CHAPTER 700 POST-CONSTRUCTION STORMWATER QUALITY MANAGEMENT

SECTION 701 INTRODUCTION

701.01 Purpose and Background

The City of Carmel has established a minimum standard that the measurement of the effectiveness of the control of stormwater runoff quality be based on the management of Total Suspended Solids (TSS). This requirement is being adopted as the basis of the City of Carmel stormwater quality management program for all areas of jurisdiction. The City of Carmel requires that all water leaving a site shall be treated by a stormwater quality management system consisting of a minimum of two different BMPs. The installed stormwater quality management system shall be capable of removing a minimum of 80% of the TSS. Additionally, one of the BMPs must be capable of removing the major pollutants identified in the Storm Water Pollution Prevention Plan.

This chapter establishes minimum standards for the selection and design of construction water quality BMPs. The information provided in this Chapter establishes performance criteria for stormwater quality management and procedures to be followed when preparing a BMP plan for compliance. Post-Construction BMPs must be sized to treat the water quality volume, WQ_v, for detention-based BMPs or the water quality discharge, Q_{wq}, for flow-through BMPs. Section 701.04 provides the methodology for calculating the WQ_v and Q_{wq} values.

BMPs noted in this Chapter refer to post-construction BMPs, which continue to treat stormwater after construction has been completed and the site has been stabilized. Installing certain BMPs, such as bioretention areas and sand filters, prior to stabilization can cause failure of the measure due to clogging from sediment. If such BMPs are installed prior to site stabilization, they should be protected by traditional erosion control measures.

Conversely, detention ponds and other BMPs can be installed during construction and used as sediment control measures. In those instances, the construction sequence must require that the pond be cleaned out with pertinent elevations and storage and treatment capacities reestablished as noted in the accepted stormwater management plan.

Also, a set of standard detail drawings is included on the City of Carmel website that provides guidance on the design and installation of various hydraulic structures that may not have been covered in this chapter. Adherence to the noted standard details shall be required in addition to other requirements in this chapter. In case of discrepancy, the most restrictive requirement shall apply.

701.02 Abbreviations and Definitions

Abbreviations

BMP:	Best Management Practice
BOD:	Biochemical Oxygen Demand.
TSS:	Total suspended solids.

Definitions:

Best Management Practices	Structural measures (wetlands, ponds, sand filters, etc.) or non-structural measures (restrictive zoning, reduced impervious areas, etc.). BMPs are designed for the benefit of water quality and quantity. For the purposes of this chapter, BMPs refer to structural water quality BMPs.
Contributing Drainage Area	The total drainage area to a given point, including offsite drainage.
Impervious Area	Areas where the land surface has been altered to decrease the amount of rainwater infiltration. Impervious surfaces include paved roads, concrete driveways and rooftops
Stormwater Quality Management	A system of vegetative, structural, and other measures that reduce or eliminate pollutants that might otherwise be carried by surface runoff.
Total P	Total phosphorus
Total N	Total nitrogen.
Treatment Train	A treatment train consists of more than one BMP in series treating Storm water runoff. Such configurations are necessary when BMPs individually cannot meet the TSS reduction goal stated in the Ordinance.
Watershed	The total drainage area contributing runoff to a single point.

701.03 Applicability

In addition to the requirements of Chapter 600, the stormwater pollution prevention plan, which is to be submitted to the City of Carmel as part of the stormwater management permit application, must also include post-construction stormwater quality measures. These measures are incorporated as a permanent feature into the site plan and are left in place following completion of construction activities to continuously treat stormwater runoff from the stabilized site. Any project located within the City of Carmel that includes clearing, grading, excavation, and other land disturbing activities is subject to the requirements of this Chapter. This includes both new development and re-development, and disturbances of land that are part of a larger common plan of development or sale if the larger common plan will ultimately disturb 1/4 acre or more of land, within the area under the jurisdictional authority of the City of Carmel.

It will be the responsibility of the project site owner to complete a stormwater permit application and ensure that a sufficient construction plan is completed and submitted to the City of Carmel in accordance with Chapter 100. It will be the responsibility of the project site owner to ensure proper construction and installation of all stormwater BMPs in compliance with this Manual and with the approved stormwater management permit, and to notify the City of Carmel with a Notice of Termination letter upon completion of the project and stabilization of the site. However, all eventual property owners of stormwater quality facilities meeting the applicability requirements must comply with the requirements of this Chapter.

701.04
Post-Construction Stormwater Quality Management Calculations

Calculation of land disturbance should follow the guidelines discussed in Chapter 600.

The calculation methods as well as the type, sizing, and placement of all stormwater quality management measures, or BMPs shall meet the design criteria, standards, and specifications outlined in the *Indiana Stormwater Quality Manual* or this chapter. The methods and procedures included in these two references are in keeping with the above stated policy and meet the requirements of IDEM's Rule 13.

Structural Water Quality BMPs are divided into two major classifications: detention BMPs and Flow-through BMPs. Detention BMPs impound (pond) the runoff to be treated, while flow through BMPs treat the runoff through some form of filtration process.

DETENTION BMP SIZING

Water Quality Detention BMPs must be designed to store the water quality volume for treatment. The water quality volume, WQ_v, is the storage needed to capture and treat the runoff from the first one-inch of rainfall. The water quality volume is equivalent to one inch of rainfall multiplied by the volumetric runoff coefficient (R_v) multiplied by the site area, or:

$$\mathbf{WQ_v = \frac{(P)\,(R_v)\,(A)}{12}}$$

where:
WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = volumetric runoff coefficient
A = area in acres

The volumetric runoff coefficient is a measure of imperviousness for the contributing area, and is calculated as:

$$\mathbf{Rv = 0.05 + 0.009(I)}$$

Where:
I is the percent impervious cover

For example, a proposed commercial site will be designed to drain to three different outlets, with the following drainage areas and impervious percentages:

Subarea ID	On-site Contributing Area (Acres)	Impervious Area %	Off-Site Contributing Area (Acres)
A	7.5	80	0.0
B	4.3	75	0.0
C	6.0	77	0.0

Calculating the volumetric runoff coefficient for subareas A, B and C yields:

Rv (subarea A) = 0.05+0.009(80)=0.77

Rv (subarea B) = 0.05+0.009(75)=0.73
Rv (subarea C) = 0.05+0.009(77)=0.74

The water quality volumes for these three areas are then calculated as:

WQv (subarea A) = (1")(Rv)(A)/12=0.77(7.5)/12=0.48 acre-feet
WQv (subarea B) = 0.73(4.3)/12=0.26 acre-feet
WQv (subarea C) = 0.74(6.0)/12=0.37 acre-feet

Note that this example assumed no offsite sources of discharge through the water quality detention BMPs. If there were significant sources of off-site runoff (sometimes called run-on for upstream areas draining to the site), the designer would have the option of diverting off-site runoff around the on-site systems, or the detention BMP should be sized to treat the water quality volume for the entire contributing area, including off-site sources.

FLOW THROUGH BMP SIZING

Flow through BMPs are designed to treat runoff at a peak design flow rate through the system. Examples of flow through BMPs include catch basin inserts, sand filters, and grassed channels. Another flow through BMP, which is gaining popularity, is a dynamic separator. Dynamic separators are proprietary, and usually include an oil-water separation component.

The following procedure should be used to estimate peak discharges for flow through BMPs (adopted from Maryland, 2000). It relies on the volume of runoff computed using the Small Storm Hydrology Method (Pitt, 1994) and utilizes the NRCS, TR-55 Method.

Using the WQv methodology, a corresponding Curve Number (CNwq) is computed utilizing the following equation:

$$CNwq = \frac{1000}{\left[10 + 5P + 10Qa - 10\sqrt{Qa^2 + 1.25QaP}\right]}$$

where:
CN_{wq} = curve number for water quality storm event
P = 1" (rainfall for water quality storm event)
Qa = runoff volume, in inches = 1"×R_v = R_v (inches)
R_v=volumetric runoff coefficient (see previous section)

Due to the complexity of the above equation, the water quality curve number is represented as a function of percent imperviousness in **Exhibit 701-1**.

The water quality curve number, CN_{wq}, is then used in conjunction with the standard calculated time-of-concentration, t_c, and drainage area as the basis input for TR-55 calculations. Using the SCS Type II distribution for 1 inch of rainfall in 24-hours, the water quality treatment rate, Q_{wq}, can then be calculated.

701.05 Pre-Approved BMPs

The City of Carmel has designated a number of pre-approved BMP methods to be used as part of the stormwater quality management system in order to achieve the TSS removal stormwater quality goals according to §6-203 of the Carmel City Code. These BMP measures are listed along with their anticipated average TSS removal rates in **Table 701-1**. Pre-approved BMPs have been proven/are assumed to achieve the average TSS removal rates indicated in **Table 701--1**. Applicants desiring to use a different TSS removal rate for these BMPs must follow the requirements discussed above for Innovative BMPs. Details regarding the applicability and design of these pre-approved BMPs are contained within fact sheets presented in **Appendix 701-1**.

A single BMP measure may not be adequate to achieve the water quality goals for all pollutants associated with a project. It is for this reason that the City of Carmel requires all water leaving a site shall be treated by a minimum of two BMPs as part of a stormwater quality management system. At least one of the BMPs must be capable of removing the major pollutants identified in the Storm Water Pollution Prevention Plan.

701.06 Innovative BMPs

BMPs not previously accepted by the City of Carmel must be certified by a professional engineer licensed in the State of Indiana and accepted through the City of Carmel. ASTM standard methods must be followed when verifying performance of new measures. New BMPs, individually or in combination, must meet the Ordinance-required TSS removal rate at 50-125 micron range (silt/fine sand) without re-entrainment and must have a low to medium maintenance requirement to be considered by the City of Carmel. Testing to establish the TSS removal rate must be conducted by an independent testing facility, not the BMP manufacturer.

In the case that an engineered oil and sediment treatment system is used, a bypass may be considered for flows in excess of the first one (1) inch of rainfall.

701.07 Easement Requirements

All stormwater quality management systems, including detention or retention basins, filter strips, pocket wetlands, in-line filters, infiltration systems, conveyance systems, structures and appurtenances located outside of the right-of-way shall be designated as common areas or incorporated into permanent easements. For developments which fall under the jurisdictional authority of the City of Carmel, the developer shall petition to establish the noted system as a portion of regulated drainage system pursuant to the provisions of I.C.-36-9-27, and the drainage plan shall not be accepted until such petition is submitted in a form accepted by the City of Carmel. For the purposes of access, monitoring, inspection, and general maintenance activities, adequate easement width, as detailed in Table 701-1, beyond the actual footprint of the stormwater quality management facility as well as a 20-foot wide access easement from a public right-of-way to each BMP shall be provided. The easement requirements noted in Table 701-1 and this section may be changed by the City of Carmel as deemed necessary for specific cases.

701.08 Inspection, Maintenance, Record Keeping, and Reporting

After the approval of the stormwater management permit by the City of Carmel and the commencement of construction activities, the City of Carmel has the authority to conduct inspections of the work being done to ensure full compliance with the provisions of this chapter, this document, and the terms and conditions of the approved permit.

Stormwater quality facilities shall be maintained in good condition, in accordance with the Operation and Maintenance procedures and schedules listed in the *Indiana Stormwater Quality Manual* or this document, and/or the terms and conditions of the approved stormwater permit and the Carmel City Code, and shall not be subsequently altered, revised, or replaced except in accordance with the approved stormwater permit, or in accordance with approved amendments or revisions in the permit. Checklists must be completed and maintained by the owner.

The City of Carmel also has the authority to perform long-term, post-construction inspection of all public or privately owned stormwater quality facilities. The inspections will follow the operation and maintenance procedures included in this document and/or permit application for each specific BMP. The inspection will cover physical conditions, available water quality storage capacity and the operational condition of key facility elements. Noted deficiencies and recommended corrective action will be included in an inspection report.

TABLE 701-1: Pre-approved Post-construction BMPs

BMP Description	Anticipated Average % TSS Removal Rate[D]	Fact Sheet	Maintenance Easement Requirements
Bioretention[A]	75	PC-101	25 feet wide along the perimeter
Constructed Wetland	65	PC-102	25 feet wide along the outer perimeter of forebay & 30 feet wide along centerline of outlet
Extended Dry Detention	72	PC-103	25 feet wide along the outer perimeter of forebay & 30 feet wide along centerline of outlet
Infiltration Basin[A]	87	PC-104	25 feet wide along the perimeter
Infiltration Trench[A]	87	PC-105	25 feet wide along the perimeter
Media Filtration – Underground Sand	80	PC-106	25 feet wide along the perimeter
Media Filtration – Surface Sand	83	PC-106	25 feet wide along the perimeter
Storm Drain Insert[C]	NA[B]	PC-107	20 feet wide strip from access easement to chamber's access shaft
Filter Strip	48	PC-108	25 feet wide along the length on the pavement side
Vegetated Swale	60	PC-109	25 feet wide along the top of bank on one side
Wet Pond	80	PC-110	25 feet wide along the outer perimeter of forebay & 30 feet wide along centerline of outlet

Notes:

A. Based on capture of 0.5-inch of runoff volume as best available data. Effectiveness directly related to captured runoff volume, increasing with larger capture volumes.

B. The removal rate for this category varies widely between various models and manufacturers. Independent testing should be provided, rather than the manufacturer's testing data.

C. Must provide vendor data for removal rates.

D. Removal rates shown are based on typical results. These rates are also dependent on proper installation and maintenance. The ultimate responsibility for determining whether additional measures must be taken to meet the Ordinance requirements for site-specific conditions rests with the applicant.

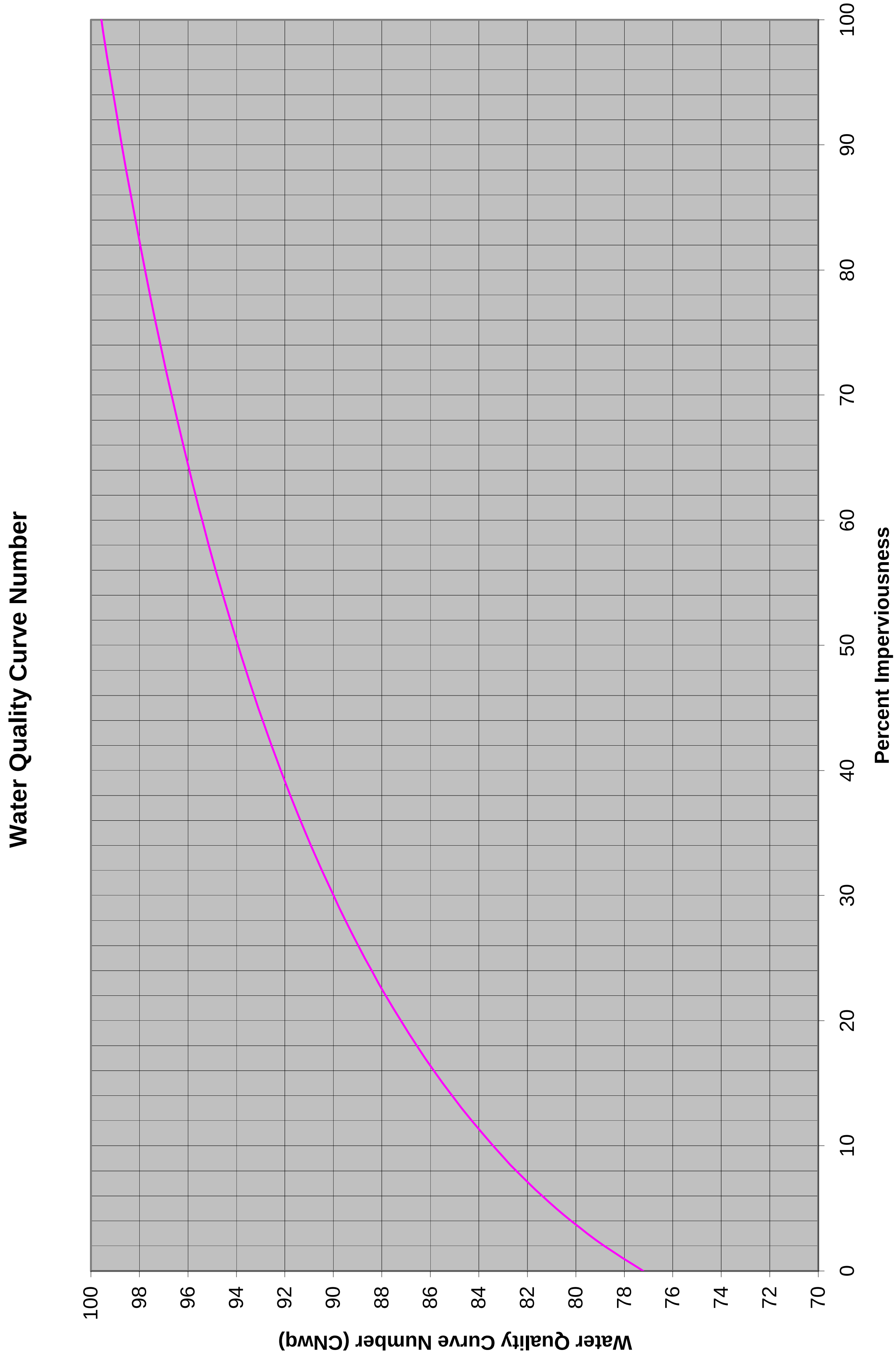

Exhibit 701-1: Curve Number Calculation for Water Quality Storm Event

APPENDIX 701-1

POST-CONSTRUCTION BMP FACT SHEETS

BMP PC – 101
BIORETENTION FACILITY

DESCRIPTION

Bioretention is a best management practice (BMP) developed in the early 1990's by the Prince George's County, MD, Department of Environmental Resources (PGDER). Bioretention utilizes soils and both woody and herbaceous plants to remove pollutants from stormwater runoff. As shown in Figure PC-101A, runoff is conveyed as sheet flow to the treatment area, which consists of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. Runoff passes first over or through a sand bed, which slows the runoff's velocity, distributes it evenly along the length of the ponding area, which consists of a surface organic layer and/or ground cover and the underlying planting soil. The ponding area is graded; its center depressed. Water is ponded to a depth of 6 inches and gradually infiltrates the bioretention area and/or is evapotranspired. Bioretention areas are applicable as on-lot retention facilities that are designed to mimic forested systems that naturally control hydrology. The bioretention area is graded to drain excess runoff over a weir and into the storm drain system. Stored water in the bioretention area planting soil infiltrates over a period of days into the underlying soils.

The basic bioretention design shown below can be modified to accommodate more specific needs. The bioretention BMP design can be modified to include an underdrain within the sand bed to collect the infiltrated water and discharge it to a downstream storm drain system. This modification may be required when impervious subsoils and marine clays prevent complete infiltration in the soil system. This modified design makes the bioretention area act more as a filter that discharges treated water than as an infiltration device.

COMPONENTS

1. Grass Buffer Strip -Designed to filter out particulates and reduce runoff velocity.
2. Sand Bed -Further reduces velocity by capturing a portion of the runoff and distributes it evenly along the length of the ponding area. Also provides aeration to the plant bed and enhances infiltration.
3. Ponding Area -Collects and stores runoff prior to infiltration.
4. Organic/Mulch Layer -Provides some filtering of runoff, encourages development of beneficial microorganisms, and protects the soil surface from erosion.
5. Planting Soil -Provides nourishment for the plant life. Clay particles within the soil also remove certain pollutants through adsorption.
6. Plants -Provides uptake of harmful pollutants.

ADVANTAGES

1. If designed properly, has shown ability to remove significant amounts of dissolved heavy metals, phosphorous, TSS, and fine sediments.
2. Requires relatively little engineering design in comparison to other stormwater management facilities (e.g. sand filters).
3. Provides groundwater recharge when the runoff is allowed to infiltrate into the subsurface.
4. Enhances the appearance of parking lots and provides shade and wind breaks, absorbs noise, and improves an area's landscape.

5. Maintenance on a bioretention facility is limited to the removal of leaves from the bioretention area each fall.
6. The vegetation recommended for use in bioretention facilities is generally hardier than the species typically used in parking lot landscapes. This is a particular advantage in urban areas where plants often fare poorly due to poor soils and air pollution.

LIMITATIONS

1. Low removal of nitrates.
2. Not applicable on steep, unstable slopes or landslide areas (slopes greater than 20 percent).
3. Requires relatively large areas.
4. Not appropriate at locations where the water table is within 6 feet of the ground surface and where the surrounding soil stratum is unstable.
5. Clogging may be a problem, particularly if the BMP receives runoff with high sediment loads.

DESIGN CRITERIA

1. Calculate the volume of stormwater to be mitigated by the bioretention facility using the water quality volume calculations outlined in Section 701-05.
2. The soil should have infiltration rates greater than 0.5 inches per hour; otherwise an underdrain system should be included (see # 11).
3. Drainage to the bioretention facility must be graded to create sheet flow, not a concentrated stream. Level spreaders (i.e. slotted curbs) can be used to facilitate sheet flow. The maximum sheet flow velocity should be 1 ft/s for the planted ground cover and 3 ft/s for mulched cover.
4. Soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than 1-inch in diameter. No other materials or substances shall be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The planting soil shall be free of noxious weeds.
5. Planting soil shall be tested and meet the following criteria:

Planting Soil Criteria	
pH range	5.2-7.0
Organic matter	1.5-4.0%
Magnesium	35 lbs. per acre, minimum
Phosphorus P_2O_5	75 lbs. per acre, minimum
Potassium K_2O	85 lbs. per acre, minimum
Soluble salts	not to exceed 500 ppm
Clay	0-25% by volume
Silt	30-55% by volume
Sand	35-60% by volume

6. It is very important to minimize compaction of both the base of the bioretention area and the required backfill. When possible, use excavation hoes to remove original soil. If excavated using a loader, the excavator should use a wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive

compaction resulting in reduced infiltration rates and storage volumes and is not acceptable. Compaction will significantly contribute to design failure.

7. Compaction can be alleviated at the base of the bioretention facility by using a primary tilling operation such as a chisel plow, ripper, or subsoiler. These tilling operations are to refracture the soil profile through the 12 inch compaction zone. Substitute methods must be approved by the engineer. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment. Rototill 2 to 3 inches of sand into the base of the bioretention facility before back filing the required sand layer. Pump any ponded water before preparing (rototilling) base.
8. When back filling topsoil over the sand layer, first place 3 to 4 inches of topsoil over the sand, then rototill the sand/topsoil to create a gradation zone. Backfill the remainder of the topsoil to final grade.
9. Mulch around individual plants only. Shredded hardwood mulch is the only accepted mulch. Shredded hardwood mulch must be well aged (stockpiled or stored for at least 12 months) for acceptance. The mulch should be applied to a maximum depth of 3-inches.
10. The plant root ball should be planted so $1/8^{th}$ of the ball is above final grade surface.
11. If used, place underdrains on a 3 feet wide section of filter cloth followed by a gravel bedding. Pipe is placed next, followed by the gravel bedding. The ends of underdrain pipes not terminating in an observation well shall be capped.
12. The main collector pipe for underdrain systems shall be constructed at a minimum slope of 0.5%. Observation wells and/or clean-out pipes must be provided (one minimum per every 1,000 square feet of surface area).
13. Size an emergency overflow weir with 6-inches of head, using the Weir equation: $Q=CLH^{3/2}$ Where C= 2.65 (smooth crested grass weir)
    Q= flow rate H = 6-inches of head L = length of weir
14. Bioretention areas should be at least 15 feet wide with a 25 foot width preferable, and a minimum length of 40 feet long. Generally, the length-to-width ratio should be around 2 to 1 to improve surface flow characteristics.
15. The plant soil depth should be 4 feet or more to provide beneficial root zone, both in terms of space and moisture content.
16. The depth of the ponding area should be limited to no more than 6 inches to limit the duration of standing water to no more than 4 days. If an underdrain system is used, the depth of the ponding area should be limited to no more than 1 foot. Longer ponding times can lead to anaerobic conditions that are not conductive to plant growth. Longer periods of standing water can also lead to the breeding of mosquitoes and other pests.
17. The bioretention area should be vegetated to resemble a terrestrial forest community ecosystem, which is dominated by understory trees, a shrub layer, and herbaceous ground covers. Three species each of both trees and shrubs are recommended to be planted at a rate of 1000 total trees and shrubs per acre. The shrub-to-tree ratio should be 2:1 to 3:1. Trees should be spread 12 feet apart and the shrubs should be spaced 8 feet apart.

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4. DEQ Storm Water Management Guidelines, Department of Environmental Quality, State of Oregon. http://waterquality.deq.state.or.us/wq/groundwa/swmgmtguide.htm
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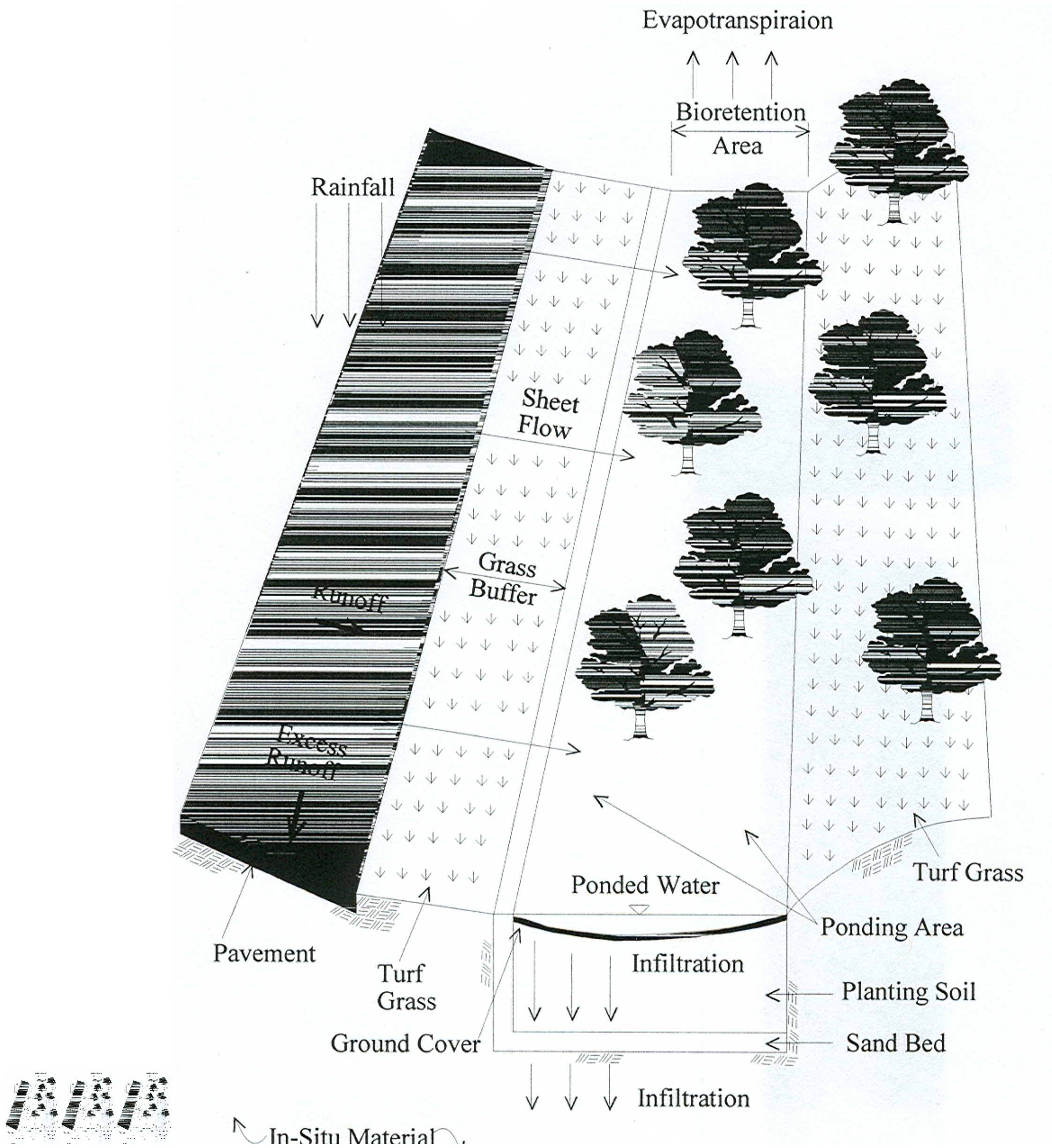

Figure PC-101A
Schematic of Bioretention Area (SUSMP, 2002)

BMP PC – 102
CONSTRUCTED WETLANDS

DESCRIPTION

Wetlands provide physical, chemical, and biological water quality treatment of stormwater runoff. Physical treatment occurs as a result of decreasing flow velocities in the wetland, and is present in the form of evaporation, sedimentation, adsorption, and/or filtration. Chemical processes include chelation, precipitation, and chemical adsorption. Biological processes include decomposition, plant uptake and removal of nutrients, plus biological transformation and degradation. Hydrology is one of the most influential factors in pollutant removal due to its effects on sedimentation, aeration, biological transformation, and adsorption onto bottom sediments (Dormann, et al., 1988). The large surface area of the bottom of the wetland encourages higher levels of adsorption, absorption, filtration, microbial transformation, and biological utilization than might normally occur in more channelized water courses.

A natural wetland is defined by examination of the soils, hydrology, and vegetation which are dominant in the area. Wetlands are characterized by the substrate being predominantly undrained hydric soil. A wetland may also be characterized by a substrate which is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. Wetlands also usually support hydrophytes, or plants which are adapted to aquatic and semi aquatic environments. Natural and artificial wetlands are used to treat stormwater runoff. Figure PC-102A illustrates an artificial wetland used for treating stormwater runoff.

The success of a wetland will be much more likely if some general guidelines are followed. The wetland should be designed such that a minimum amount of maintenance is required. This will be affected by the plants, animals, microbes, and hydrology. The natural surroundings, including such things as the potential energy of a stream or a flooding river, should be utilized as much as possible. It is necessary to recognize that a fully functional wetland cannot be established spontaneously. Time is required for vegetation to establish and for nutrient retention and wildlife enhancement to function efficiently. Also, the wetland should approximate a natural situation as much as possible and unnatural attributes, such as a rectangular shape or a rigid channel, should be avoided (Mitsch and Gosselink, 1993).

1. *Natural Wetland Systems*. Existing wetlands perform storm water treatment in the same fashion as constructed wetlands. However, current policy of the Indiana Department of Environmental Management prohibits the use of existing wetlands as a pollution control measure. Therefore, the use of existing wetlands as a proposed BMP cannot be accepted under any circumstance by the City of Carmel without the prior written acceptance by IDEM for such proposed pollution control use.

2. Constructed (*Artificial) Wetlands.* Site considerations should include the water table depth, soil/substrate, and space requirements. Because the wetland must have a source of flow, it is desirable that the water table is at or near the surface. This is not always possible. If runoff is the only source of inflow for the wetland, the water level often fluctuates and establishment of vegetation may be difficult. The soil or substrate of an

artificial wetland should be loose loam to clay. A perennial base flow must be present to sustain the artificial wetland. The presence of organic material is often helpful in increasing pollutant removal and retention.

Wetland vegetation can be categorized as emergent, floating, or submerged. Emergent vegetation is rooted in the sediments, but grows through the water and above the water surface. Floating vegetation is not rooted in the sediments, and has aquatic roots with plant parts partly submerged or fully exposed on the water or surface. Submerged vegetation includes aquatic plants such as algae or plants rooted in the sediments, with all plant parts growing within the water column. Pollutant removal rates generally improve with an increase in the diversity of the vegetation.

The depth of inundation will contribute to the pollutant removal efficiency. Generally, shallow water depths allow for higher pollutant removal efficiencies due to an increased amount of adsorption onto bottom sediments (Dormann, et al.,1988). Flow patterns in the wetland will affect the removal efficiency also. Meandering channels, slow-moving water and a large surface area will increase pollutant removal through increased sedimentation. Shallow, sheet flow also increases the pollutant removal capabilities, through assimilative processes. A deep pool sometimes improves the denitrification potential. A mixed flow pattern will increase overall pollutant removal efficiency (Dormann, et al., 1988).

Using a site where nearby wetlands still exist is recommended if possible. A hydrologic study should be done to determine if flooding occurs and saturated soils are present. A site where natural inundation is frequent is a good potential site (Mitsch and Gosselink, 1993). Loamy soils are required to permit plants to take root (Urbonas, 1992)

ADVANTAGES

1. Constructed wetlands offer natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal.
2. Constructed wetlands can offer good treatment following treatment by other BMPs, such as wet ponds, that rely upon settling of larger sediment particles (Urbonas, 1992). They are useful for large basins when used in conjunction with other BMPs.
3. Wetlands which are permanently flooded are less sensitive to polluted water inflows because the ecosystem does not depend upon the polluted water inflow.
4. Can provide uptake of soluble pollutants such as phosphorous, through plant uptake.
5. Can be used as a regional facility.

LIMITATIONS

1. Although the use of natural wetlands may be appear to be more cost effective than the use of constructed wetlands; environmental, permitting and legal issues prohibit the use of natural wetlands for this purpose.
2. Wetlands require a continuous base flow.
3. If not properly maintained, wetlands can accumulate salts and scum which can be flushed out by large storm flows.
4. Regular maintenance, including plant harvesting, is required to provide nutrient removal.
5. Frequent sediment removal is required to maintain the proper functioning of the wetland.

6. A greater amount of space is required for a wetland system than is required for an extended/dry detention basin treating the same amount of area.
7. Although constructed wetlands are designed to act as nutrient sinks, on occasion, the wetland may periodically become a nutrient source.
8. Wetlands which are not permanently flooded are more likely to be affected by drastic changes in inflow of polluted water.
9. Cannot be used on steep unstable slopes or densely populated areas.
10. Harvested wetlands may require special disposal methods, due to heavy metal uptake.
11. Threat of mosquitoes.
12. Hydraulic capacity may be reduced with plant overgrowth.

DESIGN CRITERIA

The wetland may be designed as either a stand-alone BMP, or as part of a larger non-point source treatment facility in conjunction with other devices, such as a wet pond, sediment forebay, or infiltration basin. Basic design elements and considerations are listed below.

1. *Volume.* The wetland pond should provide a minimum permanent storage equal to three-fourths of the water quality volume. The full water quality capture volume should be provided above the permanent pool. Calculate the water quality volume to be mitigated by the wetland using the method of Section 701-05.
2. *Depth.* A constant shallow depth should be maintained in the wetland, at approximately 1 ft or less (Schueler, 1987; Boutiette and Duerring, 1994), with 0.5 ft being more desirable (Schueler, 1987). If the wetland is designed as a very shallow detention pond, the pond should provide the full water quality capture volume above the permanent pool level. The permanent wetland depth should be 6 to 12 inches deep. The depth of the water quality volume above the permanent pool should not exceed 2 ft (Urbonas, 1992). Regrading may be necessary to allow for this shallow depth over a large area.

   It may also be beneficial to create a wetland with a varying depth. A varying depth within the wetland will enable more diverse vegetation to flourish. Deep water offers a habitat for fish, creates a low velocity area where flow can be redistributed, and can enhance nitrification as a prelude to later denitrification if nitrogen removal is desired. Open-water areas may vary in depth between 2 and 4 ft (Urbonas, 1992).

3. *Surface Area.* Increasing the surface area of the pond increases the nutrient removal capability (Boutiette and Duerring, 1994). A general guideline for surface area is using a marsh area of two to three percent of the contributing drainage area. The minimum surface area of the pond can also be calculated by determining the nutrient loading to the wetland. The nutrient loading to a wetland used for stormwater treatment should not be more than 45 lbs/ac of phosphorus or 225 lbs/ac of nitrogen per year. The pond could be sized to meet this minimum size requirement if the annual nutrient load at the site is known (Schueler, 1987). If unknown, the nutrient loads can be estimated using the methodology of Chapter 8.
4. *Longitudinal Slope.* Both wetland ponds and channels require a near-zero longitudinal slope (Urbonas, 1992).
5. *Base flow.* Enough inflow must be present in the wetland to maintain wetland soil and vegetation conditions. A water balance should be calculated. Dependence on groundwater for a moisture supply is not recommended.

$$S = Qi + R + Inf - Qo - ET$$

Where:
S = net change in storage
Qi = stormwater runoff inflow
R = contribution from rainfall
Inf = net infiltration (infiltration – exfiltration)
Qo = surface outflow
ET = evapotranspiration

6. *Seeding.* It is important that any seed which is used to establish vegetation germinate and take root before the site is inundated, or the seeds will be washed away. Live plants (plugs) should be considered for areas inundated even during construction.
7. *Length to Width Ratio.* The pond should gradually expand from the inlet and gradually contract toward the outlet. The length to width ratio of the wetland should be 2:1 to 4:1, with a length to width ratio of 3:1 recommended (Urbonas, 1992)
8. *Emptying Time.* The water quality volume above the permanent pool should empty in approximately 24 hours (Urbonas, 1992). This emptying time is not for the wetland itself, but for the additional storage above the wetland. Failure to approach this criteria is often the source of failure for constructed wetlands planned for the base of a water quantity storage facility.
9. *Inlet and Outlet Protection.* Inlet and outlet protection should be provided to reduce erosion of the basin. Velocity should be reduced at the entrance to reduce resuspension of sediment by using a forebay. The forebay should be approximately 5 to 10 percent of the water quality capture volume. The outlet should be placed in an offbay at least 3 ft deep. It may be necessary to protect the outlet with a skimmer shield that starts approximately one-half of the depth below the permanent water surface and extends above the maximum capture volume depth. A skimmer can be constructed from a stiff steel screen material that has smaller openings than the outlet orifice or perforations.
10. *Infiltration Avoidance.* Loss of water through infiltration should be avoided. This can be done by compacting the soil, incorporating clay into the soil, or lining the pond with artificial lining.
11. *Side Slopes.* Side slopes should be gradual to reduce erosion and enable easy maintenance. Side slopes should not be steeper than 4:1, and 5:1 is preferable (Urbonas, 1992).
12. *Open Water.* At least 25 percent of the basin should be an open water area at least 2 ft deep if the device is exclusively designed as a shallow marsh. The open water area will make the marsh area more aesthetically pleasing, and the combined water/wetland area will create a good habitat for waterfowl (Schueler, 1987). The combination of forebay, outlet and free water surface should be 30 to 50 percent, and this area should be between 2 and 4 ft deep. The wetland zone should be 50 to 70 percent of the area, and should be 6 to 12 inches deep (Urbonas, 1992).
13. *Freeboard.* The wetland pond should be designed with at least 1 ft of freeboard (Camp, Dresser and McKee, 1993).
14. *Use with Wet Pond.* Shallow marshes can be established at the perimeter of a wet pond by grading to form a 10 to 20 ft wide shallow bench. Aquatic emergent vegetation can be established in this area. A shallow marsh area can also be used near the inflow channel for sediment deposition (Schueler, 1987).
15. *Shape.* The shape is an important aspect of the wetland. It is recommended that a littoral shelf with gently sloping sides of 6:1 or milder to a point 24 to 28 inches below the water

surface (Mitsch and Gosselink, 1993). Bottom slopes of less than one percent slope are also recommended.

16. *Soils*. Clay soils underlying the wetland will help prevent percolation of water to groundwater. However, clay soils will also prevent root penetration, inhibiting growth. Loam and sandy soils may then be preferable. A good design may be use of local soils at the upper layer with clay beneath to prevent infiltration (Mitsch and Gosselink, 1993).
17. *Vegetation.* Vegetation must be established in the wetland to aid in slowing down velocities, and nutrient uptake in the wetland. A dependable way of establishing vegetation in the wetland is to transplant live plants or dormant rhizomes from a nursery. Emergent plants may eventually migrate into the wetland from upstream, but this is not a reliable source of vegetation. Transplanting vegetation from existing wetland areas is not encouraged, as it may damage the existing wetland area. Seeding is more cost effective, but is also not reliable. Vegetation should be selected by a qualified wetland scientist.
18. *Forebay.* A forebay may be provided to partially protect proposed wetland plantings from sediment loadings. If a forebay is provided, the forebay volume should be about 5 to 10 percent of the water quality volume.

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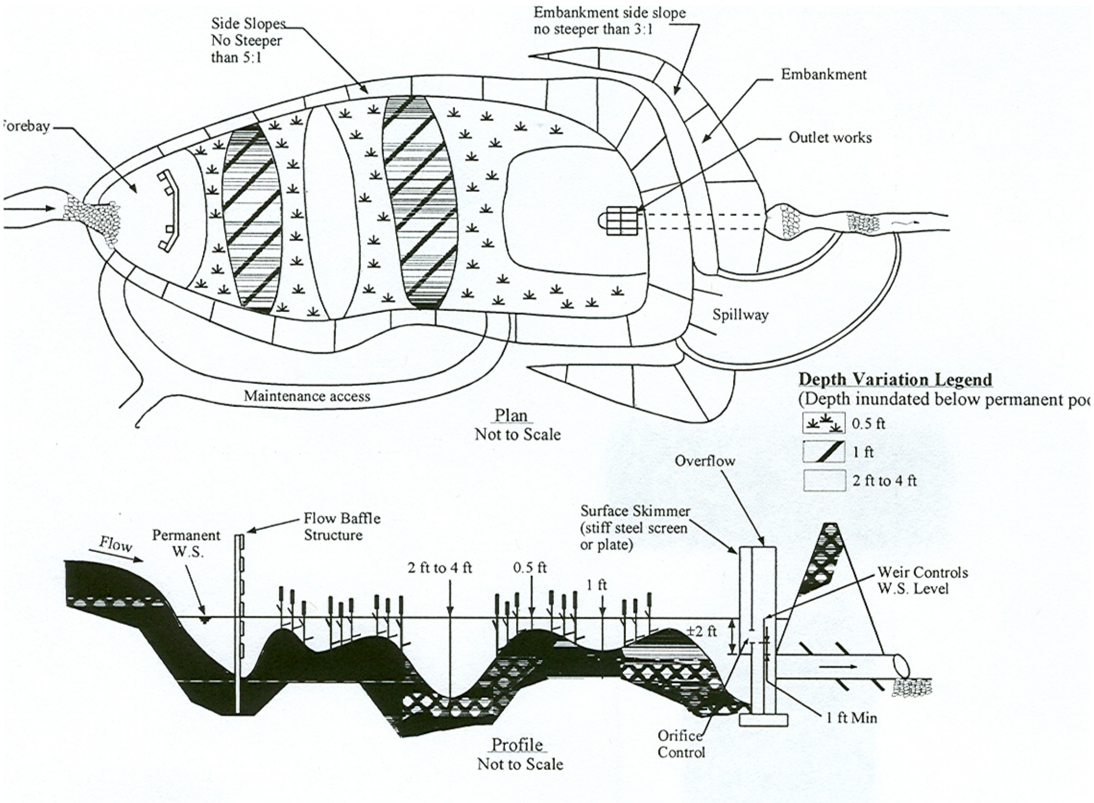

Figure PC-102A
Typical Constructed Wetland Components (SUSMP, 2002)

BMP PC – 103
EXTENDED DRY DETENTION BASINS

DESCRIPTION

Extended dry detention basins are depressed basins that temporarily store a portion of stormwater runoff following a storm event. The extended dry detention basins normally do not have a permanent water pool between storm events. The objective of these systems is to remove particulate pollutants and to reduce maximum runoff values associated with development to their pre-development levels. Detention basin facilities may be berm-encased areas or excavated basins. Figure PC-103A shows typical components of an Extended Dry Detention Basin.

ADVANTAGES

1. Modest removal efficiencies for the larger particulate fraction of pollutants.
2. Removal of sediment and buoyant materials. Nutrients, heavy metals, toxic materials, and oxygen-demanding particles are also removed with sediment substances associated with the particles.
3. Can be designed for combined flood control and stormwater quality control.
4. May requires less capital cost and land area when compared to wet pond BMP.
5. Downstream channel protection when properly designed and maintained.

LIMITATIONS

1. Require sufficient area and hydraulic head to function properly.
2. Generally not effective in removing dissolved and finer particulate size pollutants from stormwater.
3. Some constraints other than the existing topography include, but are not limited to, the location of existing and proposed utilities, depth to bedrock, location and number of existing trees, and wetlands.
4. Extended dry detention basins have moderate to high maintenance requirements.
5. Sediments can be resuspended if allowed to accumulate over time and escape through the hydraulic control to downstream channels and streams.
6. Some environmental concerns with using extended dry detention basins include potential impact on wetlands, wildlife habitat, aquatic biota, and downstream water quality.
7. May create mosquito breeding conditions and other nuisances.

DESIGN CRITERIA

EXTENDED DRY DETENTION BASINS:

Criteria	Consideration
Storage volume	Calculate the volume of stormwater to be mitigated by the extended dry detention basin using the method in Section 701-05. Provide a storage volume for 120 percent of the water quality volume. The additional 20 percent of storage volume provides for sediment accumulation and the resultant loss in storage volume.

Emptying time	A 24- to 48-hour emptying time should be used for the runoff volume generated from water quality volume, with no more than 50 percent of the water quality volume being released in 12 hours.
Basin geometry	Shape the pond with a gradual expansion from the inlet and a gradual contraction toward the outlet to limit short circuiting. The basin length to width ratio should be no less than 4:1.
Two-stage design	A two-stage design with a lower frequency pool that fills often with frequently occurring runoff and minimizes standing water and sediment deposition in the remainder of the basin can enhance water quality benefits. The bottom stage should store 10 to 25 percent of the water quality volume.
Low-flow channel	Conveys low base flows from the forebay to the outlet. Erosion protection should be provided for the low-flow channel.
Basin side slopes	Slopes should be stable to limit rill erosion and facilitate maintenance needs. Side slopes should be no steeper than 4:1, preferably flatter.
Inlet	Dissipate flow energy at basin's inflow point(s) to limit erosion and promote particle sedimentation.
Forebay design	Provide the opportunity for larger particles to settle out in an area that has, as a useful refinement, a solid surface bottom to facilitate mechanical sediment removal. The forebay volume should be 5 to 10 percent of the water quality volume.
Outlet design	Use a water quality outlet that is capable of slowly releasing the water quality over a 24- to 48-hour period. A perforated riser can be used in conjunction with orifices and a weir box opening above it to control larger storm outflows. An anti-seep collar should be considered for the outlet pipe to control seepage.
Perforation protection	Provide a crushed rock blanket of sufficient size to prevent clogging of the primary water quality outlet while not interfering significantly with its hydraulic capacity.
Dam embankment	The embankment should be designed not to fail during a 100-yr or larger storm. Embankment slopes should be no steeper than 3:1, preferably 4:1 or flatter, and planted with turf-forming grasses. Poorly compacted native soils should be excavated and replaced. Embankment soils should be compacted to at least 95 percent of their maximum density.
Vegetation	Bottom vegetation provides erosion control and sediment entrapment. Basin bottom, berms, and side-sloping areas may be planted with native grasses or with irrigated turf, depending on the local setting.
Maintenance access	Access to the forebay and outlet area shall be provided to maintenance vehicles. Maximum grades should be eight percent, and a solid driving surface of gravel, rock, concrete, gravel-stabilized turf, or other approved surface should be provided.

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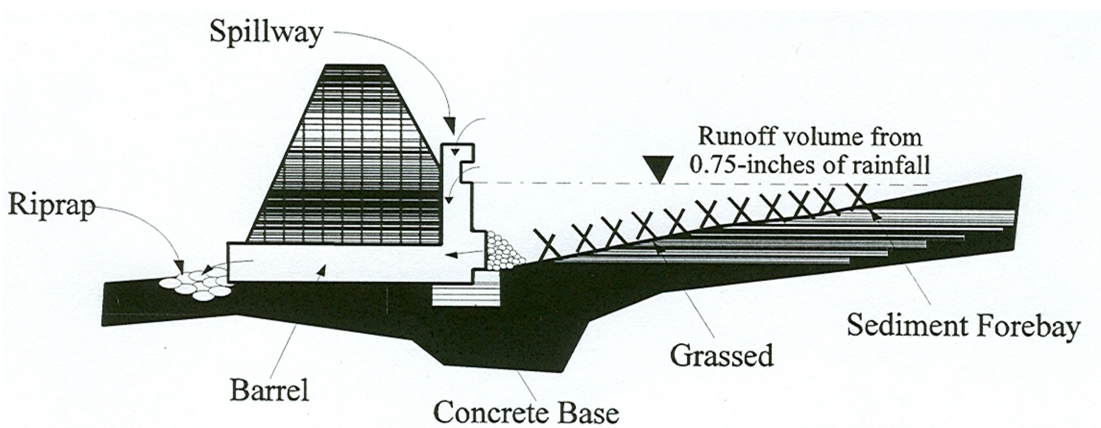

Figure PC-103A
Typical Extended Dry Detention Components (SUSMP, 2002)

BMP PC – 104
INFILTRATION BASINS

DESCRIPTION

An infiltration basin is a surface pond which captures first-flush stormwater and treats it by allowing it to percolate into the ground and through permeable soils. As the stormwater percolates into the ground, physical, chemical, and biological processes occur which remove both sediments and soluble pollutants. Pollutants are trapped in the upper layers of the soil, and the water is then released to groundwater. Infiltration basins are generally used for drainage areas between 5 and 50 acres (Boutiette and Duerring, 1994). For drainage areas less than 5 acres, an infiltration trench or other BMP may be more appropriate. For drainage areas greater than 50 acres, maintenance of an infiltration basin would be burdensome, and an extended/dry detention basin or wet pond may be more appropriate. Infiltration basins are generally dry except immediately following storms, but a low-flow channel may be necessary if a constant base flow is present.

Infiltration basins create visible surface ponds that dissipate because water is infiltrated through the pond bottom, while infiltration trenches hide surface drainage in underground void regions and the water is infiltrated below the rocks. Infiltration basins effectively remove soluble pollutants because processes such as adsorption and biological processes remove these soluble pollutants from stormwater. This kind of treatment is not always available in other kinds of BMPs.

Several types of infiltration basins exist. They can be either in-line or off-line, and may treat different volumes of water, such as the water quality volume or the 2-year or 10-year storm. A full infiltration basin is built to hold the entire water quality volume, and the only outlet from the pond is an emergency spillway. More commonly used is the combined infiltration/detention basin, where the outflow is controlled by a vertical riser. Excess flow volume spills over the drop inlet at the top of the riser, and very large storms will exit through the emergency spillway. Other types of basins include the side-by-side basin, and the off-line infiltration basin. The side-by-side basin consists of a basin with an elevated channel to carry base flows running along one of its sides. Storm flows also flow through the elevated channel, but overflow the channel and enter the basin when they become deep enough. An off-line infiltration basin is used to treat the first flush runoff, while higher flows remain in the main channel.

ADVANTAGES

1. High removal capability for particulate pollutants and moderate removal for soluble pollutants.
2. Groundwater recharge helps to maintain dry-weather flows in streams.
3. Can minimize increases in runoff volume.
4. When properly designed and maintained, it can replicate pre-development hydrology more closely than other BMP options.
5. Basins provide more habitat value than other infiltration systems.

LIMITATIONS

1. High failure rate due to clogging and high maintenance burden.
2. Low removal of dissolved pollutants in very coarse soils.
3. Not suitable on fill slopes or steep slopes.
4. Risk of groundwater contamination in very coarse soils, may require groundwater monitoring.
5. Should not be used if significant upstream sediment load exists.
6. Slope of contributing watershed needs to be less than 20 percent.
7. Not recommended for discharge to a sole source aquifer.
8. Cannot be located within 100 feet of drinking water wells.
9. Metal and petroleum hydrocarbons could accumulate in soils to potentially toxic levels.
10. Relatively large land requirement.
11. Only feasible where soil is permeable and there is sufficient depth to bedrock and water table.
12. Need to be located a minimum of 10 feet down gradient and 100 feet up gradient from building foundations because of seepage problems.
13. Infiltration facilities could fall under additional regulations of IDEM or IDNR regarding waste disposal to groundwater.

DESIGN CRITERIA

Designing an infiltration basin is a process in which several factors are examined. The soil type and the drainage area are important factors in infiltration basin design. If either one of these two is inappropriate, the infiltration basin will not function properly. The steps in the design of an infiltration basin are listed below.

1. *Drainage Area.* Drainage areas between 5 and 50 acres are good candidates for infiltration basins. Infiltration trenches might be more appropriate for smaller drainage areas, while retention ponds are more appropriate for larger drainage areas (Schueler, 1987).
2. *Soils.* The site must have the appropriate soil, or the basin will not function properly. It is important that the soil be able to accept water at a minimum infiltration rate. Soils with an infiltration rate of less than 0.3 inches per hour are not suitable sites for infiltration basins. Soils with a high percentage of clay are also undesirable, and should not be used if the percentage of clay is greater than 30. Generally, areas with fine to moderately fine soils are prevalent should not be considered as sites, because these soils do not have a high infiltration rate. Soils with greater than 40 percent combined silt/clay also should not be used. A series of soil cores should be taken to a depth of at least 5 feet below the proposed basin floor elevation to determine which kinds of soils are prevalent at the potential site.
3. *Volume.* Calculate the volume of stormwater to be mitigated by the infiltration basin using the methods in Section 701-05.
4. *Slope.* The basin floor should be as flat as possible to ensure an even infiltration surface and should not be or greater than 5 percent slope. Also, side slopes should have a maximum slope of 3 horizontal to 1 vertical (Schueler, 1987).
5. *Vegetation.* Vegetation should be established as soon as possible. Water-tolerant reed canary grass or tall fescue should be planted on the floor and side slopes of the basin (Schueler, 1987). Root penetration and thatch formation maintains and sometimes

improves infiltration capacity of the basin floor. Also, the vegetation helps to trap the pollutants by growing through the accumulated sediment and preventing resuspension. The vegetation also helps reduce pollution levels by taking up soluble nutrients for growth and converting them into less available pollutant forms.

6. *Inlet.* Sediment forebays or riprap aprons should be installed to reduce flow velocities and trap sediments upon entrance to the basin. Flow should be evenly distributed over the basin floor by a riprap apron. The inlet pile or channel should enter the basin at floor level to prevent erosion (Schueler, 1987).
7. *Drainage Time.* The basin should completely drain within 24 hours to avoid the risk of it not being empty before the next storm. Overestimation of the future infiltration capacity can result in a standing water problem. Ponds with detention times of less than six hours are not effectively removing pollutants from the storm flows (Schueler, 1987). The most common problem is setting the elevation and size of the low-flow orifice. If the orifice is too large, runoff events pass through the basin too quickly. If the low-flow orifice diameter is too narrow, there is a risk of creating an undesirable quasi-permanent pool.
8. *Buffer Zone.* A 25 foot buffer should be placed between the edge of the basin floor, and the nearest adjacent lot (Schueler, 1987). The buffer should consist of water tolerant, native plant species that provide food and cover for wildlife. This buffer zone may also act as a screen if necessary.
9. *Access.* Access to the basin floor should be provided for light equipment (Schueler, 1987).
10. *Water Table.* The basin floor should be a minimum of 10 feet above the water table.
11. *Maximum Depth.* The maximum allowable depth is equal to the infiltration rate multiplied by the maximum allowable dewatering time (24 hours).
12. *Freeboard.* A minimum of 2 feet of freeboard should be available between the spillway crest and the top of the dam (Dormann, et al., 1988).
13. *Emergency Spillway.* The emergency spillway should be able to safely pass the 100-year flood.
14. *Surface Area of the Basin Floor.* If the surface area of the basin floor is increased, the infiltration rate and quantity of runoff which can be infiltrated will be increased. Larger surface areas can also help compensate for clogging on the surface.

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BMP PC – 105
INFILTRATION TRENCHES

DESCRIPTION

An infiltration trench is basically an excavated trench that has been lined with filter fabric and backfilled with a sand filter and coarse stone to form an underground basin. Runoff is diverted into the trench and either infiltrates into the soil, or enters a perforated pipe underdrain and is routed to an outflow facility. The trench surface can be covered with grating and/or consist of stone, gabion, sand, or a grassed covered area with a surface inlet. The depths of an infiltration trench generally range between 3 and 8 feet (Schueler, 1987) and may change when site-specific factors are considered. Smaller trenches are used for water quality, while larger trenches can be constructed if stormwater quantity control is required (Schueler, 1987). Trenches are not usually feasible in ultra-urban or retrofit situations where the soils have low permeability or low voids (Schueler, 1992). They should be installed only after the contributing area has stabilized to minimize runoff of sediments. Infiltration trenches and infiltration basins follow similar design logic. The differences are that the former is for small drainage areas and stores runoff out of sight, within a gravel or aggregate matrix, whereas the latter is for larger drainage areas and water is stored in a visible surface pond. Unlike infiltration basins installed at the surface, the land above a subsurface trench system can be reclaimed and used. A trench may also be installed under a drainage swale to increase the storage of the infiltration system.

Infiltration trenches effectively remove soluble and particulate pollutants. They can provide groundwater recharge by diverting 60 to 90 percent of annual urban runoff back into the soil (Boutiette and Duerring, 1994). They are generally used for drainage areas less than 10 acres, but some references cite 5 acres as a maximum size drainage area (Schueler, 1987, 1992). Potential locations include residential lots, commercial areas, parking lots, and adjacent to road shoulders. Trenches are only feasible on permeable soils (sand and gravel), and where the water table and bedrock are situated well below the bottom of the trench (Boutiette and Duerring, 1994; Schueler, 1987). Trenches should not be used to trap course sediments, because the large sediment will clog the trench. Grass buffers can be installed to capture sediment before it enters the trench.

ADVANTAGES

1. Provides groundwater recharge.
2. Trenches fit into small areas.
3. Good pollutant removal capabilities.
4. Can minimize increases in runoff volume.
5. Can fit into medians, perimeters, and other unused areas of a development site.
6. Helps replicate pre-development hydrology and increases dry weather base flow.

LIMITATIONS

1. Slope of contributing watershed needs to be less than 20 percent.
2. Soil should have an infiltration rate greater than 0.3 inches per hour and clay

content less than 30 percent.

3. Drainage area should be between 1 to 10 acres.
4. The bottom of infiltration trench should be at least 4 feet above the underlying bedrock and the seasonal high water table.
5. High failure rates of conventional trenches and high maintenance burden.
6. Low removal of dissolved pollutants in very coarse soils.
7. Not suitable on fill slopes or steep slopes.
8. Risk of groundwater contamination in very coarse soils, may require groundwater monitoring.
9. Infiltration facilities could fall under additional regulations of IDEM or IDNR regarding waste disposal to groundwater.
10. Cannot be located within 100 feet of drinking water wells.
11. Need to be located a minimum of 10 feet down gradient and 100 feet up gradient from building foundations because of seepage problems.
12. Should not be used if upstream sediment load cannot be controlled prior to entry into the trench.
13. Metals and petroleum hydrocarbons could accumulate in soils to potentially toxic levels.

DESIGN CRITERIA

Infiltration trenches can be categorized both by trench type, and as surface or below ground. Special inlets are required for underground trenches to prevent sediment and oil or grease from clogging the infiltration trench (Schueler, 1987). Surface trenches are commonly used where land is not limiting and underground trenches are better suited for development with minimal land availabilities.

1. *Volume.* Calculate the volume of stormwater to be mitigated by the water quality volume calculation in Section 701-05.
2. *Dimensions.* Generally, soils with low infiltration rates require a higher ratio of bottom surface area to storage volume (Northern Virginia Planning District Commission and Engineers and Surveyors Institute, 1992). The following formulas can be used to determine the dimensions of the infiltration basin:

$$H_{Tmax}=E*t_{max}/P$$

$$H_{Tmin}=E*t_{min}/P$$

$$A=V/[\ E*t_{max}]$$

Where:

H_{Tmax}, H_{Tmin} = Maximum and minimum trench depths (ft)

E = Infiltration rate in length per unit time (ft/hr).
t_{max}, t_{min} = Maximum and minimum target drain-time (hr)
P= Pore volume ratio of stone aggregate (% porosity/100).
V= Fluid storage volume requirement (ft^3)

A= Trench bottom surface area (ft^2).

The actual storage volume of the facility is the void ratio multiplied by the total volume of the trench. The available land and other constraints such as depth to bedrock or water table are used to determine the final dimensions of the trench.

3. *Buffer Strip/Special Inlet.* A grass filter strip a minimum of 20 feet should surround the trench on all sides over which surface flow reaches an above-ground trench. A special inlet can be used to prevent floatable material, solids, grease, and oil from entering trenches which are located below ground.
4. *Filter Fabric.* The bottom and sides of the trench should be lined with filter fabric soon after the trench is excavated. The fabric should be flush with the sides, overlap on the order of 2 feet over the seams, and not have trapped air pockets. As an alternative, 6 inches of clean, washed sand may be placed on the bottom of the trench instead of filter fabric.
5. *Grass Cover.* If the trench is grass covered, at least 1 foot of soil should be over the trench for grass substrate.
6. *Surface Area.* The surface area of the trench can be engineered to the site with the understanding that a larger surface area of the bottom of the trench increases infiltration rates and helps to reduce clogging and that depth may be limited by seasonal groundwater.
7. *Surface Area of the Trench Bottom.* Pollutant removal in a trench can be improved by increasing the surface area of the trench bottom. This is done by adjusting the geometry to make the trench shallow and broad, rather than deep and narrow. Greater bottom surface area increases infiltration rates and provides more area and depth for soil filtering. In addition, broader trench bottoms reduce the risk of clogging at the soil/filter cloth interface by spreading infiltration over a wider area.
8. *Distance from Wells and Foundations.* The trench should be at least 100 feet from any drinking water supply well and at least 10 feet down gradient and 100 feet up gradient from building foundations (Schueler, 1987).
9. *Drain Time.* The drain time should be between two and three days. The total volume of the trench should drain in 48 hours. The minimum drain time should be 24 hours.
10. *Backfill Material.* The backfill material in the trench should have a D_{50} sized between 1.5 and 3 inches and clay content should be limited to less than 30 percent. The porosity of the material should be between 0.3 and 0.4.
11. *Observation Well.* An observation well of 4 to 6 inches diameter PVC should be located in the center of the trench and the bottom should rest on a plate. The top should be capped. The water level should be measured after a storm event. If it has not completely drained in three days, some remedial work may need to be done.
12. *Overflow Berm.* A 2 to 3 inch emergency overflow berm on the downstream side of the trench serves a twofold purpose. First, it detains surface runoff and allows it to pond and infiltrate to the trench. The berm also promotes uniform sheet flow for runoff overflow.

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BMP PC – 106
MEDIA FILTRATION

DESCRIPTION OF SAND FILTERS

Media filters are two-stage constructed treatment systems, including a pretreatment settling basin and a filter bed containing sand or other filter media. Various types of sand filter designs have been developed and implemented successfully in space-limited areas. The filters are not designed to treat the entire storm volume but rather the water quality volume (Section 701-05), that tends to contain higher pollutant levels. Sand filters can be designed so that they receive flow directly from the surface (via inlets or even as sheet flow directly onto the filter bed) or via storm drain pipes. They can be exposed to the surface or completely contained in underground pipe systems or vaults.

While there are various designs, most intermittent sand filters contain four basic components, as shown schematically in Figure PC-106A and discussed below:

1. *Diversion Structure.* Either incorporated into the filter itself or as a stand alone device, the diversion structure isolates the WQV and routes it to the filter. Larger volumes are bypassed directly to the storm drain system.
2. *Sedimentation Chamber.* Important to the long-term successful operation of any filtration system is the removal of large grained sediments prior to exposure to the filter media. The sedimentation chamber is typically integrated directly into the sand filter BMP but can also be a stand alone unit if space permits.
3. *Filter Media.* Typically consists of a 1-inch gravel layer over an 18 to 24 inch layer of washed sand. A layer of geotextile fabric can be placed between the gravel and sand layers.
4. *Underdrain System.* Below the filter media is a gravel bed, separated from the sand by a layer of geotextile fabric, in which is placed a series of perforated pipes. The treated runoff is routed out of the BMP to the storm sewer system or another BMP.

ADVANTAGES

1. May require less space than other treatment control BMPs and can be located underground.
2. Does not require continuous base flow.
3. Suitable for individual developments and small tributary areas up to 100 acres.
4. Does not require vegetation.
5. Useful in watersheds where concerns over groundwater quality or site conditions prevent use of infiltration.
6. High pollutant removal capability.
7. Can be used in highly urbanized settings.
8. Can be designed for a variety of soils.
9. Ideal for aquifer regions.

LIMITATIONS

1. Given that the amount of available space can be a limitation that warrants the consideration of a sand filter BMP, designing one for a large drainage area where there is room for more conventional structures may not be practical.
2. Available hydraulic head to meet design criteria.
3. Requires frequent maintenance to prevent clogging.
4. Not effective at removing liquid and dissolved pollutants.
5. Severe clogging potential if exposed soil surfaces exist upstream.
6. Sand filters may need to be placed offline to protect it during extreme storm events.

DESIGN CRITERIA

1. *Treatment Rate.* Calculate the flow rate of stormwater to be mitigated by the media filtration according to the method in Section 701-05.
2. *Surface Area of the Filter.* The following equation is for a maximum filtration time of 24 hours:

A. Surface Systems or Vaults

Filter area (ft2) = 3630SuAH/K(D+H)

Where: Su = unit storage (inches-acre)
A = area in acres draining to facility
H = depth (ft) of the sand filter
D = average water depth (ft) over the filter taken to be one-half the difference between the top of the filter and the maximum water surface elevation
K = filter coefficient recommended as 3.5

This equation is appropriate for filter media sized at a diameter of 0.02 to 0.04 inches. The filter area must be increased if a smaller media is used.

B. Underground Sandfilter Systems

a. Compute the required size of the sand filter bed surface area, AF. The following equation is based on Darcy's law and is used to size the sand filter bed area:

AF (ft2) = 24(WQV)(df)/ [k (hf + df) tf]
Where: Af = sand filter bed surface area (ft2)
WQV = Water quality treatment volume (ft3)
df = sand filter bed depth (ft)
k = filter coefficient recommended as 3.5 (ft/day)
hf = average height of water above the sand bed (ft)= hmax/2
hmax = elevation difference between the invert of the inlet pipe and the top of the sand filter bed (ft)
tf = time required for the runoff to filter through the sand bed (hr). (Typically 24 hr).

Note: 24 in the equation is the 24hr/day constant.

b. Choose a pipe size (diameter). The selection of pipe size should be based on site parameters such as: elevation of the runoff coming into the sand filter system, elevation of downstream connection to which the sand filter system outlet must tie into, and the minimum cover requirements for live loads. A minimum of 5' clearance should be provided between the top of the inner pipe wall and the top of the filter media for maintenance purpose. Use:

$D = d + 5$

Where:
D = pipe diameter (ft)
d = depth of sand filter and underdrain pipe media depth (ft)
= dg + df
dg = underdrain pipe media depth = 0.67’
df = sand filter bed deph (ft): 1.5 to 2.0 feet

c. Compute the sand filter width(based on the pipe geometry):

$$Wf = 2\,[R^2 - (R - d)^2\,]^{0.5}$$

Where:

Wf = filter width (ft)
R = pipe radius (ft) = D/2

d. Compute the filter length:

$$Lf = Af/\,Wf$$

Where:
Lf = filter length (ft)

3. *Configuration*

A. Surface sand filter

Criteria for the settling basin.
a. For the outlet use a perforated riser pipe.
b. Size the outlet orifice for a 24 hour drawdown
c. Energy dissipater at the inlet to the settling basin.
d. Trash rack at outlets to the filter.
e. Vegetate slopes to the extent possible.
f. Access ramp (4:1 or less) for maintenance vehicles.
g. One foot of freeboard.
h. Length to width ratio of at least 3:1 and preferably 5:1.
i. Sediment trap at inlet to reduce resuspension.

Criteria for the filter.
a. Use a flow spreader.
b. Use clean sand 0.02 to 0.04 inch diameter.
c. Some have placed geofabric on sand surface to facilitate maintenance.
d. Underdrains with:
- Schedule 40 PVC.
- 4 inch diameter.
- 3/8 inch perforations placed around the pipe, with 6 inch space between each perforation cluster.
- maximum 10 foot spacing between laterals.

- minimum grade of 1/8 inch per foot.

B. Underground sand filter

Criteria for the settling tank (if required).

a. Use orifice and/or weir structure for the outlet.

b. Size the outlet orifice or weir for a 24 hour drawdown time

c. Provide access manhole for maintenance.

Criteria for the filter.

a. Use a flow spreader.

b. Use clean sand 0.02 to 0.04 inch diameter.

c. Some have placed geofabric on sand surface to facilitate maintenance.

d. Underdrains with:

- Schedule 40 PVC.
- 4 inch diameter
- 3/8 inch perforations placed around the pipe, with 6 inch space between each perforation cluster.

e. Provide access manhole for maintenance.

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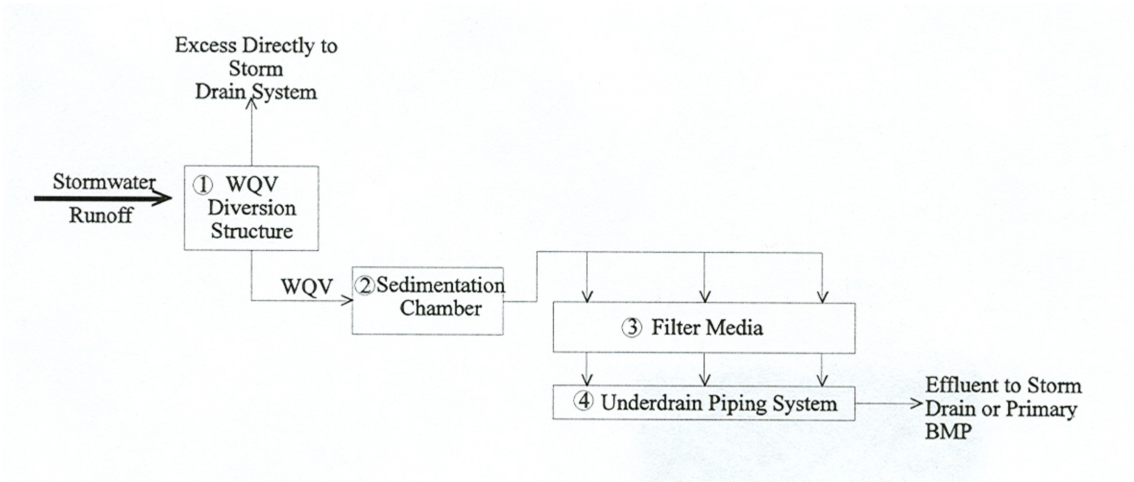

Figure PC-106A
Typical Media Filtration Schematic (SUSMP, 2002)

BMP PC – 107
STORM DRAIN INSERTS

DESCRIPTION

Storm drain inserts can be a variety of devices that are used in storm drain conveyance systems to reduce pollutant loadings in stormwater runoff. Most storm drain inserts reduce oil and grease, debris, and suspended solids through gravity, centrifugal force, or other methods. BMPs such as these can be particularly useful in areas susceptible to spills of petroleum products, such as gas stations. Figure PC-107A illustrates one of many different types of storm drain inserts. Trapped sediments and floatable oils must be pumped out regularly to maintain the effectiveness of the units.

ADVANTAGES

1. Prefabricated for different standard storm drain designs.
2. Require minimal space to install.

LIMITATIONS

1. Some devices may be vulnerable to accumulated sediments being resuspended during heavy storms.
2. Can only handle limited amounts of sediment and debris.
3. Maintenance and inspection of storm drain inserts are required before and after each rainfall event.
4. High maintenance costs.
5. Hydraulic losses.

DESIGN CRITERIA

1. Calculate the minimum flow rate to be mitigated by the storm drain insert using the methods in Section 701-05.
2. Select unit which meets Ordinance-required TSS removal rate for design flow rate.
3. Provide an overflow to bypass flows greater than the water quality treatment rate.

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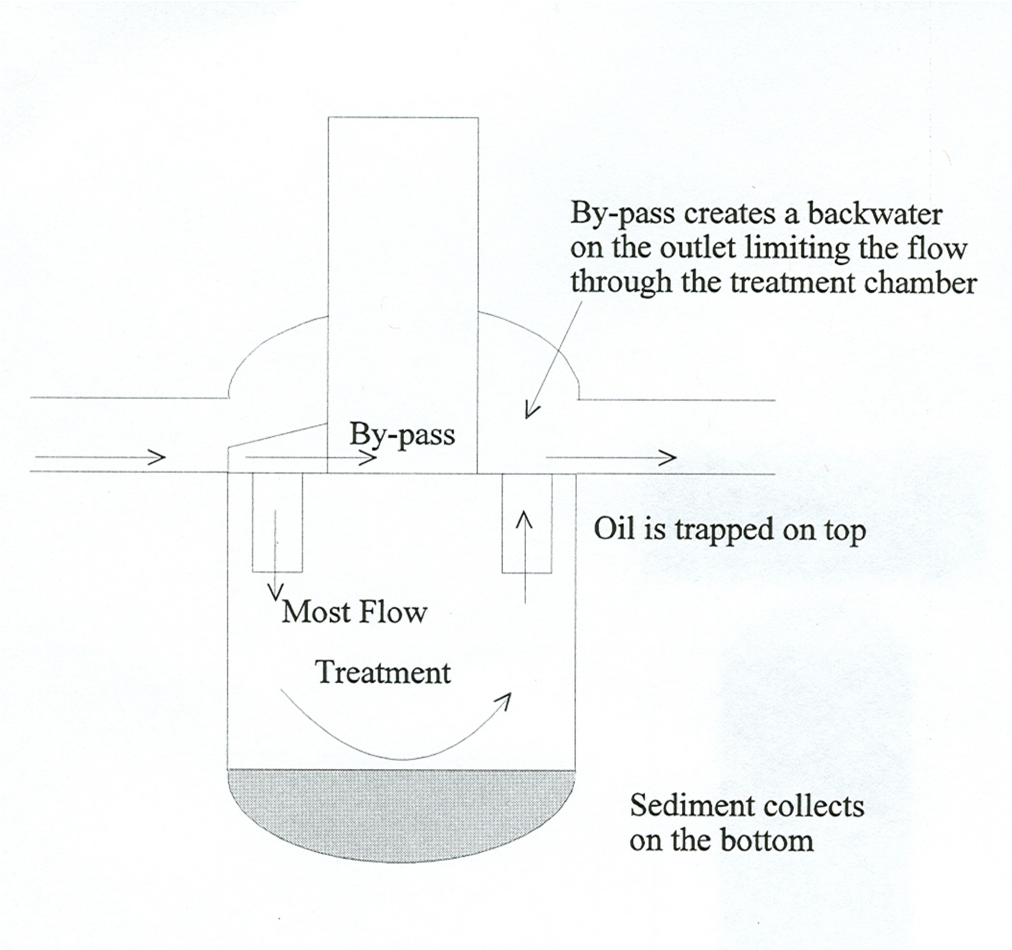

Figure PC-107A
Typical Storm Insert Schematic (SUSMP, 2002)

BMP PC – 108
VEGETATION FILTER STRIPS

DESCRIPTION

Vegetated filter strips, also known as vegetated buffer strips, are vegetated sections of land similar to vegetated swales, except they are essentially flat with low slopes, and are designed only to accept runoff overland sheet flow (Schueler, 1992). They may appear in any vegetated form from grassland to forest, and are designed to intercept upstream flow, lower flow velocity, and spread water out as sheet flow (Schueler, 1992). The dense vegetative cover facilitates conventional pollutant removal through detention, filtration by vegetation, and infiltration into soil (Yu and Kaighn, 1992). Wooded and grass filter strips have slightly higher removal rates. Dissolved nutrient removal for either type of vegetative cover is usually poor, however wooded strips show slightly higher removal due to increased retention and sequestration by the plant community (Florida Department of Transportation, 1994).

Although an inexpensive control measure, vegetated filter strips are most useful in contributing watershed areas where peak runoff velocities are low, as they are unable to treat the high flow velocities typically associated with high impervious cover (Barret, et al., 1993). Similar to vegetated swales, filter strips can last for 10 to 20 years with proper conditions and regular maintenance. Life expectancy is significantly diminished if uniform sheet flow and dense vegetation are not maintained. Figures PC-108A and PC-108B illustrate a typical Buffer Strip and its schematic.

ADVANTAGES

1. Lowers runoff velocity (Schueler, 1987).
2. Slightly reduces runoff volume (Schueler, 1987).
3. Slightly reduces watershed imperviousness (Schueler, 1987).
4. Slightly contributes to groundwater recharge (Schueler, 1987).
5. Aesthetic benefit of vegetated “open spaces” (Colorado Department of Transportation, 1992).
6. Preserves the character of riparian zones, prevents erosion along streambanks, and provides excellent urban wildlife habitat (Schueler, 1992).

LIMITATIONS

1. Filter strips cannot treat high velocity flows, and do not provide enough storage or infiltration to effectively reduce peak discharges to predevelopment levels for design storms (Schueler, 1992). This lack of quantity control dictates use in rural or low density development.
2. Requires slope less than 5%.
3. Requires low to fair permeability of natural subsoil.
4. Large land requirement.
5. Often concentrates water, which significantly reduces effectiveness.
6. Pollutant removal is unreliable in urban settings.

DESIGN CRITERIA

1. Successful performance of filter strips relies heavily on maintaining shallow unconcentrated flow (Colorado Department of Transportation, 1992). To avoid flow channelization and maintain performance, a filter strip should:

   (1) Be equipped with a level spreading device for even distribution of runoff,
   (2) Contain dense vegetation with a mix of erosion resistant, soil binding species,

(3) Be graded to a uniform, even and relatively low slope,

(4) Laterally traverse the contributing runoff area (Schueler, 1987),

(5) The area to be used for the strip should be free of gullies or rills that can concentrate overland flow (Schueler, 1987),

(6) Filters strip should be placed 3 to 4 feet from edge of pavement to accommodate a vegetation free zone (Washington State Department of Transportation, 1995). The top edge of the filter strip along the pavement should be designed to avoid the situation where runoff would travel along the top of the filter strip, rather than through it. Dilhalla, et al., (1986) suggest that berms be placed at 50 to 100 feet intervals perpendicular to the top edge of the strip to prevent runoff from bypassing it (as cited in Washington State Department of Transportation, 1995),

(7) Top edge of the filter strip should follow the same elevation contour. If a section of the edge of the strip dips below the contour, runoff will tend to form a channel toward the low spot,

(8) Filter strips should be landscaped after other portions of the project are completed (Washington State Department of Transportation, 1995). However, level spreaders and strips used as sediment control measures during the construction phase can be converted to permanent controls if they can be regraded and reseeded to the top edge of the strip.

2. Filter strips can be used on an up gradient from watercourses, wetlands, or other water bodies, along toes and tops of slopes, and at outlets of other stormwater management structures (Boutiette and Duerring, 1994). They should be incorporated into street drainage and master drainage planning (Urbonas, 1992). The most important criteria for selection and use of this BMP are soils, space, and slope, where:

(1) *Soils and moisture are adequate to grow relatively dense vegetative stands.* Underlying soils should be of low permeability so that the majority of the applied water discharges as surface runoff. The range of desirable permeability is between 0.06 to 0.6 inches/hour (Horner, 1985). Common soil textural classes are clay, clay loam, and silty clay. The presence of clay and organic matter in soils improves the ability of filter strips to remove pollutants from the surface runoff (Schueler, 1992). Greater removal of soluble pollutants can be achieved where the water table is within 3 feet of the surface (i.e., within the root zone) (Schueler, 1992). Filter strips function most effectively where the climate permits year-round dense vegetation.

(2) *Sufficient space is available.* Because filter strip effectiveness depends on having an evenly distributed sheet flow, the size of the contributing area and the associated volume runoff have to be limited (Urbonas, 1992). To prevent concentrated flows from forming, it is advisable to have each filter strip serve a contributing area of five acres or less (Schueler, 1987). When used alone, filter strip application is in areas where impervious cover is low to moderate and where there are small fluctuations in peak flow.

(3) *Longitudinal slope is five percent or less.* When filter strips are used on steep or unstable slopes, the formation of rills and gullies can disrupt sheet flow (Urbonas, 1992). As a result filter strips will not function at all on slopes greater than 15 percent and may have reduced effectiveness on slopes between 6 to 15 percent.

3. The design should be based on the same methods detailed for swales. The referred geometry of a filter strip is rectangular, and this should be used when applying the design procedures of vegetated swales.

4. The following provisions apply specifically to filter strips (Horner, 1993):

(1) Slopes should be no greater than 15 percent and should preferably be lower than 5 percent, and be uniform throughout the strip after final grading.

(2) Hydraulic residence time normally no less than 9 minutes, and in no case less than 5 minutes.

(3) Average velocity no greater than 0.9 feet/second.
(4) Manning's friction factor (*n*) of 0.02 should be used for grassed strips, *n* of 0.024 if strip is infrequently mowed, or a selected higher value if the strip is wooded.
(5) The width should be no greater than that where a uniform flow distribution can be assured.
(6) Average depth of flow (design depth) should be no more than 0.5 inches.
(7) Hydraulic radius is taken to be equal to the design flow depth.
(8) A minimum of 8 feet is recommended for filter strip width.

5. Filter strips function best with longitudinal slopes less than 10 percent, and ideally less than 5 percent. As filter strip length becomes shorter, slope becomes more influential. Therefore, when a minimum strip length of 20 feet is utilized, slopes should be graded as close to zero as drainage permits (Schueler, 1987). With steeper slopes, terracing through the use of landscape timber, concrete weirs, or other means may be required to maintain sheet flow.
6. Calculate the flow rate of stormwater to be mitigated by the vegetated filter strip using the Method outlined in Section 701-05.
7. Another design issue is runoff collection and distribution to the strip, and release to a transport system or receiving water (Horner, 1985). Flow spreader devices should be used to introduce the flow evenly to the filter strip (Urbonas, 1992). Concentrated flow needs to use a level spreader to evenly distribute flow onto a strip. There are many alternative spreader devices, with the main consideration being that the overland flow spreader be distributed equally across the strip. Level spreader options include porous pavement strips, stabilized turf strips, slotted curbing, rock-filled trench, concrete sills, or plastic-lined trench that acts as a small detention pond (Yu and Kaighn, 1992). The outflow and filter side lip of the spreader should have a zero slope to ensure even runoff distribution (Yu and Kaighn, 1992). Once in the filter strip, most runoff from significant events will not be infiltrated and will require a collection and conveyance system. Grass-lined swales are often used for this purpose and can provide another BMP level. A filter strip can also drain to a storm sewer or street gutter (Urbonas, 1992).
8. Filter strips should be constructed of dense, soil-binding deep-rooted water resistant plants. For grassed filter strips, dense turf is needed to promote sedimentation and entrapment, and to protect against erosion (Yu and Kaighn, 1992). Turf grass should be maintained to a blade height of 2 to 4 inches. Most engineered, sheet-flow systems are seeded with specific grasses. The grass species chosen should be appropriate for the climatic conditions and maintenance criteria for each project.
9. Trees and woody vegetation have been shown to increase infiltration and improve performance of filter strips. Trees and shrubs provide many stormwater management benefits by intercepting some rainfall before it reaches the ground, and improving infiltration and retention through the presence of a spongy, organic layer of materials that accumulates underneath the plants (Schueler, 1987). As discussed previously in this section, wooded strips have shown significant increases in pollutant removal over grass strips. Maintenance for wooded strips is virtually non-existent, another argument for using trees and shrubs. However, there are drawbacks to using woody plants. Since the density of the vegetation is not as great as a turf grass cover, wooded filter strips need additional length to accommodate more vegetation. In addition, shrub and tree trunks can cause uneven distribution of sheet flow, and increase the possibility for development of gullies and channels. Consequently, wooded strips require flatter slopes than a typical grass cover strip to ensure that the presence of heavier plant stems will not facilitate channelization.

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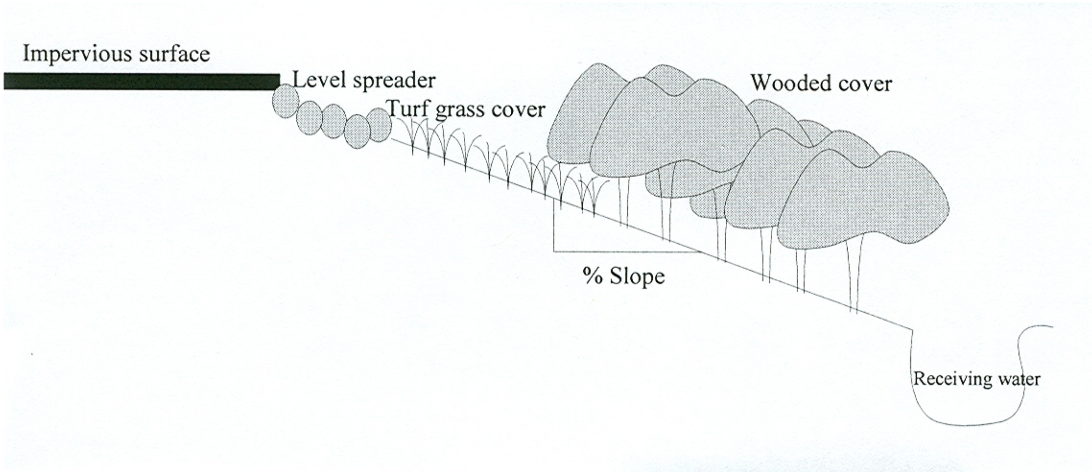

Figure PC-108A
Typical Buffer Strip (SUSMP, 2002)

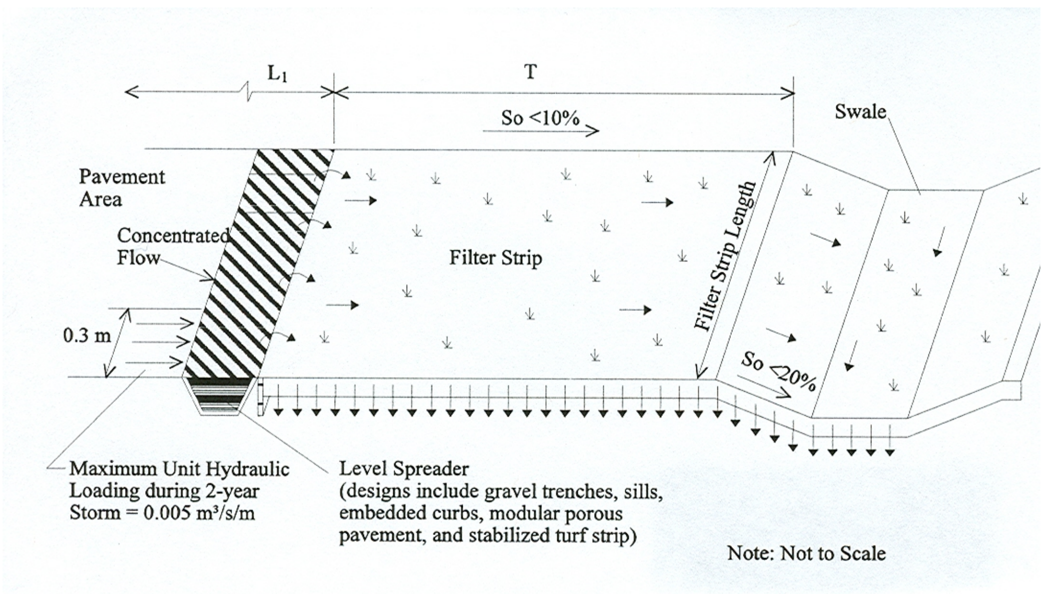

Figure PC-108B
Typical Buffer Strip Schematic (SUSMP, 2002)

BMP PC – 109
VEGETATIVE SWALE

DESCRIPTION

Vegetated swales are shallow vegetated channels to convey stormwater where pollutants are removed by filtration through grass and infiltration through soil. They look similar to, but are wider than a ditch that is sized only to transport flow. They require shallow slopes and soils that drain well. Vegetated swale designs have achieved mixed performance in pollutant removal efficiency. Moderate removal rates have been reported for suspended solids and metals associated with particulates such as lead and zinc. Runoff waters are typically not detained long enough to effectively remove very fine suspended solids, and swales are generally unable to remove significant amounts of dissolved nutrients. Pollutant removal capability is related to channel dimensions, longitudinal slope, and type of vegetation. Optimum design of these components will increase contact time of runoff through the swale and improve pollutant removal rates. Vegetated swales are primarily stormwater conveyance systems. They can provide sufficient control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low-to-moderate sloped areas as an alternative to ditches and curb and gutter drainage. Their performance diminishes sharply in highly urbanized settings. Vegetated swales are often used as a pretreatment measure for other downstream BMPs, particularly infiltration devices. Enhanced vegetative swales utilize check dams and wide depressions to increase runoff storage and promote greater settling of pollutants.

ADVANTAGES

1. Relatively easy to design, install and maintain.
2. Vegetated areas that would normally be included in the site layout, if designed for appropriate flow patterns, may be used as a vegetated swale.
3. Relatively inexpensive.
4. Vegetation is usually pleasing to residents.

LIMITATIONS

1. Irrigation may be necessary to maintain vegetative cover.
2. Potential for mosquito breeding areas.
3. Possibility of erosion and channelization over time.
4. Requires dry soils with good drainage and high infiltration rates for better pollutant removal.
5. Not appropriate for pollutants toxic to vegetation.
6. Large area requirements may make this BMP infeasible for some sites.
7. Used to serve sites less than 10 acres in size, with slopes no greater than 5 percent.
8. The seasonal high water table should be at least 2 feet below the surface.
9. Buildings should be at least 10 feet from the top of bank

DESIGN CRITERIA

Several criteria should be kept in mind when beginning swale design. These provisions, presented below, have been developed through a series of evaluative research conducted on swale performance.

Criteria for optimum swale performance (Horner, 1993)		
Parameter	***Optimal Criteria***	***Minimum Criteria****
Hydraulic Residence Time	9 min	5 min
Average Flow Velocity	≤0.9 ft/s	***N/A***
Swale Width	8 ft	2 ft
Swale Length	200 ft	100 ft
Swale Slope	2 - 4%	1%
Side Slope Ratio (horizontal:vertical)	4 : 1	3 : 1

Note: * Criteria at or below minimum values can be used when compensatory adjustments are made to the standard design. Specific guidance on implementing these adjustments will be discussed in the design section.

The following steps are recommended to be conducted in order to complete a swale design:

(1) Determine the flow rate to the system.
(2) Determine the slope of the system.
(3) Select a swale shape (skip if filter strip design).
(4) Determine required channel width.
(5) Calculate the cross-sectional area of flow for the channel.
(6) Calculate the velocity of channel flow.
(7) Calculate swale length.
(8) Select swale location based on the design parameters.
(9) Select a vegetation cover for the swale.
(10) Check for swale stability.

Recommended procedures for each task are discussed in detail below.

1. *Determine Flow Rate to the System.* Calculate the flow rate of stormwater to be mitigated by the vegetated swale using the methods outlined in Section 701-05. Runoff from larger events should be designed to bypass the swale, consideration must be given to the control of channel erosion and destruction of vegetation. A stability analysis for larger flows (up to the 100-yr 24-hour) must be performed. If the flow rate approaches or exceeds 1 ft/s, one or more of the design criteria above may be violated, and the swale system may not function correctly (Washington State Department of Transportation, 1995). Alternative measures to lower the design flow should be investigated. Possibilities include dividing the flow among several swales, installing detention to control release rate upstream, and reducing developed surface area to reduce runoff coefficient value and gain space for biofiltration (Horner, 1993).
2. *Determine the Slope of the System.* The slope of the swale will be somewhat dependent on where the swale is placed. The slope should normally be between 2 and 4 percent. A slope of less than 2 percent can be used if underdrains are placed beneath the channel to prevent ponding.
3. *Select a Swale Shape.* Normally, swales are designed and constructed in a trapezoidal or parabolic shape.
4. *Determine Required Channel Width.* Estimates for channel width for the selected shape can be obtained by applying Manning's Equation:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

Where:
Q = Flow (ft3/s).
A = Cross-sectional area of flow (ft2).
Rh = Hydraulic radius of flow cross section (ft).
S = Longitudinal slope of biofilter (ft/ft).
n = Manning's roughness coefficient.

A Manning's n value of 0.02 is used for routine swales that will be mowed with some regularity. For swales that are infrequently mowed, use a Manning's n value of 0.024. A higher n value can be selected if it is known that vegetation will be very dense (Khan, 1993).

Because the channel is wide, the hydraulic radius approaches the flow depth. Substituting the geometric equations for a trapezoidal channel into Manning's equation, the bottom width (wb) and the top width (wt) for the trapezoid swale can be computed using the following equations:

$$w_b = \frac{Qn}{1.486 y^{1.67} S^{0.5}} - Zy \quad \text{and} \quad w_t = w_b + 2Zy$$

Where:
Q = Flow rate in ft3/s.
n = Manning's roughness coefficient
y = Depth of flow.
Z = The side slope in the form of Z:1.

Typically, the depth of flow in the channel (y) is set at 3 to 4 inches. Flow depth can also be determined by subtracting 2 inches from the expected grass height, if the grass type and the height it will be maintained is known. Values lower than 3 to 4 inches can be used, but doing so will increase the computed width of the swale (Washington State Department of Transportation, 1995).

Swale width computed should be between 2 to 8 feet. Relatively wide swales (those wider than 8 feet are more susceptible to flow channelization and are less likely to have uniform sheet flow across the swale bottom for the entire swale length. The maximum width for swales is on the order of 10 feet, however widths greater than 8 feet should be evaluated to consider the effectiveness of the flow spreading design used and the likelihood of maintaining evenness in the swale bottom. Since length may be used to compensate for width reduction (and vice versa) so that area is maintained, the swale width can be arbitrarily set to 8 feet to continue with the analysis.

5. *Calculate Cross-Sectional Area.* Compute the cross-sectional area (A) for the swale.
6. *Calculate the Velocity of the Channel Flow.* Channel flow velocity (V) can be computed using the continuity equation

    V (ft/sec)=Q(cfs)/A(ft2)

This velocity should be less than 0.9 ft/s, a velocity that was found to cause grasses to be flattened, reducing filtration. A velocity lower than this maximum value is recommended to achieve the 9-minute hydraulic residence time criterion, particularly in shorter swales (at V = 0.9

ft/s, a 485-ft swale is needed for a 9-min residence time and a 269-ft swale for a 5-min residence time).

If the value of V suggests that a longer swale will be needed than space permits, investigate how the design flow Q can be reduced, or increase flow depth (y) and/or swale width (wt) up to the maximum allowable values and repeat the analysis.

7. *Calculate Swale Length.* Compute the swale length (L) using the following equation:

   $L=60Vtr$

   Where:

   L=length required to achieve residence time

   *t*r = Hydraulic residence time (in minutes).

   V=velocity of channel flow (ft/sec)

   Use tr = 9 min for this calculation.

   If a swale length greater than the space will permit results, investigate how the design flow Q can be reduced. Increase flow depth (y) and/or swale width (wb) up to the maximum allowable values and repeat the analysis. If all of these possibilities are checked and space is still insufficient, t can be reduced, but to no less than 5 minutes. If the computation results in L less than 100 ft, set L = 100 ft and investigate possibilities in width reduction. This is possible through recalculating V at the 100-ft length, recomputing cross-sectional area, and ultimately adjusting the swale width wb using the appropriate equation.

8. *Select Swale Location.* Swale geometry should be maximized by the designer, using the above equations, and given the area to be utilized. If the location has not yet been chosen, it is advantageous to compute the required swale dimensions and then select a location where the calculated width and length will fit. If locations available cannot accommodate a linear swale, a wide-radius curved path can be used to gain length.

   Sharp bends should be avoided to reduce erosion potential. Regardless of when and how site selection is performed, consideration should be given to the following site criteria:

   Soil Type. Soil characteristics in the swale bottom should be conducive to grass growth. Soils that contain large amounts of clay cause relatively low permeability and result in standing water, and may cause grass to die. Where the potential for leaching into groundwater exists, the swale bottom may need to be sealed with clay to protect from infiltration into the resource. Compacted soils will need to be tilled before seeding or planting. Topsoil should be applied at a depth of at least 6 inches using the following recommended topsoil mix: 50 to 80 percent sandy loam, 10 to 20 percent clay, and 10 to 20 percent composted organic matter (exclude animal waste).

   Slope. The natural slope of the potential location will determine the nature and amount of regrading, or if additional measures to reduce erosion and/or increase pollutant removal are required. Swales should be graded carefully to attain uniform longitudinal and lateral slopes and to eliminate high and low spots. If needed, grade control checks should be provided to maintain the computed longitudinal slope and limit maximum flow velocity (Urbonas, 1992).

   Natural Vegetation. The presence and composition of existing vegetation can provide valuable information on soil and hydrology. If wetland vegetation is present, inundated conditions may exist at the site. The presence of larger plants, trees and shrubs, may provide additional stabilization along the swale slopes, but also may shade any grass cover established. Most grasses grow best in full sunlight, and prolonged shading should be avoided. It is preferable that vegetation species be native to the region of application, where establishment and survival have been demonstrated.

9. *Select Vegetative Cover.* Select vegetation on the basis of pollution control objectives and according to what will best establish and survive in the site conditions. In general, select fine, close-growing, water-resistant grasses. Species with these desirable traits include tall fescue or mixtures of big bluestem, little bluestem, switchgrass, or Indian grass. Emergent wetland plant species or other alternative vegetation may be necessary where some period of soil saturation is expected, where particular pollutant uptake characteristics are desired. Use wetland species that are finely divided like grass and relatively resilient. Invasive species, such as cattails, should be avoided to eliminate proliferation in the swale and downstream. In swales next to roadways where de-icer is regularly used, salt tolerant species should be used. Woody or shrubby plantings can be used for landscaping on the edge of side slopes, but not in the swale treatment area. If landscape plantings are to be used, selection and planting processes should be carefully planned and carried out to avoid potential problems.
10. *Check Swale Stability.* The stability check is performed for the combination of highest expected flow and least vegetation coverage and height. Stability is normally checked for flow rate (Q) for the 100-yr, 24-hr storm unless runoff from larger such events will bypass the swale. Q can be determined using the same methods mentioned for the initial design storm computation. The maximum velocity (V_{max}) in ft/s that is permissible for the vegetation type, slope, and soil conditions should be obtained.

Maintenance for vegetated swales is as follows:

1. Groomed swales planted in grasses must be mowed regularly during the summer to promote growth and to increase density and pollutant uptake. Be sure not to cut below the design flow (maintenance personnel must be made aware of this requirement). Remove cuttings promptly and dispose in such a way as to ensure that no pollutants enter receiving waters.
2. If the objective is prevention of nutrient transport, mow grasses or cut emergent wetland-type plants to a low height at the end of the growing season. For other pollution control objectives, let the plants stand at a height exceeding the design water depth by at least two inches at the end of the growing season.
3. Remove sediments during summer months when they build up to 6 inches at any spot, cover swale vegetation, or otherwise interfere with swale operation. Use of equipment like a Ditch Master is strongly recommended over a backhoe or dragline. If the equipment leaves bare spots, reseed them immediately and take the necessary steps to ensure the stand of grass is established and the swale is stabilized.
4. Inspect swales periodically, especially after periods of heavy runoff. Remove sediments, fertilize, and reseed as necessary. Be careful to avoid introducing fertilizer to receiving waters or groundwater.
5. Clean curb cuts when soil and vegetation buildup interferes with flow introduction.
6. Perform special public education for residents near swales concerning their purpose and the importance of keeping them free of debris.
7. See that litter is removed in order to keep swales attractive in appearance.
8. Base cleaning methods and frequency on an analysis of hydraulic necessity. Use a technique such as the Ditch Master to remove only the amount of sediment necessary to restore needed hydraulic capacity, leaving vegetative plant parts in place to the maximum extent possible.

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BMP PC – 110
WET PONDS

DESCRIPTION

IMPORTANT NOTE: The material presented in this fact sheet is intended to apply to a case where a wet pond is being utilized as a post-construction stormwater quality BMP only. When the pond is being designed as a multi-purpose facility acting both as a water quality BMP and a wet-bottom detention pond described in Chapter 300, several design features must be modified to accommodate both purposes and requirements. Minimum requirements for a wet-bottom detention pond stated in Chapter 300 must be met and supersede any conflicting requirements in this fact sheet when water quality BMP features are added to a wet-bottom detention pond.

The wet pond is a facility which removes sediment, Biochemical Oxygen Demand (BOD), organic nutrients, and trace metals from stormwater runoff. This is accomplished by slowing down stormwater using an in-line permanent pool or pond affecting settling of pollutants. The wet pond is similar to a dry pond, except that a permanent volume of water is incorporated into the design. The drainage area should be such that an adequate base flow is maintained in the pond. Biological processes occurring in the permanent pond pool aid in reducing the amount of soluble nutrients present in the water, such as nitrate and ortho-phosphorus (Schueler, 1987).

The basic elements of a wet pond are shown below. A stabilized inlet prevents erosion at the entrance to the pond. It may be necessary to install energy dissipaters. The permanent pool is usually maintained at a depth between 3 and 8 ft. The shape of the pool can help improve the performance of the pond. Maximizing the distance between the inlet and outlet provides more time for mixing of the new runoff with the pond water and settling of pollutants. Overflow from the pond is released through outlet structures to discharge flows at various elevations and peak flow rates. The outfall channel should be protected to prevent erosion from occurring downstream of the outlet.

Soil conditions are important for the proper functioning of the wet pond. The pond is a permanent pool, and thus must be constructed such that the water must not be allowed to infiltrate from the permanent portion of the pool. It is difficult to form a pool in soils with high infiltration rates soon after construction. Eventually, however, deposition of silt at the bottom of the pond will help slow infiltration. If extremely permeable soils exist at the site (hydrologic soil group A or B), a geotextile or clay liner may be necessary. Typical components of a Wet Pond are illustrated in Figures PC-110A.

ADVANTAGES

1. Wet ponds have recreational and aesthetic benefits due to the incorporation of permanent pools in the design.
2. Wet ponds offer flood control benefits in addition to water quality benefits.
3. Wet ponds can be used to handle large drainage areas.
4. High pollutant removal efficiencies for sediment, total phosphorus, and total nitrogen are achievable <u>when the volume of the permanent pool is at least three times the water quality volume</u> (the volume to be treated).
5. A wet pond removes pollutants from water by both physical and biological processes, thus they are more effective at removing pollutants than extended/dry detention basins.
6. Creation of aquatic and terrestrial habitat.

LIMITATIONS

1. Wet ponds may be feasible for stormwater runoff in residential or commercial areas with a combined drainage area greater than 20 acres but no less than 10 acres.
2. An adequate source of water must be available to ensure a permanent pool throughout the entire year.
3. If the wet pond is not properly maintained or the pond becomes stagnant; floating debris, scum, algal blooms, unpleasant odors, and insects may appear.
4. Sediment removal is necessary every 5 to 10 years.
5. Heavy storms may cause mixing and subsequent resuspension of solids.
6. Evaporation and lowering of the water level can cause concentrated levels of salt and algae to increase.
7. Cannot be placed on steep unstable slopes.
8. Embankment may be regulated as a dam by IDNR.

DESIGN CRITERIA

1. *Hydrology*. If the device will also be used for stormwater quantity control, it will be necessary to reduce the peak flows after development to the levels described in Chapter 6.
2. *Volume*. Calculate the volume of stormwater to be mitigated by the wet pond using the water quality volume calculations in Section 701-05. The volume of the permanent pool should be 3 times this water quality volume.
3. *Pond Shape*. The pond should be long and narrow and generally shaped such that it discourages "short-circuiting." Short-circuiting occurs when storm flows bypass the pond and do not mix well with the pool. A length to width ratio of no less than 3:1, with 5:1 being preferred, will help minimize short circuiting. The inlet and outlet should be at opposite ends of the pond where feasible. If this is not possible, then berms can be installed to increase the flow path and water detention time. Also, the pond should gradually expand from the inlet and gradually contract toward the outlet. Several examples of ponds shaped to reduce short-circuiting are shown below. [See Figure PC-110B]
4. *Depth*. The depth of the water quality pond is important in the design of the pond. If the pond is too shallow, sediment will be easily resuspended as a result of wind. Shallow ponds should not be used unless vegetation is adequate to stabilize the pond. If the pond is too deep, safety considerations emerge and stratification may occur, possibly causing anoxic conditions near the bottom of the pond. If the pond becomes anoxic, pollutants adsorbed to the bottom sediments may be released back to the water column. The average depth should be 3 to 6 ft, and depths of more than 8 ft should be avoided (Schueler, 1987). In order for a pond to provide treatment of nutrients, a shallow, organic rich marsh fringe shall be provided. This littoral zone of 6 to 18 inches deep shall account for 30 percent of the permanent pool surface for plant growth along the perimeter of the pool.
5. *Vegetation.* Vegetation shall be planted around the perimeter of the pond on both the side slopes and littoral areas. Vegetation located near the inlet to the pond can help trap sediments; algae growing on these plants can also filter soluble nutrients in the water column. Vegetation should be kept away from the pond outlet. Native turf-forming grasses or irrigated turf should be planted on sloped areas, and aquatic species should be planted on the littoral areas (Urbonas, et al., 1992). Native grass is recommended to be planted along the outside perimeter of the pond in order to deter geese. Mowing should be kept to a minimum.
6. *Side Slopes.* Gradual side slopes of a wet pond enhance safety and help prevent erosion and make it easier to establish dense vegetation. If vegetation cannot be established, the unvegetated banks will add to erosion and subsequently the sediment load. It is recommended that side slopes be no

greater than 3:1. If slopes are greater than this, riprap should be used to stabilize the banks (Schueler, 1987).

7. *Hydraulic Devices*. An outlet device, typically a riser-pipe barrel system, should be designed to release runoff in excess of the water quality volume and to control storm peaks. The outlet device should still function properly when partial clogging occurs. Plans should provide details on all culverts, risers, and spillways. Calculations should depict inflow, storage, and outflow characteristics of the design. Some frequently used design details for extending detention times in wet ponds are shown and described below (Schueler, 1987). [See Figure PC-110C]

    a. *Slotted Standpipe from Low-Flow Orifice, Inlet Control (dry pond, shallow wet pond, or shallow marsh).* An "L"-shaped PVC pipe is attached to the low-flow orifice. An orifice plate is located within the PVC pipe which internally controls the release rate. Slots or perforations are all spaced vertically above the orifice plate, so that sediment deposited around the standpipe will not impede the supply of water to the orifice plate.

    b. *Negatively Sloped Pipe from River (wet ponds or shallow marshes)* This design was developed to allow for extended detention in wet ponds. The release rate is governed merely by the size of the pipe. The risk of clogging is largely eliminated by locating the opening of the pipe at least 1 ft below the water surface where it is away from floatable debris. Also, the negative slope of the pipe reduces the chance that debris will be pulled into the opening by suction. As a final defense against clogging, the orifice can be protected by wire mesh.

    c. *Hooded Riser (wet ponds).* In this design, the extended detention orifice is located on the face of the riser near the top of the permanent pool elevation. The orifice is protected by wire mesh and a hood, which prevents floatable debris from clogging the orifice.

8. *Inlet and Outlet Protection.* The inlet pipe should discharge at or below the water surface of the permanent pool. If it is above the pool, an outlet energy dissipater will protect the banks and side slopes of the pond to avoid erosion. The stream channel just downstream of the pond outlet should be protected from scouring by placing riprap along the channel. Also, the slope of the outlet channel should be close to 0.5 percent. Riprap between 18 and 30 inches should be used. If the outlet pipe is less than 24 inches, 9 to 12 inches riprap may be used. Stilling basins may also be installed to reduce flow velocities at the outfall (Schueler, 1987).

9. *Forebay.* A forebay may be installed as part of the wet pond to capture sand and gravel sediment. The forebay should be easily accessible for dredging out the sediment when necessary and access to the forebay for equipment should be provided. The forebay volume should typically be 5 to 10 percent of the water quality volume. If there are multiple inlets to the detention facility, each forebay should be sized based on the portion of water quality volume attributed to the particular inlet. A mechanical separator, or other oil removal structure, may also serve as pre-treatment to a pond in place of a forebay.

10. *Emptying Time*. A 12 to 48 hour emptying time may be used for the water quality volume above the permanent pool (Urbonas, et al., 1992).

11. *Freeboard.* The pond embankment should have at least 2 ft of freeboard above the emergency spillway crest elevation (Schueler, 1987).

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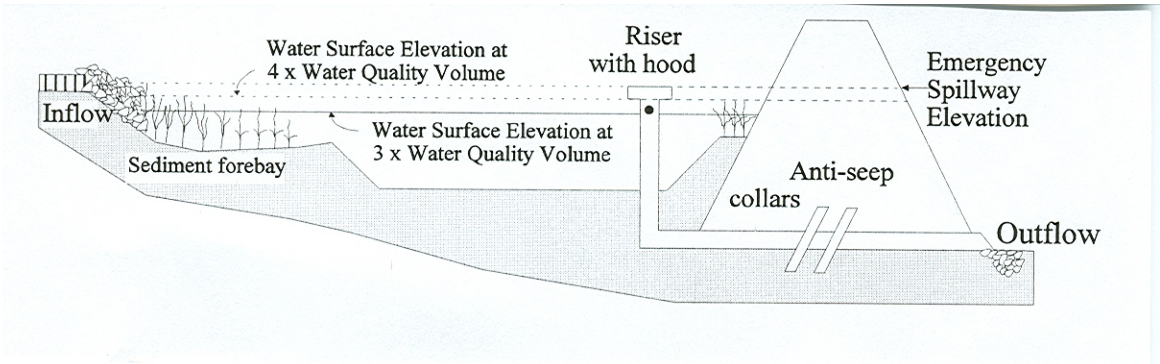

Figure PC-110A
Typical Wet Pond Components (SUSMP, 2002)

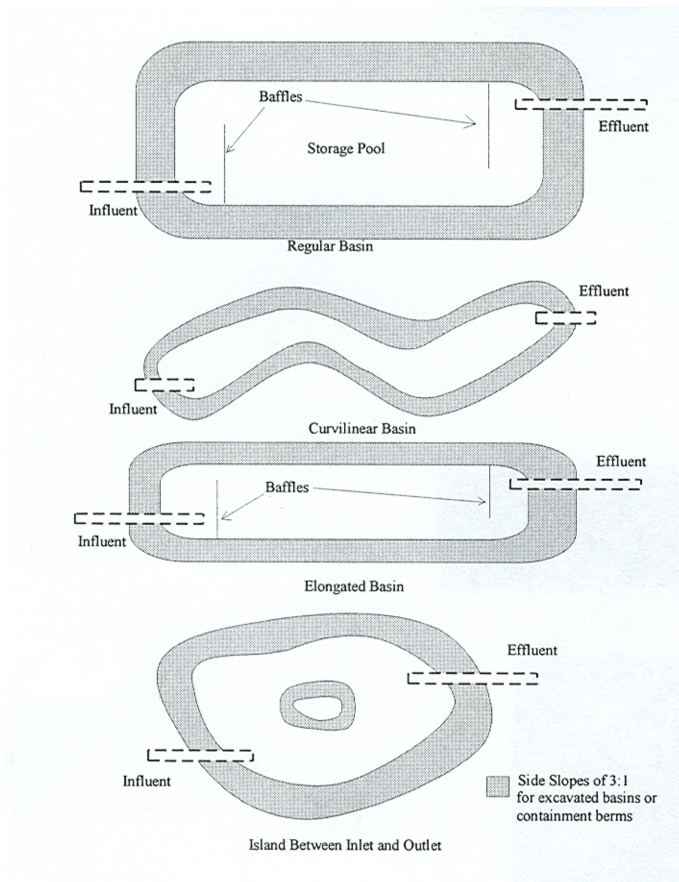

Figure PC-110B
Strategies to Increase residence time in detention facilities (SUSMP, 2002)

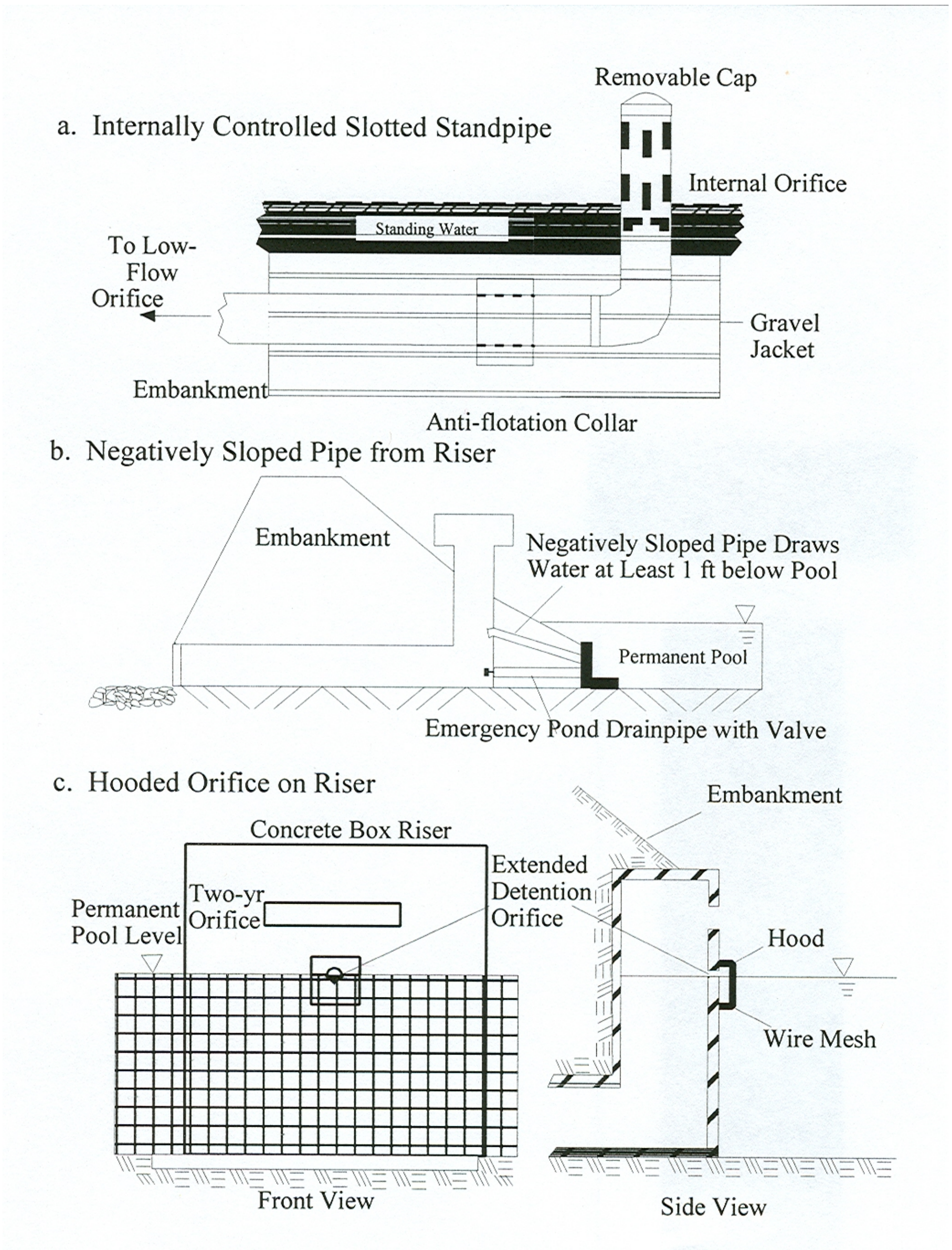

Figure PC-110C
Typical Outlet Structure Modifications to increase residence time of water quality volume (SUSMP, 2002)