0. These BMPs and their respective drain times are:

- Extended dry detention basin 48 hour drain time
- Constructed wetland basin 24 hour drain time
- Extended wet detention basin 12 hour drain time
- Porous landscape detention 12 hour drain time

With an understanding of the type of BMP to be employed and the associated drain time, and the impervious percentage of the area tributary to the BMP, Figure WQ-1 can be used to determine the



WQCV per square foot of area tributary to the storage facility.

Figure WQ-1: Water Quality Capture Volume for Bella Vista, Arkansas

The required quantity of the WQCV can be reduced through the use of BMPs that minimize the DCIA at a site. Such BMPs promote infiltr site. These BMPs also serve to filter runoff that does leave the site. Three BMPs that can be used to reduce the necessary WQCV include:

- Porous pavement
- Vegetated filter strip/grass swale
- Grass swale

The reduction in the amount of necessary WQCV provided by use of these BMPs is described in Appendix A.

3.3 Other Important Considerations for BMP Selection

In addition to the design considerations above, the following factors shall be considered when selecting BMPs for a site:

- Pollutant Controlled: The BMPs shall effectively control pollutants known to be associated with the tributary land use.
- Reliability/Sustainability: Measures shall be effective over an extended time and be able to be properly maintained over time.

- Public Acceptability: BMP selection shall consider the expected response from the public, particularly neighboring residential properties, if any.
- Agency Acceptability: BMP selection shall consider the expected response of local, state, and federal agencies that will oversee the BMPs and their relationship to regulatory requirements.
- Public Safety: Control measures shall be evaluated for risks and/or liabilities that occur during the implementation or use of the device. Public safety is always one of the most important design considerations, not only for "traditional" drainage structures, but as well as for BMPs.
- Mosquito Control: The potential for mosquito breeding and the spread of related illnesses in stormwater BMPs must be addressed. The biggest concern is the creation of areas with shallow stagnant water and low dissolved oxygen which creates prime mosquito habitat. Other habitat characteristics that may enhance breeding include dense stands of vegetation that protect larvae from natural predators and soils with high organic content. While stormwater BMPs such as detention ponds and constructed wetlands often include these features, careful design in conjunction with proper management and maintenance of systems can effectively control mosquito breeding.

  The key to minimizing breeding is to avoid creating, or allowing the formation of, areas of shallow standing water. Studies indicate that pools of deep water (over 5 feet) and residence times less than 72 hours are less likely to breed mosquitoes. Stormwater BMPs with permanent pools are generally less of a concern than dry detention basins because of their greater depth. Therefore, dry detention basins must have outlets designed to drain within 48 hours.

Once the BMPs are installed, it is necessary to ensure that proper operation and maintenance are also being implemented. This may involve requiring covenants; long-term maintenance agreements; inspecting BMPs; designating individuals responsible for BMPs; and pollution prevention education. Modifications to BMPs over time may also be necessary if land uses or other factors change or if BMPs prove to be ineffective or a nuisance.

4.0 STRUCTURAL BEST MANAGEMENT PRACTICES

Structural BMPs described in this section include vegetated filter strips; grass buffers; grass swales; extended dry detention basins; extended wet detention basins; constructed wetland basins; modular block porous pavement; porous landscape detention; and proprietary packaged stormwater treatment systems. A brief description of each BMP is provided followed by design procedures and criteria and maintenance considerations. BMPs that capture and treat the WQCV are listed first followed by BMPs that do not store the WQCV but that help to reduce the DCIA to meet the required WQCV for a site.

Experience with many BMPs in northwest Arkansas is limited since the area was first designated an urbanized area in 2000. As experience with design, construction, monitoring, and maintenance builds, the number of BMPs and their design criteria will be adjusted.

4.1 Extended Dry Detention Basin

4.1.1 Description

An extended dry detention basin is designed to collect the runoff from smaller, more frequent rainfall events and release the runoff over a period of time. An extended dry detention basin collects and treats the “first flush” runoff which frequently has a higher concentration of pollutants typically found in urban runoff. The extended dry detention basin is an adaptation of the more typical detention basin used for flood control. The primary difference is the outlet design. Extended dry detention basins are considered to be "dry" because they are designed to not have a significant permanent pool of water remaining between storm runoff events. An extended dry detention basin can be used for regional or on-site treatment or as follow-up treatment in series with other BMPs.

Photograph 1: Properly designed & maintained extended dry detention basins can provide areas for site amenities.

An extended dry detention basin is typically designed and maintained to pool water for between 24 and 48 hours. In cases where there is a sufficient distance between the extended dry detention basin and the nearest residential land use (150 feet or more), it may be desirable to allow permanent pools to form and wetland vegetation to grow. These plants generally provide water quality benefits through pollutant uptake, but often generate public complaints when located near a residential area. In addition, the bottom of an extended dry detention basin will be the depository of all the sediment that settles out in the basin and, as a result, can be muddy with an undesirable appearance. To mitigate this problem, the designer may provide a small wetland marsh or ponding area in the basin’s bottom, which may be incorporated to promote biological uptake of certain pollutants.

In addition to reducing peak runoff rates and improving water quality, an extended dry detention basin can be designed to provide recreation; wildlife habitat; and open space benefits. Extended dry detention basins may also be used during land development activities to trap sediment from construction activities within the tributary drainage area. The accumulated sediment, however, must be removed after upstream land disturbances cease and before the basin is placed into final long-term use. As with other BMPs, public safety issues need to be addressed through proper design.

4.1.2 Design Considerations

Major considerations for the design of an extended dry detention basin are summarized below.

- ***Space requirements:*** It is imperative to plan the use of land correctly to account for an extended dry detention basin. The land required for an extended dry detention basin is about 0.5% to 2.0% of the total tributary development area, depending on DCIA and other factors.
- ***Presence of groundwater or base flow:*** Special consideration must be made when placing an extended dry detention basin in an area of high groundwater; wet weather springs; or areas that have other base flow. Consideration shall be given to constructing an extended wet detention basin or a wetland bottom in those cases. If an extended dry detention basin is constructed, a low flow channel shall be constructed to maintain positive drainage. Sites with persistent flow typically require a special design by a Professional Engineer registered in the State of Arkansas to appropriately address the unique conditions of the site.
- ***Flood control considerations:*** Extended dry detention basins shall be incorporated into a larger flood control basin whenever possible. In all cases, the embankments and spillway shall be designed to safely pass the 100-year flow as described in Chapter 6 – *Detention Design*.
- ***Geology and soils:*** Soil maps should be consulted, and soil borings may be needed to establish geotechnical design parameters; deeper basins; or when certain other sensitive geologic features, such as bedrock or karst formations are believed to be present. A regular concern with storage basins in Bella Vista is “puncturing” limestone during the course of excavation, thereby providing a conduit for stormwater into the shallow groundwater system.
- ***Inundation of open space:*** When multiple uses such as recreation or habitat creation are incorporated into a detention basin, a multiple-stage design shall be used to limit the frequency of inundation of passive recreational areas. Generally, the area within the WQCV section is not well suited for active recreation facilities such as ballparks, playing fields, and picnic areas. These are best located above the WQCV pool level as part of the flood control basin.
- ***Maintenance access:*** Access to critical elements of the pond, such as the inlet; outlet; spillway; low flow channel; and sediment collection areas must be provided for inspection and maintenance purposes. Each access must have a maximum grade of 10 percent and have an all-weather solid driving surface composed of gravel; crushed rock; concrete; asphalt; other pavement; or a reinforced and stabilized turf section.

4.1.3 Design Procedure and Criteria

The following steps outline the design procedure and criteria for an extended dry detention basin. Figure WQ-2 shows a representative layout of an extended dry detention basin.

1. ***Calculate design volume:*** Calculate the design volume, *V*, as follows. A multiplier of 1.25 is applied to account for sediment accumulation.

   $$V = WQCV \cdot 1.25 \qquad \textbf{(Equation WQ-1)}$$

   where WQCV is the Water Quality Capture Volume. See Section 3.2 for calculation methodology. This design volume accounts only for water quality and not for flood control.

2. ***Basin length to width ratio:*** The basin length to width ratio (L:W) shall be between 2:1 and 4:1, and the inlets shall be as far as possible from the outlet. Maximizing the distance between the inlet and the outlet as well as the shaping the pond so it has a gradual expansion from the inlet followed by a gradual contraction toward the outlet to minimize short-circuiting within the basin.

3. ***Basin side slopes:*** Basin side slopes shall be a maximum of 3H:1V. The use of flatter slopes in an upper zone and/or creation of a “safety bench” (a flatter zone near the edge of the pond) is encouraged to facilitate maintenance, access, and safety. The safety bench shall extend outward from the pond edge for a minimum distance of 10 feet, with a maximum slope of 5% and maximum water depth of 18 inches.

4. ***Basin geometry:*** Determine the preliminary basin geometry necessary to provide the design volume. Select the preferred depth of the extended dry detention basin, then solve for the basin bottom width that will provide adequate storage of the design volume. Assume a trapezoidal pond with the selected L:W ratio, side slopes, and basin depth.

5. ***Outlet structure:*** Design the outlet structure to release the WQCV (not the “design volume” from Step 1) over a 48-hour period. Outlet structures should include a perforated plate with a stainless steel well-screen or aluminum bar trash rack. Figure WQ-3 shows details for a perforated plate outlet structure.

   For perforated plates, select the perforation diameter, number of holes per row, row spacing and total number of rows to meet the requirements in Table WQ-1. Use the fewest number of columns possible to maximize the perforation diameter. This helps to reduce clogging problems. The perforation geometry shall then be modified as necessary to achieve an acceptable drain time.

Table WQ-1: Requirements for Water Quality Outlet Structures

Parameter	Perforated Plate Requirement
Minimum perforation diameter	1/2 inch
Maximum perforation diameter	4 inches
Minimum number of holes per row	1
Maximum number of holes per row	8
Minimum row spacing	4 to 8 inches [1]
Maximum row spacing	12 inches
Minimum riser pipe diameter	n/a

[1] The minimum row spacing for a perforated plate varies based on the perforation diameter.

6. ***Trash rack:*** Provide a trash rack of sufficient size to prevent clogging of the primary water quality outlet. Size the rack so as not to interfere with the hydraulic capacity of the outlet. Using the total outlet area and Figure WQ-4 to determine the minimum open area required for the trash rack. Use 50% of the total outlet area to calculate the trash rack's size. This accounts for the variable inundation of the outlet orifices. The trash rack shall extend 24 inches below the lowest perforation and a micro-pool shall be provided. The micro-pool is a small area of ponded water adjacent to the outlet that provides a flow path for water to discharge when the trash rack becomes clogged with floating trash and debris (see Figure WQ-2). The volume of the micro-pool shall be at least 5% of the WQCV.

7. ***Freeboard:*** A freeboard of at least 12 inches shall be provided above the 100-year water surface elevation for all extended dry detention basins (including facilities that are solely for water quality purposes and allow larger flows to "pass through") in accordance with Chapter 6 – *Detention Design*.

8. ***Low flow channel:*** A low flow channel shall be provided when groundwater or base flow exists in the basin or as required in Chapter 6 – *Detention Design*.

9. ***Vegetation types:*** Consideration shall be given to the use of native grasses and plants for pond bottoms, berms, and side slopes. However, the species selected shall be water tolerant in areas where periodic inundation is anticipated. It may be desirable to consult a plant specialist when selecting the appropriate type of vegetation. A list of plant species for different portions of an extended dry detention basin is provided in Table WQ-2 on the next page.

10. ***Maintenance access:*** Access to the facility shall be provided for inspection and maintenance. Grades of the access shall not exceed 10%, and a stabilized, all-weather driving surface must be provided.

11. ***Energy dissipation:*** Energy dissipation and erosion control shall be provided at inlets and outfalls in accordance with Chapter 6 – *Detention Design*.

Table WQ-2: Suggested Plant List for Extended Dry Detention Basins

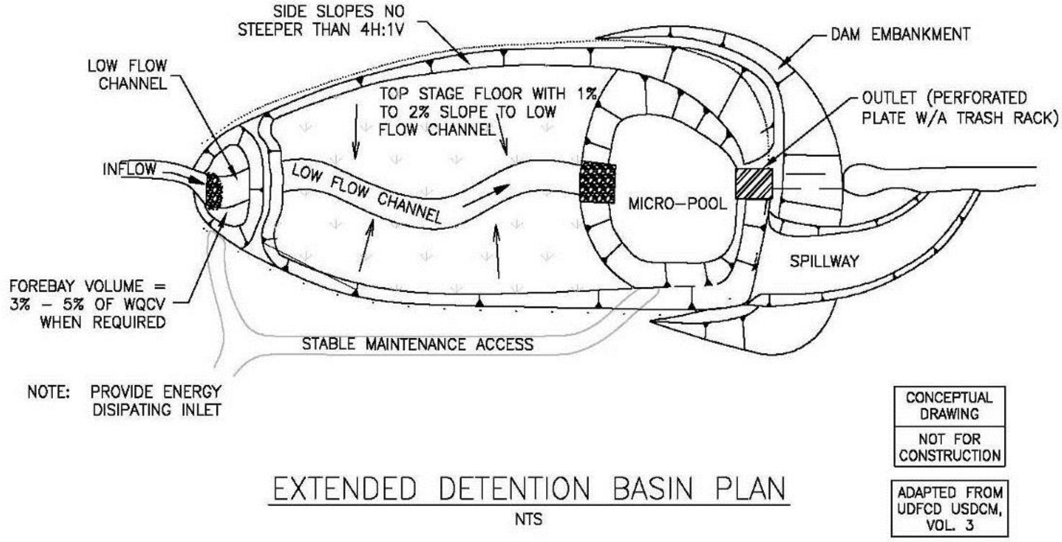
Basin Area	Plant Species (Botanical Name)	Plant Species (Common Name)	Planting Guidelines
Micro-pool	Equisetum hyemale	Horsetail/Scouring Rush	1 gallon plant spaced 30” O.C.
	Typha Angustifolia	Narrow-leaved Cattail	
	Pontederia cordata	Pickeral Weed	
	Scirpus zebrinus	Zebra Rush	
Pond Bottom	Juncus effuses	Soft Rush	1 gallon plant spaced 18” O.C.
	Acourus calamus	Sweet Flag	
	Carex stricta ‘Bowles Golden’	Bowles Golden Sedge	1 gallon plant spaced 24” O.C.
	Caltha palustris	Marsh Marigold	
	Peltandra virginica	Arrow Arum	
	Equisetum hyemale	Horsetail/Scouring Rush	1 gallon plant spaced 30” O.C.
	Typha Angustifolia	Narrow-leaved Cattail	
Interior side slopes	Juncus effuses	Soft Rush	1 gallon plant spaced 18” O.C.
	Acourus calamus	Sweet Flag	
	Carex stricta ‘Bowles Golden’	Bowles Golden Sedge	1 gallon plant spaced 24” O.C.
	Caltha palustris	Marsh Marigold	
	Iris ensata	Japanese Iris	1 gallon plant spaced 12” O.C.
	Iris fulva	Copper Iris	1 gallon plant spaced 15” O.C.

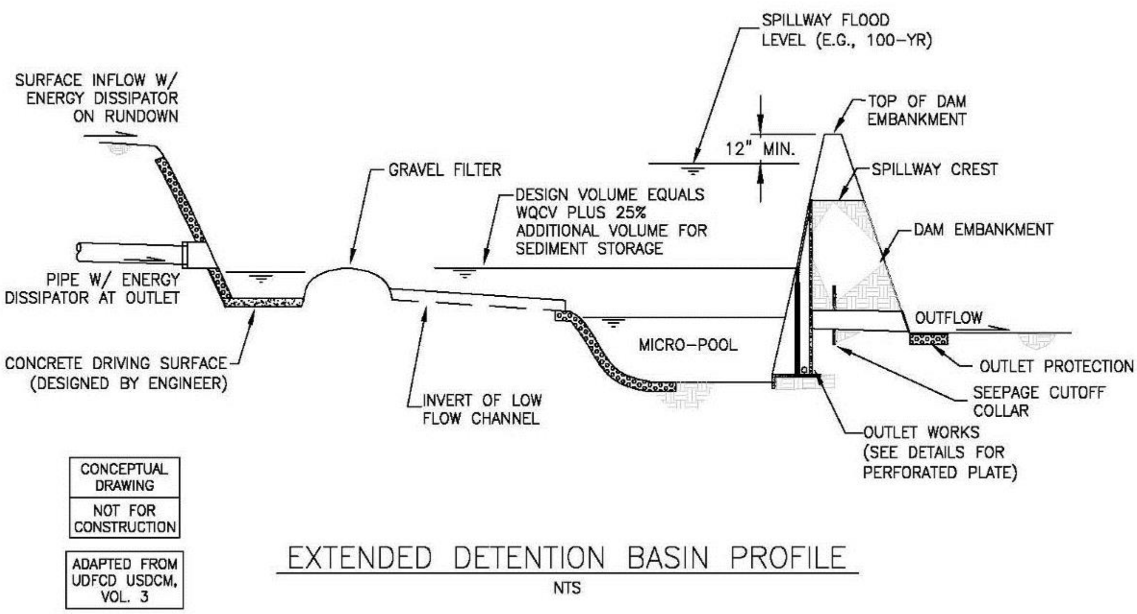
12. ***Combination of water quality and flood control facilities:*** Combining the water quality facility with a flood control facility is acceptable. Design of the flood control volume may assume the extended dry detention basin is dry at the beginning of the storm. Additional information can be found in Chapter 6 – *Detention Design*.

13. ***Neighborhood compatibility:*** Plan and design the facility with appearance and neighborhood compatibility as design objectives.

14. ***Forebay:*** A forebay is required for all extended dry detention basins. A forebay provides an opportunity for larger particles to settle out in the inlet area, which facilitates mechanical sediment removal. The forebay volume for the extended dry detention basin should be between 3% and 5% of the design volume. Outflow from the forebay to the basin shall be through a gravel filter designed to be stable under maximum design flow conditions. The top of the gravel filter shall be set equal to the stage of the design volume. The floor of the forebay shall be concrete and contain a low flow channel to define sediment removal limits. Assure that good, long term access to the perimeter of the forebay is provided, including necessary easements.

Figure WQ-2: Plan and Profile of an Extended Dry Detention Basin





4.1.4 Inspection and Maintenance

Inspection and maintenance shall be performed regularly to clean out the extended dry detention basin and its forebay when sediment accumulates to a depth of 6 inches. A depth gauge at the outlet will help to facilitate determining when sediment removal is necessary. Also, appearance may dictate more frequent cleaning.

Inspection should occur annually and after every major storm.

Eventually maintenance will be required to repair areas of erosion; to remove excessive trash and/or debris; to remove sediment clogging the outlet; or to reconstruct failing slopes due to piping under the pond's walls. Design grades must be maintained to ensure shallow ponding does not occur, particularly when the basin is located within 150 feet or less of residential areas.

Figure WQ-3: Details for a Perforated Plate and Trash Rack

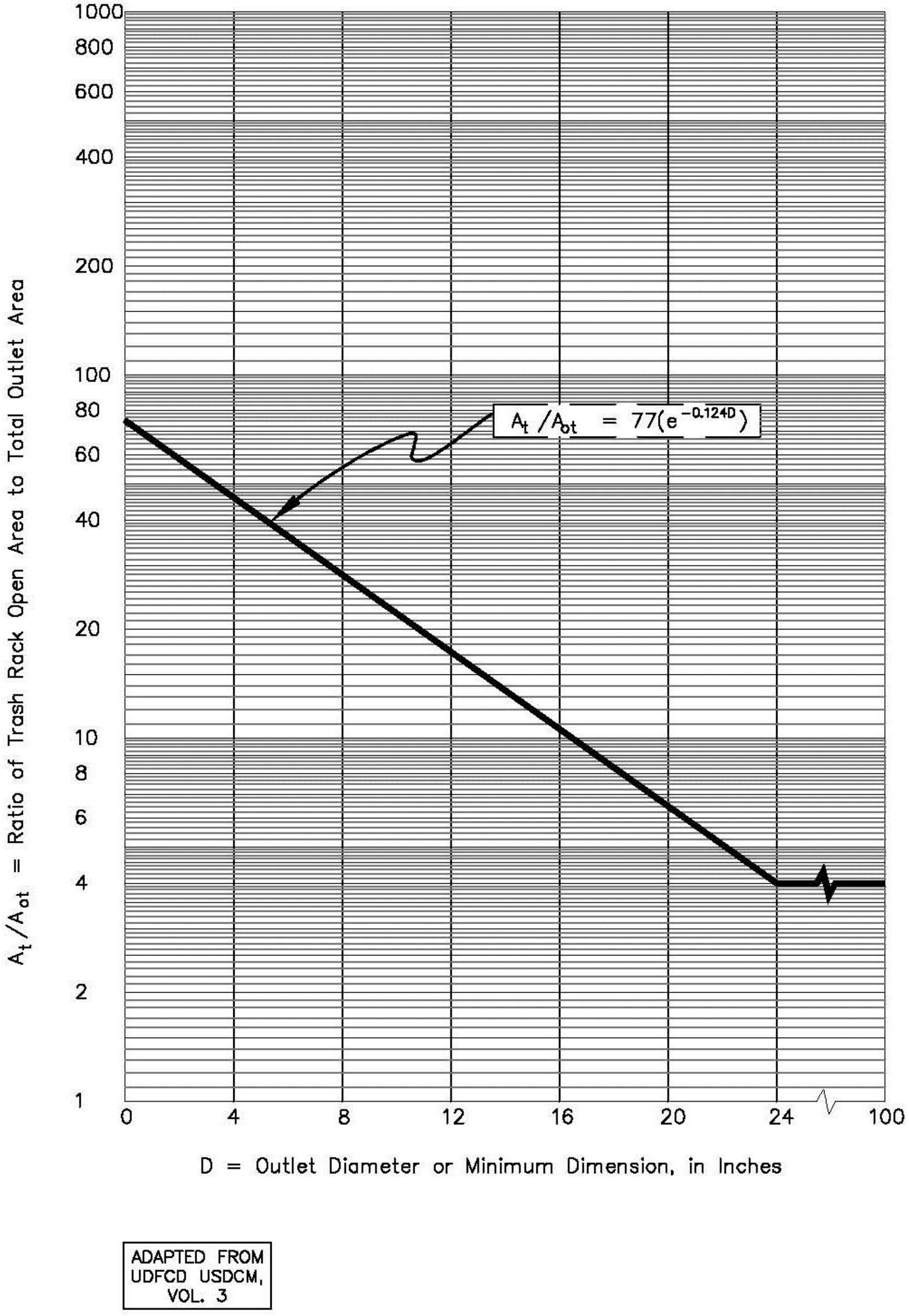
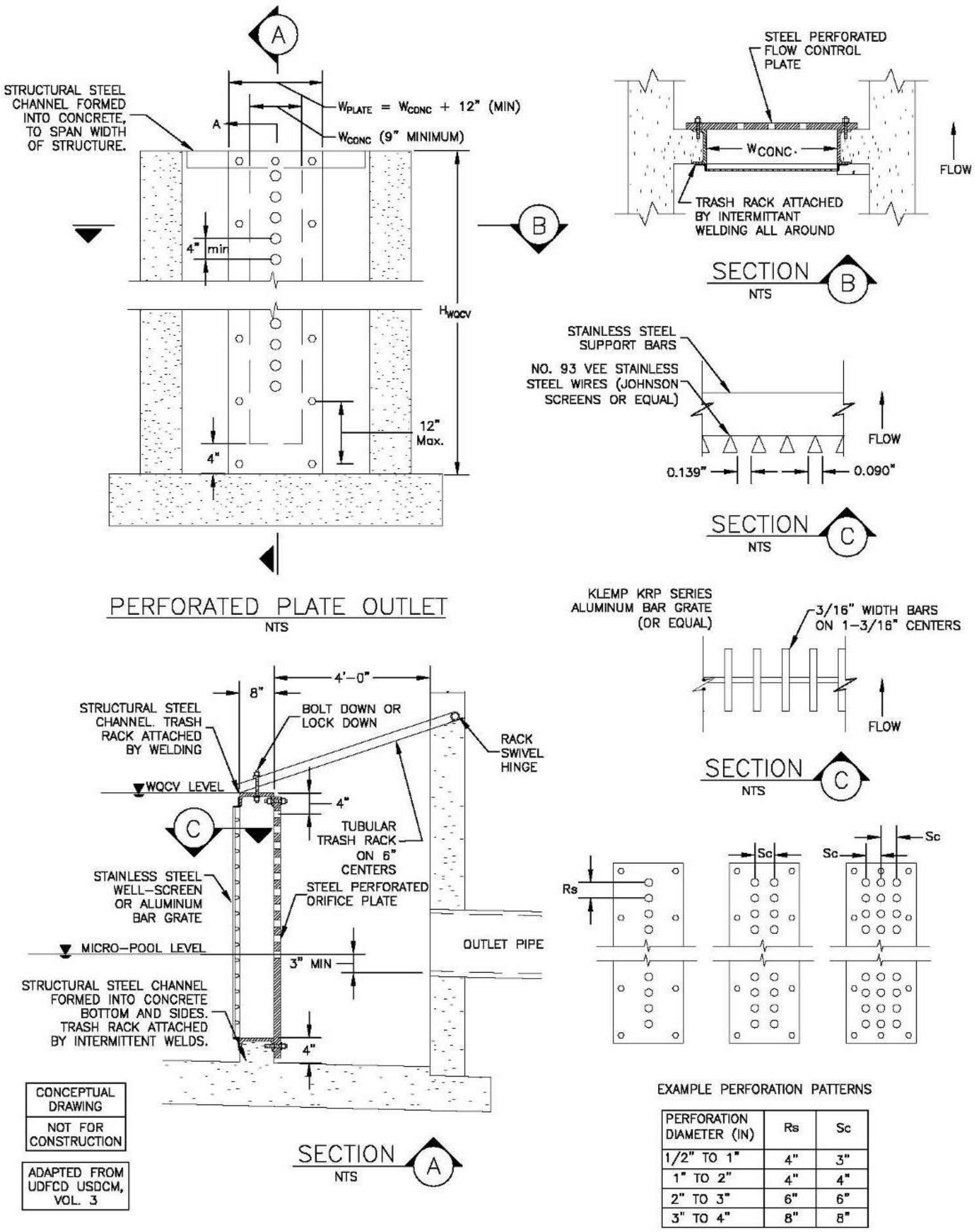


Figure WQ-4: Trash Rack Sizing



4.2 Extended Wet Detention Basin

4.2.1 Description

An extended wet detention basin differs from an extended dry detention basin in that it is designed with a permanent pool to provide water quality benefits. Also influent water mixes with the permanent pool water and most of the sediment deposits remain in the permanent pool zone. Similar to an extended dry detention basin, an extended wet detention basin is designed to collect the runoff from small frequent rainfall events and release the runoff over a period of time. The design collects and treats the “first flush” runoff, which frequently has a higher concentration of most pollutants found in urban runoff. Like an extended dry detention basin, an extended wet detention basin can be used for regional or on-site treatment and as follow-up treatment in series with other BMPs.

An extended wet detention basin provides a similar level of water quality treatment to an extended dry detention basin, but in less time because the outflow occurs above the bottom of the basin in the permanent pool and sedimentation continues after the captured surcharge volume is emptied.

Photograph 2: This extended wet detention basin is aesthetically pleasing; serves as an amenity to the community; & provides water quality benefits.

An extended wet detention basin shall be designed with the WQCV above the permanent pool, and the outlet structure shall be sized to drain the WQCV in approximately 12 to 15 hours. The reduced drain time (when compared to the extended dry basin) is due to water quality benefits provided by the permanent pool. Flood control volume may also be provided above the permanent pool by including modified outlet controls; a minimum of 12 inches of freeboard above the 100-year water surface; and a 100-year (minimum) overflow spillway.

Extended wet detention basins can be very effective in removing pollutants and, when properly designed and maintained, can satisfy multiple objectives such as the creation of wildlife habitats; provision of recreational, aesthetic, and open space opportunities; and inclusion into a larger, regional flood control basin. An extended wet detention basin must be carefully designed and maintained to address safety concerns; bank erosion; sediment removal; and upstream and downstream impacts to waterways.

Extended wet detention basins have the potential for floating litter; debris; algae growth; nuisance odors; and mosquito problems. Aquatic plant growth can be a factor in clogging outlet works. The permanent pool can attract waterfowl, which can add to the nutrient and bacteria loads entering and leaving the pond. Design considerations for an extended wet detention basin are described below in Section 5.4.2. Refer to Chapter 6 – *Detention Design* for additional design criteria.

4.2.2 Design Considerations

Major considerations for the design of an extended wet detention basin are summarized below:

Basin volume: The total basin volume of an extended wet detention basin facility consists of: 1) the permanent pool volume; 2) the WQCV above the permanent pool; and 3) the flood control volume above the WQCV (if included). Care shall be taken to assess the complete water budget of the watershed to account for runoff; base flow; evaporation; evapo-transpiration; seepage; and other losses to assure the permanent pool can be maintained.

Design considerations unique to an extended wet detention basin: In addition to the considerations typically given to an extended dry detention basin, design considerations for an extended wet detention basin include:

- Water balance calculations shall be conducted (including inflow; outflow; evaporation; and subsurface flows in and out of the pond) to assure there is adequate flow to maintain a desirable permanent pool and provide adequate flushing through the basin.
- Edge treatments that will prevent bank erosion must be considered.
- To minimize the potential of algae growth, a minimum permanent pool depth of 6 feet must be provided. Other control methods in addition to the 6-foot pool depth (such as aeration or upstream BMPs) may also be provided. If an algae problem develops, the property owner, POA, or other designated person must demonstrate that a reasonable effort to remedy the condition has been made within one month of confirmation of the on-going problem.
- Basin lining must be provided to ensure the basin is watertight and a permanent pool will be maintained. This is particularly important where karst geology exists and the potential for a leaky pond is high. Lining ponds can be difficult and expensive. A regular concern with storage basins in Bella Vista is “puncturing” limestone during the course of excavation, thereby providing a conduit for stormwater to escape or leak into the shallow groundwater system.
- The embankments must be carefully designed with keys and cutoff collars to prevent seepage and piping that can lead to loss of the permanent pool or dam failure.
- A detention time of 12 to 15 hours may be used due to the inherent sedimentation that occurs in a wet basin.
- A fence surrounding the pond is required unless the pond design incorporates a safety bench.

4.2.3 Design Procedure and Criteria

The following steps outline the design procedure and criteria for an extended wet detention basin. Figure WQ-5 shows a representative layout for an extended wet detention basin.

1. ***Residence time:*** For large ponds, if the residence time for the permanent pool volume is 24 hours or greater during a 2-year, 24-hour storm event, the surcharge WQCV is not required above the permanent pool. The residence time, *t* (hr), is calculated by dividing the permanent pool volume by the average inflow rate during a 2-year, 24-hour storm event, as shown in Equation WQ-2. The 2-year, 24 hour average inflow rate is equal to the total event runoff volume divided by the event duration (24 hours). The runoff volume must be calculated using the appropriate hydrologic analysis method presented in Chapter 5 – *Determination of Stormwater Runoff*.

$$t = \frac{V_p}{Q_{2-yr\ avg} \cdot 3600}$$ **(Equation WQ-2)**

2. ***WQCV (if needed*):** If the residence time in the permanent pool is less than 24 hours, the WQCV shall be added above the permanent pool and shall be calculated using the method provided in Section 3.2 of this chapter. The WQCV is the surcharge volume above the permanent pool. Generally, an extended wet detention basin shall be located away from any offsite drainage crossing the site to ensure proper function. If offsite area is drained through the facility, that area must be included in all volume calculations.

3. ***Minimum volume required:*** The minimum volume required for the permanent pool is a function of the WQCV and is calculated using Equation WQ-3.

   $$V_p = 1.2 \cdot WQCV$$ **(Equation WQ-3)**

   The permanent pool shall have a depth of at least 6 feet to decrease the likelihood of algae growth. An option to improve water quality treatment and minimize bank erosion is to provide a littoral zone 18 inches deep and 10 feet wide for aquatic plant growth along the perimeter of the permanent pool. This also serves as a safety bench and enhances pond safety.

4. ***Outlet works:*** The outlet is to be designed in accordance with requirements set forth in the Design Procedure and Criteria for an extended dry detention basin, with the exception being that the outlet must be designed to release the WQCV over a 12- to 15-hour period.

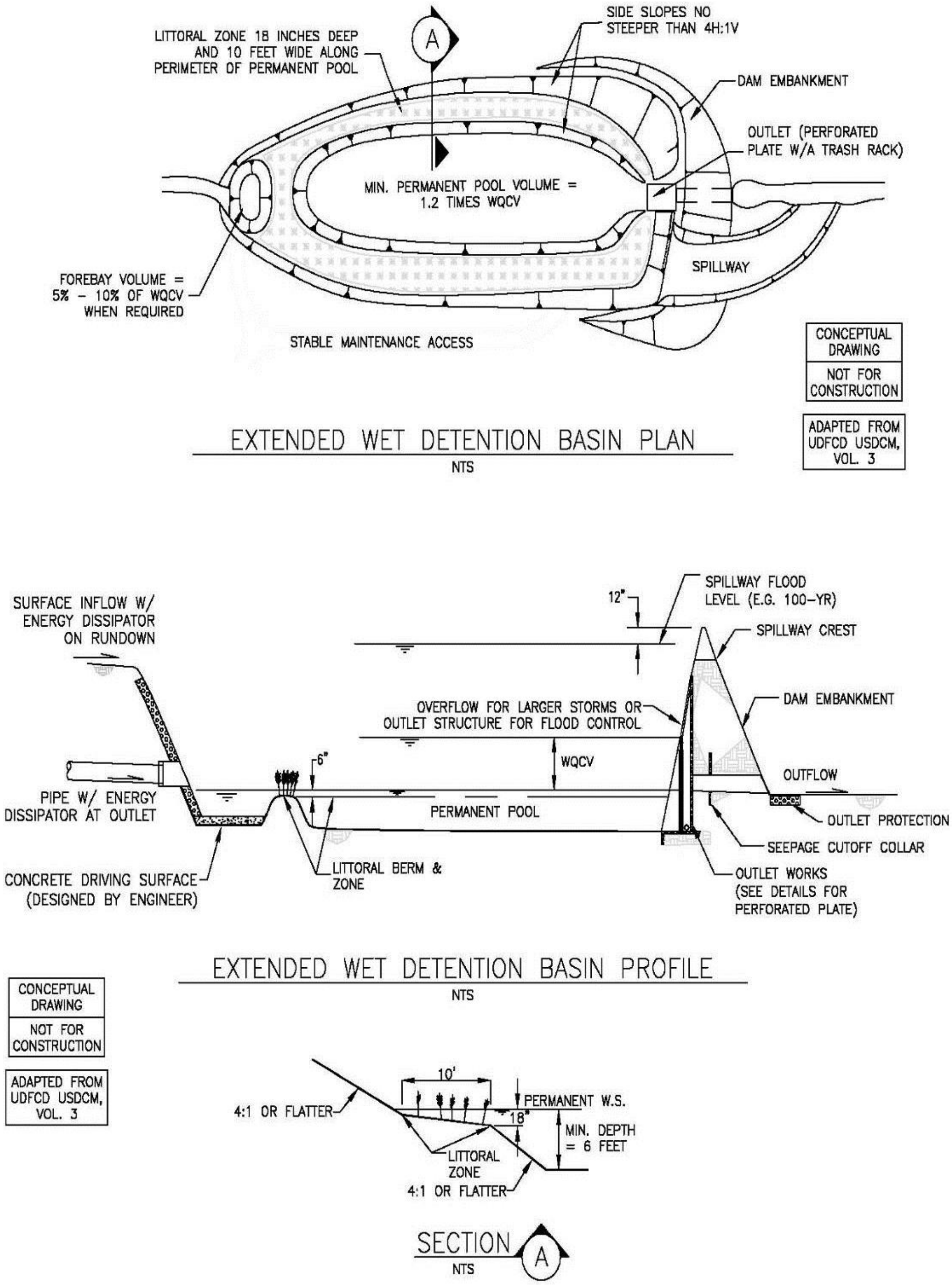
5. ***Trash rack:*** The trash rack is to be designed in accordance with requirements set forth in the Design Procedure and Criteria for an extended dry detention basin. The trash rack shall extend at least 24 inches below the permanent pool level.
6. ***Basin length-to-width ratio:*** The basin length to width ratio shall be between 2:1 and 4:1. Maximizing the distance between the inlet and the outlet as well as the shaping the pond so it has a gradual expansion from the inlet followed by a gradual contraction toward the outlet to minimize short-circuiting within the basin.
7. ***Basin side slopes:*** Basin side slopes above the permanent pool shall be no steeper than 3:1, preferably 5:1 or flatter to limit rill erosion and facilitate maintenance and safety. The use of flatter slopes in an upper zone and/or creation of a “safety bench” (a flatter zone near the edge of the pond) is encouraged to facilitate maintenance, access, and safety. The safety bench shall extend outward from the pond edge for a minimum distance of 10 feet, with a maximum slope of 5% and maximum water depth of 18 inches.
8. ***Establishing vegetation:*** A 4- to 6-inch organic topsoil layer, vegetated with aquatic species, shall be provided on the littoral bench, if incorporated. Areas of vegetation above the permanent pool shall include water tolerant species in anticipation of periodic inundation. It may be desirable to consult a plant specialist when selecting the appropriate type of vegetation. A list of plant species for different portions of extended detention basins are provided in Table WQ-2.
9. ***Maintenance access:*** Access to the basin bottom, forebay, and outlet area must be provided for inspection personnel and maintenance vehicles. Grades of the access shall not exceed 10% and a stabilized, all-weather driving surface must be provided.
10. ***Erosion protection:*** Provide erosion protection at all inlets to the pond.
11. ***Forebay:*** A forebay shall be required for Extended Wet Detention Basins. Forebays provide an opportunity for larger particles to settle out in a controlled location where sediment and debris can be more easily removed. Install a solid pervious driving surface on the bottom and sides below the permanent water line to facilitate sediment removal. A berm consisting of rock and topsoil mixture shall be part of the littoral bench to create the forebay. The forebay volume within the permanent pool volume shall be between 5% and 10% of the design WQCV.

4.2.4 Inspections and Maintenance

Inspections shall occur annually as well as after every major storm.

Intermittent maintenance may be necessary to remove floating trash; debris; and algae from the surface of the permanent pool. If an algae problem develops, the property owner, POA, or other designated person must make a reasonable effort to remedy the condition. This may include using chemical treatments. It may also be necessary to remove accumulated sediments from the pond bottom on a regular basis. A maintenance plan and/or long-term agreement shall be recorded with the City.

Figure WQ-5: Plan, Profile, and Details of an Extended Wet Detention Basin



4.3 Constructed Wetland Basin

4.3.1 Description

A constructed wetland basin is a shallow extended wet detention basin that requires a perennial base flow to maintain microorganism habitat and to permit the growth of rushes, willows, cattails, and reeds. The wetland vegetation functions to slow runoff and allow time for sedimentation, filtering, and biological uptake. Existing small wetlands along ephemeral drainageways could be enlarged and incorporated into a constructed wetland system. Such action, however, requires the approval of federal and state regulators. The City of Bella Vista development approval process would also have to approve such a change to any drainageway within their jurisdictional control.

Photograph 3: Constructed wetland basins can provide multiple benefits. Proper design is essential to avoid nuisance conditions, such as algae growth.

When properly designed, a constructed wetland basin can offer several potential advantages, such as natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. Additionally, the constructed wetland basin can act as part of a multi-use facility by providing flood control storage above the WQCV pool or by providing effective follow-up treatment to other BMPs (such as onsite BMPs or source controls) that rely upon settling of larger sediment particles.

The primary constraint of a constructed wetlands basin is the need for a relatively continuous base flow to ensure viable wetland growth. In addition, silt and algae can accumulate and be flushed out during larger storms which can adversely affecting downstream water quality unless the wetlands are properly designed and built. Also, in order to maintain healthy wetland growth, the surcharge depth for WQCV above the permanent water surface cannot exceed roughly 24 inches. Another potential concern is that a wetland BMP may require a Section 404 permit from the USACE for significant maintenance if the site of the facility is considered a jurisdictional wetland. Jurisdictional wetlands are subject to strict regulatory requirements will be administered by the USACE. These issues shall be reviewed with the USACE during the design process.

The City will review wetlands projects on a case-by-case basis. The City reserves the right to deny use of a constructed wetland because of these potential concerns.

4.3.2 Design Considerations

Major considerations for the design of a constructed wetland basin are summarized below:

Water budget: Development and analysis of a water budget is needed to show the net inflow of water is sufficient to meet all the projected losses (such as evaporation, evapo-transpiration, and seepage for each season of operation) and ensure a perennial base flow. Insufficient inflow can cause the wetland to become salty, brackish, briny, sterile, or die.

Soils analysis: Loamy soils are needed in a wetland bottom to permit plants to take root. Exfiltration through a wetland bottom cannot be relied upon because the bottom should be either covered by soils of low permeability or because the groundwater is higher than the wetland's bottom. If karst topography is suspected, then the possibility of leakage out of the bottom of the bottom should be designed against.

Longitudinal slope: Wetland basins require a near-zero longitudinal slope, which can be provided using embankments.

4.3.3 Design Procedure and Criteria

The following steps outline the design procedure for a constructed wetland basin. Figure WQ-6 illustrates an idealized constructed wetland basin.

1. ***WQCV:*** Calculate the WQCV using the method described in Section 3.2 of this chapter. The WQCV is the surcharge volume above the permanent wetland pool.
2. ***Permanent pool volume:*** The volume of the permanent wetland pool shall be at least 75% of the WQCV.
3. ***Pool area and depth:*** Proper distribution of wetland habitat is needed to establish a diverse plant community. Distribute pond area in accordance with Table WQ-3.

Table WQ-3: Wetland Pond Water Design Depths

Components	% of Permanent Pool Surface Area	Water Design Depth
Forebay, outlet and free water surface areas	30% to 50%	24 to 48 inches
Wetland zones with emergent vegetation	50% to 70%	6 to 12 inches*

* 33% to 50% of this zone should be 6 inches deep.

4. ***WQCV surcharge depth:*** The surcharge depth of the WQCV above the permanent pool's water surface shall not exceed 24 inches.

5. ***Outlet works:*** The outlet works shall be designed in accordance with requirements set forth for extended dry detention basins in Section 4.1, with the following exceptions:
    a. Design the outlet works to release the WQCV in 22 to 28 hours.
    b. Outlet design shall consider the increased potential for wetland vegetation growth and clogging around the outlet. A micro-pool shall be incorporated into the outlet design to allow sub-surface flow to go under the pool surface (where debris typically accumulates against the trash rack) and through the lower portion of the trash rack.
6. ***Trash rack:*** The trash rack shall be designed in accordance with requirements set forth for extended detention basins in Section 4.1. The trash rack shall extend at least 24 inches below the permanent pool level.
7. ***Basin Usage:*** Determine whether flood storage or other uses will be provided and design accordingly for combined uses.
8. ***Basin length-to-width ratio:*** The basin length to width ratio shall be between 2:1 and 4:1. Maximizing the distance between the inlet and the outlet as well as the shaping the pond so it has a gradual expansion from the inlet followed by a gradual contraction toward the outlet to minimize short-circuiting within the basin.
9. ***Basin side slopes:*** Basin side slopes shall be no steeper than 4:1, preferably 5:1 or flatter to facilitate maintenance, safety, and access. The use of flatter slopes in an upper zone and/or creation of a “safety bench” (a flatter zone near the edge of the pond) is encouraged to facilitate maintenance, access, and safety. The safety bench shall extend outward from the pond edge for a minimum distance of 10 feet, with a maximum slope of 5% and maximum water depth of 18 inches.
10. ***Water balance:*** A net influx of water must be available through a perennial base flow and must exceed the losses. A hydrologic balance shall be used to estimate the net quantity of base flow available at a site.
11. ***Energy dissipation:*** Provide energy dissipation at all inlets and outlets to limit sediment re-suspension.
12. ***Forebay:*** Design considerations and criteria for extended wet detention basins (described in Section 4.2) shall be followed.
13. ***Wetland vegetation:*** Cattails, sedges, reeds, and other native wetland grasses shall be planted in the wetland bottom. Qualified professionals must be utilized to develop the planting plan and to plant the wetland vegetation. Berms and side-slopes shall be planted with native or turf-forming grasses. Initial establishment of the wetland requires control of the water depth. After planting wetland species, the permanent wetland pool shall 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 shall be raised to its final operating level. Suggested plant species are provided in Table WQ-2. The planting plan for wetlands must be developed by a qualified Wetland Scientist or a Landscape Architect with wetland experience. The wetland plantings must be guaranteed to have a minimum survival rate of three years.

14. ***Maintenance access:*** Provide inspection personnel and maintenance vehicular access to the forebay and outlet areas for inspections; maintenance; and removal of bottom sediments. Maximum grades shall not exceed 10% and a stabilized, all-weather driving surface must be provided.

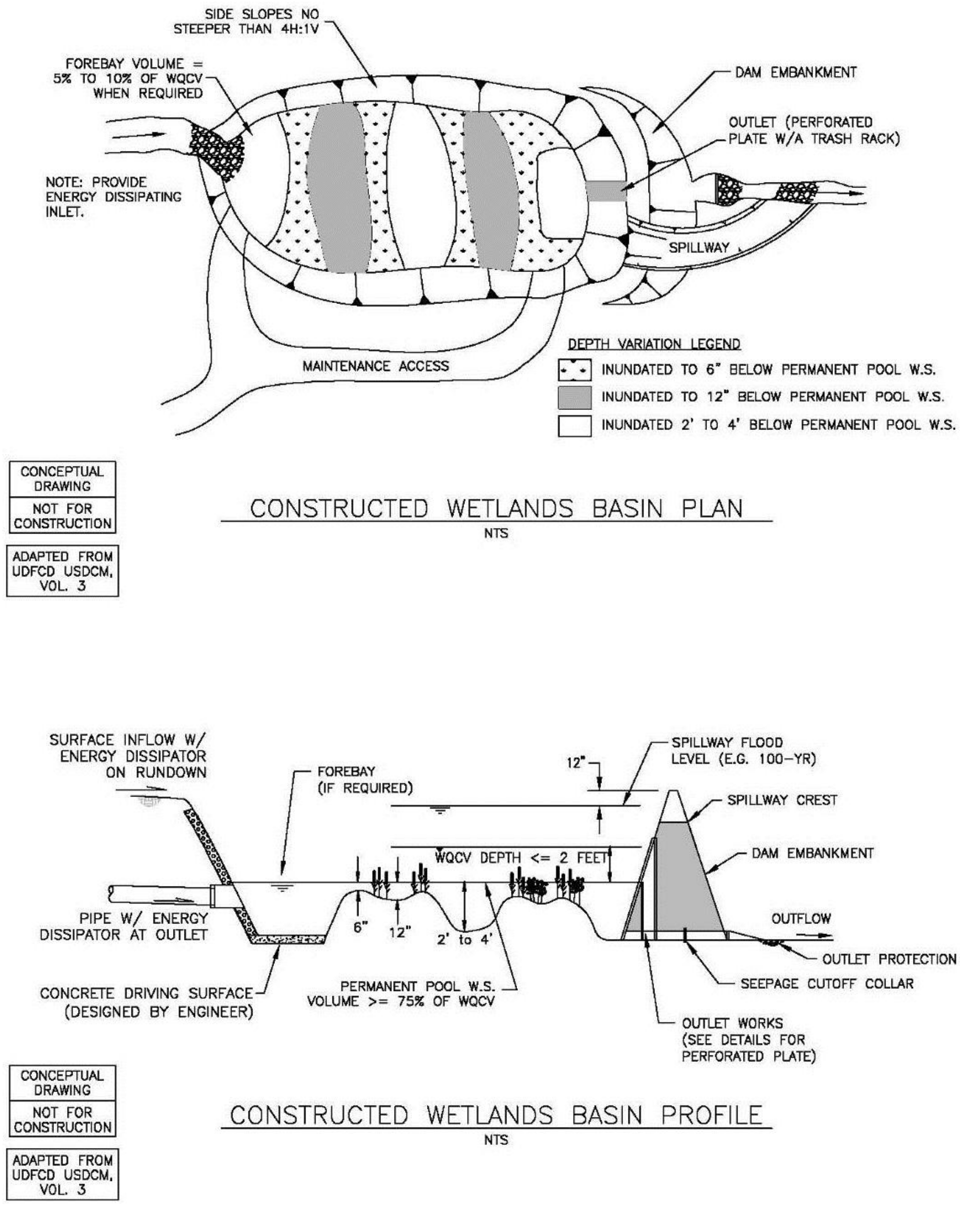
4.3.4 Maintenance

Because proper maintenance of a constructed wetland is necessary to achieve optimal performance, submittal of a maintenance plan for the wetlands will be required for the City to approve a constructed wetlands project. The maintenance plan must include tasks and schedule for both routine and non-routine maintenance, including the following major categories:

- Conduct routine inspections semi-annually and perform minor maintenance, such as the removal of accumulated litter and debris; burrows; integrity of the outlet; and sediment accumulation.
- Perform non-routine maintenance based on the findings from the routine maintenance inspections. Remove accumulated sediment in forebay and main pool basin, as necessary. Removal of sediment from the main pool is required whenever sediment accumulation occupies approximately 20% of the WQCV. Periodic sediment removal is also needed if water movement within the wetland is restricted.

The USACE shall be consulted regarding maintenance of a wetland with respect to Section 404 Permit requirements.

Figure WQ-6: Plan and Profile of an Idealized Constructed Wetland Basin



4.4 Porous Landscape Detention

4.4.1 Description

Porous landscape detention consists of a low-lying vegetated area underlain by a porous media bed with an under-drain pipe, which gradually dewaters the porous media bed and discharges the runoff to a nearby channel, swale, or drainage system. A shallow surcharge zone exists above the porous landscape detention for temporary storage of the WQCV. During a storm, accumulated runoff ponds in the vegetated zone and gradually infiltrates into the underlying porous media bed.

Photograph 4: Porous landscape detention can be integrated into a wide variety of development conditions. They can be particularly beneficial for sites with limited green space, such as this parking lot.

Porous landscape detention is ideally suited for small installations such as parking lot islands, street medians, roadside swale features, and site entrance or buffer features. This BMP may also be implemented at a larger scale, serving as an infiltration basin for an entire site, provided the WQCV and average depth requirements contained in this section are met. Vegetation may consist of turf or native grasses, shrubs, trees, and/or other vegetative plantings.

The primary disadvantage of porous landscape detention is the potential for clogging if moderate to high quantities of silts and clays are allowed to flow into the facility. Also, this BMP shall be avoided within 20 feet of building foundations, although an under-drain and impermeable liner can address the concern of saturation, shrink, and swell near a foundation. Additionally, this BMP has a relatively flat surface area and may be difficult to incorporate into steeply sloping terrains.

4.4.2 Example Applications

The photograph to the right shows an example of a relatively large porous landscape detention facility featuring a dense turf grass bottom with a putting green.

4.4.3 Design Considerations

When implemented using multiple small installations on a site, it is important to accurately account for each upstream drainage area tributary to each porous landscape detention site to make sure that each facility is properly sized for the tributary area.

Photograph 5: Porous landscape detention facilities can be implemented in many creative ways.

4.4.4 Design Procedure

The following steps outline the porous landscape detention design procedure and criteria. Figure WQ-7 shows a cross-section for a porous landscape detention.

1. ***WQCV:*** Calculate the WQCV based on Section 3.2 of this chapter. The storage volume equals the WQCV.

2. ***Minimum surface area:*** Calculate the minimum required surface area, A_s, as follows:

$$A_S = \frac{WQCV}{d_{av}} \qquad \textbf{(Equation WQ-4)}$$

   in which:

   d_{av} = Average depth of the porous landscape detention basin (between 6- and 12-inches)

3. ***Vegetation growth medium:*** To treat stormwater and also serve as a medium for plant growth, provide a well-mixed layer composed of Planting Soil, Mulch, and sand (ASTM C-33), as shown in Figure WQ-7. The depth of the media should range from 18 to 36 inches in cases where deeper-rooted plants will be used. Compost should not be used for the growth media. The media should have a maximum hydraulic conductivity of approximately 20 inches/hour while sustained plant growth prefers with less than 8 inches/hour. The top surface should be as flat as possible, with side slopes steeper than 4:1 not recommended. If steeper side slopes are necessary, use vertical walls to contain the growth medium.

4. ***Sub-base:*** Install an 8-inch layer of No. 57 aggregate. Install 4-inch under-drains at the bottom of the granular layer. Underdrains shall be spaced at a maximum of 20 feet with a minimum slope of 0.2%. Underdrains shall connect to an existing drainage system or daylight to an appropriate stormwater drainage channel. Use porous geo-textile fabric to line the entire basin bottom and

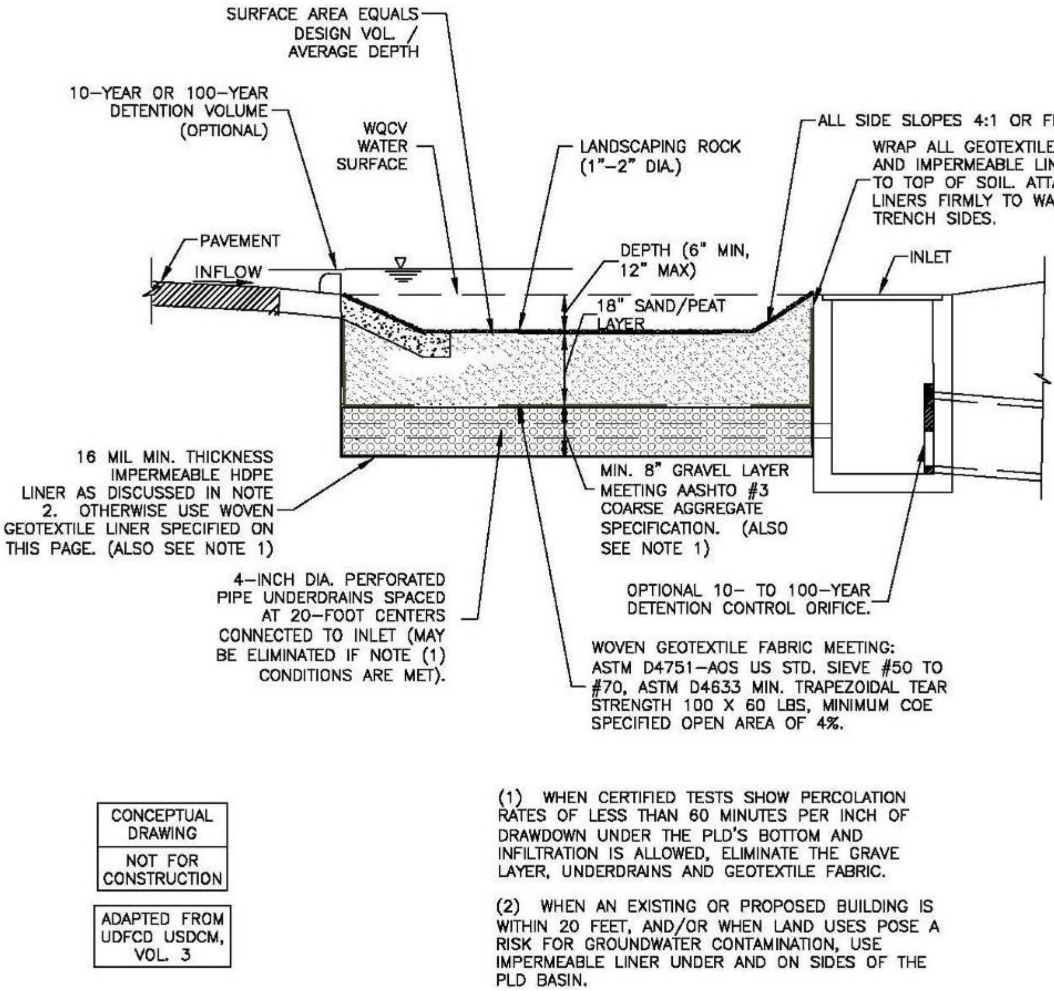
sides. When certified tests show percolation rates of less than 60 minutes per inch of drawdown under the bottom of the basin and infiltration is acceptable, eliminate the gravel layer, under-drains and geo-textile fabric.

5. ***Impermeable liner (if needed):*** When an existing or proposed building is within 20 feet, and/or when land uses pose a risk for groundwater contamination, use an impermeable liner under and on all sides of the porous landscape detention basin.

4.4.5 Maintenance

Periodic maintenance will be necessary for the landscaping in the porous landscape detention. Porous landscape detention eventually will require cleanout and replacement of the porous media. If a high level of silts and clays are allowed to flow into the facility, the porous media may become clogged and require replacement more often. The Low Impact Development Center website (www.lowimpactdevelopment.org) provides additional design and maintenance recommendations for bio-retention cells, which are comparable to porous landscape detention.

Figure WQ-7: Porous Landscape Detention



4.5 Modular Block Porous Pavement

4.5.1 Description

Modular block porous pavement is intended for use in low vehicle movement areas such as residential driveways and parking pads to accommodate vehicles while simultaneously facilitating stormwater infiltration from precipitation on the porous pavement. These pavements can also be used for residential street parking lanes; maintenance roads and trails; emergency vehicle and fire access lanes in apartment or office complexes; low vehicle movement zones such as parking aprons and maintenance roads; and emergency stopping lanes, crossovers, or parking lanes on divided highways.

Modular block porous pavement consists of open void concrete block units laid on a gravel sub-grade. The surface voids are filled with sand or sandy loam turf. An alternate approach is to use reinforced grass porous pavement, consisting of grass turf reinforced with plastic rings and filter fabric underlain by gravel. The modular block porous pavement shall be mildly sloped, but not completely flat, to decrease the effective imperviousness of a site without creating standing water problems. The porous pavement can be considered to reduce the imperviousness over the installation area by approximately 25%, depending on the exact void ratio of the block.

Photograph 6: Modular block porous pavement helps to reduce imperviousness and promote infiltration in low vehicle movement areas.

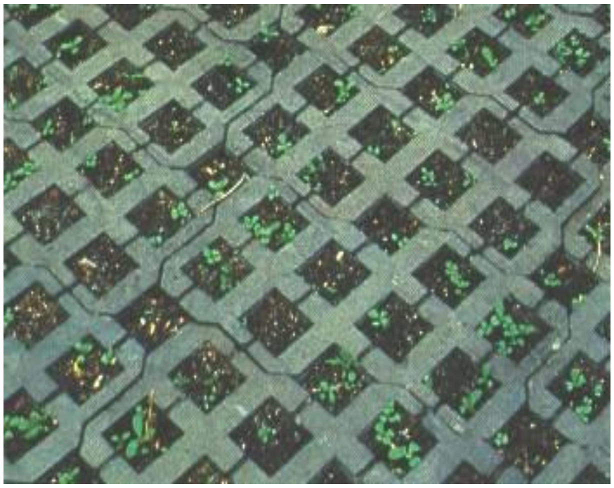
In addition to serving the function of removing particulate pollutants and other constituents, similar to a sand filter application, modular block porous pavement can reduce flooding potential by infiltrating or slowing down runoff. Modular block patterns, colors, and materials can serve both functional and aesthetic purposes.

The primary disadvantages of modular block porous pavement are cost and the lack of performance data in areas that are subject to severe freeze-thaw cycles. However, observations indicate that such pavements function well in freeze-thaw cycles when properly designed and installed. Other potential disadvantages are uneven driving surfaces; potential traps for high-heeled shoes; and the cost of restorative maintenance can be relatively high if the system gets plugged with sediment. Maintenance of modular block porous pavement is the responsibility of the property owner or POA.

4.5.2 Design Considerations

Drainage - Modular block porous pavement must be installed with a free draining subgrade or an under-drain system to ensure drainage of the gravel subgrade. This BMP may not be used at industrial, transportation, or similar sites where chemical or petroleum spills are a possibility unless an impermeable membrane is installed to prevent groundwater contamination.

Vehicle access lanes - Vehicle movement (i.e. not parking) lanes that lead up to the modular block porous pavement need to be solid asphalt or concrete pavement.



Photograph 7: A variety of designs are available for porous pavement that can be selected to best fit the site surroundings.

Void area - Multiple block patterns are acceptable, provided they have at least 20% (40% is preferred) of the surface area as voids. Upon installation, every effort shall be made to assure even flow distribution over the entire porous surface. The pervious area is generally assumed equal to the surface void area of the modular block.

4.5.3 Design Procedure and Criteria

The following steps outline the modular block porous pavement design procedure and criteria.

Figure **WQ-**8 shows cross-sections of modular block installation and its subgrade.

1. ***Block selection:*** Select appropriate modular blocks that have at least 20% (40% is preferred) of the surface area open and have a minimum thickness of 3 inches. The manufacturer's installation requirements shall be followed with the exception that Void Space Fill Material and Base Course minimum dimensions and requirements in this section shall be followed.

2. ***Void space fill material:*** The modular block porous pavement openings shall be filled with ASTM C-33 graded sand (fine concrete aggregate) and shall be placed on a leveling course of the sand that is at least 1-inch thick.

3. ***Base course and geo-technical report:*** The base course shall be AASHTO # 3 coarse

aggregate with all fractured surfaces and have a minimum depth of 8 inches. For drainage volume calculations, assuming 30% of the total base coarse volume to be open pore space. Unless an under-drain is provided, at least 6 inches of the subgrade underlying the base course shall be sandy and gravely material with a maximum clay fraction of 1%. The geo-technical characteristics of the base course and subgrade shall be documented in a report from a geo-technical engineer.

4. ***Geo-textile:*** Place a woven geo-textile fabric *over* the base course as shown in
5. Figure **WQ-**8. Use a geo-textile material that meets the following requirements: ASTM D4751 – AOS U.S. Std. Sieve #50 to #70; D4632 – Trapezoidal tear strength over 100 x 60 lbs; and USACE specified minimum open area greater than 4%.
6. ***Barrier for pollutants (if needed:*** If the contributing drainage area is a land use with potential activities that store; manufacture; or handle fertilizers, chemical, or petroleum products; install an uninterrupted, puncture-free 16-mil polyethylene or PVC impermeable membrane; and provide an under-drain system *under* the base course. Otherwise, to permit infiltration, use a geo-textile material that meets the ASTM requirements listed under Item 4 above.
7. ***Geo-textile placement:*** Place geo-textile fabric and impermeable membrane by rolling fabric parallel to the contours, starting at the most downstream part of the pavement. Provide a minimum of 18 inches overlap between adjacent sheets. Bring up geo-textile and impermeable membrane to within 1 inch of the top of the perimeter walls. Attach membrane and fabric to walls with roofing tar or other adhesive. Seal all joints of impermeable membrane to be totally leak free.
8. ***Required porous pavement area:*** The design area ratio of contributing impervious area to porous pavement area shall not exceed 2.
9. ***Perimeter wall:*** If a concrete perimeter wall is provided, it should confine the edges of the modular block porous pavement block area. The wall shall be a minimum of 6-inches wide and 12-inches deeper than all the porous media and modular block depth combined. See
10. Figure **WQ-**8.
11. ***Flow cut-off barrier:*** Provide a 16-mil or thicker polyethylene or PVC membrane liner placed vertically on the concrete walls to separate individual cells of the porous base course to cut-off horizontal flow of water. See
12. Figure **WQ-**8.

Space these cut-off barriers according to the following equation:

$$L_{MAX} = \frac{D}{1.5 S_O}$$ **(Equation WQ-5)**

in which:

L_{MAX} = Maximum distance between cut-off membrane normal to the flow (ft)

S_O = Slope of the base course (ft/ft)

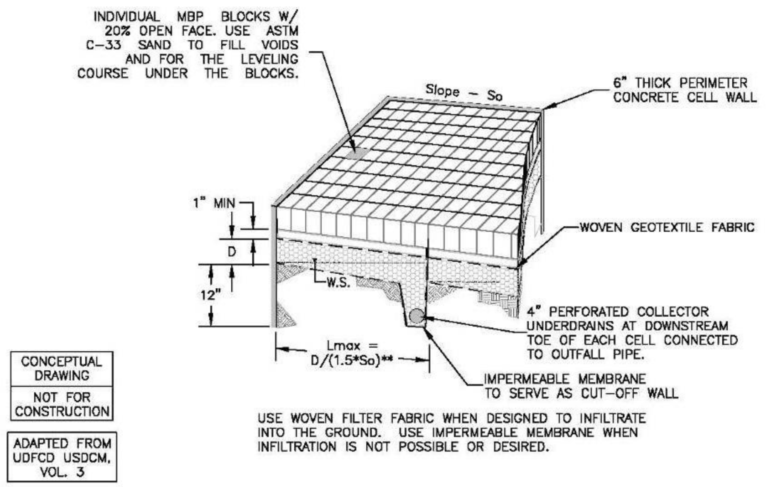
D = depth of gravel base course (ft)

13. ***Under-drains:*** When necessary, install 4-inch under-drains at the bottom of the coarse aggregate layer. Under-drains shall be spaced at a maximum of 20 feet with a minimum slope of 0.2%. Under-drains shall connect to an existing storm sewer or daylight to an appropriate stormwater drainage conveyance.

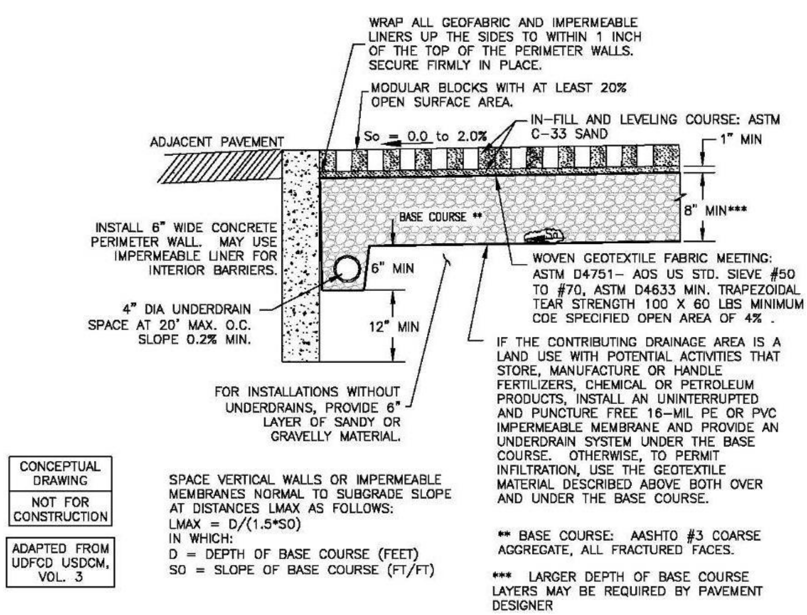
4.5.4 Maintenance

The sand filling the voids within the concrete block pavement will need to be replaced when clogging is evident. Intermittent repairs to the modular blocks may be necessary due to potential for breakage or displaced blocks caused by heavy machinery or trucks on the modular block porous pavement. Maintenance of modular block porous pavement is the responsibility of the property owner or POA. Use of modular block pavement in areas used by the public requires a maintenance plan to be approved by the City.

Figure WQ-8: Modular Block Porous Pavement



PERSPECTIVE VIEW OF SIDE-BY-SIDE MBP CELLS
NTS



4.6 Vegetated Filter Strip/Grass Buffer

4.6.1 Description

Vegetated filter strips/grass buffer strips are uniformly graded and densely vegetated areas of turf grass, planted native grasses, or adequate existing grass. They require sheet flow to promote filtration; infiltration; and settling of runoff pollutants. Grass buffers differ from grass swales since they are designed to accommodate overland sheet flow rather than concentrated or channelized flow. Grass and other vegetation provide aesthetically pleasing open space, which can be incorporated into a landscaping and buffer yard plan. In addition, they typically add little cost to a development when incorporated into the existing green space requirements. Maintenance requirements are comparable to routine maintenance of onsite landscaping.

Grass buffers can be utilized for a variety of land uses and are typically located adjacent to impervious areas. Because of the large amount of space required for grass buffers to satisfy all water quality requirements, additional BMPs are often required. Grass buffers can be used on many sites and are strongly encouraged to provide first flush pollutant removal and infiltration for small rainfall events.

Because the effectiveness of grass buffers depends on having an evenly distributed sheet flow over their surface, the size of the contributing area and the associated volume of runoff must be limited. Whenever concentrated runoff occurs, it shall be evenly distributed across the width of the buffer via a flow spreader or other type of structured BMP used to achieve uniform sheet-flow conditions.

Photograph 8: Healthy, dense vegetation in this grass buffer helps filter runoff from an adjacent road and parking lot.

4.6.2 Design Considerations

Major considerations for the design of a vegetated filter strip/grass buffer are summarized below:

Preservation of sheet flow: Design of a grass buffer is largely based on maintaining sheet-flow conditions across a uniformly graded area with a gentle slope and a dense grass cover. When a grass buffer is used in areas with unstable slopes, soils or vegetation, formation of rills and gullies will form and disrupt sheet flow. The resultant short-circuiting will eliminate the intended water quality benefits and must be corrected through repairs, maintenance, or replacement.

Shape of grass buffer area: The preferred shape for a grass buffer is a rectangular strip. The strip shall be free of gullies or rills that could concentrate the flow over it. Concentrated runoff shall be evenly distributed across the width of the grass buffer via a flow spreader.

Protection of vegetation: Grass buffers should be protected from excessive pedestrian or vehicular traffic that can damage the grass and affect the distribution. A 4-inch topsoil layer that is free of rocks and debris must be spread over the grass buffer area prior to vegetation to promote a healthy stand of grass. A mixture of grass, shrubs, trees, and other plantings may offer benefits for slope stability and improved aesthetics.

4.6.3 Design Procedure and Criteria

The following steps outline the grass buffer design procedure and criteria. Figure WQ-9 is a schematic of a grass buffer facility and its components.

1. ***Peak flow rate:*** Calculate the 2-year peak flow rate of the area draining to the grass buffer as described in Chapter 5 – *Determination of Stormwater Runoff*.
2. ***Minimum design width:*** The minimum design width, W_G, (normal to flow) is calculated as:

$$W_G = \frac{Q_{2-year}}{0.05}$$ **(Equation WQ-6)**

3. ***Minimum design length:*** The minimum design length, L_G, is dependent on the upstream flow conditions.

   For sheet flow conditions, L_G (ft) is calculated as the greater of the following:

$$L_G = 0.2L_t \text{ or 6 feet}$$ **(Equation WQ-7)**

   in which:

   L_t = Flow path length (ft) of sheet flow over the tributary impervious surface

   For concentrated flow conditions, L_G is calculated as the greater of the following:

$$L_G = 0.15(A_t / W_t) \quad \text{or 6 feet}$$ **(Equation WQ-8)**

   in which:

   W_t = Width of the tributary inflow normal to the flow spreader (i.e. width of flow spreader) (ft)

   A_t = Tributary area (ft^2)

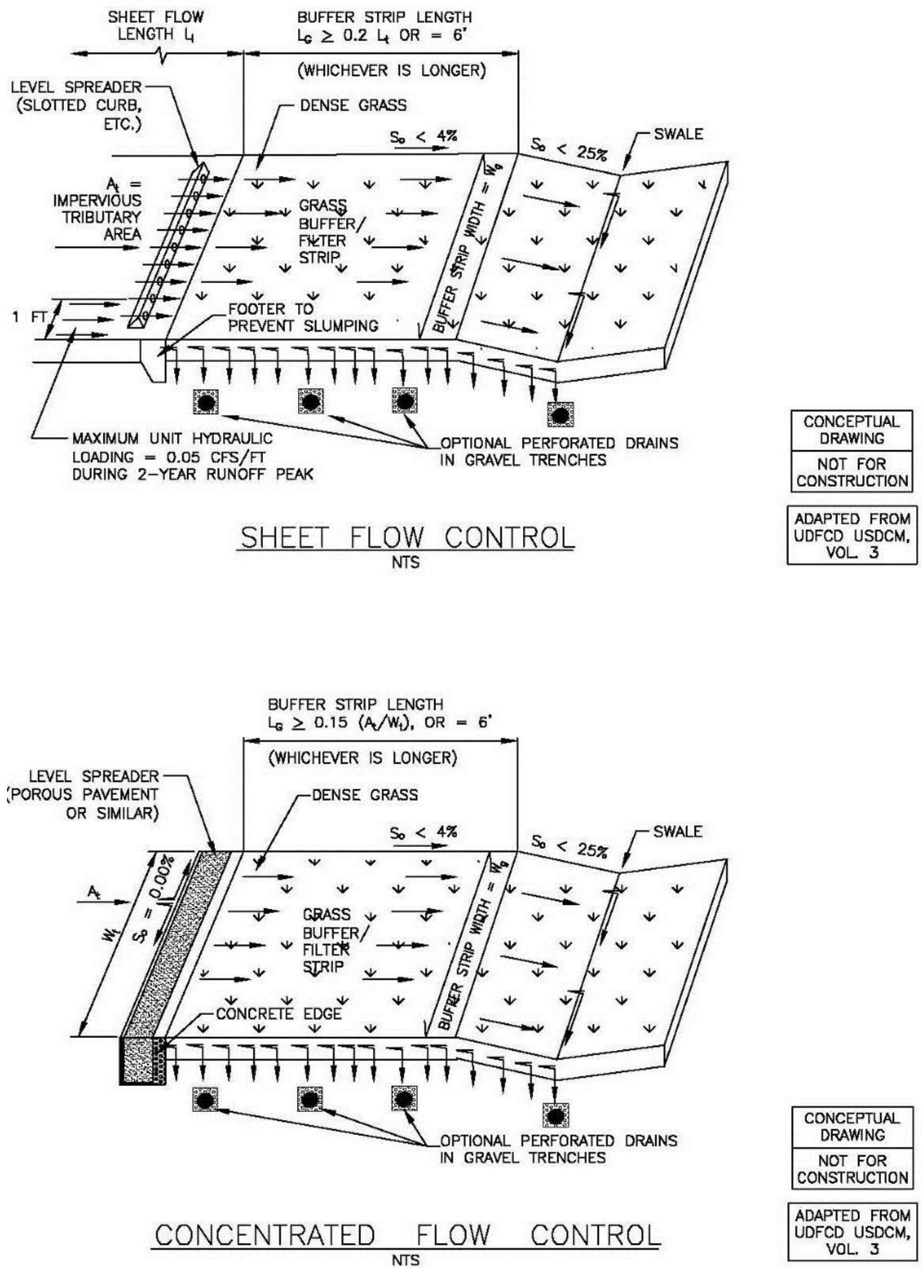
4. ***Longitudinal slope:*** The slope in the direction of flow, S, shall not exceed 4%.
5. ***Flow dispersal:*** Incorporate a device on the upstream end of the buffer to evenly distribute flows

along the design length if runoff re-concentrates. Intermediate units can also be incorporated.

6. ***Establishment of vegetation:*** Sod the grass buffer; plant an alternative vegetation cover approved by the City; or cover with other permanent, suitable erosion control measures.

7. ***Collection of outflow:*** Provide a means for outflow collection. The buffer can drain to a grass swale, storm sewer, or street gutter in accordance with design criteria for those facilities. In some cases, the use of under-drains can maintain better infiltration rates as the soil saturates. This will help dry out the buffer after storms or periods of irrigation.

Figure WQ-9: Application of Grass Buffers (Filter Strips)



4.6.4 Maintenance

If the grass buffer is located adjacent to urban activity, routine mowing of the strip may be necessary for aesthetic purposes. Eventually, the grass strip next to the spreader or the pavement will accumulate a sufficient amount of sediment to block runoff. At that time, a portion of the grass buffer strip and spreader will need to be removed; the accumulated soil behind the spreader removed; and the sod and spreader replaced.

4.7 Grass Swale

4.7.1 Description

A grass swale is a densely vegetated drainageway with gentle side slopes that collects and slowly conveys runoff. A grass swale can be located to collect overland flows from areas such as parking lots, buildings, residential yards, roadways, and vegetative filter strips/grass buffers. A grass swale is set below adjacent ground level and runoff enters the swale over grassy banks. Swales in residential and commercial settings can also minimize DCIA by using them as an alternative to a curb-and-gutter system. A grass swale is generally less expensive to construct than a concrete or rock-lined drainage system, and its infiltration can also provide some reduction in runoff volumes from small storms. The grass swale shall be vegetated with dense grasses, plants, and/or mulch that can reduce flow velocities and protect against erosion during larger storm events.

Photograph 9: This grass swale filters runoff from a road and helps reduce flow velocities.

4.7.2 Design Considerations

Major considerations for the design of a grass swale are summarized below:

Swale slope: A grass swale is sized to maintain a low velocity during small storms and to collect and convey larger runoff events. A grass swale generally shall not be used where site slopes exceed 5%. The longitudinal slope of a grass swale shall be kept to less than 1%, the use of grade control checks or drop structures will need to be added along its alignment. Figure WQ-10 shows trapezoidal and triangular swale configurations.

Use of a swale as a grass buffer: If one or both sides of the grass swale are also to be used as a grass buffer, the design of the grass buffer must incorporate the requirements of Section 4.6 of this chapter.

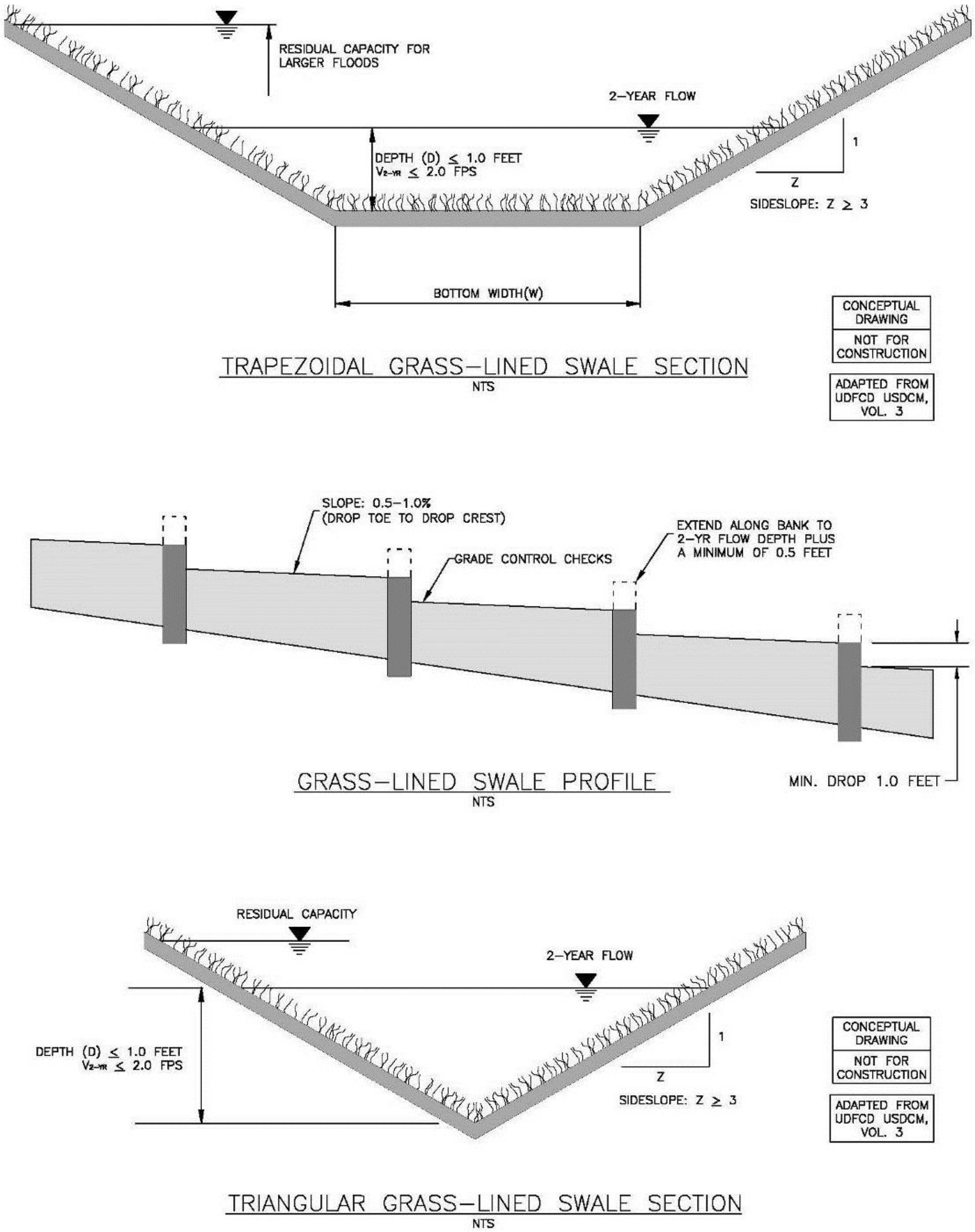
4.7.3 Design Procedure and Criteria

The following steps outline the grass swale design procedure and criteria. Figure WQ-10 is a schematic of a grass swale facility and its components.

1. ***Peak flow rate:*** Calculate the 2-year peak flow rate, $Q_{2\text{-}year}$, to be conveyed in the grass swale using a method described in Chapter 5 – *Determination of Stormwater Runoff*. For public improvements, the grass swale must also meet the criteria provided in Chapter 8 – *Open Channel Flow Design*. For all developments with detention, it must be shown that the channel can convey the maximum design flow to the detention basin and that bypass will not occur.

2. ***Swale cross-section geometry:*** The geometry of the cross-section shall be either trapezoidal or triangular with side slopes of 3H:1V or flatter.

Figure WQ-10: Profile and Sections of a Grass Swale



3. ***Longitudinal slope:*** The longitudinal slope, S_o, of the grass swale shall be kept to less than 1%. If the longitudinal slope requirements cannot be met with the available terrain, grade-control checks or small drop structures must be incorporated to maintain the required longitudinal slope. See Chapter 8 – *Open Channel Flow Design*.
4. ***Maximum velocity:*** To promote sedimentation and enhanced water quality, the maximum velocity of the 2-year peak flow shall not exceed 2 fps and the maximum flow depth of the same flow shall not exceed 12 inches.
5. ***Vegetation*** - Sod the grass swale; plant alternative vegetation approved by the City; or cover with other permanent suitable erosion control measure.

4.7.4 Maintenance

Dense turfgrass must be maintained within a grass swale to retain optimal performance as a water quality BMP. The grass swale must be mowed in accordance with City ordinance unless a maintenance plan for other maintenance methods has been approved by the City Planning, Building, and Code Enforcement Department. If check dams are installed in the grass swale, sediment may accumulate up-gradient of the dams. Accumulated sediment shall be removed when sediment depth exceeds 6 inches, or as necessary to prevent the deposition of sediment downstream.

4.8 Covering of Storage/Handling Areas

Facilities that handle or store potential industrial or commercial pollutants (such as salt piles, oil products, pesticides, fertilizers, etc.) are required to institute practices that reduce the likelihood of stormwater contamination while preventing the loss of material from wind or rainfall erosion. Development plans for these facilities must specify how potential pollutants will be covered and handled to prevent discharge of the pollutant into the City. Covering is appropriate for areas where solids (e.g. building materials; gravel; salt; compost) or liquids (e.g. oil; gas; tar) are stored, prepared, or transferred. Coverings shall be permanent in nature. Handling procedures must be carried through plans and policies in place at the operating facility.

Photograph 10: This industrial loading dock is covered to prevent loss of material during transfer.

4.9 Spill Containment and Control

Spill containment within industrial and some commercial sites includes berms, walls, and gates that control spilled material. Berms consist of temporary or permanent curbs, dikes, or other containment to prevent spilled material from entering surface waters or storm sewer systems. The berm or wall may be made of concrete; asphalt; earthen material; metal; synthetic form or liners; or any material that will safely contain the spill. The containment area must have an impermeable floor (asphalt or concrete) or liner so that contamination of groundwater does not occur.

Two methods of berming can be used: 1) containment berm that contains an entire spill, or 2) curb that routes spill material to a collection basin. Both methods shall be sized to safely contain a spill from the largest storage tank, rail car, tank truck, or other primary storage device located inside the possible spill area. A collection basin shall be provided to hold stormwater and spills until the filtration or treatment of the collected runoff and/or spill can occur and removal of all pollutant(s) is possible.

Photograph 11: Spill containment structure with valve control. Valve is the painted yellow object in the lower left of the photograph.

4.10 Alternative Structural BMPs

Site conditions may be conducive to the use of alternative BMPs such as proprietary packaged stormwater treatment units. Site conditions may include limited space in an ultra-urban or redevelopment setting; sensitive receiving water or feature; or a site with a high pollutant discharge potential. All proposed units of this type must be reviewed and accepted by the City prior to installation.

5.0 LOW IMPACT DEVELOPMENT

LID is an overall development approach that is designed to mimic a site's pre-development hydrology. The major components of LID include:

1. Conservation and protection of site features such as streams, wetlands, and valuable habitat areas and avoidance of potential problem areas such as steep slopes.
2. Minimization of site impacts by minimizing clearing and grading; preserving soils with high infiltration capacities (Hydrologic Soil Group A and B soils); limiting lot disturbance; incorporating

soil amendments; disconnecting impervious surfaces; and reducing impervious surfaces.

3. Maintaining the natural time of concentration through using open drainages; incorporating green spaces; flattening slopes; dispersing drainage; lengthening flow paths; using vegetative swales; maintaining natural flow paths; maximizing stream setbacks; and maximizing sheet flow.

4. Implementing LID integrated management practices (IMPs) that address runoff at its source by using design techniques that infiltrate; filter; store; evaporate; and detain runoff close to its source. Instead of conveying and treating stormwater in facilities located at the bottom of drainage areas, LID relies on practices such as open drainage swales; bio-retention cells (similar to porous landscape detention); rain gardens; rain barrels; rooftop storage; depression storage; soil amendments; infiltration swales; and other similar features. A typical LID site will have multiple dispersed IMPs throughout the site, rather than having a single BMP at the low corner of a development.

5. Implementing pollution prevention practices that focus on maintenance practices and proper use, handling and storage of materials such as pesticides, fertilizers, household hazardous waste, etc.

Photograph 12: This rain garden is a LID technique that serves as a landscape amenity while also helping to reduce runoff volumes and pollutant loading.

Many of the components of the LID approach have been previously discussed in this chapter. The difference with LID is the overall site design process incorporates all of the steps described above which results in a multi-faceted site design approach.

Many LID features are natural in appearance and may rely on natural site features (e.g. preservation of soils with high infiltration capacities). It is imperative that the soil structure in these areas is not modified or compacted during construction since these actions reduce the natural infiltration capacity of the soil. This will require careful restriction on the routing of construction equipment; verification that infiltration capacities have been maintained; and possibly addition of soil amendments.

Another critical requirement for a successful LID site is assuring that regular and proper maintenance is conducted. If the dispersed LID components are not regularly maintained by a qualified landscape professional, the LID site will likely not function as intended. Maintenance costs must be borne by the property owner or POA. Maintenance easements must be provided to allow for proper access. Property owners and POA members must also be educated to prevent removal or disturbance of the LID areas.

When designing a LID site, it is important to ensure that the landscape practices (such as rain gardens) are attractive and perceived by the property owner as adding value to the property. If these LID practices are viewed as assets, the long-term maintenance by property owners or the POA will continue protecting their vested economic interests.

Photograph 13: This porous detention island is designed to reduce runoff rates and volumes and pollutant loading.

The City has not had significant experience with overall LID site designs. Additional design guidance may be incorporated into this Manual in the future regarding LID. In the interim, the Low Impact Development Center website (www.lowimpactdevelopment.org/) provides a good reference for more detailed design guidance, design drawings, and specifications. For example, specifications for engineered soils can be downloaded from the LID website for bioretention cells and swales. LID site designs must be approved by the Planning, Building, and Code Enforcement Department and must be discussed early in the site planning process.

6.0 REFERENCES

American Society of Civil Engineers and Water Environment Federation. 1992. *Design and Construction of Urban Stormwater Management Systems.* ASCE Manual and Report on Engineering Practice No. 77 and WEF Manual of Practice FD-20. Alexandria,VA: Water Environment Federation.

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Appendix A: Adjustment to the Water Quality Capture Volume

The required WQCV for a site can be reduced if measures are implemented to reduce the Directly Connected impervious Area (DCIA) at the site. A DCIA is an impermeable area that drains directly to the improved storm drainage system without an opportunity to infiltrate into the ground. Minimizing DCIA is a land development design approach that reduces paved areas and/or directs storm water runoff to landscaped areas; grass buffer strips; and grass-lined swales. The purpose is to slow down the rate of runoff; reduce runoff volumes; attenuate peak flows; and facilitate the infiltration and filtering of storm water. Minimizing DCIA can also reduce pollutant loads to the storm water treatment system because of increased infiltration of runoff near the point where the runoff can begin.

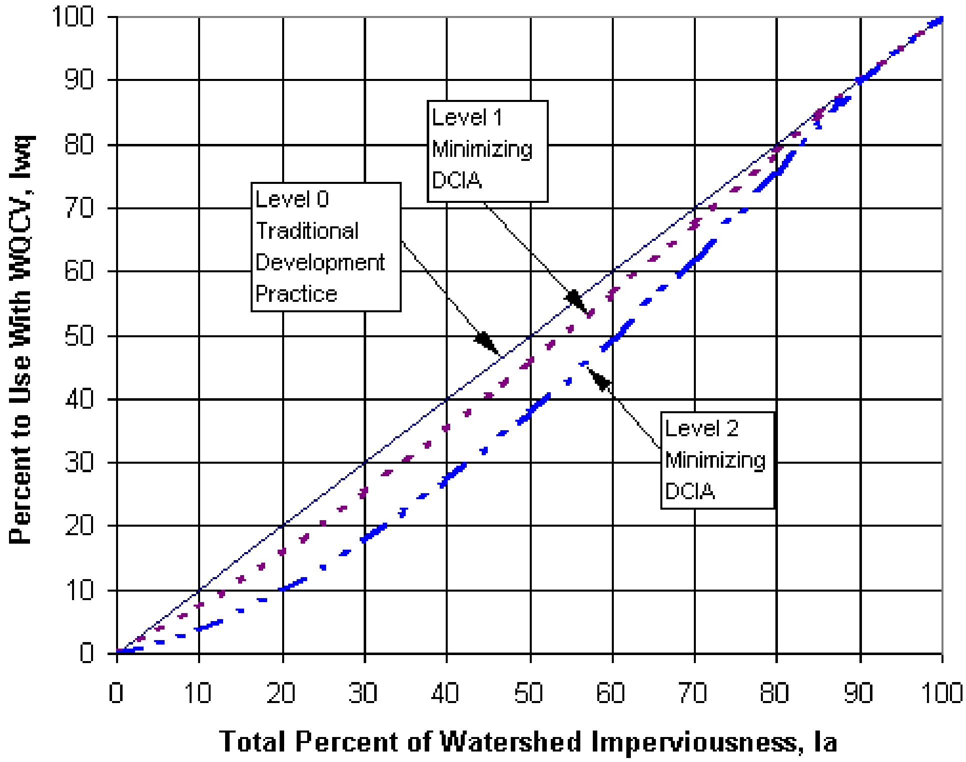
To reduce the amount of DCIA, slopes on a site should be designed to direct storm water runoff as sheet flow away from buildings, roads, and parking lots toward grass-covered or other pervious areas prior to reaching the storm water conveyance systems or other BMPs. In areas with high permeability soils (Hydrologic Soil Groups A and B), surface runoff may be successfully infiltrated whereas areas with less permeable soils may require underdrain systems to reduce surface runoff. Sites with average slopes that exceed 5% may not be well suited to implementing some aspects of these BMPs because of the reduced potential for infiltration. Steep sites can be addressed by using terracing or retaining walls.

Minimizing DCIA can be implemented in varying degrees. UDFCD (1999) characterizes two general levels associated with minimizing DCIA as follows:

- Level 1 DCIA – Level 1 DCIA involves minimizing DCIA at the individual site development level. This approach generally involves directing runoff from impervious surfaces to flow over grass-covered areas (e.g. filter strips or swales) and providing sufficient travel time to encourage the removal of suspended solids before runoff leaves the site and enters the municipal collection system. To gain credit for using Level 1 DCIA, *all* impervious surfaces must be designed to drain over grass buffer strips or swales before reaching a storm water conveyance system.
- Level 2 DCIA - A more advanced approach for minimizing DCIA involves minimizing DCIA at the subdivision level (in addition to the individual site development level of Level 1). In addition to the measures taken in Level 1, Level 2 involves replacing solid street curb and gutter systems with slotted or no curbing, low-velocity grass-lined swales, and pervious street shoulders. Conveyance systems and storm sewer inlets will still be necessary to collect runoff at intersections and crossings or where storm water flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways unless inlets are provided to convey the flow to a storm sewer. Implementing Level 2 DCIA involves a public street design differing from public improvement standards and will therefore require early planning with City staff may require variances in accordance with subdivision regulations.

Based on the extent of measures used to minimize DCIA (i.e. Level 1 versus Level 2), Figure A-1 can be used to convert the actual impervious area of a site (horizontal scale) to an effective impervious area (vertical scale) for use in calculating the WQCV. The effective impervious area adjustment for Level 1 and 2 DCIA needs to be incorporated into and reported in the submitted development's Drainage Report for City staff to review as part of a large-scale development or variance application and approval processes.

Figure A-1: Imperviousness Adjustments for Levels 1 and 2 of Minimizing DCIA



(Source: Urban Storm Drainage Criteria Manual, Volume 3, Best Management Practices, UDFCD, 1999)