POST-CONSTRUCTION STORM WATER BEST MANAGEMENT PRACTICES RESEARCH REPORT

Tennessee Department of Transportation

Prepared for:

TDOT
Go.

Prepared by:

TriAD Environmental Consultants, Inc
Suite 200
207 Donelson Pike
Nashville, TN 37214
615-889-6888

TriAD Project No. 04-SAI16-03

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1.0 INTRODUCTION

This Post-Construction Storm Water Best Management Practices (BMPs) Research Report has been prepared for submission to the Tennessee Department of Transportation (TDOT), by TriAD Environmental Consultants, Inc. (TriAD) to assist TDOT in the implementation of permit requirements contained in the TDOT Municipal Separate Storm Sewer System Permit No. TNS077585, Section 2.1.5 Post Construction Storm Water Management, Subsection F:

> *Research other DOT's post construction storm water activities. Conduct a literature review of post-construction storm water quality runoff best management practices. Research how other DOTs are handling post-construction storm water quality from highway and facility sites. Develop a report outlining the findings and incorporate the findings into the research to be conducted in activity A and activity E in this table.*

2.0 RESEARCH

Several sources were consulted for information on post-construction BMPs for storm water (SW) runoff. Information about BMPs used by other Departments of Transportation (DOTs) in their post-construction SW programs was accessed and researched using the internet. In addition, several surrounding states were contacted via email and telephone regarding their post-construction SW programs. The information compiled from other DOTs is provided in Section 4.0. Other sources utilized for BMP information include, but are not limited to; the International Stormwater BMP Database (http://www.bmpdatabase.org); the Environmental Protection Agency's (EPA) National Pollutant Discharge Elimination System (NPDES) database (http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/index.cfm); the Metropolitan Government of Nashville and Davidson County Stormwater Management Manual, Volume 4 Best Management Practices; and the Natural Resources Conservation Service.

3.0 BEST MANAGEMENT PRACTICES

3.1 Researched BMPs

Similar BMPs are grouped below by use as a structural versus non-structural practice. Structural BMPs are practices that physically treat SW problems (basins, filters, etc.). Non-Structural BMPs are practices that address SW problems from a planning or administrative viewpoint (low-impact development, conservation easements, etc.). Descriptions of BMPs, selected for one or more highway or facility scenario, are included in Appendix 1. All researched BMPs are included in the following list.

Structural BMPs

- Dry Detention Basin / Pond
- Wet Pond / Water Quality Pond / Retention Pond / Extended Detention*
- Infiltration Basin
- Infiltration / Exfiltration Trench
- Porous Pavement / Pervious Paving / Pervious Paver*
- Bioretention / Bioretention Cell / Vegetated Buffer*
- Sand and Organic Filters
- Storm Water Wetland / Constructed Wetland*
- Grassed, Wet, or Dry Swale / BioSwale / Biofilter*
- Grassed / Vegetated Filter Strip*
- Catch Basin with Manufactured System*
- In-Line Storage*
- Dry Weather Flow Diversion*
- Energy Protection Area*
- Gross Solid Removal Devices*
- Traction Sand Trap
- Level Spreader*
- Preformed Scour Hole*
- Hydrodynamic Separator
- Oil / Water Separator*

- Water Quality Inlets
- Infiltration Drainfields
- Modular Treatment Systems

Non-Structural BMPs

- Alum Injection
- Conservation Easement / Buffer Zones
- Narrower Residential Streets
- Eliminating Curbs and Gutters
- BMP Inspection and Maintenance
- Wetland or Stream Setback

* Included in Appendix 1

3.2 BMP Comparisons

A comparison of structural SW practices is included in Appendix 2 in the form of a table (Post-Construction Storm Water Best Management Practices). The table was developed to group similar BMPS with different names together and to compare the same information for each BMP. The table includes the following information, if available, for each BMP:

- Why is a SW BMP needed at this location?
    - Flood Control
    - Channel Protection
    - Groundwater Recharge
    - Pollutant Removal
        - Which pollutants are effectively removed?

- Will the BMP receive flow from a large or small drainage area?

- What maintenance is required for the BMP to work effectively and how often will maintenance be required?

- Are there regional considerations that would affect the BMP or negatively affect the downstream receiving waters?
  - Will the BMP be located in an ultra-urban setting?
  - Are there contaminated areas (hot spots) upstream of the BMP?
  - Will the receiving waters be cold streams?
  - Will the BMP be located in karst topography?
  - Will the BMP be located in an arid climate?

- What is the cost of the BMP?

4.0 DEPARTMENT OF TRANSPORTATION RESEARCH

Ten states were contacted via email and/or phone or researched online to determine which SW BMPs were being successfully implemented. A brief summary of each state's program is detailed below:

4.1 Arkansas

Arkansas is also currently researching and creating a database of post-construction BMPs. No SW BMPs are currently recommended by the Arkansas Department of Transportation for post-construction activities.

4.2 California

California completed an extensive BMP retrofit pilot program and released the results in a final report dated January 2004. The Executive Summary, Table of Contents, and applicable excerpts from the report detailing the results of the study are provided in Appendix 3. The types of BMPs included in the study are listed below:

- Media Filters
- Extended Detention Basins

- Drain Inlet Inserts
- Biofiltration
- Infiltration Devices
- Wet Basins
- Oil/Water Separators
- Continuous Deflective Separation

A *Statewide Stormwater Management Plan* was adopted in June 2007. Excerpts of this plan have also been included in Appendix 3. The term Design Pollution Prevention BMP is used in place of post-construction BMP in the Plan. Approved treatment BMPs are listed below:

- Biofiltration: Strips/Swales
- Infiltration Devices
- Detention Devices
- Traction Sand Traps
- Dry Weather Flow Diversion
- Media Filters
- Multi-Chamber Treatment Trains
- Wet Basins
- Gross Soilds Removal Devices

4.3 Florida

Florida does not have a formal post-construction SW BMP program. All construction SW controls remain in-place until final stabilization is achieved and any runoff from impervious sources is directed to detention or retention ponds (depending on the site conditions) and vegetated swales. Pervious pavement or concrete is utilized when applicable.

4.4 Georgia

Georgia DOT does not have a formal program; however, they do use pervious ditch lining, such as grass, and vegetated swales instead of concrete lined ditches.

4.5 Indiana

Indiana DOT entered into a joint transportation research program with Purdue University. The study results were published in a final report dated October 2006. The applicable excerpts from the report, *Assessment and Selection of Stormwater Best*

Management Practices for Highway Construction, Retrofitting, and Maintenance, are included in Appendix 3. Appendix 4 of the Purdue Report, also included in Appendix 3, contains post-construction BMP fact sheets. The following BMPs are listed in the appendix for use by Indiana DOT:

- Dry Pond
- Extended Detention Pond with Micropool
- Wet Pond
- Dry Swale
- Stormwater Wetland
- Wet Swale
- Infiltration Trench
- Infiltration Basin
- Bioretention
- Filter Strip
- Turf Reinforcement Mat
- Native Vegetation – Permanent
- Hydrodynamic Separators

4.6 Kentucky

Kentucky does not have a formal post-construction SW BMP plan; however, a design memorandum, included in Appendix 3, details the policy for BMPs to be used in karst areas. The memorandum lists the following BMPs:

- Grass Swale with interceptor ditches to divert offsite flow
- Detention/Containment Basins downstream of grassed swales

4.7 North Carolina

North Carolina DOTs Highway Stormwater Program has recently developed a *Best Management Practices Toolbox.* An excerpt from a draft copy of the toolbox is included in Appendix 3. The excerpt provides information on each of the following BMPs:

- Level Spreader
- Preformed Scour Hole
- Dry Detention Basin
- Grass Swale
- Forebay
- Hazardous Spill Basin

The state has also developed a *Structural Stormwater Control Field Guide* to assist in recognition of the practices in the field. A copy of this guide is also included in Appendix 3. The SW BMPs included in the guide are listed below:

- Filtration Basin
- Bioretention Basin
- Dry Detention Basin
- Wet Detention Basin
- Infiltration Basin
- Hazardous Spill Basin
- Stormwater Wetland
- Swale
- Level Spreader
- Filter Strip
- Buffer
- Preformed Scour Hole
- Forebay
- Catch Basin Insert
- Swirl Concentrator
- Wet Vaults

4.8 Ohio

Ohio has chosen nine specific post-construction BMPs, listed below, to implement. *The Location and Design Manual, Volume 2 (Drainage Design)* provided by Ohio DOT provides regulations and details for each of these practices. Relevant sections of the manual are provided in Appendix 3.

- Exfiltration Trench
- Manufactured Systems
- Vegetated Biofilter
- Extended detention
- Retention Basin
- Bioretention Cell
- Infiltration Trench
- Infiltration Basin
- Constructed Wetlands

4.9 South Carolina

South Carolina does not have a formal post-construction BMP program; however, there are several BMPs that are used by the DOT:

- Grassed swales

- Wet Ponds
- Proprietary Devices (Crystal Streams, Storm Septor, Vortech CVS, Base Saver)
- Infiltration Systems (Ponds and Underground Systems)
- Detention Basins

4.10 Virginia

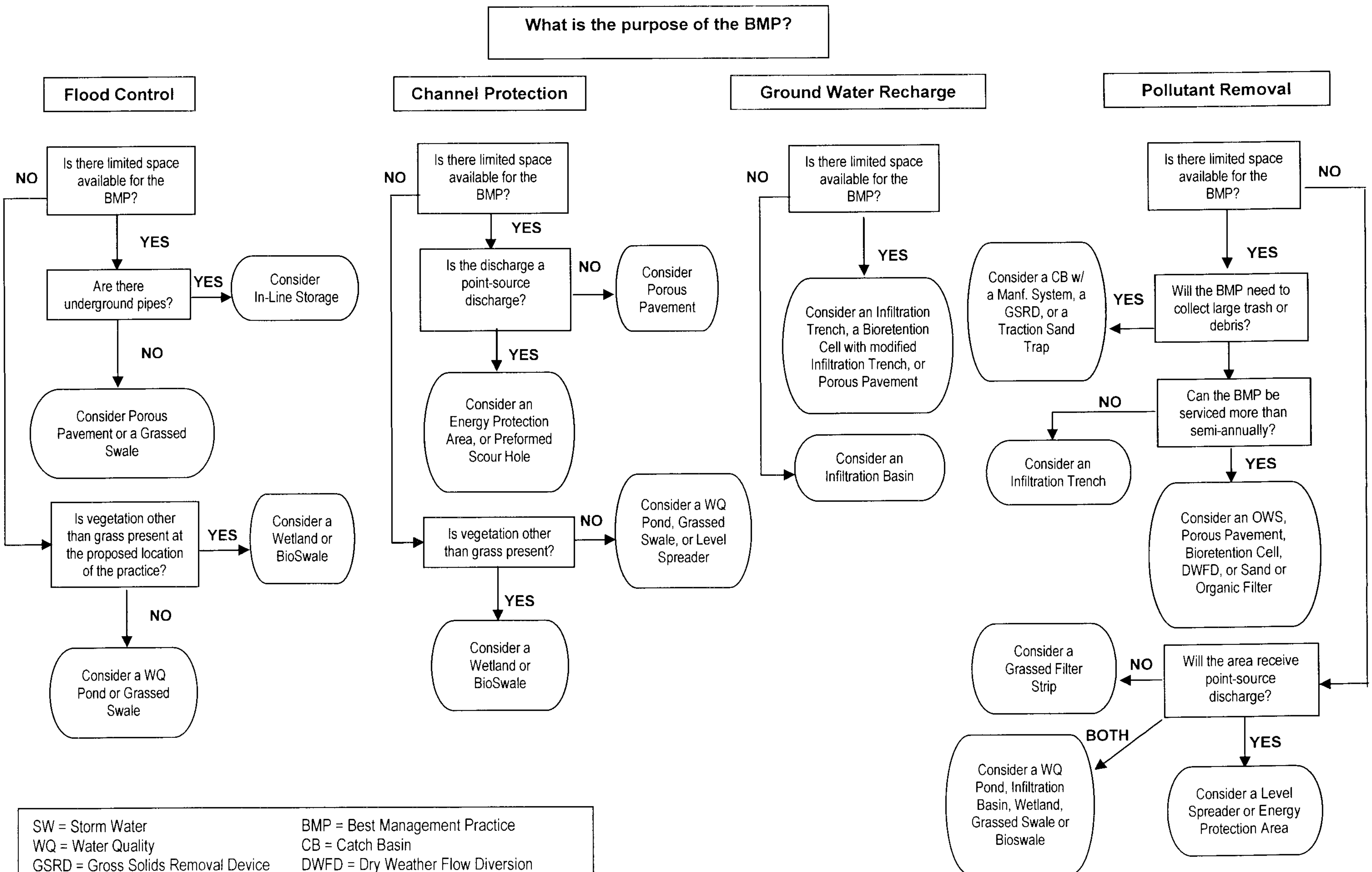
Virginia DOT has several post-construction BMPs that are approved for use. The selection of BMPs is based on the percent of impervious cover upstream of the practice. The Location and Design Division of the Virginia DOT issued an instruction and information memorandum on the management of SW. A copy of this memorandum is included in Appendix 3. Although alternative BMPs are allowed, with approval, the following are approved practices:

- Vegetated filter strip
- Grassed swale
- Constructed Wetlands
- Extended detention
- Retention basin
- Bioretention basin
- Bioretention filter
- Extended detention-enhanced
- Retention basin II
- Infiltration
- Sand filter
- Infiltration
- Retention basin III (with aquatic bench)

5.0 BEST MANAGEMENT PRACTICE SELECTION

Four BMPs were selected for each scenario based on the BMP Selection Flow Chart, included below. The flow chart was designed using a process that began with a resource protection category classification. Structural practices were classified into four resource protection categories: flood control, channel protection, ground water recharge, and pollutant removal. Some practices are located in more than one category, but all SW BMPs will fall into at least one of the resource protection categories

Post-Construction Storm Water Best Management Practices Flow Chart



SW = Storm Water
WQ = Water Quality
GSRD = Gross Solids Removal Device
BMP = Best Management Practice
CB = Catch Basin
DWFD = Dry Weather Flow Diversion

Each category was then divided based on space available for installation or implementation of the BMP. The remaining BMPs in each category were then evaluated based on differences in the remaining practices. The BMPs chosen for each scenario are discussed in the following sections.

6.0 HIGHWAY SCENARIO DEVELOPMENT

Eight scenarios of mature TDOT sites were selected to model SW BMPs. A mature site is defined as a site that has been constructed for at least two years. The first four scenarios were based on roadway design configurations selected in the PART 2 Storm Water NPDES Permit Application dated September 2001. These scenarios are located in urban surroundings. Additionally, two roadway scenarios were selected based on rural settings and two scenarios were selected for facilities. A description of each scenario is included below:

Scenario 1: Interstate highways configured with multiple lanes and a center concrete dividing barrier. Runoff from the innermost lane on straight runs of roadway normally drains to drop inlets at the dividing barrier from which it is piped to the shoulder. The outermost lanes on straight runs of roadway drain to the shoulder that is sloped to grass or aggregate lined ditches.

Scenario 2: Divided highways (including interstate highways) where the innermost shoulders drain to grass medians on straight runs of roadway, and roadway pavement and outside shoulders drain to grass shoulders and side ditches.

Scenario 3: Multiple lane roads where the pavement drains to curbs at the shoulder. The curbs are equipped with drop inlets that direct the runoff to underground storm sewers. The roadways may receive runoff from up-gradient adjacent residential or commercial property lying outside the right-of-way.

Scenario 4: Multiple lane roads without medians or center barriers where all runoff flow from the pavement is directed to the shoulders. The side ditches may receive runoff from upgradient adjacent residential or commercial property lying outside of the right-of-way.

Scenario 5: Two-lane state route with very narrow shoulders with steep drop-offs or vertical faces adjacent to the roadway. Runoff flow from the pavement is directed to vegetated, paved, or rip-rapped ditches. The ditches may receive runoff from upgradient adjacent residential or commercial property lying outside of the right-of-way.

Scenario 6: Two-lane state route with narrow, paved shoulders located in an agricultural setting with flat, vegetated areas lying adjacent to the right-of-way. Runoff flow from the pavement is directed to vegetated or rip-rapped ditches. The ditches may receive runoff from upgradient adjacent residential or commercial property lying outside of the right-of-way.

Scenario 7: A TDOT facility with a large drainage area where runoff is generally directed to point source outfalls via grassed, rip-rapped, or paved ditches; curbs and gutters; or drop inlets and culverts. SW may also leave the site as sheetflow. The facility will include buildings, asphalt or gravel paved areas, and vegetated areas.

Scenario 8: A TDOT facility with a small drainage area where runoff is generally directed to point source outfalls via grassed, rip-rapped, or paved ditches; curbs and gutters; or drop inlets and culverts. SW may also leave the site as sheetflow. The facility will include buildings, asphalt or gravel paved areas, and vegetated areas.

Although the selected scenarios are a good representation of TDOT transportation roadways and facilities, every situation should be individually evaluated to determine which BMPs are best suited for each project. This process should include an evaluation of the BMP specifics detailed in Section 3.0 (included in Appendix 2), in conjunction with field specifications, and the BMP Selection Flow Chart included in Section 5.0 before a specific BMP or set of BMPs is chosen.

6.1 Scenario One

Scenario one is an interstate highway configured with multiple lanes and a center concrete dividing barrier. Runoff from the innermost lane on straight runs of roadway normally drains to drop inlets at the dividing barrier from which it is piped to the shoulder. The outermost lanes on straight runs of roadway drain to the shoulder that is sloped to grass or aggregate lined ditches.

6.1.1 Catch Basin with Manufactured System

The first practice recommended is a catch basin with a manufactured system installed at the drop inlets along the dividing barrier. A manufactured system installed within a catch basin will provide pollutant removal. This practice will not only provide pretreatment for downstream BMPs, but the filter systems can also be purchased pre-engineered or specifically configured for existing drop inlets. Depending on the size of the inlet and the amount of flow diverted to each inlet, maintenance activities should occur one to two times a year. Average unit prices range from $400 to $2,000 each based on prices found in the Average Unit Prices – 2006 Awarded Contracts information located on TDOTs website. The cost of installation of the manufactured system is not included in this price and will vary depending on the design and size of the system and access to the inlet. If maintenance of the catch basin system requires the use of a vacuum truck, the cost of purchasing a truck or subcontracting maintenance activities should be considered. A new vacuum truck with a 1,500- to 2,000-gallon tank is estimated to cost $200,000 to $305,000; however, a used truck could possibly be purchased for $100,000 to $140,000. California, North Carolina, Ohio, and South Carolina DOTs currently use this type of practice.

6.1.2 In-Line Storage

In-line storage allows for storage of SW underground, within the system. This type of practice provides flood control for SW. Although this option may not be applicable as a retrofit, in-line storage can be a viable option for post-construction BMPs included in the design stage. This option is beneficial in areas where aboveground storage is not feasible (urban areas or areas with high land values). Most systems are designed with a self-cleaning flow regulator; therefore, very little maintenance is required. Since the system is self-cleaning, underground, and located within an oversized, storm drain system; purchase and installation costs consist of a larger diameter pipe or manhole and a flow regulator. Maintenance costs should include an annual inspection. In-line storage is a BMP that provides flood control. California and North Carolina currently use this type of practice with modified designs.

6.1.3 Grassed Swale

A grassed swale is ideal for highways since it is a linear practice; however, the exterior part of the right-of-way must be vegetated, and swales are best suited for small drainage areas. Swales can provide flood control, channel protection, minor groundwater recharge, and pollutant removal for SW treatment. Maintenance would include mowing as necessary to maintain healthy vegetation. Mowing or vegetative maintenance requirements would be less if a grassed swale was modified to a bioswale. The cost is estimated to be between \$0.25 and \$0.50 per ft^2 for installation. Swales are a good retrofit to existing grassed channels with the addition of check dams. California, Florida, Georgia, Indiana, North Carolina, Ohio, South Carolina, and Virginia utilize swales for SW treatment.

6.1.4 Water Quality Pond

A water quality or retention pond (designed with a permanent pool) is a good final practice for SW treatment. Water quality ponds provide flood control, channel protection, and pollutant removal. SW that has been pretreated by any, all, or none of the previous practices can be diverted to a pond. A pond may not be ideal for scenario one if the project is located in a highly-urbanized environment where lack of space is a consideration. Maintenance includes mowing of side banks as needed to maintain healthy vegetation, debris removal as needed, and clean out of the pond every five to seven years. Using upstream SW BMPs will lengthen the life of the pond and maximize the time between cleanouts. Semi-annual inspections will help to determine the frequency of required mowing and debris removal maintenance. The EPAs National Menu for BMPs sites a study by Brown and Schueler, 1997, that resulted in a cost equation for the construction, design, and permitting costs for ponds:

$$C = 24.5 * V^{0.705}$$

The formula is based on the volume (V) of the pond in cubic feet and ranges from $45,700 for a one acre-foot pond to $232,000 for a ten acre-foot pond. California, Florida, Indiana, North Carolina, Ohio, South Carolina, and Virginia utilize water quality ponds of different designs; however, all ponds have a permanent pool. Some states also utilize dry ponds.

6.2 Scenario Two

Scenario two includes divided highways (including interstate highways) where the innermost shoulders drain to grass medians on straight runs of roadway, and roadway pavement and outside shoulders drain to grass shoulders and side ditches.

6.2.1 Bioswale

A bioswale is a version of a grassed swale that utilizes native vegetation. Bioswales require less maintenance than grassed swales. Maintenance would include mowing when needed to maintain healthy vegetation and removal of sediment buildup. The cost of a bioswale is slightly higher (greater than $0.50 per ft^2) than a grassed swale due to the purchase of native plants. Swales are a good retrofit to existing grassed channels with the addition of check dams. Swales can provide flood control, channel protection, minor groundwater recharge, and pollutant removal. California and Georgia utilize bioswales.

6.2.2 Storm Water Wetland

A SW wetland can be constructed in a large median or within the shoulder. SW wetlands provide flood control, channel protection, and pollutant removal treatment of SW. The drainage area contributing to the wetland should be large to provide sufficient SW to provide a permanent pool during drier seasons. Wetlands generally cover more surface area than water quality ponds. Maintenance for wetlands consists of mowing around the perimeter, debris removal, and repair of undercut or eroded areas. All of these items should be conducted as needed which can be monitored during quarterly or bi-annual inspections or the maintenance activities can be incorporated into a maintenance schedule. The same study by Brown and Shueler, 1997, that derived a cost for ponds, developed an equation for the cost of SW wetlands:

$$C = 30.6 * V^{0.705}$$

The cost is based on the volume (V) of the wetland in cubic feet and ranges from $57,100 for a 1 acre-foot wetland to $289,000 for a 10 acre-foot wetland. Another assumption from the National Menu for BMPs by EPA states that costs are typically 25 percent more than costs for a pond of equivalent volume. Indiana, Ohio, and Virginia utilize SW wetlands.

6.2.3 Water Quality Pond

Water quality ponds were previously discussed in Section 6.1.4.

6.2.4 Infiltration Trench

Infiltration or exfiltration trenches, also know as infiltration galleys, are aggregate lined trenches that filter water into the surrounding soil that provide groundwater recharge and pollutant removal for SW. Infiltration trenches can be modified to include a perforated pipe at the bottom or downgradient end of the trench to convey filtered SW to a storm sewer system. They are not recommended in areas with karst topography unless the trench is lined or designed with an outlet (perforated pipe to storm sewer). Maintenance should be performed semi-annually. Studies have shown that pretreatment of SW will prolong the life of the trench. The Southwestern Wisconsin Regional Planning Commission and the Brown and Shueler report from 1997 both estimate the cost for an infiltration trench to be approximately $5 per cubic foot of treated SW. California, Indiana, Ohio, South Carolina, and Virginia utilize infiltration trenches.

6.3 Scenario Three

Scenario three includes multiple lane roads where the pavement drains to curbs at the shoulder. The curbs are equipped with drop inlets that direct the runoff to underground storm sewers. The roadways may receive runoff from up-gradient adjacent residential or commercial property lying outside the right-of-way.

6.3.1 Catch Basin with Manufactured System

The selection and use of a catch basin with a manufactured system for a post-construction BMP was previously discussed in Section 6.1.1.

6.3.2 Gross Solid Removal Device

Gross solid removal devices (GSRD) are usually underground and placed in-line with the SW system. GSRD are used for pollutant removal. The devices are proficient in removing all types of solids, including but not limited to, sediment, garbage, and organic debris. There are many different design variations. Devices can be rectangular, placed in manholes, screens retrofitted to catch basin inlets, etc. Other names for these types of devices are hydrodynamic separators and swirl concentrators. Maintenance of GSRDs is usually quarterly, but the frequency will differ based on the design of the device and the pollutant load. Prices vary widely based on design and maintenance requirements. The purchase cost of a system starts at $1,200 but can be as much as $4,000. Some GSRDs require replacement of filters or liners, while other devices require cleanout by hand or a vacuum truck. California, Indiana, Ohio, North Carolina, and South Carolina, utilize these types of devices.

6.3.3 In-Line Storage

The selection and use of in-line storage as a post-construction BMP was discussed in Section 6.1.2.

6.3.4 Dry Weather Flow Diversion

Dry weather flow diversions (DWFD) divert SW flow to publicly owned treatment works (POTW) for small rain events. Dry weather flow diversions provide pollutant removal, but have limited applicability. Diversions can only be used in areas with a POTW that will accept the extra flow. Most POTWs are operating at or near capacity and will not accept SW flow. Flow from large events is routed around the diversion and not sent to the POTW. Diversions are very successful at removing pollutants, especially since runoff from small rain events flush the largest percentage of motor vehicle pollutants from streets and roads. Diversions can be berms or channels used to divert SW or low-flow diversion pipes placed in storm sewer manholes that divert flow to sanitary sewer manholes. If the diversions are located in sanitary and/or storm sewers that are self-cleaning, maintenance considerations are minimal after the first year of installation. DWFDs are utilized in California.

6.4 Scenario Four

Scenario four is a multiple lane road without medians or center barriers where all runoff flow from the pavement is directed to the shoulders. The side ditches may receive runoff from upgradient adjacent residential or commercial property lying outside of the right-of-way.

6.4.1 Bioswale

Bioswales were discussed in Section 6.2.1.

6.4.2 Storm Water Wetland

Storm water wetlands were previously discussed in Section 6.2.2.

6.4.3 Water Quality Pond

Water quality ponds were previously discussed in Section 6.1.4.

6.4.4 Level Spreader

Level spreaders are very similar to vegetated filter strips; however, level spreaders are designed to be placed downgradient of point-source outfalls, whereas vegetated filter strips are placed downgradient of sheet flow areas. The practice provides channel protection and pollutant removal. The spreaders can be built with a concrete or vegetated channel. A vegetated channel with concrete lip is recommended for TDOT applications to reduce maintenance frequencies and discourage the formation of mosquito habitat. Maintenance should occur frequently until vegetation is established. After vegetation is established semi-annual inspections/maintenance should occur with inspections after large rain events. The cost of a level spreader will include the construction of the concrete lip and vegetation downstream of the spreader. Vegetation costs are estimated at $2.18 to $2.40 per square yard for sod (TDOT Average Unit Prices – 2006 Awarded Contracts) and $0.30 per square foot for seeding (National Menu for BMP Practices).

6.5 Scenario Five

Scenario Five includes two-lane state routes with very narrow shoulders with steep drop-offs or vertical faces adjacent to the roadway. Runoff flow from the pavement is directed to vegetated, paved, or rip-rapped ditches. The ditches may receive runoff from upgradient adjacent residential or commercial property lying outside of the right-of-way.

6.5.1 Catch Basin with Manufactured Filter System

The selection and use of a catch basin with a manufactured system for a post-construction BMP was previously discussed in Section 6.1.1.

6.5.2 Energy Protection Area

Energy protection areas reduce SW flow velocities and concentrations at SW inlets to reduce scouring around the inlet and channel erosion downstream of the inlet. The practice provides channel protection and reduces pollutants. The areas are usually fifteen feet wide at the channel bottom, lined with twelve inches of appropriately sized rip-rap, and fifty feet long. Maintenance is minimal and consists of quarterly monitoring for debris removal and erosion of the channel. Areas should also be monitored after 10-year, 24 hour or larger storms. Energy protection area costs are minimal, as part of the protection area is included in the original drainage structure. Energy protection areas provide some pollutant removal but are generally used for channel protection. Energy protection areas are utilized by Ohio.

6.5.3 Bioswale

Bioswales were discussed is Section 6.2.1.

6.5.4 Water Quality Pond

Water quality ponds were previously discussed in Section 6.1.4.

6.6 Scenario Six

Scenario Six includes two-lane state routes with narrow, paved shoulders located in an agricultural setting with flat, vegetated areas lying adjacent to the right-of-way. Runoff flow from the pavement is directed to vegetated or rip-rapped ditches. The ditches may receive runoff from upgradient adjacent residential or agricultural property lying outside of the right-of-way.

6.6.1 Grassed Swale

Grassed swales were previously discussed in Section 6.1.3.

6.6.2 Storm Water Wetland

Storm water wetlands were previously discussed in Section 6.2.2.

6.6.3 Energy Protection Area

Energy protection areas were previously discussed in Section 6.5.2.

6.6.4 Water Quality Pond

Water quality ponds were previously discussed in Section 6.1.4.

6.7 Scenario Seven

Scenario seven is a TDOT facility with a large drainage area where runoff is generally directed to point-source outfalls via grassed, rip-rapped, or paved ditches; curbs and gutters; or drop inlets and culverts. SW may also leave the site as sheetflow. The facility will include buildings, asphalt or gravel paved areas, and vegetated areas.

6.7.1 Storm Water Wetland

Storm water wetlands were previously discussed in Section 6.2.2.

6.7.2 Porous Pavement

Porous or permeable pavement is ideal for parking areas, but requires more maintenance than other BMPs. Porous pavement provides flood control, channel protection, and pollutant removal treatment for SW. Other similar products are pervious pavers, which are interlocking blocks filled with soil or gravel. Porous pavement is effective at removing motor oils from SW but requires monthly inspections and as frequent as quarterly vacuum/sweeping of the pavement. Porous pavement is more expensive than bituminous asphalt. The National Menu for BMP Practices estimates the price to be 3 to 4 times the cost. The chart below lists price comparisons from a supplier of permeable surfaces for various products.

Product	Cost for Installed Pavement (per ft^2)
Asphalt	\$0.50 to \$1
Grass/Gravel Pavers	\$1.50 to \$5.75
Porous Concrete	\$2.00 to \$6.50

Product	Cost for Installed Pavement (per ft^2)
Interlocking Concrete Paver Blocks	$5.00 to $10.00

Porous pavement is utilized by Florida.

6.7.3 Vegetated Filter Strip

Vegetated or grassed filter strips provide pollutant removal for SW at sheet flow areas, and are very effective as pre-treatment for other BMPs. Filter strips are ideal for drainage from parking lots at TDOT facilities. If the parking lot is salted frequently during the colder months, a salt-tolerant grass can be planted on the vegetated section of the filter strip. Maintenance includes mowing and monitoring for erosion (rivulets, channels, etc.) caused by channelized flow. Because filter strips are located in areas that normally would be vegetated ($0.30 per ft^2 for seeding and $0.70 per ft^2 for sod), the cost of the filter strip is the berm and gravel diaphragm installed at the beginning of the strip. Because filter strips consume more area than other BMPs, the total cost will be higher in areas with high land values. California, North Carolina, and Virginia utilize filter strips.

6.7.4 Oil/Water Separator

Oil/water separators (OWS) are very effective at pollutant removal and are currently in use at most TDOT facilities for wash water treatment and at large facilities, including all of the Region garages, for SW treatment. Designs vary considerably and the systems can be installed in-line, aboveground, or below ground and be connected to the sanitary sewer, discharge to holding tanks, or discharge to waters of the state. Maintenance and costs are based on the design and capacity of the system. Maintenance of the systems usually occurs frequently but is based on the capacity of the system, the types of filters installed, and amount of flow through the system. At least quarterly inspections would be recommended during the first year with inspections also occurring after large rain events. Costs of conventional systems vary widely from $4,000 to $20,000. Oil/coalescing vaults range from $5,000 to $50,000. OWSs are extremely effective at removing pollutants from SW if properly maintained. California is the only state that provided information regarding the use of OWSs for SW management.

6.8 Scenario Eight

Scenario eight is a TDOT facility with a small drainage area where runoff is generally directed to point source outfalls via grassed, rip-rapped, or paved ditches; curbs and gutters; or drop inlets and culverts. SW may also leave the site as sheetflow. The facility will include buildings, asphalt or gravel paved areas, and vegetated areas.

6.8.1 Storm Water Wetland

Storm water wetlands were previously discussed in Section 6.2.2.

6.8.2 Porous Pavement

Porous pavement was previously discussed in Section 6.7.2.

6.8.3 Bioretention Cell

Bioretention cells are generally used in urban settings for small sites to reduce pollutants in SW. Bioretention cells can be integrated into parking lot designs in landscaped medians. Because these areas usually require landscaping maintenance the only additional maintenance required is the removal of sediment and debris that would normally flow into storm drains instead of the bioretention cell. Landscaping plants will have to be tolerant to both wet and dry conditions. Costs for bioretention cells have been estimated by Brown and Schueler, 1997, based on the volume (V) in cubic feet of water treated:

$$C = 7.30 * V^{0.99}$$

California, Indiana, and Virginia utilize bioretention cells.

6.8.4 Oil/Water Separator

OWSs were previously discussed in Section 6.7.4.

APPENDIX 1

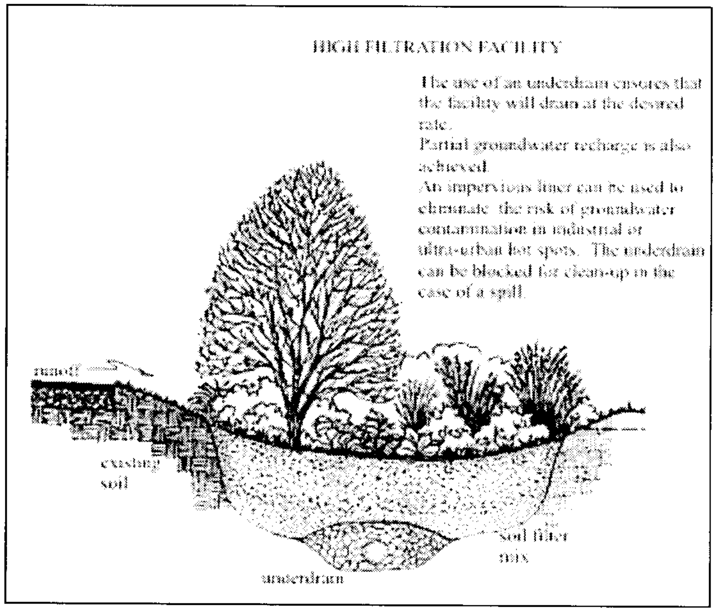
SELECTED POST-CONSTRUCTION STORM WATER BEST MANAGEMENT PRACTICES

BIORETENTION / BIORETENTION CELL / VEGETATED BUFFER

Low Impact Development Center, Inc.

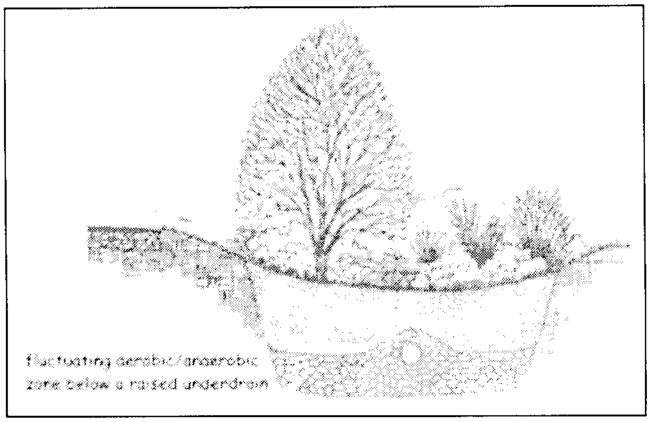
Watershed Benefits of Bioretention Techniques

Pollutant Filtering



Bioretention areas function as soil and plant-based filtration devices that remove pollutants through a variety of physical, biological, and chemical treatment processes. The reduction of pollutant loads to receiving waters is necessary for achieving regulatory water quality goals. For example, several states, including Maryland, have agreed to work towards reducing nutrient runoff to the Chesapeake Bay by 40%. A number of laboratory and field experiments have been conducted by the University of Maryland in conjunction with Prince George's County Department of Environmental Resources and the National Science Foundation in order to quantify the effectiveness of bioretention cells in terms of pollutant removal.[1] A web site dedicated to this work can be found at http://www.ence.umd.edu/~apdavis/Bioret.htm.

In general, the studies have found that properly designed and constructed bioretention cells are able to achieve excellent removal of **heavy metals**. Users of this technique can expect typical copper (Cu), zinc (Zn), and lead (Pb) reductions of greater than 90%, with only small variations in results. Removal efficiencies as high as 98% and 99% have been achieved for Pb and Zn. The mulch layer is credited with playing the greatest role in this uptake, with nearly all of the metal removal occurring within the top few inches of the bioretention system. Heavy metals affiliate strongly with the organic matter in this layer. On the other hand, **phosphorus** removal appears to increase linearly with depth and reach a maximum of approximately 80% by about 2 to 3 feet depth. The likely mechanism for the removal of the phosphorus is its sorption onto aluminum, iron, and clay minerals in the soil. **TKN (nitrogen)** removal also appears to depend on depth but showed more variability in removal efficiencies between studies. An average removal efficiency for cell effluent is around 60%. Generally 70 to 80% reduction in **ammonia** was achieved in the lower levels of sampled bioretention cells. Finally, **nitrate** removal is quite variable, with the bioretention cells demonstrating a production of nitrate in some cases due to nitrification reactions. Currently, the University of Maryland research group is looking at the possibility of incorporating into the bioretention cell design a fluctuating aerobic/anaerobic zone below a raised underdrain pipe in order to facilitate denitrification and thus nitrate removal.[2]

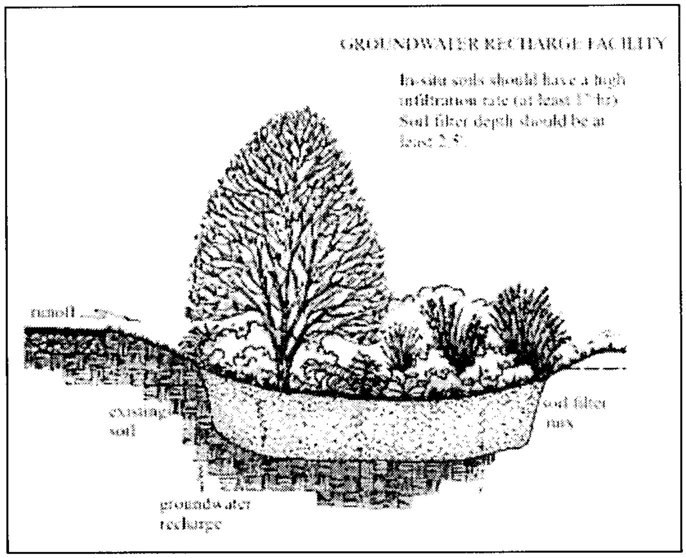


These studies indicate that in urban areas where heavy metals are the focal pollutants, shallow bioretention facilities with a significant mulch layer may be recommended. In residential areas, however, where the primary pollutants of concern are nitrogen and phosphorus, the depth dependence will require deeper cells that reach approximately 2 to 3 feet.

Other pollutants of concern are also addressed by the bioretention cells. For example, sedimentation can occur in the ponding area as the velocity of the runoff slows and solids fall out of suspension. Field studies at the University of Virginia have indicated 86% removal for **Total Suspended Solids (TSS)**, 97% for **Chemical Oxygen Demand (COD)**, and 67% for **Oil and Grease**. [3] Additional work with laboratory media columns at the University of Maryland has demonstrated potential bioretention cell removal efficiencies greater than 98% for total suspended solids and oil/grease.[4]

Runoff Volume and Timing

One of the primary objectives of LID site design is to minimize, detain, and retain post development runoff uniformly throughout a site so as to mimic the site's predevelopment hydrologic functions.[5] Originally designed for providing an element of water quality control, bioretention cells can achieve ***quantity* control** as well. By infiltrating and temporarily storing runoff water, bioretention cells reduce a site's overall runoff volume and help to maintain the predevelopment peak discharge rate and timing. The volume of runoff that needs to be controlled in order to replicate natural watershed conditions changes with each site based on the development's impact on the site's curve number (CN). The bioretention cell sizing tool can be used to determine what cell characteristics are necessary for effective volume control. Keep in mind that the use of underdrains can make the bioretention cell act more like a filter that discharges treated water to the storm drain system than an infiltration device.[6] Regardless, the ponding capability of the cell will still reduce the immediate volume load on the storm drain system and reduce the peak discharge rate. Where the infiltration rate of *in situ* soils is high enough to preclude the use of underdrains (at least 1"/hr), increased **groundwater recharge** also results from the use of the bioretention cell. If used for this purpose, care should be taken to consider the pollutant load entering the system, as well as the nature of the recharge area. An additional hydrologic benefit of the bioretention cell is the **reduction of thermal pollution**. Heated runoff from impervious surfaces is filtered through the bioretention facility and cooled; one study observed a temperature drop of 12°C between influent and effluent water.[7] This function of the bioretention cell is especially useful in areas such as the Pacific Northwest where cold water fisheries are important.



Additional Ecosystem Benefits

Bioretention cells are dynamic, living, micro-ecological systems.[8] They demonstrate how the landscape can be used to protect ecosystem integrity. The design of bioretention cells involves, among other things, the hydrologic cycle, nonpoint pollutant treatment, resource conservation, habitat creation, nutrient cycles, soil chemistry, horticulture, landscape architecture, and ecology[8]; the cell thus necessarily demonstrates a multitude of benefits. Beyond its use for stormwater control, the bioretention cell provides attractive landscaping and a natural habitat for birds and butterflies. The increased soil moisture, evapotranspiration, and vegetation coverage creates a more comfortable local climate. Bioretention cells can also be used to reduce problems with on-site erosion and high levels of flow energy.

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Graphics were adapted from The Bioretention Manual, Prince George's County Department of Environmental Resources Programs and Planning Division, Maryland, 2001.

[1] Davis, A.P., M. Shokouhian, H. Sharma and C. Minami, 2001: Laboratory study of biological retention for urban stormwater management. Water Environment Research, 73(1), 5-14.

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[3] Yu, S.L., X. Zhang, A. Earles and M. Sievers, 1999: Field testing of ultra-urban BMPs. Proceedings of the 26th Annual Water Resources Planning and Management Conference ASCE, 6-9 June, Tempe, Arizona.

[4] Hsieh, C. and A.P. Davis, 2002: Engineering bioretention for treatment of urban stormwater runoff. WEF Watershed 2002 Specialty Conference, 23-27 February, Ft. Lauderdale, Florida.

[5] Coffman, L.S., R. Goo and R. Frederick, 1999: Low impact development an innovative alternative approach to stormwater management. Proceedings of the 26th Annual Water Resources Planning and Management Conference ASCE, June 6-9, Tempe, Arizona.

[6] Los Angeles County BMP Design Criteria

[7] United States Environmental Protection Agency Office of Water, 2000: Bioretention Applications - Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. EPA-841-B-00-005A.

[8] Winogradoff, D.A. and L.S. Coffman, 1999: Bioretention water quality performance data and design modifications. Proceedings of the 26th Annual Water Resources Planning and Management Conference ASCE, June 6-9, Tempe, Arizona.

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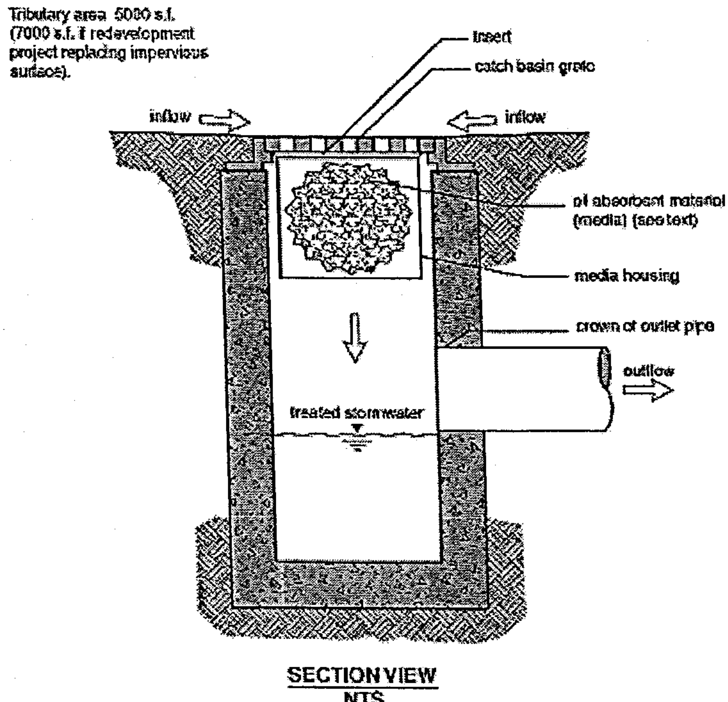
CATCH BASIN WITH MANUFACTURED SYSTEM

Manufactured Products for Storm Water Inlets

Postconstruction Storm Water Management in New Development and Redevelopment



The typical design of a catch basin insert is a set of filters that are specifically chosen to address the pollutants expected at that site (Source: King County, Washington, 2000)

Description

A variety of products for storm water inlets known as swirl separators, or hydrodynamic structures, have been widely applied in recent years. Swirl separators are modifications of the traditional oil-grit separator and include an internal component that creates a swirling motion as storm water flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as storm water moves in this swirling path. Additional compartments or chambers are sometimes present to trap oil and other floatables. There are several different types of proprietary separators, each of which incorporates slightly different design variations, such as off-line application. Another common manufactured product is the catch basin insert. These products are discussed briefly in the <u>Catch Basin</u> fact sheet.

Applicability

Swirl separators are best installed on highly impervious sites. Because little data are available on their performance, and independently conducted studies suggest marginal pollutant removal, swirl separators should not be used as a stand-alone practice for new development. The best application of these products is as pretreatment to another storm water device, or in a retrofit situation where space is limited.

Limitations

Limitations to swirl separators include:

- Very little data are available on the performance of these practices, and independent studies suggest only moderate pollutant removal. In particular, these practices are ineffective at removing fine particles and soluble pollutants.
- The practice has a high maintenance burden (i.e., frequent cleanout).
- Swirl concentrators are restricted to small and highly impervious sites.

Siting and Design Considerations

The specific design of swirl concentrators is specified by product literature available from each manufacturer. For the most part, swirl concentrators are a rate-based design. That is, they are sized based on the peak flow of a specific storm event. This design contrasts with most other storm water management practices, which are sized based on capturing and storing or treating a specific volume. Sizing based on flow rate allows the practice to provide treatment within a much smaller area than other storm water management practices.

Maintenance Considerations

Swirl concentrators require frequent maintenance (typically quarterly). Maintenance is performed using a vactor truck, as is used for catch basins (see Catch Basin). In some regions, it may be difficult to find environmentally acceptable disposal methods. The sediments may not always be land-filled, land-applied, or introduced into the sanitary sewer system due to hazardous waste, pretreatment, or groundwater regulations. This is particularly true when catch basins drain runoff from hot spot areas.

Effectiveness

While manufacturers' literature typically reports removal rates for swirl separator design, there is actually very little independent data to evaluate the effectiveness of these products. Two studies investigated one of these products. Both studies reported moderate pollutant removal. While the product outperforms oil/grit separators, which have virtually no pollutant removal (Schueler, 1997), the removal rates are not substantially different from the standard catch basin. One long-term advantage of these products over catch basins is that, if they incorporate an off-line design, trapped sediment will not become resuspended. Data from two studies are presented below. Both of these studies are summarized in a Claytor (1999).

Table 1. Effectiveness of manufactured products for storm water inlets

Study	Greb et al., 1998	Labatiuk et al., 1997
Notes	Investigated 45 precipitation events over a 9-month period. Percent removal rates reflect overall efficiency, accounting for pollutants in bypassed flows.	Data represent the mean percent removal rate for four storm events.
TSS[a]	21	51.5
TDS[a]	-21	-
TP[a]	17	-
DP[a]	17	-
Pb[a]	24	51.2
Zn[a]	17	39.1
Cu[a]	-	21.5
PAH[a]	32	-
NO_2+NO_3[a]	5	-

[a] TSS=total suspended solids; TDS=total dissolved solids; TP=total phosphorus; DP=dissolved phosphorus; Pb=lead; Zn=zinc; Cu=copper; PAH=polynuclear aromatic hydrocarbons; NO_2+NO_3=nitrite+nitrate-nitrogen

Cost Considerations

A typical swirl separator costs between $5,000 and $35,000, or between $5,000 and $10,000 per impervious acre. This cost is within the range of some sand filters, which also treat highly urbanized runoff (see Sand Filters). Swirl separators consume very little land, making them attractive in highly urbanized areas.

The maintenance of these practices is relatively expensive. Swirl concentrators typically require quarterly maintenance, and a vactor truck, the most common method of cleaning these practices, costs between $125,000 and $150,000. This initial cost may be high for smaller Phase II communities. However, it may be possible to share a vactor truck with another community. Depending on the rules within a community, disposal costs of the sediment captured in swirl separators may be significant.

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Greb, S., S. Corsi, and R. Waschbusch. 1998. Evaluation of Stormceptor® and multi-chamber treatment train as urban retrofit strategies. In *Proceedings: National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Chicago, IL, February 9–12, 1998.* U.S. Environmental Protection Agency, Washington, DC.

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DRY WEATHER FLOW DIVERSION

Dry Weather Flow Diversion

- Concept: diverts non-storm water and low flows to sanitary sewer system for conveyance to Publicly Owned Treatment Works (POTW)
- May consist of a berm or other means to divert low flows to the sanitary sewer and bypass high storm flows to the storm drain system

Dry Weather Diversion - Siting Criteria

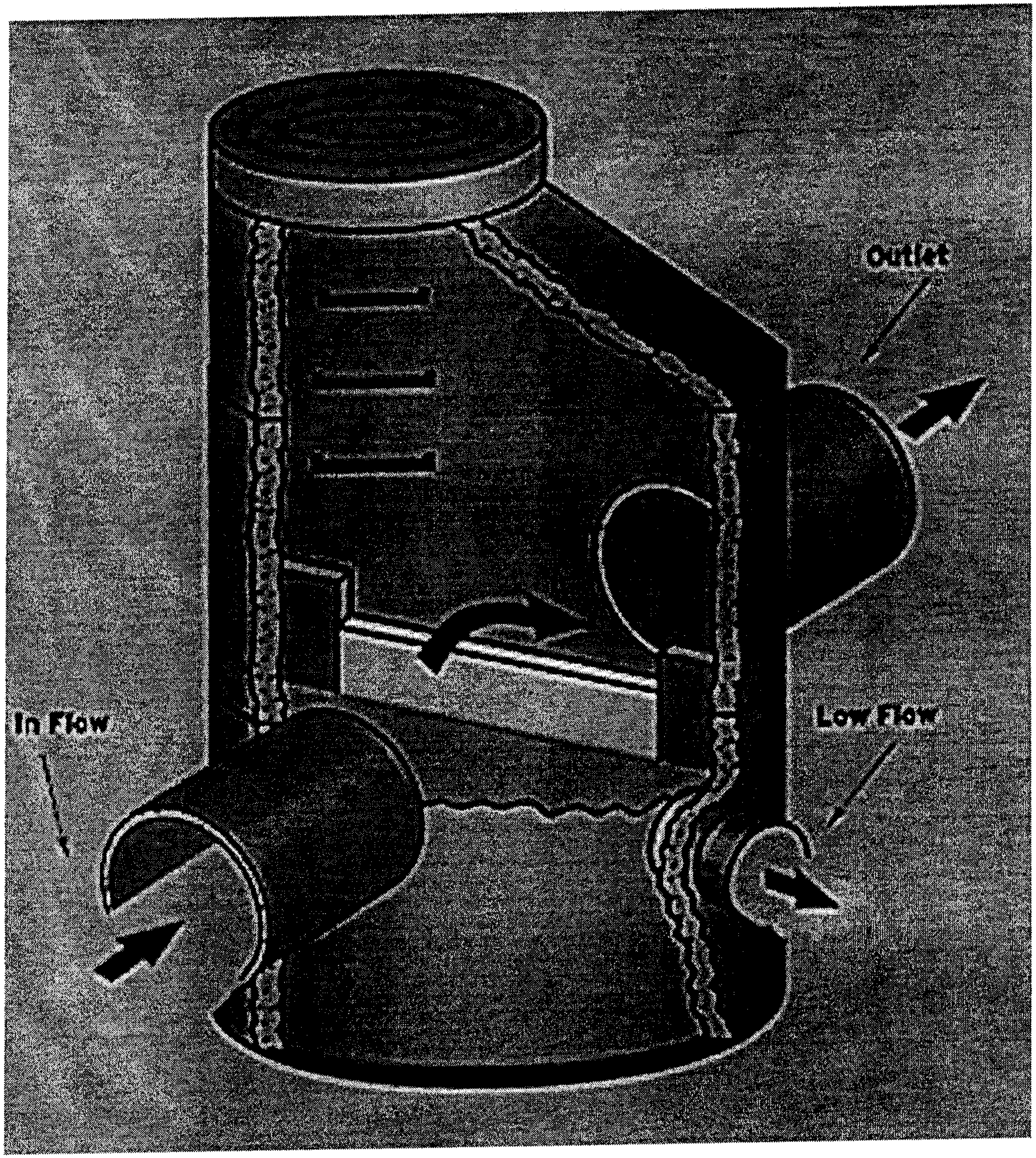
- Dry Weather flow is persistent over significant parts of the year
- A relatively easy connection to the sanitary sewer is available
- The POTW is willing to accept additional flow during the dry season
- Diversion is recommended by the local health officials to benefit receiving waters

Target Pollutants

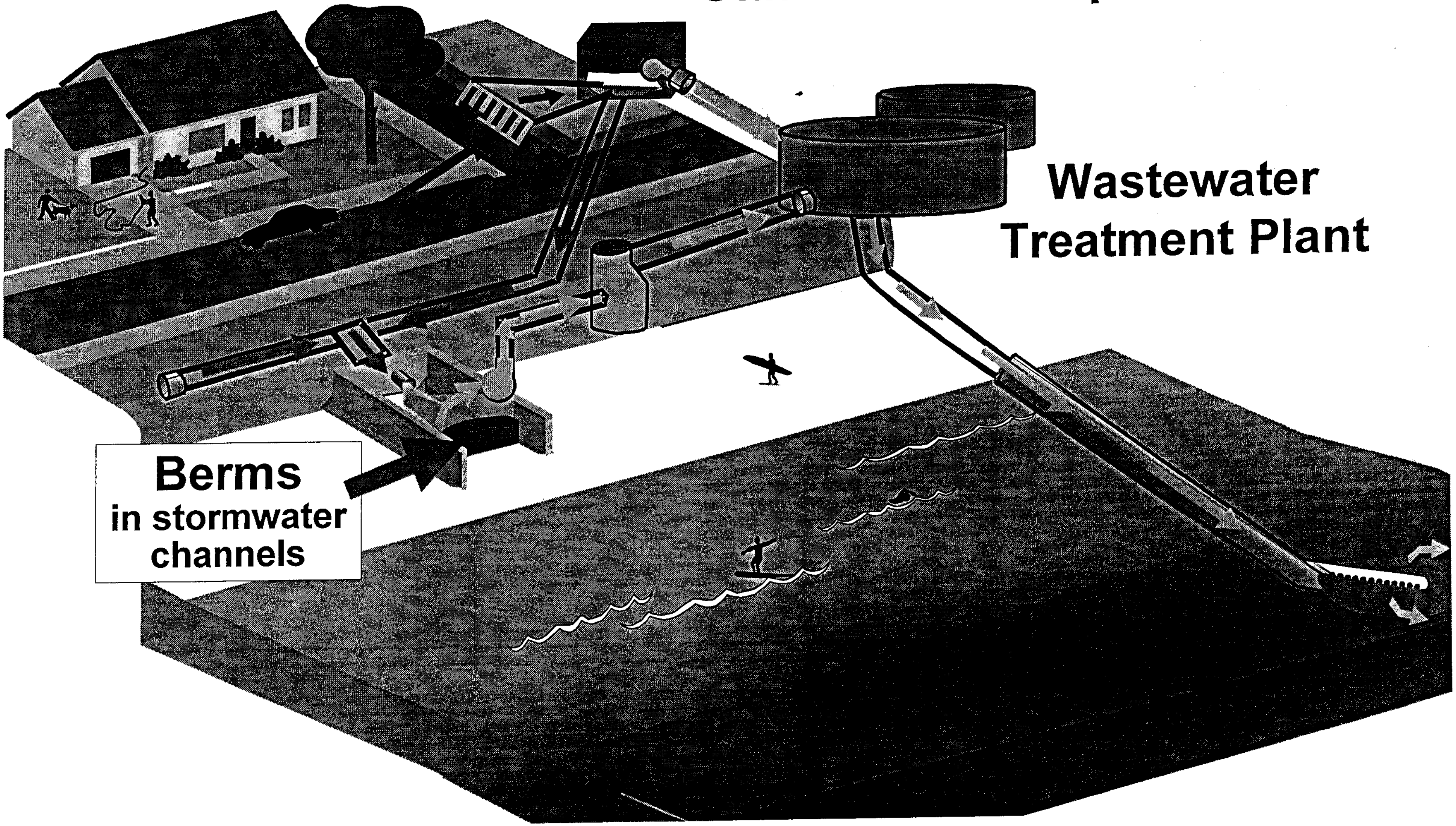
	Biofil Sys	Dry Weather Flow Diversions[1]	Gross Solids Removal Devices	Traction Sand Traps
Total Suspended Solids		✓		✓
Nutrients		✓		
Pesticides		✓		
Particulate Metals		✓		
Dissolved Metals		✓		
Pathogens		✓		
Litter		✓	✓	
Biochemical Oxygen Demand		✓		
Total Dissolved Solids		✓		

PPDG Table 2-2, Page 2-7

Dry Weather Diversion



Dry Weather Diversion



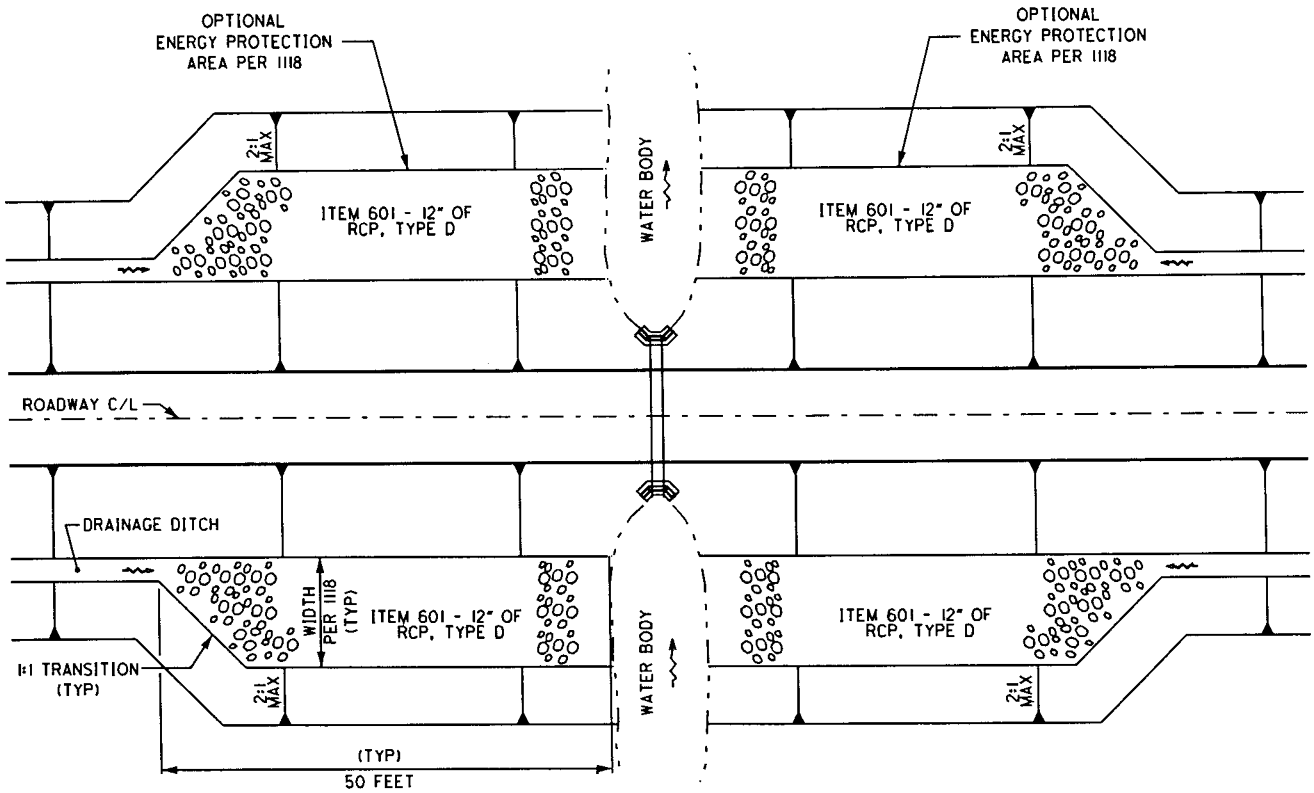
Dry Weather Diversion

- Actual design of Dry Weather Diversion structures are normally provided by the Publicly Owned Treatment Works (POTW)
- Consult your District NPDES Storm Water Coordinator

ENERGY PROTECTION AREA

January 2006

ENERGY PROTECTION AREA DETAIL	1118-5 **REFERENCE SECTION** 1118



PLAN VIEW
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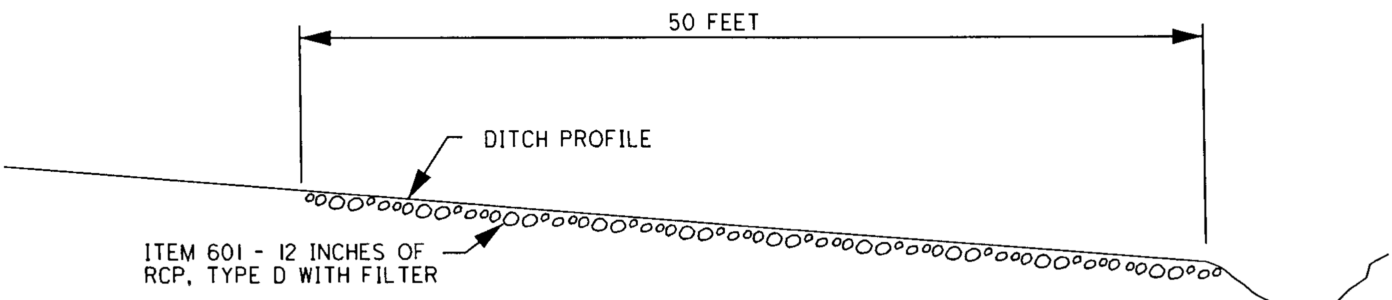

PROFILE
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GRASSED / VEGETATED FILTER STRIP

Vegetated Filter Strip

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Minimum Measure: Post-Construction Stormwater Management in New Development and Redevelopment

Subcategory: Filtration

Description

Vegetated filter strips (grassed filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice, and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. One challenge associated with filter strips, however, is that it is difficult to maintain sheet flow, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.

Applicability

Filter strips are applicable in most regions, but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer (see Riparian/Forested Buffer fact sheet), or as pretreatment to a structural practice. This recommendation is consistent with recommendations in the agricultural setting that filter strips are most effective when combined with another practice (Magette et al., 1989). In fact, the most recent stormwater manual for Maryland does not consider the filter strip as a treatment practice, but does offer stormwater volume reductions in exchange for using filter strips to treat some of a site.

Regional Applicability

Filter strips can be applied in most regions of the country. In arid areas, however, the cost of irrigating the grass on the practice will most likely outweigh its water quality benefits.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Filter strips are impractical in ultra-urban areas because they consume a large amount of space.

Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station. Filter strips should not receive hot spot runoff, because the practice encourages infiltration. In addition, it is questionable whether this practice can reliably remove pollutants, so it should definitely not be used as the sole treatment of hot spot runoff.

Stormwater Retrofit

A stormwater retrofit is a stormwater management practice (usually structural), put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Filter strips are generally a poor retrofit option because they consume a relatively large amount of space and cannot treat large drainage areas.

Cold Water (Trout) Streams

Some cold water species, such as trout, are sensitive to changes in temperature. While some treatment practices, such as wet ponds (see Wet Ponds fact sheet), can warm stormwater substantially, filter strips do not warm pond water on the surface for long periods of time and are not expected to increase stormwater temperatures. Thus, these practices are good for protection of cold-water streams.

Siting and Design Considerations

Siting Considerations

In addition to the restrictions and modifications to adapting filter strips to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting filter strips.

Drainage Area

Typically, filter strips are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the practice treats but the length of flow leading to it. As stormwater runoff flows over the ground's surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets which are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip. Furthermore, this concentrated flow can lead to scouring. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (CWP, 1996). Using this rule, a filter strip can treat one acre of impervious surface per 580-foot length.

Slope

Filter strips should be designed on slopes between 2 and 6 percent. Greater slopes than this would encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff would pond on the surface on slopes flatter than 2 percent, creating potential mosquito breeding habitat.

Soils /Topography

Filter strips should not be used on soils with a high clay content, because they require some infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor.

Ground Water

Filter strips should be separated from the ground water by between 2 and 4 ft to prevent contamination and to ensure that the filter strip does not remain wet between storms.

Design Considerations

Filter strips appear to be a minimal design practice because they are basically no more than a grassed slope. However, some design features are critical to ensure that the filter strip provides some minimum amount of water quality treatment.

- A pea gravel diaphragm should be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.
- The filter strip should be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½-inch of runoff over the entire drainage area to the practice.
- The filter strip should be at least 25 feet long to provide water quality treatment.
- Designers should choose a grass that can withstand relatively high velocity flows and both wet and dry periods.
- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

Regional Variations

In cold climates, filter strips provide a convenient area for snow storage and treatment. If used for this purpose, vegetation in the filter strip should be salt-tolerant, (e.g., creeping bentgrass), and a maintenance schedule should include the removal of sand built up at the bottom of the slope. In arid or semi-arid climates, designers should specify drought-tolerant grasses (e.g., buffalo grass) to minimize irrigation requirements.

Limitations

Filter strips have several limitations related to their performance and space consumption:

- The practice has not been shown to achieve high pollutant removal.
- Filter strips require a large amount of space, typically equal to the impervious area they treat, making them often infeasible in urban environments where land prices are high.
- If improperly designed, filter strips can allow mosquitos to breed.
- Proper design requires a great deal of finesse, and slight problems in the design, such as improper grading, can render the practice ineffective in terms of pollutant removal.

Maintenance Considerations

Filter strips require similar maintenance to other vegetative practices (see Grassed Swales fact sheet). These maintenance needs are outlined below. Maintenance is very important for filter strips, particularly in terms of ensuring that flow does not short circuit the practice.

Table 1. Typical maintenance activities for vegetated filter strips (Source: CWP, 1996)

Activity	Schedule
• Inspect pea gravel diaphragm for clogging and remove built-up sediment. • Inspect vegetation for rills and gullies and correct. Seed or sod bare areas. • Inspect to ensure that grass has established. If not, replace with an alternative species.	Annual inspection (semi-annual the first year)
• Remove sediment build-up within the bottom when it has accumulated to 25% of the original capacity.	Regular (infrequent)

Effectiveness

Structural stormwater management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. The first two goals, flood control and channel protection, require that a stormwater practice be able to reduce the peak flows of relatively large storm events (at least 1- to 2-year storms for channel protection and at least 10- to 50-year storms for flood control). Filter strips do not have the capacity to detain these events, but can be designed with a bypass system that routes these flows around the practice entirely.

Filter strips can provide a small amount of ground water recharge as runoff flows over the vegetated surface and ponds at the toe of the slope. In addition, it is believed that filter strips can provide modest pollutant removal. Studies from agricultural settings suggest that a 15-foot-wide grass buffer can achieve a 50 percent removal rate of nitrogen, phosphorus, and sediment, and that a 100-foot buffer can reach closer to 70 percent removal of these constituents (Desbonette et al., 1994). It is unclear how these results can be translated to the urban environment, however. The characteristics of the incoming flows are radically different both in terms of pollutant concentration and the peak flows associated with similar storm events. To date, only one study (Yu et al., 1992) has investigated the effectiveness of a grassed filter strip to treat runoff from a large parking lot. The study found that the pollutant removal varied depending on the length of flow in the filter strip. The narrower (75-foot) filter strip had moderate removal for some pollutants and actually appeared to export lead, phosphorus, and nutrients (See Table 2).

Table 2. Pollutant removal of an urban vegetated filter strip (Source: Yu et al., 1993)

	Pollutant Removal (%)	
	75-Ft Filter Strip	150-Ft Filter Strip
Total suspended solids	54	84
Nitrate+nitrite	-27	20
Total phosphorus	-25	40
Extractable lead	-16	50
Extractable zinc	47	55

Cost Considerations

Little data are available on the actual construction costs of filter strips. One rough estimate can be the cost of seed or sod, which is approximately 30¢ per ft^2 for seed or 70¢ per ft^2 for sod. This amounts to between $13,000 and $30,000 per acre for a filter strip, or the same amount per impervious acre treated. This cost is relatively high compared with other treatment practices. However, the grassed area used as a filter strip may have been seeded or sodded even if it were not used for treatment. In these cases, the only additional costs are the design, which is minimal, and the installation of a berm and gravel diaphragm. Typical maintenance costs are about $350/acre/year (adapted from SWRPC, 1991). This cost is relatively inexpensive and, again, might overlap with regular landscape maintenance costs.

The true cost of filter strips is the land they consume, which is higher than for any other treatment practice. In some situations this land is available as wasted space beyond back yards or adjacent to roadsides, but this practice is cost-prohibitive when land prices are high and land could be used for other purposes.

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GRASSED, WET, OR DRY SWALE / BIOSWALE / BIOFILTER

Bioswales

NRCS Natural Resources Conservation Service

. . . absorb and transport large runoff events

2005

What are bioswales?

Bioswales are storm water runoff conveyance systems that provide an alternative to storm sewers. They can absorb low flows or carry runoff from heavy rains to storm sewer inlets or directly to surface waters. Bioswales improve water quality by infiltrating the first flush of storm water runoff and filtering the large storm flows they convey.

The majority of annual precipitation comes from frequent, small rain events. Much of the value of bioswales comes from infiltrating and filtering nearly all of this water.

Designing a bioswale

For best results, enhance and utilize existing natural drainage swales whenever possible. Existing swales can be enhanced with native plants. The thicker and heavier the grasses, the better the swale can filter out contaminants. Additionally, subgrade drains and amended soils may be needed to facilitate infiltration.

Other considerations when designing or maintaining bioswales:

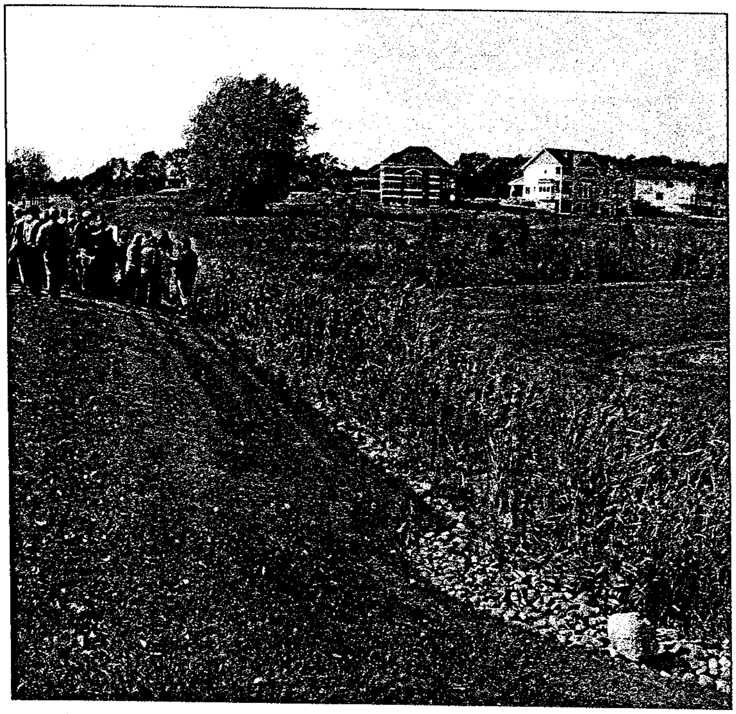
- Costs vary greatly depending on size, plant material, and site considerations. Bioswales are generally less expensive when used in place of underground piping.
- Deep-rooted native plants are preferred for infiltration and reduced maintenance.
- Soil infiltration rates should be greater than one-half inch per hour.
- A parabolic or trapezoidal shape is recommended with side slopes no steeper than 3:1.
- Avoid soil compaction during installation.
- Swales should be sized to convey at least a 10-year storm (or about 4.3 inches in 24 hours).

A bioswale featuring native vegetation shows its fall colors.

Photo Courtesy Jim Patchett

Maintaining a bioswale

Once established, bioswales require less maintenance than turf grass because they need less water and no fertilizer. Native grasses and forbs are adapted to Iowa rainfall patterns. Natives also resist local pests and disease.



A road ditch can serve as a bioswale. The rock trench and wetland vegetation are notable features, along with the natural drainageway in the background that serves as a bioswale for residential runoff.

For More Information

Find more information about low impact development and bioswales by visiting the following websites:

www.iowasudas.org
www.lid-stormwater.net
www.cwp.org
www.iowastormwater.org

Low Impact Development

Traditionally, storm water management has involved the rapid conveyance of water via storm sewers to surface waters. Low Impact Development (LID) is a different approach that retains and infiltrates rainfall on-site. The LID approach emphasizes site design and planning techniques that mimic the natural infiltration-based, groundwater-driven hydrology of our historic landscape. Bioswales are one component of LID.

Why is LID important:

to the environment?

- protects sensitive areas
- increases habitat for wildlife by preserving trees and vegetation
- protects local and regional water quality by reducing sediment and nutrient loads
- reduces streambank and channel erosion by reducing the frequent surges/bounces of higher flows from storm sewer discharges
- reduces frequent high and low flows associated with surface runoff, stabilizing stream flow volumes by restoring ground water discharges into receiving waters
- may reduce potential for flooding

to residents?

- increases community character
- improves quality of life
- more access to trails and open space
- pedestrian-friendly

to developers?

- reduces land clearing and grading costs
- reduces infrastructure costs (streets, curbs, gutters, sidewalks)
- increases community marketability

to communities?

- balances growth needs with environmental protection
- reduces infrastructure and utility maintenance costs

The USDA is an equal opportunity provider and employer.

GROSS SOLID REMOVAL DEVICES

GSRDs: Phase I

Caltrans

Phase I
Gross Solids Removal Devices Pilot Study: 2000 - 2002

Final Report
October 2003

State of California
Department of Transportation

CTSW-RT-03-072.31.22

- Limited engineering was performed to estimate order-of-magnitude sizing and propose preliminary design criteria.
- Generic, non-site-specific design concepts were developed.
- Opportunities, feasibility issues, and constraints associated with each concept were identified.
- Initial concept design alternatives were presented to Caltrans' New Technology team for evaluation.

Three preliminary design concepts for different GSRDs were developed. These design concepts included the Linear Radial, the Inclined Screen, and the Baffle Box. The Linear Radial and Inclined Screen design concepts included two variations. Summaries of the design assumptions that underlie the concepts are presented in the following sections on a device-specific basis.

Several types of screens were investigated for use in this pilot study. They included:

- Rigid mesh screens
- Bi-wave wedge wire screens
- Louvered or slotted screens

The type of screen to be used for each GSRD was selected based on an evaluation by the design team considering what would perform best with respect to site conditions such as available footprint, slopes, hydraulic head, and other conditions. For example, all three screens potentially could be used for the Inclined Screen device with varying degrees of success but the wedge wire screens were expected to perform the best. Inclined wedge wire screens have exhibited proven performance in the food industry to separate solids from liquids. Due to the steep inclination of the screen, the Inclined Screen device could only be incorporated in sites which had sufficient hydraulic head.

2.2.1 Linear Radial – Configuration #1

This GSRD utilizes a modular well casing with 5 mm x 64 mm (0.2 in x 2.5 in nominal) louvers to serve as the screen (Figure 2-1). Flows are routed through the louvers and into a vault. Key design and operational concepts are as follows:

- Inflow is directed into the louvered screen contained within a concrete vault. The louvered screen and vault are linear and aligned parallel to the direction of flow.
- Flows pass radially through the louvered screen and into the vault.
- The louvered screen has a smooth, solid bottom section (extending 60 degrees) to facilitate the movement of settled gross solids toward the downstream end of the pipe.

- Sufficient screen area and volume are provided to accommodate the estimated annual volume of gross solids and to pass the required design storm.
- The vault can be configured with grates or covers, traffic or non-traffic rated, depending upon location within the highway right-of-way.
- The first section of pipe nearest the influent pipe has the same diameter as the louvered screen sections with an open top for emergency overflow. The overflow is designed to convey the Caltrans design flow and the opening has the same open cross sectional area as the pipe.

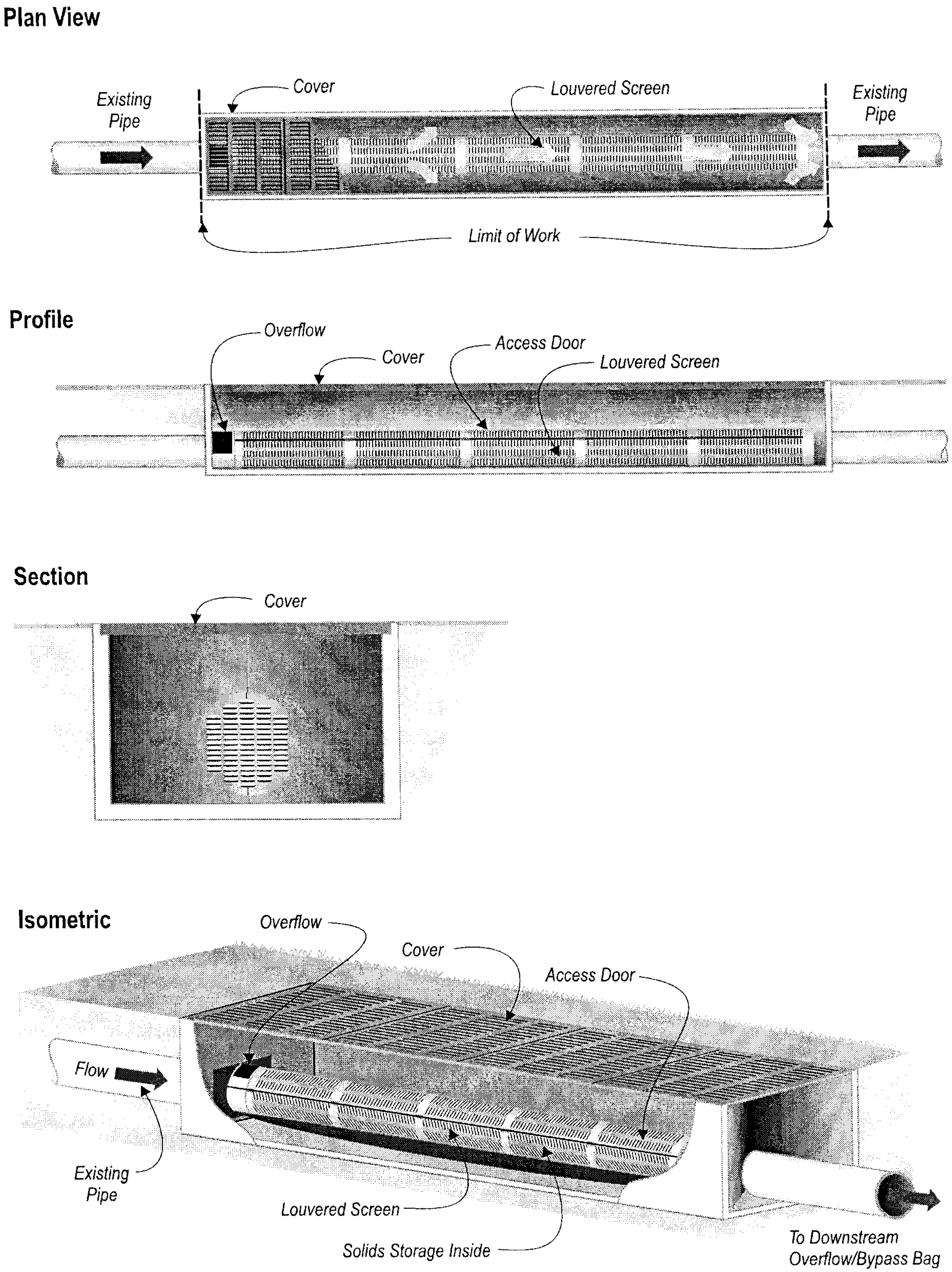


Figure 2-1
Concept Linear Radial Configuration #1

2.2.2 Linear Radial – Configuration #2

This GSRD utilizes a modular 5 mm x 5 mm (0.2 in x 0.2 in nominal) rigid mesh screen housing (Figure 2-2). Inside the rigid mesh screen are nylon mesh bags (5 mm [0.2 in] mesh) that capture gross solids. Flows are routed into the nylon mesh bags and exit into a vault. Key design and operational concepts are as follows:

- Inflow enters a mesh bag contained within the rigid mesh screen, which are both contained within a concrete vault. The screen and vault are linearly aligned and parallel to the direction of flow.
- The nylon mesh bags and rigid mesh screen provide sufficient area and volume to accommodate an estimated once per year cleaning without plugging.
- The vault can be configured with grates or covers, traffic or non-traffic rated, depending upon location within the highway right-of-way.
- The nylon mesh bags are placed inside the screen for ease of maintenance.
- In the case that the screens are plugged, storm water would flow over the screen housing to the outflow pipe.

2.2.3 Inclined Screen – Configuration #1

This GSRD uses a 3 mm (0.125 in nominal) spaced parabolic wedge-wire screen with the slotting perpendicular (horizontal orientation) to the direction of flow (Figure 2-3). The device is configured with an influent trough to allow some solids to settle. The flow then overtops a weir and falls through the inclined screen. After passing through the screen, the flow exits the GSRD. Gross solids are retained in a confined storage area that can be accessed by maintenance equipment. Key design and operational concepts are as follows:

- Inflow enters a trough to distribute flows along the length of the screen. The trough also provides an area of reduced velocity where larger solids can settle.
- The trough is drained by a series of weep holes. Sufficient weep holes are provided to drain the trough within 72 hours to prevent vector propagation.
- Flowing storm water pushes the gross solids. The gross solids are moved by gravity down the face of the screen to the gross solids storage area.
- The gross solids storage area is sloped and configured with a drain pipe and inlet grate to allow it to drain between storm events.
- The vault can be configured with grates or covers, traffic or non-traffic rated, depending upon location within the highway right-of-way.
- In the case that the screens are completely plugged, storm water would overflow the entire device to the downstream receiving waters.

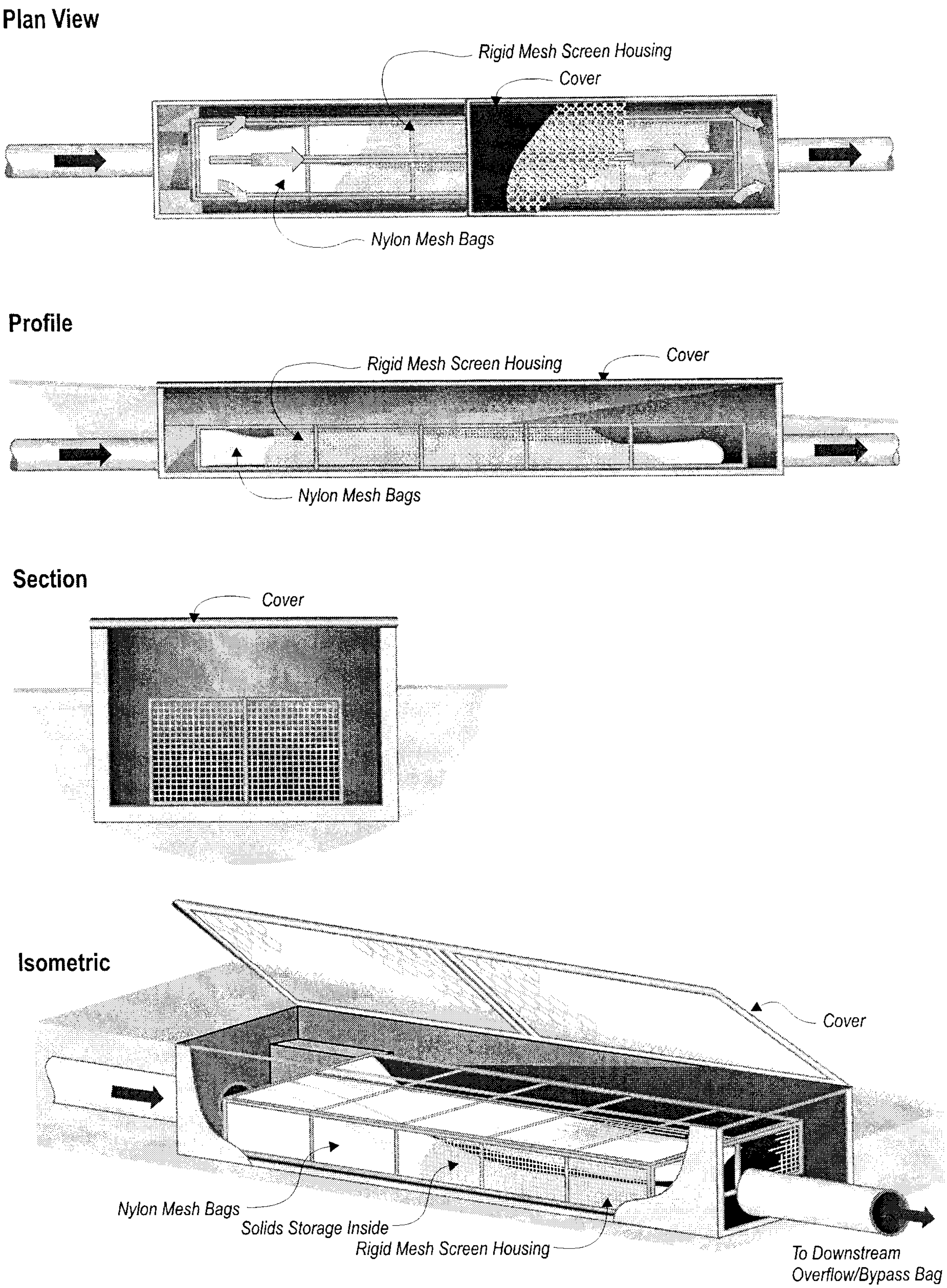
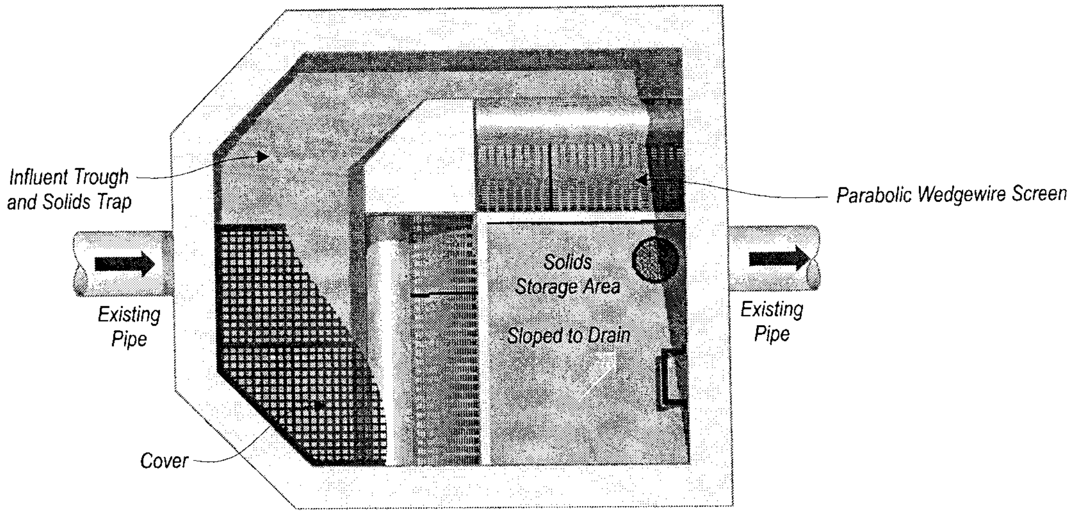
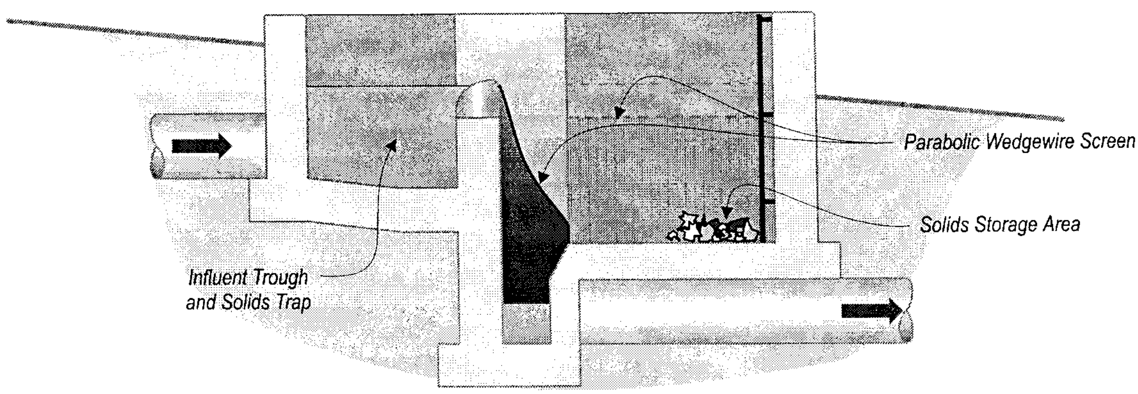


Figure 2-2
Concept Linear Radial
Configuration #2

Plan View



Profile



Isometric

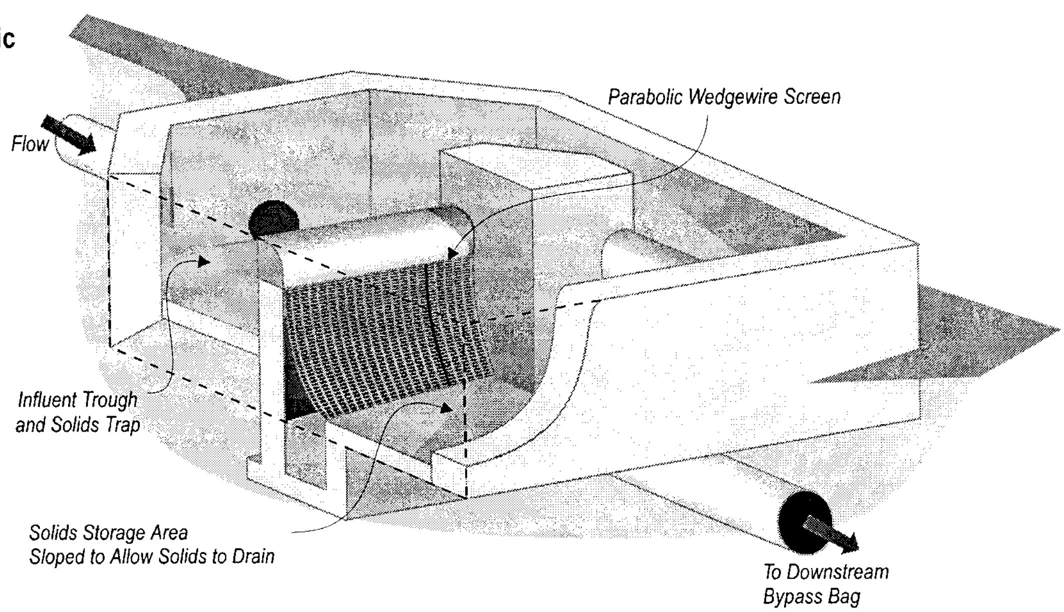


Figure 2-3
Concept Inclined Screen
Configuration #1

2.2.4 Inclined Screen – Configuration #2

This GSRD uses a 5 mm (0.2 in nominal) spaced parabolic bar screen with the slotting parallel (vertical orientation) to the direction of flow (Figure 2-4). The device is configured with an influent trough to allow solids to settle. The flow overtops a weir and falls through the inclined screen located after the influent trough. After passing through the screen, the flow exits the GSRD. Gross solids are retained in a confined storage area that can be accessed by maintenance equipment. Key design and operational concepts are as follows:

- Inflows enter a trough to distribute flows along the length of the screen. The trough also provides an area of reduced velocity where larger solids can settle.
- The trough is drained by a series of small plastic risers. Sufficient risers are provided to drain the trough within 72 hours to prevent vector propagation.
- Flowing storm water pushes the gross solids. The gross solids are moved by gravity down the face of the screen to the gross solids storage area.
- The gross solids storage area is sloped to allow it to drain between storm events.
- The vault can be configured with grates or covers, traffic or non-traffic rated, depending upon location within the highway right-of-way.
- An overflow weir is provided to convey emergency bypass flow, and an overflow basket is attached to capture any solids that flow over the weir.

2.2.5 Baffle Box

This GSRD applies a two-chamber concept: the first chamber utilizes an underflow weir to trap floatable gross solids, and the second chamber uses a bar rack to capture materials that get past the underflow weir (Figure 2-5). Key design and operational concepts are as follows:

- Inflow enters the first chamber, where solids are allowed to settle.
- A hinged chain-link screen allows high flows to pass and keeps the majority of floatable solids in the first chamber.
- The flow of storm water along the slotted screen is designed to provide a self-cleaning action. The slotted screen is sized to accommodate partial plugging.
- Plastic risers in the first chamber drain water from the device, allowing solids to fall to the bottom of the chamber.
- An overflow weir is provided to convey emergency bypass flow, and an overflow basket is attached to capture any solids that flow over the weir.

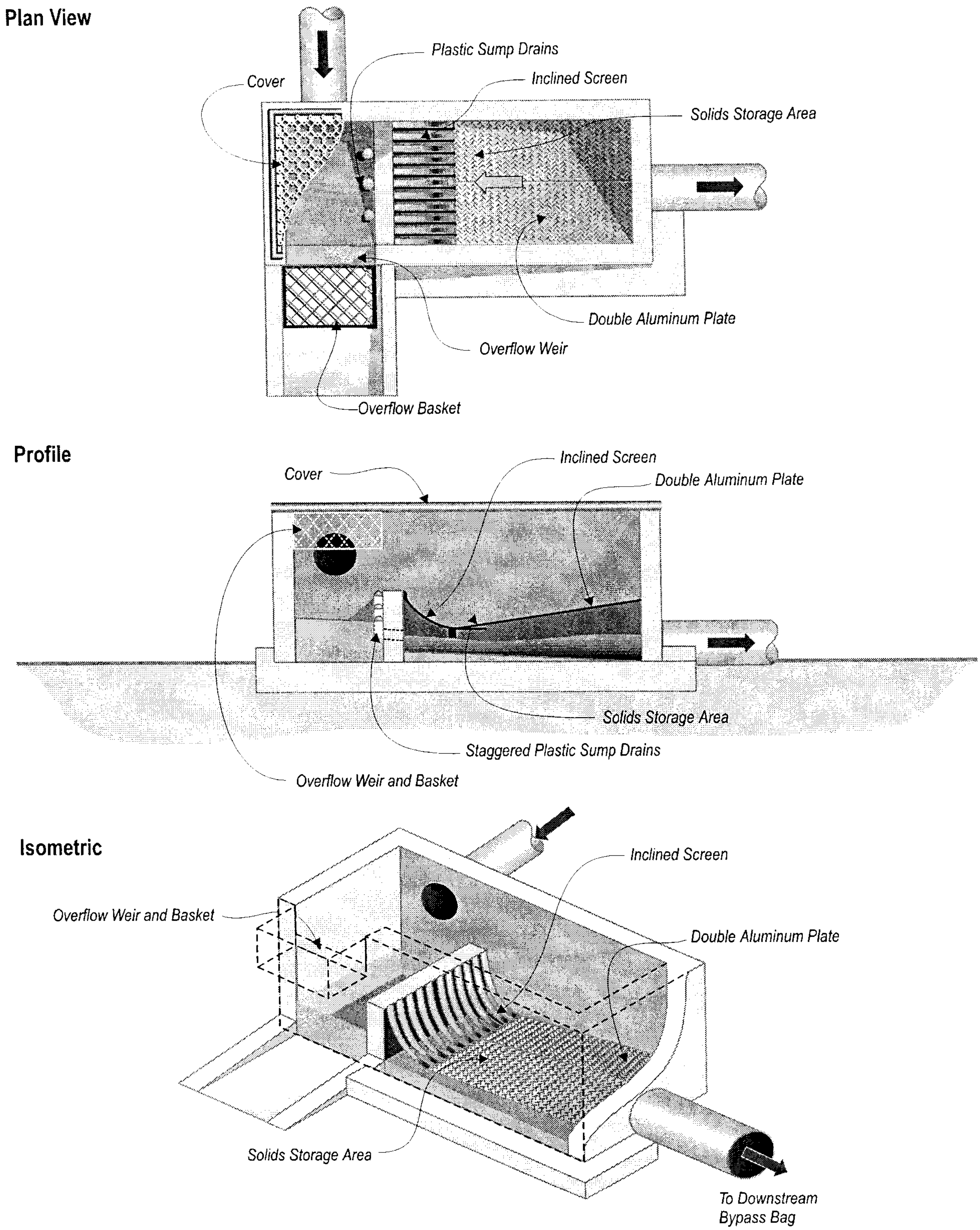


Figure 2-4
Concept Inclined Screen
Configuration #2

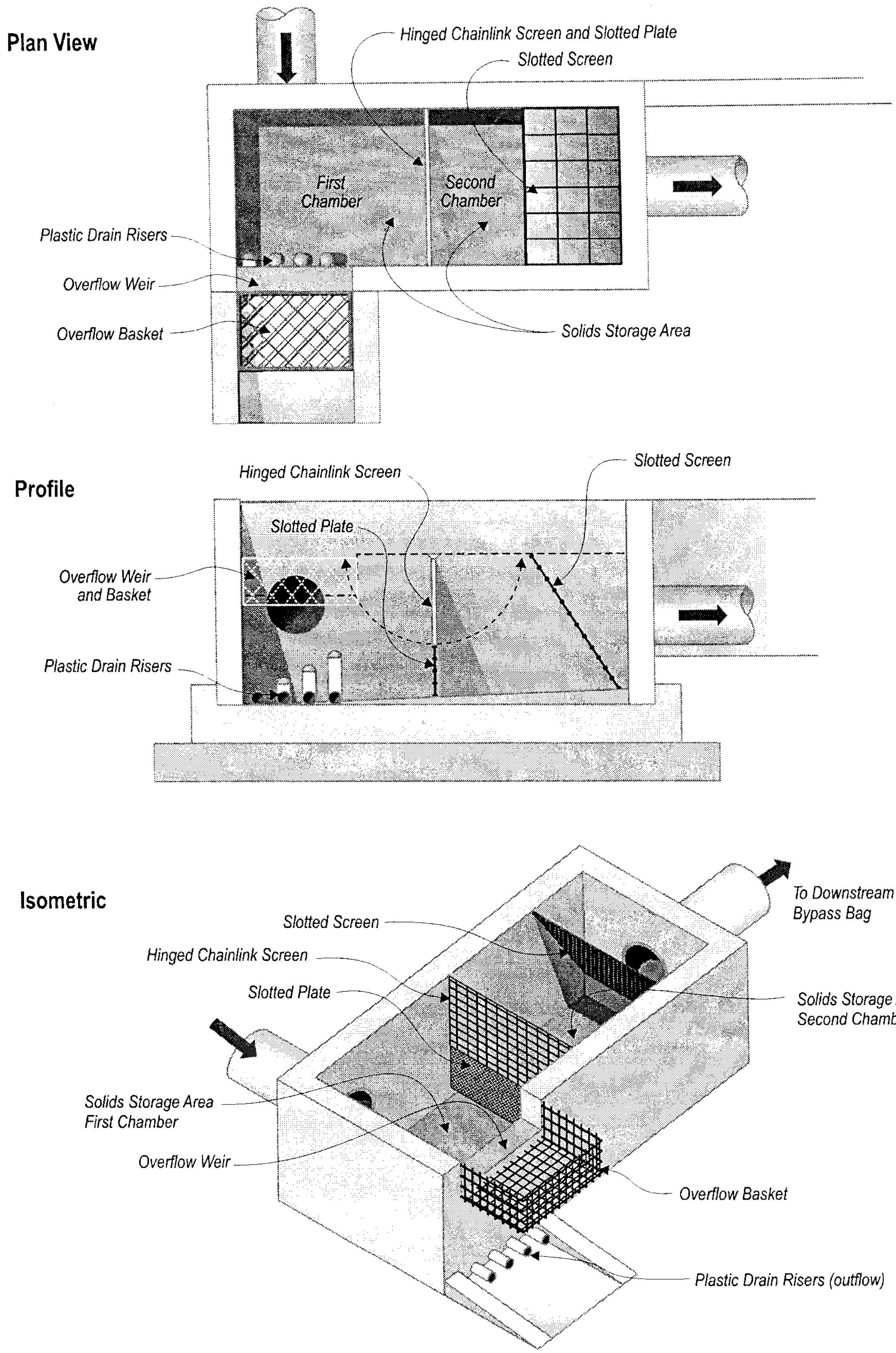


Figure 2-5
Concept Baffle Box

INFILTRATION TRENCH

Infiltration Trench

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Minimum Measure: Post-Construction Stormwater Management in New Development and Redevelopment

Subcategory: Infiltration

Description

An infiltration trench (a.k.a. infiltration galley) is a rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is filtering through the soil.

Applicability

Infiltration trenches have select applications. While they can be applied in most regions of the country, their use is sharply restricted by concerns due to common site factors, such as potential ground water contamination, soils, and clogging.

Regional Applicability

Infiltration trenches can be utilized in most regions of the country, with some design modifications in cold and arid climates. In regions of karst (i.e., limestone) topography, these stormwater management practices may not be applied due to concerns of sink hole formation and ground water contamination.

Ultra-Urban Areas

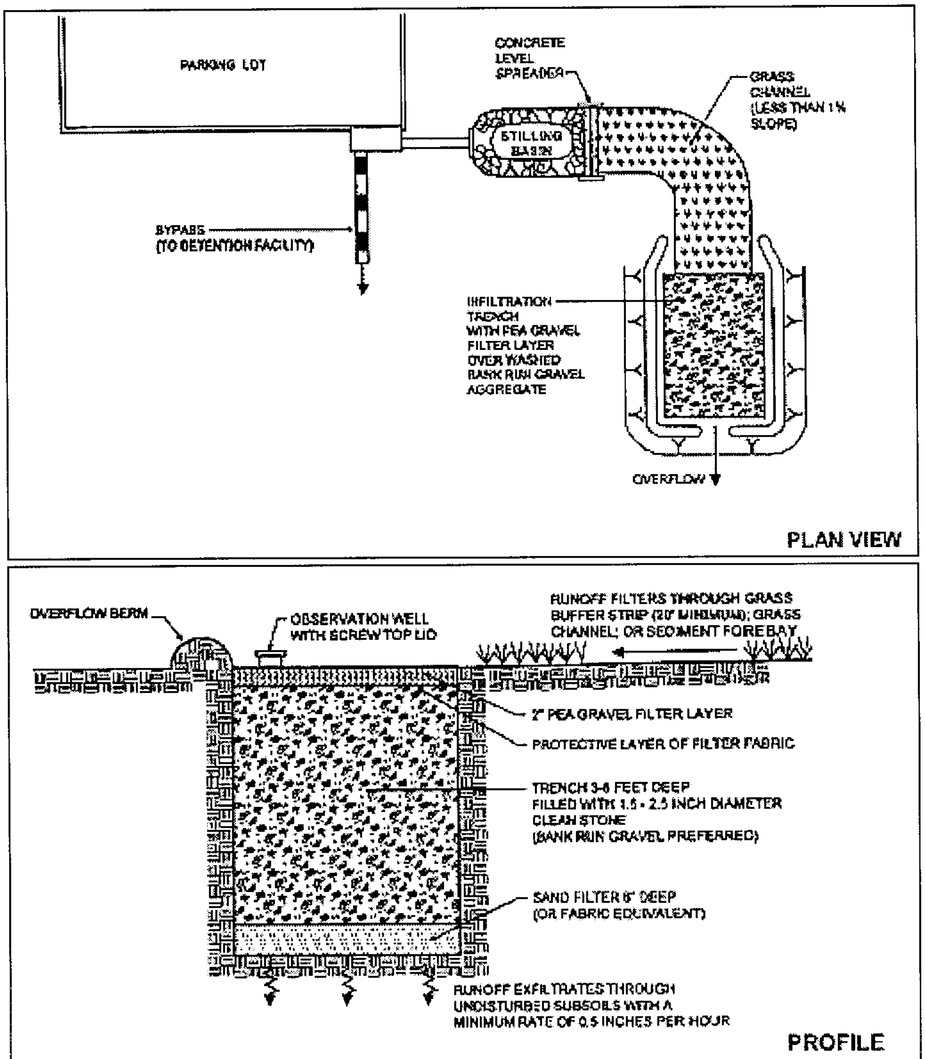
Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Infiltration trenches can sometimes be applied in the ultra-urban environment. Two features that can restrict their use are the potential of infiltrated water to interfere with existing infrastructure, and the relatively poor infiltration capacity of most urban soils.

Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. Infiltration trenches should not receive runoff from stormwater hot spots, unless the stormwater has already been treated by another stormwater management practice, because of potential ground water contamination.

Siting and Design Considerations

Infiltration trenches have select applications. Although they can be applied in a variety of situations, the use of infiltration trenches is restricted by concerns over ground water contamination, soils, and clogging.



A schematic of an infiltration trench (Source: MDE, 2000)

Siting Considerations

Infiltration practices need to be sited extremely carefully. In particular, designers need to ensure that the soils on site are appropriate for infiltration and that designs minimize the potential for ground water contamination and long-term maintenance.

Drainage Area

Infiltration trenches generally can be applied to relatively small sites (less than 5 acres), with relatively high impervious cover. Application to larger sites generally causes clogging, resulting in a high maintenance burden.

Slope

Infiltration trenches should be placed on flat ground, but the slopes of the site draining to the practice can be as steep as 15 percent.

Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the stormwater can infiltrate quickly enough to reduce the potential for clogging. In addition, soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for ground water contamination. The infiltration rate should range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20 percent clay content, and less than 40 percent silt/clay content (MDE, 2000). The infiltration rate and textural class of the soil need to be confirmed in the field; designers should not rely on more generic information such as a soil survey. Finally, infiltration trenches may not be used in regions of karst topography, due to the potential for sinkhole formation or ground water contamination.

Ground Water

Designers always need to provide significant separation (2 to 5 feet) from the bottom of the infiltration trench and the seasonally high ground water table, to reduce the risk of contamination. In addition, infiltration practices should be separated from drinking water wells.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration trench designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural stormwater management practices, but it is particularly important for infiltration practices. To ensure that pretreatment mechanisms are effective, designers should incorporate "multiple pretreatment," using practices such as grassed swales, vegetated filter strips, detention, or a plunge pool in series.

Treatment

Treatment design features enhance the pollutant removal of a practice. During the construction process, the upland soils of infiltration trenches need to be stabilized to ensure that the trench does not become clogged with sediment. Furthermore, the practice should be filled with large clean stones that can retain the volume of water to be treated in their voids. Like infiltration basins, this practice should be sized so that the volume to be treated can infiltrate out of the trench bottom in 24 hours.

Conveyance

Stormwater needs to be conveyed through stormwater management practices safely, and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. Infiltration trenches should be designed to treat only small storms, (i.e., only for water quality). Thus, these practices should be designed "off-line," using a structure to divert only small flows to the practice. Finally, the sides of an infiltration trench should be lined with a geotextile fabric to prevent flow from causing rills along the edge of the practice.

Maintenance Reduction

In addition to regular maintenance activities, designers also need to incorporate features into the design to ensure that the maintenance burden of a practice is reduced. These features can make regular maintenance activities easier or reduce the need to perform maintenance. As with all management practices, infiltration trenches should have an access path for maintenance activities. An observation well (i.e., a perforated PVC pipe that leads to the bottom of the trench) can enable inspectors to monitor the drawdown rate. Where possible, trenches should have a means to drain the practice if it becomes clogged, such as an underdrain. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of filtering practices to collect and remove filtered runoff. An underdrain pipe with a shutoff valve can be used in an infiltration system to act as an overflow in case of clogging.

Landscaping

In infiltration trenches, there is no landscaping on the practice itself, but it is important to ensure that the upland drainage is properly stabilized with thick vegetation, particularly following construction.

Regional Variations

Arid or Semi-Arid Climates

In arid regions, infiltration practices are often highly recommended because of the need to recharge the ground water. One concern in these regions is the potential of these practices to clog, due to relatively high sediment concentrations in these environments. Pretreatment needs to be more heavily emphasized in these dryer climates.

Cold Climates

In extremely cold climates (i.e., regions that experience permafrost), infiltration trenches may be an infeasible option. In most cold climates, infiltration trenches can be a feasible management practice, but there are some challenges to their use. The volume may need to be increased in order to treat snowmelt. In addition, if the practice is used to treat roadside runoff, it may be desirable to divert flow around the trench in the winter to prevent infiltration of chlorides from road salting, where this is a problem. Finally, a minimum setback from roads is needed to ensure that the practice does not cause frost heaving.

Limitations

Although infiltration trenches can be a useful management practice, they have several limitations. While they do not detract visually from a site, infiltration trenches provide no visual enhancements. Their application is limited due to concerns over ground water contamination and other soils requirements. Finally, maintenance can be burdensome, and infiltration practices have a relatively high rate of failure.

Maintenance Considerations

In addition to incorporating features into the design to minimize maintenance, some regular maintenance and inspection practices are needed. Table 1 outlines some of these practices.

Table 1. Typical maintenance activities for infiltration trenches (Source: Modified from WMI, 1997)

Activity	Schedule
• Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.	Semi-annual inspection
• Remove sediment and oil/grease from pretreatment devices and overflow structures.	Standard maintenance
• If bypass capability is available, it may be possible to regain the infiltration rate in the short term by using measures such as providing an extended dry period.	5-year maintenance
• Total rehabilitation of the trench should be conducted to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate limit. • Trench walls should be excavated to expose clean soil.	Upon failure

Infiltration practices have historically had a high rate of failure compared to other stormwater management practices. One study conducted in Prince George's County, Maryland (Galli, 1992), revealed that less than half of the infiltration trenches investigated (of about 50) were still functioning properly, and less than one-third still functioned properly after 5 years. Many of these practices, however, did not incorporate advanced pretreatment. By carefully selecting the location and improving the design features of infiltration practices, their performance should improve.

Effectiveness

Structural stormwater management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Infiltration trenches can provide ground water recharge, pollutant control, and can help somewhat to provide channel protection.

Ground Water Recharge

Infiltration trenches recharge the ground water because runoff is treated for water quality by filtering through the soil and discharging to ground water.

Pollutant Removal

Very little data are available regarding the pollutant removal associated with infiltration trenches. It is generally assumed that they have very high pollutant removal, because none of the stormwater entering the practice remains on the surface. Schueler (1987) estimated pollutant removal for infiltration trenches based on data from land disposal of wastewater. The average pollutant removal, assuming the infiltration trench is sized to treat the runoff from a 1-inch storm, is:

TSS 75%

Phosphorous 60-70%

Nitrogen 55-60%

Metals 85-90%

Bacteria 90%

These removal efficiencies assume that the infiltration trench is well designed and maintained. The information in the Siting and Design Considerations and Maintenance Considerations sections represent the best available information on how to properly design these practices. The design references below provide additional information.

Cost Considerations

Infiltration trenches are somewhat expensive, when compared to other stormwater practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about $5 per ft^3 of stormwater treated (SWRPC, 1991; Brown and Schueler, 1997).

Infiltration trenches typically consume about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration trenches have a high failure rate (see Maintenance Considerations). In general, maintenance costs for infiltration trenches are estimated at between 5 percent and 20 percent of the construction cost. More realistic values are probably closer to the 20 percent range, to ensure long-term functionality of the practice.

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IN-LINE STORAGE

U.S. Environmental Protection Agency

National Pollutant Discharge Elimination System (NPDES)

In-Line Storage

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Minimum Measure: Post-Construction Stormwater Management in New Development and Redevelopment

Subcategory: Retention/Detention

Description

In-line storage refers to a number of practices designed to use the storage within the storm drain system to detain flows. While these practices can reduce storm peak flows, they are unable to improve water quality and offer limited protection of downstream channels. Hence, EPA does not recommend using these practices in many circumstances. Storage is achieved by placing devices in the storm drain system to restrict the rate of flow. Devices can slow the rate of flow by backing up flow, as in the case of a dam or weir, or through the use of vortex valves, devices that reduce flow rates by creating a helical flow path in the structure. A description of various flow regulators is included in Urbonas and Stahre (1990).

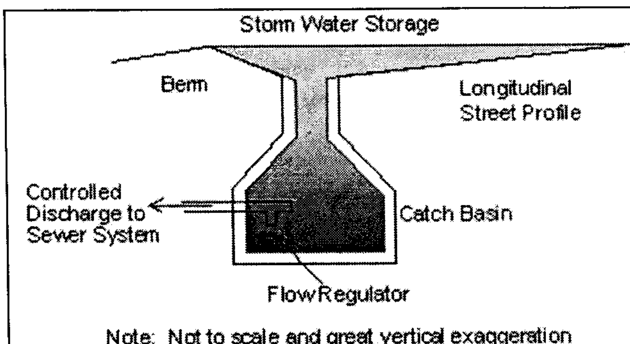
Applicability

In-line storage practices serve a similar purpose as traditional detention basins (see Dry Extended Detention Ponds fact sheet). These practices can act as surrogates for aboveground storage when little space is available for aboveground storage facilities.

Limitations

In-line storage has significant limitations, including:

- In-line storage practices only control flow, and thus are not able to improve the water quality of stormwater runoff. As a result, other stormwater BMPs such as Green Roofs or Bioretention Rain Gardens should be considered and used if possible, particularly for new construction projects.
- If improperly designed, these practices may cause upstream flooding.



Catch basins can be equipped with flow restrictors to temporarily detain stormwater in the conveyance system

Siting and Design Considerations

Flow regulators cannot be applied to all storm drain systems. In older cities, the storm drain pipes may not be oversized, and detaining stormwater within them would cause upstream flooding. Another important issue in siting these practices is the slope of the pipes in the system. In areas with very flat slopes, restricting flow within the system is likely to cause upstream flooding because introducing a regulator into the system will cause flows to back up a long distance before the regulator. In steep pipes, on the other hand, a storage flow regulator cannot utilize much of the storage available in the storm drain system.

Maintenance Considerations

Flow regulators require very little maintenance, because they are designed to be "self cleaning," much like the storm drain system. In some cases, flow regulators may be modified based on downstream flows, new connections to the storm drain, or the application of other flow regulators within the system. For some designs, such as check dams, regulations will require only moderate construction in order to modify the structure's design.

Effectiveness

The effectiveness of in-line storage practices is site-specific and depends on the storage available in the storm drain system. In one study, a single application was able to reduce peak flows by approximately 50 percent (VDCR, 1999).

Cost Considerations

Flow regulators are relatively low cost options, particularly since they require little maintenance and consume little surface area.

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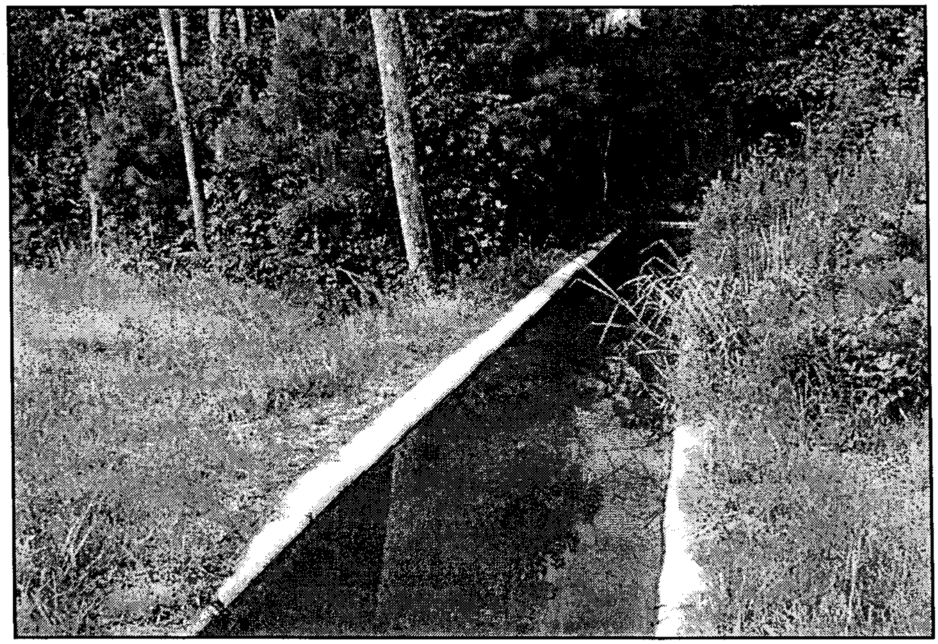
LEVEL SPREADER

CHAPTER 3 Level Spreader



OVERVIEW

A LEVEL SPREADER is a structural BMP that redistributes concentrated stormwater flow into diffuse flow.

PURPOSE AND DESCRIPTION

- A level spreader provides a nonerosive outlet for concentrated runoff by diffusing the water uniformly across a stable slope.
- A level spreader consists of a trough with a level nonerosive lip.

APPLICATIONS

- Level spreaders should be implemented only where uniform, diffuse flow can be achieved downgrade of the level spreader.
- Level spreaders are appropriate when concentrated runoff from a project area is conveyed by roadside ditches and/or storm pipes toward the buffer zone of a receiving water body.
- Level spreaders comply with NCDENR Riparian Buffer Protection Rules that restrict concentrated flow through buffer zones.
- Level spreaders are suitable for many highway applications, including interchanges, intersections, linear roadways, bridges, and facility areas.

WATER QUALITY BENEFITS

- Diffuse flow exiting a level spreader increases stormwater infiltration.
- Level spreaders mitigate downgrade erosion and ponding.
- Level spreaders reduce the water velocity, which allows larger particles to settle.

3.1 Description

The main components of a level spreader are the trough and the nonerosive lip. Runoff enters the trough of a level spreader via a conveyance system, such as a pipe or roadside ditch outlet, and exits the level spreader via the lip. The lip must be level to ensure uniform diffuse flow along the length of the level spreader as the water overflows the trough. The level spreader trough may be constructed using either concrete or vegetation.

The designer should consider reviewing soil survey maps before selecting a trough type.

An example of a level spreader and its components is shown in Figure 3-1.

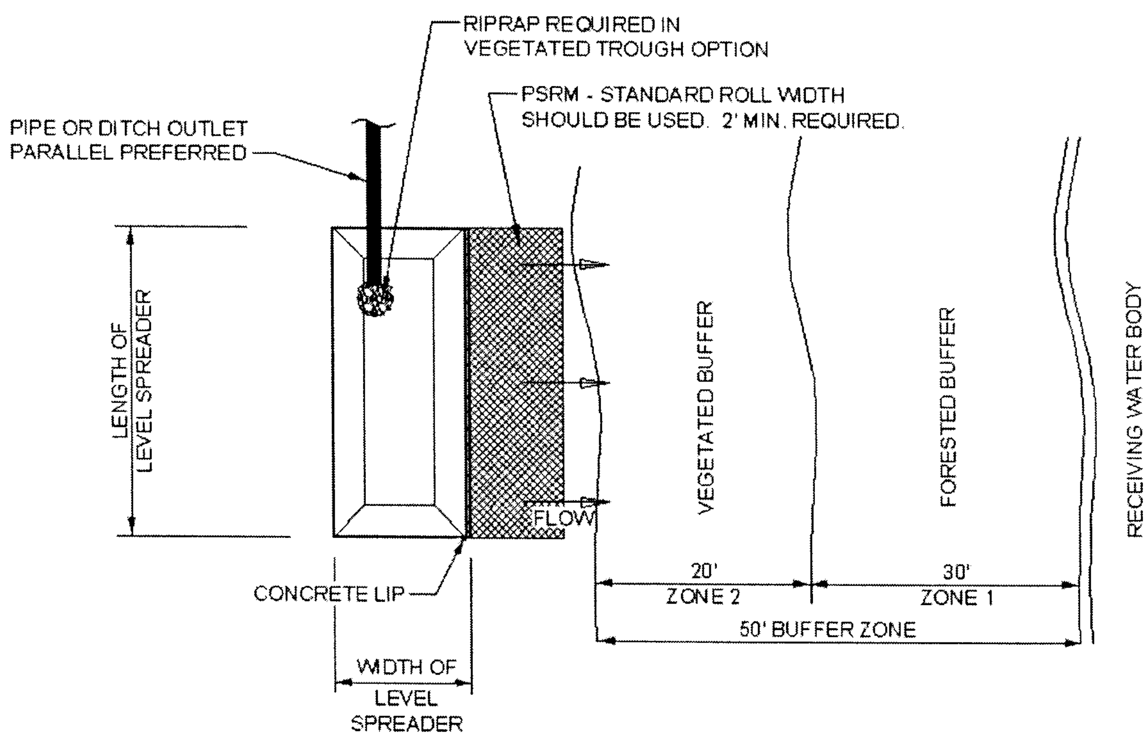


Figure 3-1. Typical level spreader layout and components

Concrete Trough

This level spreader type, illustrated in Figure 3-2, is constructed of concrete. Weep holes within level spreader troughs are optional at the discretion of the engineer. Weep holes are recommended where a water-filled trough is a safety concern, such as near parks where children play or in areas where mosquitoes breed. If weep holes are used to draw down water in the trough, they should discharge into a stone "dry cell." The dry cell should be wrapped in geotextile fabric and should run the entire length of the level spreader.

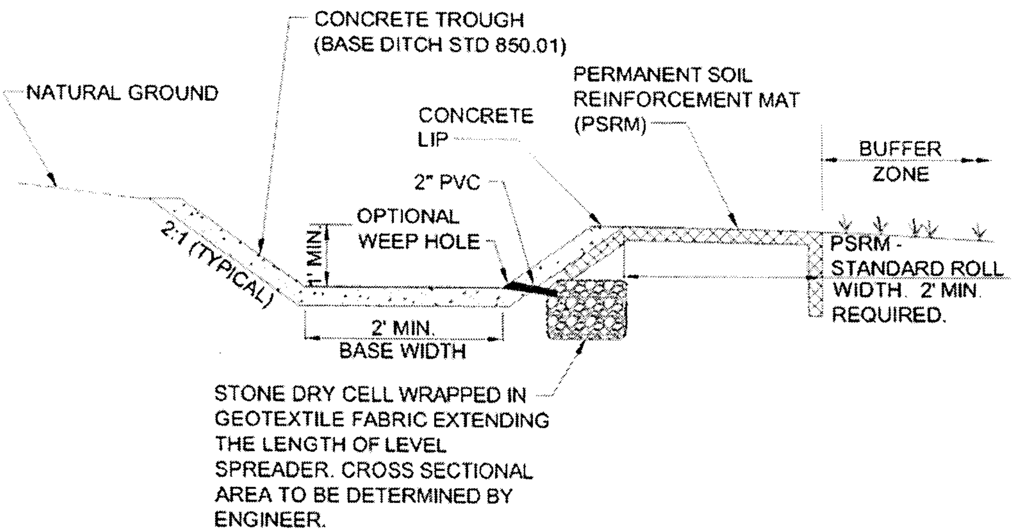


Figure 3-2. Level spreader with concrete trough

Vegetated Trough

Portions of the level spreader trough can be constructed using the existing vegetation cover or approved vegetation types. The vegetation should have a dense root mass and be easily maintained. Only the upstream slope and base of the trough should be constructed using the selected vegetation type. The lip of the level spreader must be made of concrete to prevent the lip from eroding. Figure 3-3 is an example of a level spreader with a vegetated trough.

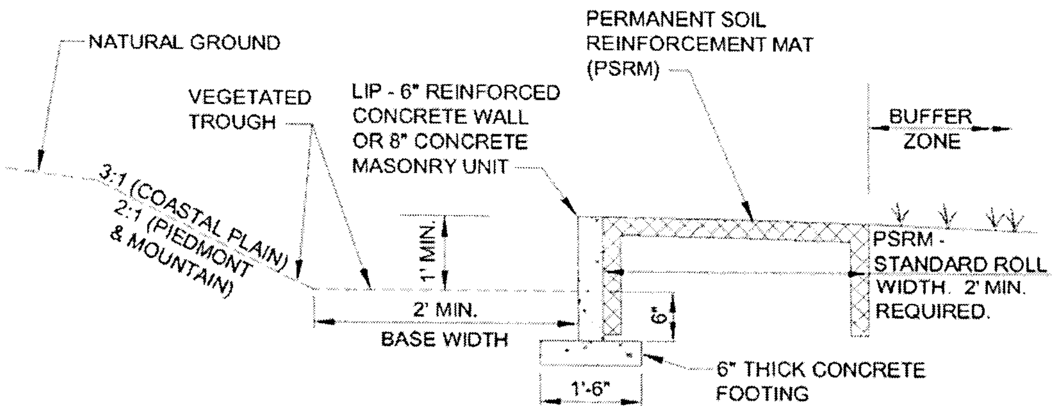


Figure 3-3. Level spreader with vegetated trough

3.2 Applications

The level spreader is applicable primarily when a concentrated flow is discharged upstream of a protected buffer. The release of concentrated flow in regulated buffer zones is restricted unless runoff is treated by acceptable practices. An example of a level spreader in a field setting is shown in Figure 3-4. Although level spreaders alone have been proven to provide stormwater treatment, they are often combined with existing buffers and/or other BMPs to enhance pollutant removal capabilities.

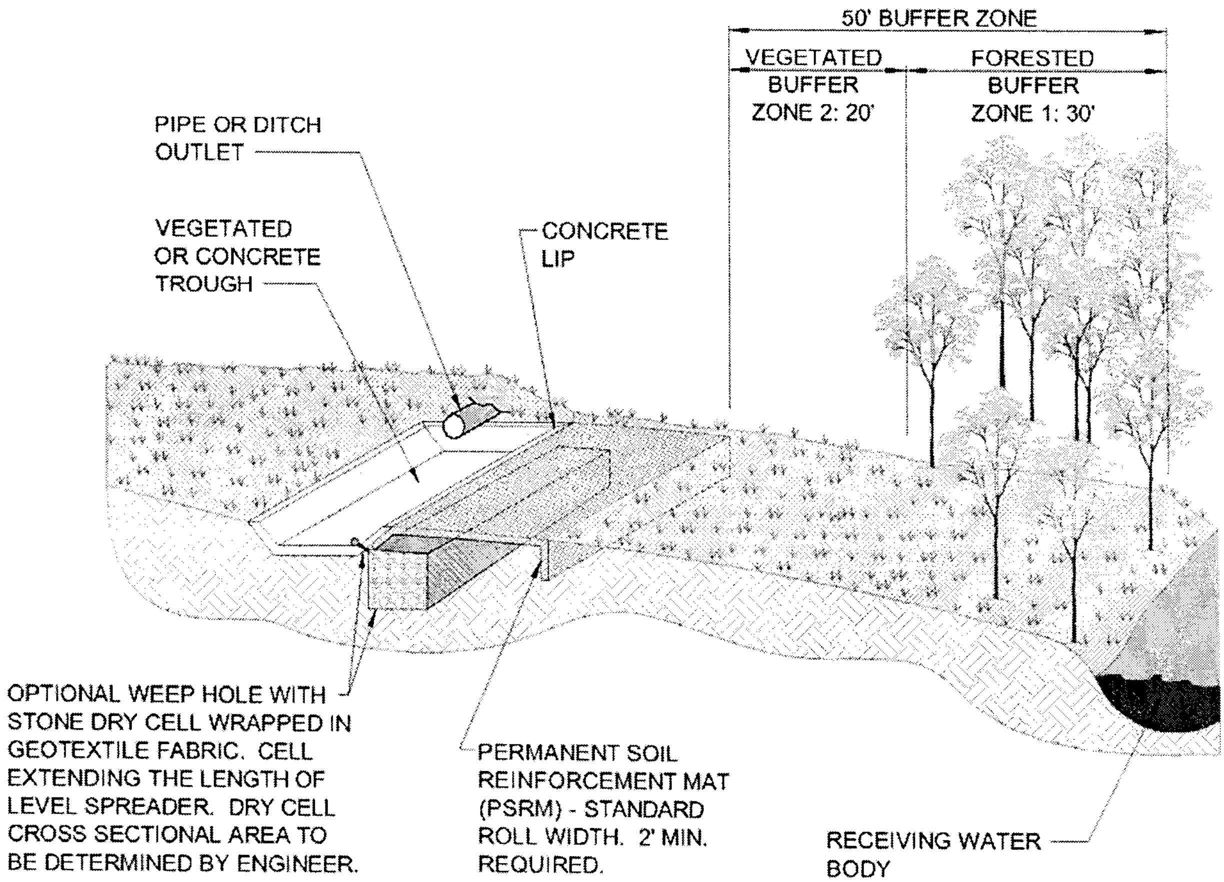


Figure 3-4. Typical level spreader with buffer

Level spreaders are commonly used on many highway facility types such as linear roadways, interchanges, intersections, bridges, and facility areas. The use of a level spreader may not be feasible in every linear highway application and will depend on site-specific constraints such as limited right-of-way or steep slopes.

3.3 Design

The entire level spreader system must pass a 10-year storm event without degrading the buffer or receiving stream. The designer must determine the contributing impervious drainage area and the Q_{10} discharge using the rational method. The rational method is described in more detail in Chapter 2.

When the Q_{10} is less than or equal to 10 cfs and the site is flat, a preformed scour hole may be a better treatment option than the level spreader to promote diffuse flow. Compared to level spreaders, preformed scour holes typically require a smaller construction area and are less expensive. Additional information on the design of this BMP can be found in Chapter 4.

Design criteria must consider watershed/contributing area, design storm event, and level spreader specifications. For a list of the required design criteria, see the Design Criteria Summary box.

DESIGN CRITERIA SUMMARY

- ❒ Contributing area to the outfall should be delineated to determine the water quality volume and Q_{10} discharge.
- ❒ The entire system must pass a 10-year storm event without degrading the buffer or receiving stream.
- ❒ Length of the level spreader should be a minimum of 10 feet and a maximum of 300 feet.
- ❒ Lip of the level spreader must be on a zero percent grade.
- ❒ The trough should have a minimum depth of 1 foot with a minimum base width of 2 feet.
- ❒ The trough should transition smoothly into the existing ground and have maximum side slopes of 2H:1V.
- ❒ Site selection will ensure that the hydraulic grade line does not propagate to the upstream drainage system or adjacent private properties.

The level spreader design flowchart provided in Figure 3.5 is intended to guide the designer to the most appropriate BMP option for a particular site. Although the flowchart is a support tool for determining the best design, the designer must still evaluate other design considerations addressed in this section.

CONVENTIONAL DESIGN OPTIONS

Conventional design options include a combination of the level spreader with existing buffer areas without the use of a bypass (Figure 3-6). The conventional design options must be capable of passing the entire Q_{10} discharge through the level spreader and buffer. Other design criteria are listed in the Conventional Design Options Summary.

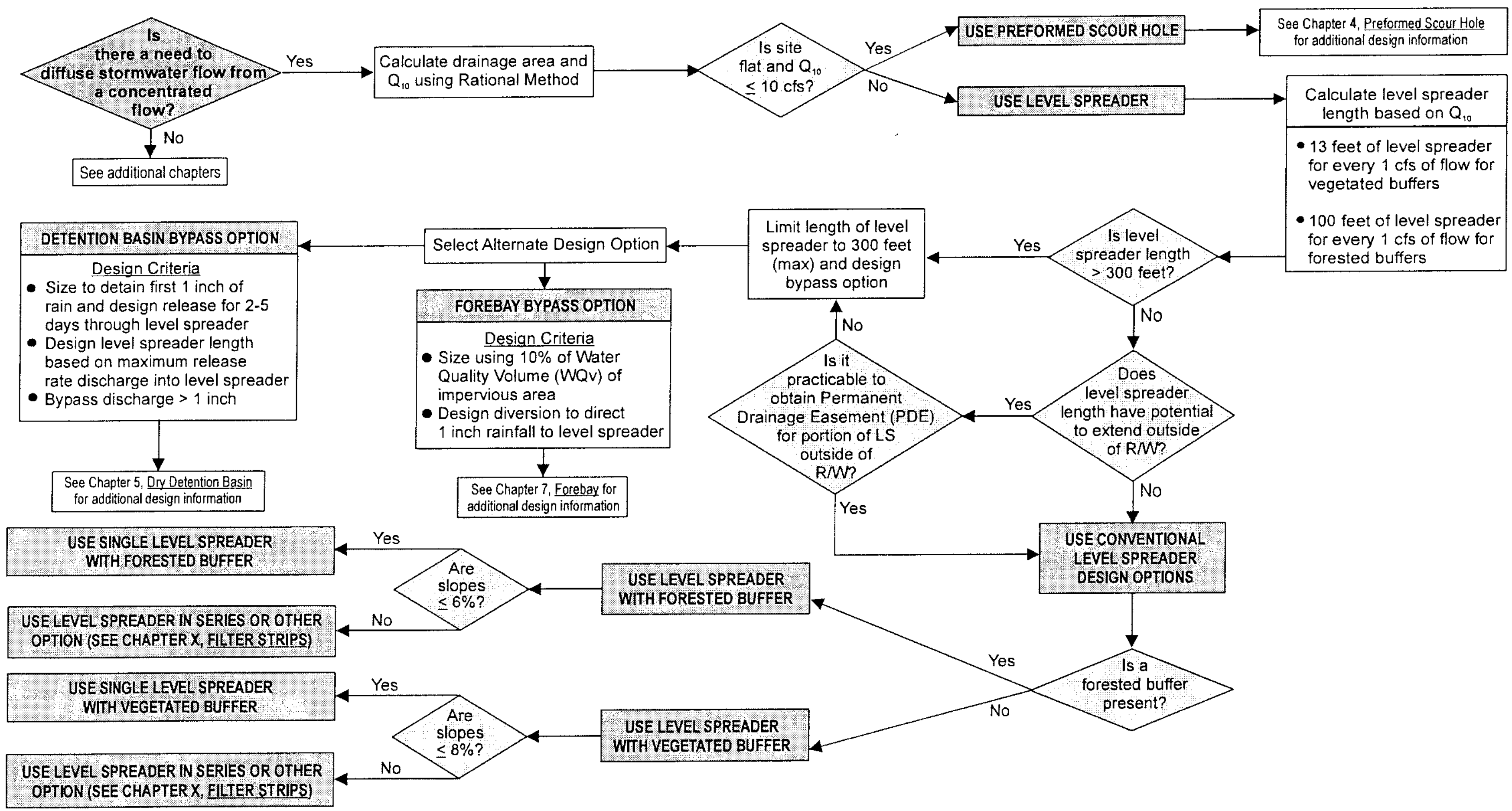


Figure 3-5. Level spreader design flowchart

Conventional Design Options Summary

Level Spreader with Vegetated Buffer

- Level spreader length is based on the Q_{10} discharge.
- 13 feet of level spreader is required for every 1 cfs.
- Level spreaders can be installed upstream of vegetated buffers where buffer slopes are 8% or less.

Level Spreader with Forested Buffer

- Level spreader length is based on the Q_{10} discharge.
- 100 feet of level spreader is required for every 1 cfs.
- Level spreaders can be installed upstream of forested buffers where buffer slopes are 6% or less.

Level Spreaders in Series

- Level spreader length is based on the Q_{10} discharge.
- Level spreaders in series can be used with vegetated buffers for buffer slopes between 8% and 25%.
- Level spreaders in series can be used with forested buffers for buffer slopes between 6% and 15%.
- Concrete level spreaders must be located outside of the buffer zones. Vegetated level spreaders with concrete lips are allowed in Zone 2.

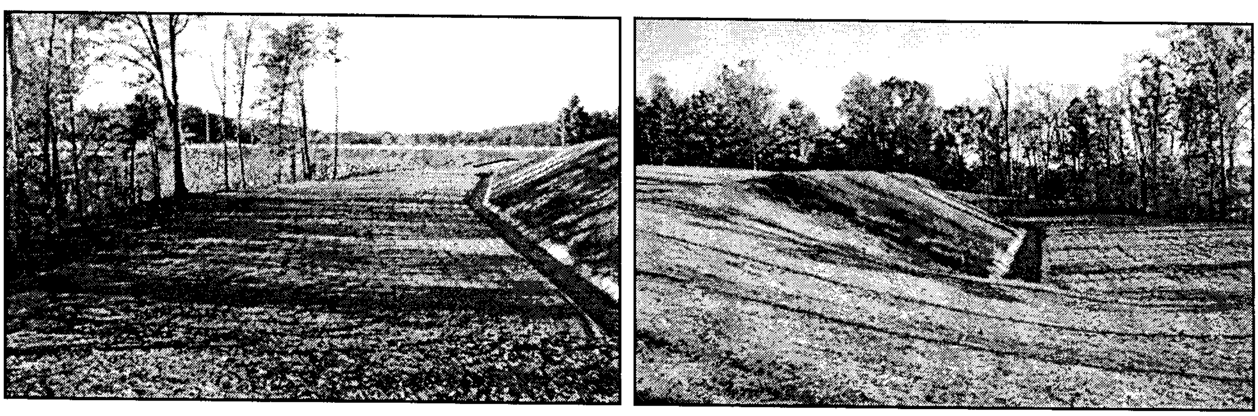


Figure 3-6. Level spreader with mixed vegetated and forested buffers

Alternative Design Options

Conventional designs may not be capable of passing the Q_{10} discharge because of topography, size and imperviousness of the drainage area, limited right-of-way, or other site constraints. To meet the Q_{10} requirement, it may be necessary to implement an alternative level spreader design with bypass. Alternative designs include pairing a dry detention basin or a forebay with a level spreader. In both treatment trains, discharge events greater than the 1-inch storm bypass the BMPs through a pipe, a riprap-lined ditch, or a grassed swale.

According to the NCDWQ Riparian Buffer Protection Rules, these alternative design options are "allowable" activities for some protected buffers, pending North Carolina Division of Water Quality (NCDWQ) approval. As the Rules vary by watershed, confirmation of allowable activities in the buffer zone should be made before the alternative design is selected.

Bypass combinations described in the following box are used most frequently; however, other bypass options may be more appropriate, depending on site-specific conditions.

Alternative Design Options Summary

Level Spreader with Dry Detention Basin and Bypass

- ❒ Level spreader length is based on the maximum discharge release rate.
- ❒ For forested buffer, 100 feet of level spreader is required for every 1 cfs.
- ❒ For vegetated buffer, 13 feet of level spreader is required for every 1 cfs.
- ❒ Dry detention basin is sized to detain the first inch of rain using the water quality volume method. The water is then released over 2–5 days through the level spreader.
- ❒ Discharges greater than the 1-inch storm bypass the BMP through an overflow weir.

Level Spreader with Forebay and Bypass

- ❒ Level spreader length is based on the 1-inch-per-hour-intensity storm.
- ❒ For forested areas, 100 feet of level spreader is required for every 1 cfs.
- ❒ For grass or thick ground cover, 13 feet of level spreader is required for every 1 cfs.
- ❒ Forebay size is calculated by taking 10% of the water quality volume (WQv) based on the impervious area.
- ❒ Diversion pipe is sized to route the 1-inch-per-hour-intensity storm to the level spreader.
- ❒ Discharges greater than the 1-inch storm bypass the BMP through a conveyance system.

Level Spreader with Dry Detention Basin

A dry detention basin, when combined with a level spreader, should be sized to detain a 1-inch rain event and release the stormwater over 2–5 days through a level spreader. The basin should include an overflow device that allows the system to bypass storms greater than 1 inch. An overflow weir and channel are examples of bypass conveyance systems. Further information on dry detention basins can be found in Chapter 5.

Level Spreader with Forebay

Using a level spreader with a forebay is an option that is suitable for relatively small, impervious drainage areas, usually less than 5 acres. Typical sizing of the basin is calculated by taking 10 percent of the water quality volume (WQv) based on the impervious area. The WQv Method is discussed in Chapter 2. Additional information on forebay design is provided in Chapter 7.

In most designs, the forebay receives the point discharge directly and collects sediment. It is optional, however, for a diversion to be placed within or prior to the forebay. The diversion pipe directs the 1-inch storm to the level spreader. Discharges greater than the 1-inch storm are bypassed through a designed conveyance channel or pipe.

Design and Construction Considerations

The design of the level spreader must take into account the topography of the site. The designer must locate the level spreader so that ground contours are parallel to the lip, and the downgrade slope to the stream is smooth. The smooth transition from the level spreader to the stream will prevent diffuse flow from rechannelizing as stormwater makes its way through the buffer. If diffuse flow is not attainable based on site conditions, then a level spreader should not be used.

Additional design recommendations follow:

- Use proper energy dissipation (i.e., concrete trough or riprap) where perpendicular or angular inflows to the level spreader are necessary.
- Design the BMP to include components (i.e., berms, bypass systems) that prevent off-site flows from entering the BMP.
- Design the transition between the level spreader and other BMPs or buffers to avoid erosion once installation is complete.
- Place the level spreader outside of Zone 2.
- Ensure that the location of the BMP is outside of roadway clear recovery zones.
- Ensure safe ingress and egress of the level spreader for inspection and maintenance.
- Check the available right-of-way when determining the BMP footprint.
- Construct the level spreader on undisturbed soil.
- Install the level spreader and lip at zero percent grade.
- Determine whether weep holes are necessary.
- Position level spreader lip parallel to inflow device (perpendicular to direction of diffuse flow) if possible.

- Verify existing soil types using either soil survey maps or existing geotechnical reports when determining whether to use a vegetated trough.
- Include permanent soil reinforced mats (PSRMs) at the transition between the trough lip and buffers to prevent erosion at the interface.

3.4 Inspection and Maintenance

Periodic cleaning is required as a part of routine maintenance to prevent clogging of weep holes and to ensure the overall performance of the BMP. General inspection and maintenance recommendations are as follows:

- Inspection of level spreaders should be performed by experienced personnel.
- Until vegetation is established, the level spreader should be inspected frequently and after major rain events.
- Once vegetation is established, the level spreader should be inspected periodically.

3.5 Safety Considerations

Any BMP that has the potential for standing water presents a drowning hazard. Consider fencing the area to ensure safety. See NCDOT Specification 866 for fencing options.

POROUS PAVEMENT/PERVIOUS PAVING/PERVIOUS PAVER

Porous Pavement

Click here to comment on this fact sheet

Minimum Measure: Post-Construction Stormwater Management in New Development and Redevelopment

Subcategory: Infiltration

Description


A porous pavement parking lot (Source: Invisible Structures, no date)

Porous pavement is a permeable pavement surface, often built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil. Porous pavement replaces traditional pavement, allowing parking lot stormwater to infiltrate directly and receive water quality treatment. There are various types of porous surfaces, including porous asphalt, pervious concrete, and even grass or permeable pavers. From the surface, porous asphalt and pervious concrete appear to be the same as traditional pavement. However, unlike traditional pavement, porous pavement contains little or no "fine" materials. Instead, it contains voids that encourage infiltration. Porous asphalt pavement consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to make it highly permeable to water. Pervious concrete typically consists of specially formulated mixtures of Portland cement, uniform, open-graded coarse aggregate, and water. Pervious concrete has enough void space to allow rapid percolation of liquids through the pavement. Grass or permeable pavers are interlocking concrete blocks or synthetic fibrous grids with open areas that allow grass to grow within the voids. Some grid systems fill the voids with sand or gravel to allow infiltration (see Alternative Pavers fact sheet). Other alternative paving surfaces can help reduce runoff from paved areas, but do not incorporate a stone trench for temporary storage below the pavement (see Green Parking fact sheet). While porous pavement can be a highly effective treatment practice, maintenance and proper installation are necessary to ensure its long-term effectiveness.

Like all BMPs, porous pavement should be combined with other practices to capitalize on each technology's benefits and to allow protection in case of BMP failure. However, construction using pervious materials may not require as much treatment as other BMP approaches. For instance, a small facility using porous pavement may only need several bioretention basins or a grass swale, rather than a full dry detention basin. This combined approach might prove less land intensive and more cost effective. It may increase the amount of open space for public or tenant use. It may also lead to an increase in environmental benefits.

Application

Medium traffic areas are the ideal application for porous pavement. It may also have some application on highways, where it is currently used to reduce hydroplaning. In some areas, such as truck loading docks and areas of high commercial traffic, porous pavement may be inappropriate.

Regional Applicability

Porous pavement is suitable for most regions of the country, but cold climates present special challenges. Road salt contains chlorides that may migrate through the porous pavement into ground water. Plowing may present a challenge to block pavers, because snow plow blades can catch the block's edge and damage its surface. Infiltrating runoff may freeze below the pavement causing frost heave, though design modifications can reduce this risk. These potential problems do not mean that porous pavement cannot be used in cold climates. Porous pavement designed to reduce frost heave has been used successfully in Norway (Stenmark, 1995). Furthermore, experience suggests that rapid drainage below porous surfaces increases the rate of snow melt above (Cahill Associates, 1993).

Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff. Hot spot runoff frequently contains pollutant concentrations exceeding those typically found in stormwater. Hot spots include commercial nurseries, auto recycle facilities, fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading and unloading facilities, public works storage areas, hazardous materials generators (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing and steam cleaning facilities. Since porous pavement is an infiltration practice, it should not be applied at stormwater hot spots due to the potential for ground water contamination.

Stormwater Retrofit

A stormwater retrofit is a stormwater management practice (usually structural) installed post development to improve water quality, protect downstream channels, reduce flooding, or to meet other specific objectives. The best retrofit application for porous pavement is parking lot replacement on individual sites. If many impervious lots are replaced with pervious concrete, pavers, or porous asphalt, then overall stormwater peak flows can be reduced.

Cold Water (Trout) Streams

Porous pavement can help lower high water temperatures commonly associated with impervious surfaces. Stormwater pools on the surface of conventional pavement, where it is heated by the sun and the hot pavement surface. By rapidly infiltrating rainfall, porous pavement reduces stormwater's exposure to sun and heat.

Siting and Design Considerations

Siting Considerations

Porous pavement has the same siting considerations as other infiltration practices (see Infiltration Trench fact sheet). The site needs to meet the following criteria:

- Soils need to have a permeability of at least 0.5 inches per hour. An acceptable alternative design for soils with low porosity would be the installation of a discharge pipe from a storage area to the traditional storm sewer system (with approval from the municipality). The modified design allows the treatment of stormwater from small to medium stormwater events while allowing a bypass for large events, which will help prevent flooding.
- The bottom of the stone reservoir should be flat, so that runoff can infiltrate through the entire surface.
- If porous pavement is used near an industrial site or similar area, the pavement should be sited at least 2 to 5 feet above the seasonally high ground water table and at least 100 feet away from drinking water wells.
- Porous pavement should be sited on low to medium traffic areas, such as residential roads and parking lots.

Design Considerations

Some basic features should be incorporated into all porous pavement practices. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

1. *Pretreatment.* In porous pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Because of this, frequent maintenance of the surface, such as sweeping, is critical to prevent clogging. A layer of fine gravel can be laid atop the coarse gravel treatment reservoir as an additional pretreatment item. Both of these pretreatment measures are marginal.

2. *Treatment.* If used, the stone reservoir below the pavement surface should be composed of layers of small stone laid directly below the pavement surface. The stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, porous pavement is sized to treat a small event, such as a water quality storm (i.e., the storm that will be treated for pollutant removal), which can range from 0.5 to 1.5 inches. As in infiltration trenches, water can be stored in the voids of the stone reservoir. With certain designs in warm weather climates, the pavement can also store stormwater if it is properly maintained.

3. *Conveyance.* Water conveyed to the stone reservoir though the pavement surface infiltrates into the ground below. A geosynthetic liner and a sand layer may be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs also need a means to convey larger amounts of stormwater to the storm drain system. Storm drain inlets set slightly above the pavement surface is one option. This allows for some ponding above the surface, but bypasses flows too large to be treated by the system or when the surface clogs.

4. *Maintenance Reduction.* One nonstructural component that can help ensure proper maintenance of porous pavement is a carefully worded maintenance agreement providing specific guidance, including how to conduct routine maintenance and how the surface should be repaved. Ideally, signs should be posted on the site identifying porous pavement areas.

   One design option incorporates an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the pavement surface. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, stormwater will flow over the surface and into the trench where some infiltration and treatment will occur.

5. *Landscaping.* For porous pavement, the most important landscaping feature is a fully stabilized upland drainage. Reducing sediment loads entering the pavement can help to prevent clogging.

Design Variations

In one design variation, the stone reservoir below the filter can also treat runoff from other sources, such as rooftop runoff. In this design, pipes are connected to the stone reservoir to direct flow throughout the bottom of the storage reservoir (Cahill Associates, 1993; Schueler, 1987). However, treating stormwater from other areas with porous pavement can cause failures, as it is more likely to carry clogging sediments. If used to treat off-site runoff, porous pavement should incorporate pretreatment, as with all structural management practices. Off site runoff should never come from areas that carry high sediment loadings.

Regional Adaptations

In cold climates, the base of the stone reservoir should be below the frost line or other accommodations should be designed to facilitate the drainage of stormwater away from the aggregate recharge bed. Such modification will help reduce the risk of frost heave.

Limitations

In addition to the siting requirements of porous pavement, a major limitation to the practice is the poor success rate it has experienced in the field. Several studies indicate that with proper maintenance porous pavement can retain its permeability (e.g., Goforth et al., 1983; Gburek and Urban, 1980; Hossain and Scofield, 1991). Dated studies indicate that when porous pavement was implemented in communities, the failure rate was as high as 75 percent over 2 years (Galli, 1992). Newer studies, particularly with permeable pavers and pervious concete, indicate that success rates can be substantially higher when the paving medium is properly installed (Brattebo and Booth, 2003).

Maintenance Considerations

Owners should be aware of a site's porous pavement because failure to perform maintenance is a primary reason for failure of this practice. Furthermore, using knowledgeable contractors skilled in techniques required for installation of pervious concrete, permeable pavers, or porous asphalt will increase performance and longetivy of the system. Typical requirements are shown in Table 1.

Table 1. Typical maintenance activities for porous pavement (Source: WMI, 1997)

Activity	Schedule
• Do not seal or repave with non-porous materials.	N/A
• Ensure that paving area is clean of debris. • Ensure that paving dewaters between storms. • Ensure that the area is clean of sediments.	Monthly
• Mow upland and adjacent areas, and seed bare areas. • Vacuum sweep frequently to keep the surface free of sediment.	As needed (typically three to four times per year).
• Inspect the surface for deterioration.	Annual

Effectiveness

Porous pavement can be used to provide ground water recharge and to reduce pollutants in stormwater runoff. Some data suggest that as much as 70 to 80 percent of annual rainfall will go toward ground water recharge (Gburek and Urban, 1980). These data will vary depending on design characteristics and underlying soils. Two studies have been conducted on the long-term pollutant removal of porous pavement, both in the Washington, DC area. They suggest high pollutant removal, although it is difficult to extrapolate these results to all applications of the practice. The results of the studies are presented in Table 2.

Table 2. Effectiveness of porous pavement pollutant removal (Schueler, 1987)

	Pollutant Removal (%)				
Study	**TSS**	**TP**	**TN**	**COD**	**Metals**
Prince William, VA	82	65	80	-	-
Rockville, MD	95	65	85	82	98-99

A third study by Brattebo and Booth (2003) indicates that many trademarked permeable paver systems effectively reduced concentrations of motor oil, copper, and zinc. Furthermore, the study found that almost all precipitation that fell on the permeable pavers infiltrated even after 6 years of daily use as a parking area.

Cost Considerations

Porous pavement is more expensive than traditional asphalt. While traditional asphalt and concrete costs between \$0.50 to \$3.00 per ft^2, porous pavement can range from \$2 to \$8 per ft^2, depending on the design. However, porous pavement, when used in combination with other techniques such as bioretention cells, vegetated swales, or vegetated filter strips, may eliminate or reduce the need for land intensive BMPs, such as dry extended detention or wet retention ponds. In areas where land prices are high, the savings associated with decreased land consumption should be considered. The cost of vacuum sweeping may be substantial if a community does not already perform vacuum sweeping operations. Finally, if not designed and maintained properly, porous pavment's effective lifespan may be short because of the potentially high risks of clogging.

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OIL/WATER SEPARATOR

Oil/Water Separators

Courtesy of the Environmental Protection Agency

DESCRIPTION

Oil/water separators (O/WSs) are devices used to remove oils and greases (and sometimes solids) from storm water. A variety of methods to separate oil from water are involved, including gravity separation, filters, coagulation/flocculation, and flotation. Gravity separation is not always the most successful at oil removal to meet regulatory discharge requirements. In these cases, **coalescing oil/water separators**, which are essentially enhanced gravity-type O/WSs, are needed to achieve greater separation efficiency.

[1] Minton, Gary. "Gravity Separation." Stormwater Treatment. P. 199-120. 2002

APPLICABILITY

The primary use of oil/water separators is where oil spills are a concern. Their inclusion in these guidelines is merely to provide a wide range of possible stormwater BMP choices. If an oil/water separator is to be used for treatment it should be located off-line from the primary conveyance/detention system. The contributing drainage area should be completely impervious and as small as necessary to contain the sources of oil. Under no circumstances should any portion of the contributing drainage area contain disturbed pervious areas which can be sources of sediment.

LIMITATIONS

Oil/Water Separators have limited application in stormwater treatment because their treatment mechanisms are not well suited to the characteristics of stormwater runoff (i.e., highly variable flow with high discharge rates, turbulent flow regime, low oil concentration, high suspended solids concentration). In addition, separators can require intensive maintenance, further restricting their desirability as a stormwater treatment BMP.

SITING & DESIGN

While the use of oil/water separators may be appropriate for high traffic areas or areas where oil is more prevalent (parking lots, gas stations, etc.), the decision to use an oil/ water separator should be made on a case-by-case basis.

1. Separators should precede all other stormwater treatment.
2. They should be provided with adequate access for observation and maintenance.
3. Stormwater from building rooftops and other impervious surfaces are not likely to be contaminated by oil and should not be discharged to the separator.
4. Any pump mechanism should be installed downstream of the separator to prevent oil emulsification.

Absorbent pillows may be used in separators. For API and CPS-type separators should be placed in an afterbay. With the SC-separator, absorbent materials should be placed in the manhole/vault. Used absorbent pillows will need to be properly disposed of.

Sizing Procedure

Stokes Law is a basis for sizing oil/water separators. According to Gary Minton's book on Stormwater Treatment, "as the specific gravity is less than one, the settling velocity is negative and is therefore referred to as the rise rate. The rise rate is analogous to the hydraulic loading rate. To size an oil/water separator, the droplet size is selected such that removing it and all larger droplets provides the desired removal efficiency." Oil droplets exist in water in a wide distribution of sizes. The separator therefore is sized to remove all droplets of particular size and greater which will ensure that sufficient oil is removed to achieve the effluent standard. The temperature of water and the specific gravity impact the sizing as well.[1]

There are no data on the size distribution of dispersed oil in stormwater from commercial or industrial land uses with the exception of petroleum projects storage terminals. This data indicates that by volume, about 80 percent of the droplets are greater than 90 micron and less than 30 percent are greater than 150 microns.

[1] Minton, Gary. "Gravity Separation." Stormwater Treatment. P. 120. 2002

MAINTENANCE

Oil/water separators must be cleaned frequently to keep accumulated oil from escaping during storms. As a rule of thumb, the following should be done. Be aware that climate conditions, such as dry/wet seasons, will affect the maintenance procedures.

1. The facility should be inspected weekly by the owner.
2. Oil absorbent pads are to be replaced as needed but should always be replaced in the fall prior to the wet season and in the spring.
3. The effluent shutoff valve is to be closed during cleaning operations.
4. Waste oil and residuals should be disposed in accordance with current local government health department requirements.
5. Any standing water removed during the maintenance operation must be disposed to a sanitary sewer at a discharge location approved by the local government.
6. Any standing water removed should be replaced with clean water to prevent oil carry-over through the outlet weir or orifice.

COST

Oil/water separators range in price varies according to the flow rate and level of treatment required, in addition to the climate and regional requirements. Costs may range from $4,000 to $20,000. Oil/coalescing vaults range from $5,000 to $50,000. Additional costs are required to maintain, especially replacing the media packs inside the units. Media pack costs depend on the frequency of maintenance and the type of media used.

- Courtesy of Vortechnics, Inc.

STORM WATER WETLAND / CONSTRUCTED WETLAND

U.S. Environmental Protection Agency

National Pollutant Discharge Elimination System (NPDES)

Stormwater Wetland

Click here to comment on this fact sheet

Minimum Measure: Post-Construction Stormwater Management in New Development and Redevelopment

Subcategory: Retention/Detention

Description

A stormwater wetland detains stormwater, removes pollutants, and provides habitat and aesthetic benefits (Source: The Bioengineering Group, Inc., no date)

Stormwater wetlands (a.k.a. constructed wetlands) are structural practices similar to wet ponds (see Wet Ponds fact sheet) that incorporate wetland plants into the design. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the practice. Wetlands are among the most effective stormwater practices in terms of pollutant removal and they also offer aesthetic and habitat value. Although natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life. Several design variations of the stormwater wetland exist, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland.

A distinction should be made between using a constructed wetland for stormwater management and diverting stormwater into a natural wetland. The latter practice is not recommended because altering the hydrology of the existing wetland with additional stormwater can degrade the resource and result in plant die-off and the destruction of wildlife habitat. In all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased stormwater runoff. This is especially important because natural wetlands provide stormwater and flood control benefits on a regional scale.

Applicability

Constructed wetlands are widely applicable stormwater management practices. While they have limited applicability in highly urbanized settings and in arid climates, wetlands have few other restrictions.

Regional Applicability

Stormwater wetlands can be applied in most regions of the United States, with the exception of arid climates. In arid and semi-arid climates, it is difficult to design any stormwater practice that has a permanent pool. Because stormwater wetlands are shallow, a large portion is subject to evaporation relative to the volume of the practice. This makes maintaining the permanent pool in wetlands more challenging and important than maintaining the pool of a wet pond (see Wet Ponds fact sheet).

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use stormwater wetlands in the ultra-urban environment because of the land area each wetland consumes. They can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site.

Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station. Wetlands can accept runoff from stormwater hot spots, but need significant separation from ground water if they will be used for this purpose. Caution also needs to be exercised, if these practices are designed to encourage wildlife use, to ensure that pollutants in stormwater runoff do not work their way through the food chain of organisms living in or near the wetland.

Stormwater Retrofit

A stormwater retrofit is a stormwater management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. When retrofitting an entire watershed, stormwater wetlands have the advantage of providing both educational and habitat value. One disadvantage to wetlands is the difficulty of storing large amounts of runoff without consuming a large amount of land. It is also possible to incorporate wetland elements into existing practices, such as wetland plantings (see Wet Ponds and Dry Detention Ponds fact sheets).

Cold Water (Trout) Streams

Wetlands could pose a risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince George's County, Maryland, investigated the thermal impacts of a wide range of stormwater management practices (Galli, 1990). In this study, only one wetland was investigated, which was an extended detention wetland (see Design Variations). The practice increased the average temperature of stormwater runoff that flowed through the practice by about 3°F. As a result, wetlands can release water that is warmer than stream temperatures.

Siting and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Siting Considerations

In addition to the restrictions and modifications to adapting stormwater wetlands to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting wetlands.

Drainage Area

Wetlands need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall.

Slope

Wetlands can be used on sites with an upstream slope of up to about 15 percent. The local slope should be relatively shallow, however. While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 3 to 5 feet).

Soils/Topography

Wetlands can be used in almost all soils and geology, with minor design adjustments for regions of karst (i.e. limestone) topography (see Design Considerations).

Ground Water

Unless they receive hot spot runoff, wetlands can often intersect the ground water table. Some research suggests that pollutant removal is reduced when ground water contributes substantially to the pool volume (Schueler, 1997b). It is assumed that wetlands would have a similar response.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wetland designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In wetlands, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10 percent of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. The purpose of most of these features is to decrease the rate of stormwater movement through the wetland. Some typical design features include

- The surface area of wetlands should be at least 1 percent of the drainage area to the practice.
- Wetlands should have a length-to-width ratio of at least 1.5:1. Making the wetland longer than it is wide helps prevent "short circuiting" of the practice.
- Effective wetland design displays "complex microtopography." In other words, wetlands should include zones of both very shallow (<6 inches) and moderately shallow (<18 inches) water, using underwater earth berms to create the zones. This design will provide a longer flow path through the wetland to encourage settling, and it provides two depth zones to encourage plant diversity.

Conveyance

Conveyance of stormwater runoff into and through a stormwater management practice is a critical component of any practice. Stormwater should be conveyed to and from practices safely and to minimize erosion potential. The outfall of wetlands should always be stabilized to prevent scour. In addition, dependent upon local conditions, an emergency spillway might need to be provided to safely convey large flood events. To help mitigate warming at the outlet channel, designers should provide shade around the channel at the wetland outlet.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of stormwater practices, some design features can be incorporated to ease the maintenance burden of each practice. In wetlands, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wetlands is clogging of the outlet. Wetlands should be designed with a nonclogging outlet such as a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3 inches in diameter. Smaller orifices are generally more susceptible to clogging, without specific design considerations to reduce this problem. Another feature that can help reduce the potential for clogging of the outlet is to incorporate a small pool, or "micropool" at the outlet.

Design features are also incorporated to ease maintenance of both the forebay and the main pool of wetlands. Wetlands should be designed with a maintenance access to the forebay to ease this relatively routine (5- to 7-year) maintenance activity. In addition, the permanent pool should have a drain to draw down the water for the more infrequent dredging of the main cell of the wetland.

Landscaping

Landscaping of wetlands can make them an asset to a community and can also enhance the pollutant removal of the practice. In wetland systems, landscaping is an integral part of the design. To ensure the establishment and survival of wetland plants, a landscaping plan should provide detailed information about the plants selected, when they will be planted, and a strategy for maintaining them. The plan should detail wetland plants, as well as vegetation to be established adjacent to the wetland. Native plants should be used if possible.

A variety of techniques can be used to establish wetland plants. The most effective techniques are the use of nursery stock as dormant rhizomes, live potted plants, and bare rootstock. A "wetland mulch," soil from a natural wetland or a designed "wetland mix," can be used to supplement wetland plantings or alone to establish wetland vegetation. Wetland mulch carries with it the seed bank from the original wetland, and can help to enhance diversity in the wetland. The least expensive option to establish wetlands is to allow the wetland to colonize itself. One disadvantage to this last technique is that invasive species such as cattails or Phragmites (common reed) may dominate the wetland.

When developing a plan for wetland planting, care needs to be taken to ensure that plants are established in the proper depth and within the planting season. This season varies regionally, and is generally between 2 and 3 months long in the spring to early summer. Plant lists are available for various regions of the United States through wetland nurseries, extension services, and conservation districts.

Design Variations

There are several variations of the wetland design. The designs are characterized by the volume of the wetland in deep pool, high marsh, and low marsh, and whether the design allows for detention of small storms above the wetland surface. Other design variations help to make wetland designs practical in cold climates.

Shallow Marsh

In the shallow marsh design, most of the wetland volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland and the micropool at the outlet. One disadvantage to this design is that, since the pool is very shallow, a large amount of land is typically needed to store the water quality volume (i.e., the volume of runoff to be treated in the wetland).

Extended Detention Wetland

This design is the same as the shallow marsh, with additional storage above the surface of the marsh. Stormwater is temporarily ponded above the surface in the extended detention zone for between 12 and 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate wet and dry periods should be specified in the extended detention zone.

Pond/Wetland System

The pond/wetland system combines the wet pond (see Wet Ponds fact sheet) design with a shallow marsh. Stormwater runoff flows through the wet pond and into the shallow marsh. Like the extended detention wetland, this design requires less surface area than the shallow marsh because some of the volume of the practice is in the relatively deep (i.e., 6-8 feet) pond.

Pocket Wetland

This design is very similar to the pocket pond (see Wet Ponds fact sheet). In this design, the bottom of the wetland intersects the ground water, which helps to maintain the permanent pool. Some evidence suggests that ground water flows may reduce the overall effectiveness of stormwater management practices (Schueler, 1997b). This option may be used when there is not significant drainage area to maintain a permanent pool.

Gravel-Based Wetlands

In this design, runoff flows through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the rocks and pollutant uptake by the plants. This practice is fundamentally different from other wetland designs because, while most wetland designs behave like wet ponds with differences in grading and landscaping, gravel-based wetlands are more similar to filtering systems.

Regional Variations

Cold Climates

Cold climates present many challenges to designers of wetlands. During the spring snowmelt, a large volume of water runs off in a short time, carrying a relatively high pollutant load. In addition, cold winter temperatures may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting, as well as sediment loads from road sanding, may impact wetland vegetation.

One of the greatest challenges of stormwater wetlands, particularly shallow marshes, is that much of the practice is very shallow. Therefore, much of the volume in the wetland can be lost as the surface of the practice freezes. One study found that the performance of a wetland system was diminished during the spring snowmelt because the outlet and surface of the wetland had frozen. Sediment and pollutants in snowmelt and rainfall events "skated" over the surface of the wetland, depositing at the outlet of the wetland. When the ice melted, this sediment was washed away by storm events (Oberts, 1994). Several design features can help minimize this problem, including:

- "On-line" designs allowing flow to move continuously can help prevent outlets from freezing.
- Wetlands should be designed with multiple cells, with a berm or weir separating each cell. This modification will help to retain storage for treatment above the ice layer during the winter season.
- Outlets that are resistant to freezing should be used. Some examples include weirs or pipes with large diameters.

The salt and sand used to remove ice from roads and parking lots may also create a challenge to designing wetlands in cold climates. When wetlands drain highway runoff, or parking lots, salt-tolerant vegetation, such as pickle weed or cord grass should be used. (Contact a local nursery or extension agency for more information in your region). In addition, designers should consider using a large forebay to capture the sediment from road sanding.

Karst Topography

In karst (i.e., limestone) topography, wetlands should be designed with an impermeable liner to prevent ground water contamination or sinkhole formation, and to help maintain the permanent pool.

Limitations

Some features of stormwater wetlands that may make the design challenging include the following:

- Each wetland consumes a relatively large amount of space, making it an impractical option on some sites.
- Improperly designed wetlands might become a breeding area for mosquitoes if improperly designed.
- Wetlands require careful design and planning to ensure that wetland plants are sustained after the practice is in place.
- It is possible that stormwater wetlands may release nutrients during the nongrowing season.
- Designers need to ensure that wetlands do not negatively impact natural wetlands or forest during the design phase.

Maintenance Considerations

In addition to incorporating features into the wetland design to minimize maintenance, some regular maintenance and inspection practices are needed. Table 1 outlines these practices.

Table 1. Regular maintenance activities for wetlands (Source: Adapted from WMI, 1997, and CWP, 1998)

Activity	Schedule
• Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	One-time
• Inspect for invasive vegetation and remove where possible.	Semi-annual inspection
• Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and are operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Frequent (3-4 times/year) maintenance
• Supplement wetland plants if a significant portion have not established (at least 50% of the surface area). • Harvest wetland plants that have been "choked out" by sediment build-up.	Annual maintenance (if needed)
• Remove sediment from the forebay.	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	20- to 50-year maintenance

Effectiveness

Structural stormwater management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Wetlands can provide flood control, channel protection, and pollutant removal.

Flood Control

One objective of stormwater management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wetlands can easily be designed for flood control by providing flood storage above the level of the permanent pool.

Channel Protection

When used for channel protection, wetlands have traditionally controlled the 2-year storm. It appears that this control has been relatively ineffective, and research suggests that control of a smaller storm may be more appropriate (MacRae, 1996).

Ground Water Recharge

Wetlands cannot provide ground water recharge. The build-up of debris at the bottom of the wetland prevents the movement of water into the subsoil.

Pollutant Removal

Wetlands are among the most effective stormwater management practices at removing stormwater pollutants. A wide range of research is available to estimate the effectiveness of wetlands. Wetlands have high pollutant removal rates, and are articularly effective at removing nitrate and bacteria. Table 2 provides pollutant removal data derived from the Center for Watershed Protections's National Pollutant Removal Database for Stormwater Treatment Practices (Winer, 2000).

Table 2. Typical Pollutant Removal Rates of Wetlands (%) (Winer, 2000)

Pollutant	**Stormwater Treatment Practice Design Variation**			
	Shallow Marsh	ED Wetland[1]	Pond/Wetland System	Submerged Gravel Wetland[1]
TSS	83±51	69	71±35	83
TP	43±40	39	56±35	64
TN	26±49	56	19±29	19
NOx	73±49	35	40±68	81
Metals	36-85	(80)-63	0-57	21-83
Bacteria	76[1]	NA	NA	78

[1]Data based on fewer than five data points

The effectiveness of wetlands varies considerably, but many believe that proper design and maintenance help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wetlands. A joint project of the American Society of Civil Engineers (ASCE) and the U.S. EPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of stormwater practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. More information on this database is available on the BMP database EXIT Disclaimer .

Cost Considerations

Wetlands are relatively inexpensive stormwater practices. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25 percent more expensive than stormwater ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of wet ponds can be modified to estimate the cost of stormwater wetlands using the equation:

$$C = 30.6V^{0.705}$$

where:

C = Construction, design, and permitting cost;

V = Wetland volume needed to control the 10-year storm (ft^3).

Using this equation, typical construction costs are the following:

$ 57,100 for a 1 acre-foot facility

$ 289,000 for a 10 acre-foot facility

$ 1,470,000 for a 100 acre-foot facility

Wetlands consume about 3 to 5 percent of the land that drains to them, which is relatively high compared with other stormwater management practices.

For wetlands, the annual cost of routine maintenance is typically estimated at about 3 percent to 5 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Wetlands are long-lived facilities (typically longer than 20 years). Thus, the initial investment into these systems may be spread over a relatively long time period.

Although no studies are available on wetlands in particular, there is some evidence to suggest that wet ponds may provide an economic benefit by increasing property values. The results of one study suggest that "pond frontage" property can increase the selling price of new properties by about 10 percent (USEPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25 percent when located near a wet pond (Emmerling-Dinovo, 1995). It is anticipated that well-designed wetlands, which incorporate additional aesthetic features, would have the same benefit.

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WATER QUALITY POND

Wet Ponds

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Minimum Measure: Post-Construction Stormwater Management in New Development and Redevelopment

Subcategory: Retention/Detention

Description

Wet ponds (a.k.a. stormwater ponds, wet retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). Ponds treat incoming stormwater runoff by allowing particles to settle and algae to take up nutrients. The primary removal mechanism is settling as stormwater runoff resides in this pool, and pollutant uptake, particularly of nutrients, also occurs through biological activity in the pond. Traditionally, wet ponds have been widely used as stormwater best management practices.

The primary functions of a wet pond are to detain stormwater and facilitate pollutant removal through settling and biological uptake.

Applicability

Wet ponds are widely applicable stormwater management practices. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions.

Regional Applicability

Wet ponds can be applied in most regions of the United States, with the exception of arid climates. In arid regions, it is difficult to justify the supplemental water needed to maintain a permanent pool because of the scarcity of water. Even in semi-arid Austin, Texas, one study found that 2.6 acre-feet per year of supplemental water was needed to maintain a permanent pool of only 0.29 acre-feet (Saunders and Gilroy, 1997). Other modifications and design variations are needed in cold climates and karst (i.e., limestone) topography.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in the ultra-urban environment because of the land area each pond consumes. They can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site.

Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station. Wet ponds can accept runoff from stormwater hot spots, but need significant separation from ground water if they will be used for this purpose.

Stormwater Retrofit

A stormwater retrofit is a stormwater management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Wet ponds are very useful stormwater retrofits and have two primary applications as a retrofit design. In many communities, detention ponds have been designed for flood control in the past. It is possible to modify these facilities to develop a permanent wet pool to provide water quality control (see Treatment under Design Considerations), and modify the outlet structure to provide channel protection.

Cold Water (Trout) Streams

Wet ponds pose a risk to cold water systems because of their potential to warm the water. When water remains in the permanent pool, it is heated by the sun. A study in Prince George's County, Maryland, found that stormwater wet ponds heat stormwater by about 9°F from the inlet to the outlet (Galli, 1990).

Siting and Design Considerations

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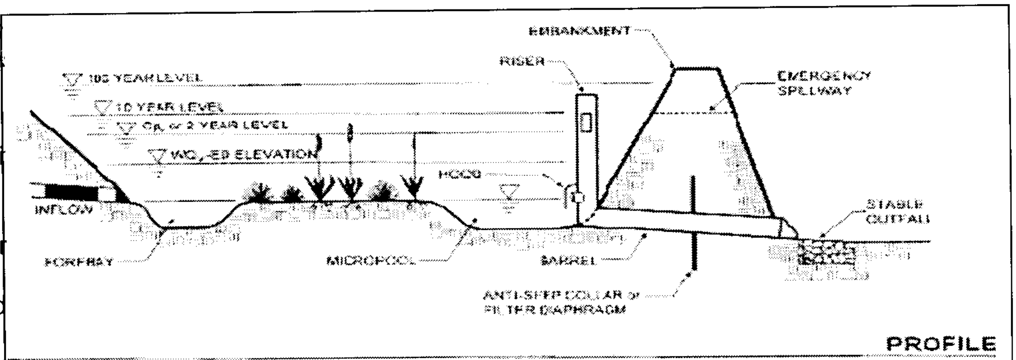

Example profile view of a wet pond design.

In add to the restr and mod to adap wet ponds to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting wet ponds.

Drainage Area

Wet ponds need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall. BMPs that focus on source control such as bioretention, should be considered for smaller drainage areas.

Slope

Wet ponds can be used on sites with an upstream slope up to about 15 percent. The local slope should be relatively shallow, however. Although there is no minimum slope requirement, there does need to be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system.

Soils / Topography

Wet ponds can be used in almost all soils and geology, with minor design adjustments for regions of karst topography (see Design Considerations).

Ground Water

Unless they receive hot spot runoff, ponds can often intersect the ground water table. However, some research suggests that pollutant removal is reduced when ground water contributes substantially to the pool volume (Schueler, 1997b).

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wet pond designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10 percent of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. The purpose of most of these features is to increase the amount of time that stormwater remains in the pond.

One technique of increasing the pollutant removal of a pond is to increase the volume of the permanent pool. Typically, ponds are sized to be equal to the water quality volume (i.e., the volume of water treated for pollutant removal). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorous removal in a lake system. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that sufficient inflow is available to maintain the permanent pool.

Other design features do not increase the volume of a pond, but can increase the amount of time stormwater remains in the practice and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system. Additionally, a vegetated buffer with shrubs or trees around the pond area should provide shading and consequent cooling of the pond water.

If designers of wet ponds are anticipating ponds that stratify in the summer, they might want to consider installing a fountain or other mixing mechanism. This will ensure that the full water column remains oxic.

Conveyance

Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. To help mitigate warming at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of stormwater practices, some design features can be incorporated to ease the maintenance burden of each practice. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wet ponds is clogging of the outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3 inches in diameter. (Smaller orifices are more susceptible to clogging).

Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with maintenance access to the forebay to ease this relatively routine (5.7 year) maintenance activity. In addition, ponds should generally have a pond drain to draw down the pond for the more infrequent dredging of the main cell of the pond.

Landscaping

Landscaping of wet ponds can make them an asset to a community and can also enhance the pollutant removal of the practice. A vegetated buffer should be preserved around the pond to protect the banks from erosion and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an aquatic bench (i.e., a shallow shelf with wetland plants) around the edge of the pond. This feature may provide some pollutant uptake, and it also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

Design Variations

There are several variations of the wet pond design. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities.

Wet Extended Detention Pond

The wet extended detention pond combines the treatment concepts of the dry extended detention pond and the wet pond. In this design, the water quality volume is split between the permanent pool and detention storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 12 to 48 hours. This design has similar pollutant removal to a traditional wet pond and consumes less space. Wet extended detention ponds should be designed to maintain at least half the treatment volume of the permanent pool. In addition, designers need to carefully select vegetation to be planted in the extended detention zone to ensure that the selected vegetation can withstand both wet and dry periods.

Water Reuse Pond

Some designers have used wet ponds to act as a water source, usually for irrigation. In this case, the water balance should account for the water that will be taken from the pond. One study conducted in Florida estimated that a water reuse pond could provide irrigation for a 100-acre golf course at about one-seventh the cost of the market rate of the equivalent amount of water ($40,000 versus $300,000).

Regional Adaptations

Semi-Arid Climates

In arid climates, wet ponds are not a feasible option (see Applicability), but they may possibly be used in semi-arid climates if the permanent pool is maintained with a supplemental water source, or if the pool is allowed to vary seasonally. This choice needs to be seriously evaluated, however. Saunders and Gilroy (1997) reported that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet in Austin, Texas. Hence, wet ponds are normally not ideal in semi-arid environments.

Cold Climates

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load and a large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting, and sediment loads from road sanding, may impact pond vegetation as well as reduce the storage and treatment capacity of the pond. Designers should consider planting the pond with salt-tolerant vegetation if the facility receives road runoff.

One option to deal with high pollutant loads and runoff volumes during the spring snowmelt is the use of a seasonally operated pond to capture snowmelt during the winter, and retain the permanent pool during warmer seasons. In this option, proposed by Oberts (1994), the pond has two water quality outlets, both equipped with gate valves. In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring melt begins, the lower outlet is closed to provide detention for the melt event. This method can act as a substitute for using a minimum extended detention storage volume. When wetlands preservation is a downstream objective, seasonal manipulation of pond levels may not be desired. An analysis of the effects on downstream hydrology should be conducted before considering this option. In addition, the manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

Several other modifications may help to improve the performance of ponds in cold climates. In order to counteract the effects of freezing on inlet and outlet structures, the use of inlet and outlet structures that are resistant to frost, including weirs and larger diameter pipes, may be useful. Designing structures on-line, with a continuous flow of water through the pond, will also help prevent freezing of these structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it may be useful to incorporate extended detention into the design to retain usable treatment area above the permanent pool when it is frozen.

Karst Topography

In karst (i.e., limestone) topography, wet ponds should be designed with an impermeable liner to prevent ground water contamination or sinkhole formation, and to help maintain the permanent pool.

Limitations

Limitations of wet ponds include:

- If improperly located, wet pond construction may cause loss of wetlands or forest.
- Wet ponds are often inappropriate in dense urban areas because each pond is generally quite large.
- Their use is restricted in arid and semi-arid regions due to the need to supplement the permanent pool.
- In cold water streams, wet ponds are not a feasible option due to the potential for stream warming.
- Wet ponds may pose safety hazards.

Maintenance Considerations

In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed. The table below outlines these practices.

Table 1. Typical maintenance activities for wet ponds (Source: WMI, 1997)

Activity	Schedule
• If wetland components are included, inspect for invasive vegetation.	Semi-annual inspection
• Inspect for damage. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Monthly maintenance
• Manage and harvest wetland plants.	Annual maintenance (if needed)
• Remove sediment from the forebay.	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic.	20-to 50-year maintenance

Effectiveness

Structural stormwater management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Wet ponds can provide flood control, channel protection, and pollutant removal.

Flood Control

One objective of stormwater management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wet ponds can easily be designed for flood control by providing flood storage above the level of the permanent pool.

Channel Protection

When used for channel protection, wet ponds have traditionally controlled the 2-year storm. It appears that this control has been relatively ineffective, and research suggests that control of a smaller storm may be more appropriate (MacRae, 1996).

Ground Water Recharge

Wet ponds cannot provide ground water recharge. Infiltration is impeded by the accumulation of debris on the bottom of the pond.

Pollutant Removal

Wet ponds are among the most effective stormwater management practices at removing stormwater pollutants. A wide range of research is available to estimate the effectiveness of wet ponds. Table 2 summarizes some of the research completed on wet pond removal efficiency. Typical removal rates, as reported by Schueler (1997a) are:

Total Suspended Solids: 67%

Total Phosphorous: 48%

Total Nitrogen: 31%

Nitrate Nitrogen: 24%

Metals: 24.73%

Bacteria: 65%

Table 2. Wet pond percent removal efficiency data

Wet Pond Removal Efficiencies							
Study	TSS	TP	TN	NO_3	Metals	Bacteria	Practice Type
City of Austin, TX 1991. Woodhollow, TX	54	46	39	45	69.76	46	wet pond
Driscoll 1983. Westleigh, MD	81	54	37	-	26.82	-	wet pond
Dorman et al., 1989. West Pond, MN	65	25	-	61	44.66	-	wet pond
Driscoll, 1983. Waverly Hills, MI	91	79	62	66	57.95	-	wet pond
Driscoll, 1983. Unqua, NY	60	45	-	-	80	86	wet pond
Cullum, 1985. Timber Creek, FL	64	60	15	80	-	-	wet pond
City of Austin, TX 1996. St. Elmo, TX.	92	80	19	-17	2.58	89-91	wet pond
Horner, Guedry, and Kortenhoff, 1990. SR 204, WA	99	91	-	-	88.90	-	wet pond
Horner, Guedry, and Kortenhoff, 1990. Seattle, WA	86.7	78.4	-	-	65.67	-	wet pond
Kantrowitz and Woodham, 1995. Saint Joe's Creek, FL	45	45	-	36	38.82	-	wet pond
Wu, 1989. Runaway Bay, NC	62	36	-	-	32.52	-	wet pond
Driscoll 1983. Pitt-AA, MI	32	18	-	7	13.62	-	wet pond
Bannerman and Dodds, 1992. Monroe Street, WI	90	65	-	-	65.75	70	wet pond
Horner, Guedry, and Kortenhoff, 1990. Mercer, WA	75	67	-	-	23.51	-	wet pond
Oberts, Wotzka, and Hartsoe 1989. McKnight, MN	85	48	30	24	67	-	wet pond
Yousef, Wanielista, and Harper 1986. Maitland, FL	-	-	-	87	77.96	-	wet pond

Wu, 1989. Lakeside Pond, NC	93	45	-	-	80.87	-	wet pond
Oberts, Wotzka, and Hartsoe, 1989. Lake Ridge, MN	90	61	41	10	73	-	wet pond
Driscoll, 1983. Lake Ellyn, IL	84	34	-	-	71-78	-	wet pond
Dorman et al., 1989. I-4, FL	54	69	-	97	47.74	-	wet pond
Martin, 1988. Highway Site, FL	83	37	30	28	50.77	-	wet pond
Driscoll, 1983. Grace Street, MI	32	12	6	-1	26	-	wet pond
Occoquan Watershed Monitoring Laboratory, 1983. Farm Pond, VA	85	86	34	-	-	-	wet pond
Occoquan Watershed Monitoring Laboratory, 1983. Burke, VA	-33.3	39	32	-	38.84	-	wet pond
Dorman et al., 1989. Buckland, CT	61	45	-	22	-25 to -51	-	wet pond
Holler, 1989. Boynton Beach Mall, FL	91	76	-	87	-	-	wet pond
Urbonas, Carlson, and Vang 1994. Shop Creek, CO	78	49	-12	-85	51.57	-	wet pond
Oberts and Wotzka, 1988. McCarrons, MN	91	78	85	-	90	-	wet pond
Gain, 1996. FL	54	30	16	24	42.73	-	wet pond
Ontario Ministry of the Environment, 1991. Uplands, Ontario	82	69	-	-	-	97	wet extended detention pond
Borden et al., 1996. Piedmont, NC	19.6	36.5	35.1	65.9	-4 to-97	-6	wet extended detention pond
Holler, 1990. Lake Tohopekaliga District, FL	-	85	-	-	-	-	wet extended detention pond
Ontario Ministry of the Environment 1991. Kennedy-Burnett, Ontario	98	79	54	-	21.39	99	wet extended detention pond
Ontario Ministry of the Environment 1991. East Barrhaven, Ontario	52	47	-	-	-	56	wet extended detention pond
Borden et al., 1996. Davis, NC	60.4	46.2	16	18.2	15.51	48	wet extended detention pond

There is considerable variability in the effectiveness of ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wet ponds. A joint project of the American

Society of Civil Engineers (ASCE) and the USEPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of stormwater practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. More information on this database is available from the BMP database EXIT Disclaimer.

Cost Considerations

The construction costs associated with wet ponds range considerably. A recent study (Brown and Schueler, 1997) estimated the cost of a variety of stormwater management practices. The study resulted in the following cost equation, adjusting for inflation:

$C = 24.5V^{0.705}$

where:

C = Construction, design and permitting cost;

V = Volume in the pond to include the 10-year storm (ft^3).

Using this equation, typical construction costs are:

$45,700 for a 1 acre-foot facility

$232,000 for a 10 acre-foot facility

$1,170,000 for a 100 acre-foot facility

Ponds do not consume a large area relative to the drainage size of the watershed (typically 2.3 percent of the contributing drainage area). It is important to note, however, that these facilities are generally large and require a relatvely large contiguous area. Other practices, such as filters or swales, may be "squeezed" into relatively unusable land, but ponds need a relatively large continuous area.

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into pond systems may be spread over a relatively long time period.

In addition to the water resource protection benefits of wet ponds, there is some evidence to suggest that they may provide an economic benefit by increasing property values. The results of one study suggest that "pond front" property can increase the selling price of new properties by about 10 percent (USEPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25 percent when located near a wet pond (Emmerling-Dinovo, 1995).

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Post-Construction Storm Water Best Management Practices

	Structural Maintenance Practice				Regional Applicability												
	FC	CP	GWR	PR	Ultra-Urban	Hot Spots	Cold Streams	Karst Topo.	Arid Climate	Retrofit	Cost	Possible Mosquito Nuisance	LID	Maintenance**	Main pollutant removed	Drainage Area (acres)	Other Notes
Dry Detention Ponds	√	√	X	minor	X	X	X	liner	√		low	√	X	semi-annual inspection, clean out 5-7 years	Suspended solids	>10	Install sediment forebay, micropool at outlet, and non-clogging outlet to extend maintenance schedule.
Wet Ponds/Water Quality Ponds/Retention Ponds/Extended Detention	√	√	X	√	X	liner	X	liner	X		low	√	X	monthly mowing and debris removal, semi-annual inspection, clean out 5-7 years	Sediment	~25	Install sediment forebay and non-clogging outlet to extend maintenance schedule.
Infiltration Basin	X	X	√	√	X	X	√	X	√		med.	√	X	semi-annual inspection, clean out 5 years	TSS, Metals, Bacteria	<5	Relatively high failure rate due to clogging.
Infiltration/Exfiltration Trench	X	X	√	√	possibly	X	√	X	√	X	high			semi-annual inspection	TSS, Metals, Bacteria	<5	Pretreatment will extend the life of the practice.
Porous Pavement/Pervious Paving/Pervious Paver	√	√	√/X	√	√	X	√	√	√	√	high		√	monthly inspection, quarterly vacuum sweep	TSS, motor oil, metals		High failure rate
Bioretention/ Bioretention Cell/Vegetated Biofilter	X	X	X*	minor	√	√	√	√	√	√	high		√	monthly	Heavy metals, TSS, COD, oil and grease	<5	
Sand and Organic Filters (surface, underground, perimeter, pocket sand filter)	X	X	X	√	√	√	√	√	√	√	?? High		√	monthly	TSS and metals	2 to 10	Many design and application variations; pre-treatment is essential to the life of the filter, usually an U/S sediment basin/chamber
SW/Constructed Wetland	√	√	X	√	possibly	√	X	liner	X	√	low	√		quarterly mowing and debris removal	Nitrate, bacteria, TSS	~25	
Grassed/Wet/Dry Swales/BioSwale/ Biofilters	√	√	minor	√	X	X	√	√	X	√	low	√	√	mowing as needed	TSS	<5	Dry swales outperform grassed channels and wet swales for pollutant removal. Bioswales need much less maintenance.
Grassed/Vegetated Filter Strip	X	X	minor	√	X	X	√	√	X	X		√		mowing as needed	Nitrogen, Phos., and Sediment	small	Consume large amounts of space.
Catch Basin with a Manufactured System	X	X	X	√	√		√	√	√	√				depends on design and use of filters	depends on design and additional products		Catch basins need to be used in conjunction with a manufactured system for successful pollutant removal.
In-line Storage	√	X	X	X	√		√	√	√	X	low			most are self-cleaning	NA		Just used to reduce storm peak flows, unless used in conjunction with another practice.
Traction Sand Trap	X	X	minor	√	√	X	√	√	√	√			√	as needed	sediment		Would be most beneficial downgradient of material storage areas
Dry Weather Flow Diversion	X	X	X	√	√	√	√	√	√					Depends on type of diversion used, but probably quarterly	Pollutants removed by local POTW		Dependent upon local POTW approval.
Energy Protection Area	X	√	X	√	√	X	X	√	√	√	low			semi-annual and after large rain events	TSS		Not much info, but promising for channel protection

Post-Construction Storm Water Best Management Practices

	Structural Maintenance Practice				Regional Applicability					Retrofit	Cost	Possible Mosquito Nuisance	LID	Maintenance**	Main pollutant removed	Drainage Area (acres)	Other Notes
	FC	CP	GWR	PR	Ultra-Urban	Hot Spots	Cold Streams	Karst Topo.	Arid Climate								
Gross Solid Removal Devices	X	X	X	√	√	X	X	√	√	√			√	Depends on the amount of debris, at least quarterly	debris, sediment		Many different pre-manufactured designs
Oil/Water Separator	X	X	X	√	√	√		√	√	√				Depends on design and application			
Level Spreader	minor	√	X	√	X		X	√	√	√		√		frequent until establishment of vegetation, then semi-annual	sediment		Only information was obtained from North Carolina and Florida (construction BMPs)
Preformed Scour Hole	X	√	X	minor	X			√	√	√	low	√		semi-annual and after large rain events	sediment		

FC = Flood Control
CP = Channel Protection
GWR = Groundwater Recharge
PR = Pollutant Removal
LID = Low Impact Development

*Design variation, partial exfiltration design will recharge.
**Only the most frequently required maintenance requirements are listed.

APPENDIX 3

DOT INFORMATION FROM OTHER STATES

CALIFORNIA

BMP Retrofit Pilot Program

FINAL REPORT

REPORT ID CTSW - RT - 01 - 050
JANUARY 2004
California Department of Transportation
CALTRANS, DIVISION of ENVIRONMENTAL ANALYSIS
1120 N Street
Sacramento, CA 95814

Dedication

On August 27, 2001, Mr. Peter Van Riper, who coordinated the efforts of Caltrans District 7, passed away. Mr. Van Riper played an integral role in the completion of the BMP Retrofit Pilot program and made a significant contribution to the project. His dedication to the pursuit of an objective and practical study, and his relaxed and positive style was appreciated by all who worked with him. He will be sorely missed. This report is dedicated to his memory.

EXECUTIVE SUMMARY

Introduction

Litigation between the California Department of Transportation (Caltrans) and the Natural Resources Defense Council (NRDC), Santa Monica BayKeeper, the San Diego BayKeeper, and the United States Environmental Protection Agency (USEPA) resulted in a requirement that Caltrans develop a Best Management Practice (BMP) Retrofit Pilot Program in Caltrans Districts 7 (Los Angeles) and 11 (San Diego). The objective of this program was to acquire experience in the installation and operation of a wide range of structural BMPs for treating stormwater runoff from existing Caltrans facilities and to evaluate the performance and costs of these devices. A study team made up of representatives from the parties to the lawsuit, their attorneys, local vector control agencies, and outside technical experts provided oversight of the retrofit pilot program.

Technical feasibility and costs were assessed through detailed records kept on the process of designing, building, operating and maintaining each retrofit device. Technical feasibility considered siting, design, construction, operation, maintenance, safety, performance and public health issues. These elements are elaborated on in Section 1.10. In addition, by establishing the life-cycle costs and performance for each of the technologies, a basis for selecting one technology over another was developed. The benefit assessment used in this project was based primarily on the pollutant removal of each of the tested technologies.

Each BMP was designed, constructed, and maintained at what was "state-of-the-art" at the time the project began. The types of BMP pilot projects included in the study are shown in Table 1.

Table 1 BMP Types included in the Retrofit Study

Media Filters	**Biofiltration**
Austin sand filter (5)	Swale (6)
Delaware sand filter (1)	Strip (3)
Multi-Chambered Treatment Train (2)	**Infiltration Devices**
Storm-Filter™ (1)	Basin (2)
Extended Detention Basins (5)	Trench (2)
Drain Inlet Inserts	**Wet Basin (1)**
FossilFilter™ (3)	**Oil-water Separator (1)**
StreamGuard™ (3)	**Continuous Deflective Separation (1)**

Sites selected for retrofit with the piloted technologies were considered to be the most appropriate and feasible in terms of siting criteria established for each BMP. The potential sites for each type of technology were ranked using a weighted decision matrix; BMPs with the most restrictive siting criteria (such as infiltration) were sited prior to BMPs with less restrictive criteria. No right-of-way was purchased for the project; instead, all BMPs were retrofitted within existing State-owned areas.

Retrofit Pilot Program Accomplishments

The retrofit pilot program is thought to be the most comprehensive test of common stormwater management BMPs ever conducted, and the first significant evaluation in a climate of southern California's type. The program succeeded in demonstrating the effectiveness of several BMP types in reducing pollutant concentrations and mass loadings. The results generally are consistent with the performance of these devices measured in previous studies.

The program further yielded substantial information on the technical feasibility of the BMPs as retrofits in highway and support facility settings. The determination of the technical feasibility at any particular location requires site specific evaluation. The team conducting the program surmounted a number of challenges to constructability and operation.

The project also accounted for the costs of construction and operations and maintenance under pilot program circumstances. Potential cost reduction strategies were identified and are detailed in Chapter 14.

Technical Feasibility and Benefits

This study was designed to allow the parties to gain experience with the actual design, installation, operation, and maintenance of structural BMPs in the setting of the freeway system in southern California. Many BMPs have been used in other parts of the country, but cost, performance, and operation data were not generally available for retrofit implementation, especially in a semi-arid highway environment. In addition, the study included a number of proprietary BMPs. Many of these BMPs are relatively specialized for specific constituents, flow or physical conditions, limiting their applicability. Accordingly, the study was designed to confirm or determine the technical feasibility for potential retrofit of the selected BMPs into the Caltrans highway environment.

In several instances, siting of the BMPs presented technical challenges, among them the restrictive siting requirements related to the need for specific soil and subsurface conditions (infiltration devices), available space, or perennial baseflow (wet basin). At many of the sites a significant portion of the cost was associated with changes to the original storm drain system to direct more runoff to the test sites. These difficulties point out the need to include planning for BMP retrofit in the early stages of reconstruction projects to take advantage of possible drainage system reconstruction.

An unexpected element encountered at the beginning of the study was the importance of avoiding standing water in the BMPs. Standing water presents opportunities for vectors to establish themselves, and mosquito breeding was observed at all of the sites where standing water persisted for at least 72 hours. In addition to the technologies that incorporate a permanent pool (i.e., wet basin, MCTT, Storm-Filter™, Continuous Deflective Separation (CDS®) and Delaware sandfilter), standing water also occurred in stilling basins, around riprap used for energy dissipation, in flow spreaders, and in some outlet structures. Consequently, many of the BMPs were modified during the course of the study to eliminate standing water. To minimize vector concerns in future installations, the potential for standing water should be avoided during design.

A significant component of the overall reduction in constituent load of several of the BMPs was infiltration of runoff into the soil. This includes not only infiltration basins and trenches, where infiltration is the primary mechanism for mitigation of stormwater impacts, but also in unlined extended detention basins and biofiltration swales and strips. Although infiltration of runoff clearly reduces the potential impacts on surface water quality of highway runoff, there remains the possibility for groundwater contamination. The portion of the study concerned with identifying the impacts of infiltration devices on groundwater quality was not successful. Consequently, additional investigation of the potential for groundwater contamination from infiltrated runoff is warranted.

In general, the pollutant removal effectiveness of the tested BMPs was consistent with previously reported values. Analysis of the water quality data collected during the study indicated that in many cases the traditional method of reporting performance as a percent reduction in the influent concentration did not correctly convey the relative performance of the BMPs. The problem was primarily the result of differences in influent runoff quality among the various sites and was especially noticeable for the MCTTs. These devices were installed at park-and-rides, where the untreated runoff had relatively low constituent concentrations. These low influent concentrations resulted in a low calculated removal efficiency even though the quality of the effluent was equal to that achieved in the best of the other BMPs. Consequently, a methodology was developed using linear regression to predict the expected effluent quality for each of the BMPs as if they were subject to identical influent quality. The study found that a comparison on this basis resulted in a more valid assessment of the relative performance of the technologies. Table 2 presents the expected effluent quality for total suspended solids (TSS), total phosphorus, and total zinc that would be achieved if each of the BMPs were subject to runoff with influent concentrations equal to that observed on average for highway and maintenance stations during the study. Effective effluent concentrations of 0 are shown for the infiltration devices, since there is no discharge to surface waters. As experience with BMP selection, design and operational performance increases, it is expected that benefits measured in terms of pollutant removal and receiving water quality improvement will also increase.

Table 2 Effluent Expected Concentrations for BMP types

Device	TSS (Influent 114 mg/L)	Total Phosphorus (Influent 0.38 mg/L)	Total Zn (Influent 355 ug/L)
Austin Sand Filter	7.8	0.16	50
Delaware Sand Filter	16.2	0.34	24
EDB unlined	36.1	0.24	139
EDB lined	57.1	0.31	132
Wet Basin	11.8	0.54	37
Infiltration Basin	0	0	0
Infiltration Trench	0	0	0
Biofiltration Swale	58.9	0.62	96
Biofiltration Strip	27.6	0.86	79
Storm-Filter™	78.4	0.30	333
MCTT	9.8	0.24	33
CDS®	68.6	0.28	197

The retrofit pilot program findings provide a basis to develop a procedure for selecting the technically feasible BMP expected to provide the greatest and most consistent reduction of pollutants of interest in highway runoff. The procedure guides judgment of technical feasibility and utilizes graphs and equations developed from the program's database to estimate effectiveness in reducing pollutant mass loadings and when regulatory effluent limits exist.

All sediment and collected material that accumulated in the BMPs was tested for hazardous materials prior to disposal. The BMPs that required disposal of accumulated material were the three Austin sand filters in District 7, the one Delaware sand filter in District 11, the Storm-Filter™ and the material in the spreader ditch of one of the biofiltration strips in District 7. Title 22 testing was done and all locations were found to have non-hazardous material and therefore all material was disposed of at the landfill.

Media Filters

The Austin and Delaware sand filters and the MCTT provided substantial water quality improvement and produced a very consistent, relatively high quality effluent. Although the greatest concentration reduction occurred for constituents associated with particles, substantial reduction in dissolved metals concentrations was also observed when the influent concentrations were sufficiently high, contradicting expectations that little removal of the dissolved phase would occur in this type of device. Maintenance of the sand filter beds to alleviate clogging was not excessive at the test sites, and the siting requirements are compatible with the small, highly impervious watersheds characteristic of Caltrans facilities. Consequently, the piloted Austin and Delaware sand filters, and the MCTT sand filters are considered technically feasible.

The Delaware and MCTT designs both incorporate permanent pools in the sedimentation chamber, which can increase vector concerns and maintenance requirements. The Delaware filter could be applicable at certain sites where an underground vault system is desired or where a perimeter location is preferred, assuming the vector issues associated with the permanent pool are addressed. The MCTT was found to have a similar footprint and provide a water quality benefit comparable to the Austin sand filter; however, higher life-cycle cost, and the permanent pool and associated vector issues of the MCTT suggest that in general the Austin filter would be preferred.

The Storm-Filter™ did not perform on par with other media filters tested, showing little attenuation of the peak runoff rate and producing a reduction in most constituent concentrations that was not statistically significant. In addition, the standing water in the Storm-Filter™ has the potential to breed mosquitoes. Although technically feasible at the piloted location, the Storm-Filter™ pollutant removal was less and its life-cycle cost was more than the Austin filter. Therefore, the Storm-Filter™ will not be considered to be preferable for use at Caltrans facilities based on the media evaluated in this study, even if the vector problems were avoided.

Maintenance and operation of pumps at several sites was a recurring problem. Consequently, other technologies should be considered at sites with insufficient hydraulic head for operation of media filters by gravity flow.

Future research on construction methods and materials for sand filters is needed to improve the cost/benefit ratio for these devices. In addition, evaluation of alternative media may also allow the targeting of specific constituents or improvement in the performance for soluble constituents, such as nitrate, which are not effectively removed by a sand medium.

Extended Detention Basins

Extended detention basins have an especially extensive history of implementation in many areas and are recognized as one of the most flexible structural controls. The pollutant removal observed in the extended detention basins was similar to that reported in previous studies (Young, 1996) and appeared to be independent of length/width ratio, which is a commonly used design parameter. Resuspension of previously accumulated material was more of an issue in the concrete-lined basin, which exhibited less constituent concentration reduction than in-situ, earthen designs. Based on these findings, unlined extended basins are preferred except where potential groundwater contamination is an over-riding concern.

There are few constraints for siting extended detention basins, although larger tributary areas can reduce the unit cost and increase the size of the outlet orifices, making clogging less likely. The relatively small head requirement (as compared to Austin sand filters) associated with this technology is particularly useful in retrofit situations where the elevation of existing stormwater infrastructure is a design constraint. The unlined installations in southern California did not experience any problems associated with establishment of wetland vegetation, erosion or excessive maintenance (as compared to the lined basin). Except where groundwater quality may be impacted, unlined basins are preferred on a water quality basis because of the substantial infiltration and associated pollutant load reductions that were observed at these sites.

This study reaffirms the flexibility and performance of this conventional technology and confirms their technical feasibility, depending on site specific conditions. The effectiveness, small head requirement and few siting constraints suggest that these devices are one of the most applicable technologies for stormwater treatment at Caltrans facilities.

Wet Basin

One wet basin was successfully sited and operated for this study, and observed pollutant removal was substantial. An important finding of this study is that the discharge quality from a wet basin with a large permanent pool volume is largely a function of the quality of the baseflow used to maintain that pool and of the transformation of the quality of that flow during its residence time in the basin. It should be noted that for this specific pilot installation and receiving water (impaired by nutrients), an ancillary benefit was the treatment provided in the wet basin for the 'offsite' base flow and the substantial nutrient reduction observed during dry weather periods.

Depending on site specific information, wet basins are considered technically feasible for highway stormwater treatment; however, there are a number of concerns regarding the applicability of wet basins for retrofit of Caltrans facilities. The long-term maintenance requirements and costs of wet basins may not have been accurately estimated because some major maintenance activities did not occur during the study period. The potential for the basin to become a habitat for endangered species may result in required consultation with the USFWS and subsequent mitigation, should habitat 'take' occur during routine maintenance activities. The cost of these potential mitigation activities also is unknown. Consequently, wet basins warrant further study to understand the risk and cost of habitat mitigation and other potential impacts of endangered or threaten species issues.

Vector (mosquito) control required additional vegetation management that resulted in observed maintenance that was much higher than for other devices. Vector control experts were only marginally satisfied with the level of vector prevention provided by mosquito fish, although they were generally effective in reducing mosquitoes.

A primary siting constraint of this technology is the need for a perennial flow to sustain the permanent pool. The siting process showed that the vast majority of the pilot BMP locations constructed were in small, highly impervious watersheds with no dry weather flow.

Basin size also limited siting opportunities. With a permanent pool volume three times the water quality volume, the wet basin had as much as four times the volume of other technologies, such as detention basins. The larger size results in higher cost and land requirements higher than those of alternative technologies. Many other criteria for sizing the permanent pool have been recommended, which may reduce the facility size while providing only slightly less pollutant removal. (See *Composite Siting Study, District 11*, Appendix A)

A number of questions are left unanswered by this study and warrant further investigation. Additional work could help define the relationship between permanent pool volume, construction cost, and water quality benefit. An assessment of the feasibility of a seasonal wet basin, where the pool was allowed to go dry during the summer, would increase siting opportunities by potentially allowing siting of these devices where perennial flow is not present. Finally, additional work is needed to evaluate the impact of endangered and threatened species that would be attracted to the basin and affect the maintenance schedule or requirements.

Biofiltration

Biofiltration BMPs, including bioswales and biofiltration strips are considered technically feasible depending on site-specific considerations. Overall, the reduction of concentration and load of the constituents monitored was comparable to the results reported in other studies, except for nutrients. Nutrient removal was compromised by the natural leaching of phosphorus from the salt grass vegetation used in the pilot study. This condition was not known at the start of the project but was discovered later in the program (see Chapter 8 for details). While space limitations in highly urban areas may make siting these BMPs difficult, they are suitable for fitting into available space such as medians and shoulder areas. Their use should be considered where existing space and hydraulic conditions permit.

Although irrigation was used to establish vegetation for the pilot biofiltration swales and strips, natural moisture from rainfall was sufficient to maintain them once they were established. Complete vegetation coverage, especially on the sideslopes of swales, was difficult to maintain, even with repeated hydroseeding of these areas. Lower vegetation density and occasional bare spots are to be expected in an arid climate, but do not appear to seriously compromise pollutant removal. An important lesson of this study is that a mixture of drought-tolerant native grasses is preferred to the salt grass monoculture used at the pilot sites. In southern California, it is preferable to specify species that grow best during the winter and spring (the wet season) and to schedule vegetation establishment accordingly. Few erosion problems were noted in the operation of the sites; however, damage by burrowing gophers was a problem at several sites.

Biofiltration swales and strips were among the least expensive devices evaluated in this study and were among the best performers in reducing sediment and heavy metals in runoff. Removal of phosphorus was less than that reported by Young et al. (1996) but may be related to leaching of nutrients from the saltgrass during its dormant season. The swales are easily sited along highways and within portions of maintenance stations, and do not require specialized maintenance. In addition, the test sites were similar in many ways to the vegetated shoulders and conveyance channels common along highways in many areas of the state. Consequently, these areas, which were not designed as treatment devices, could be expected to offer water quality benefit comparable to these engineered sites. More research is needed to investigate this possibility.

The research needs involving biofiltration devices center on refinement of the design criteria and evaluation of the performance with vegetation other than salt grass. The current design criteria for strips are especially poor with little guidance on the relative size of the tributary area to the buffer strip, and almost no data on the effect of slope and length on removal efficiency. In southern California and other relatively dry climates, it is also important to establish the minimum vegetation coverage needed to provide effective pollutant removal.

Infiltration

Infiltration basins and trenches are considered be technically feasible depending on site specific conditions. However, there are three main constraints to widespread implementation of infiltration devices: locating sites with appropriate soils, the potential threat to groundwater quality, and the risk of site failure due to clogging. Further investigation of these constraints is recommended.

Infiltration basins and trenches can be an especially attractive option for BMP implementation, since they provide the highest level of surface water quality protection. In addition, they reduce the total amount of runoff, restoring some of the original hydrologic conditions of an undeveloped watershed. Although trenches and basins are similar in terms of their water quality benefits, the siting and maintenance requirements of the two devices are distinctly different. Infiltration basins generally treat runoff from relatively larger tributary areas and require more routine maintenance such as vegetation management, but they are easier to rehabilitate when clogged. Conversely, infiltration trenches generally treat runoff from smaller areas, and their smaller footprint allows them to be sited in more space-constrained areas. Observed routine maintenance was less; however, once clogged, partial or complete reconstruction may be required, resulting in uncertain long-term cost.

The original siting study did not identify sufficient suitable locations for the number of infiltration installations specified in the District 7 Stipulation within the time frame provided in the agreement. This study is being followed by assessments in both Districts to gauge the potential extent of infiltration opportunities. In Los Angeles, the assessment is being accomplished with field investigations in selected highway corridors and in San Diego by existing data, but more broadly based through the District. In addition, there is concern at the state and regional levels about the impact on groundwater quality from infiltrated runoff. The portion of this study that was implemented to assess the potential impact to groundwater quality from infiltrated stormwater runoff was largely unsuccessful and longer term, more comprehensive studies than were possible under this pilot program are warranted. Despite these uncertainties, the parties in this study worked cooperatively to develop interim guidelines for siting infiltration devices in response to requests by the State and Regional Water Quality Control Boards.

In summary, infiltration can be a more challenging technology in that site assessment, groundwater concerns, and long-term maintenance issues are important elements that are subject to some uncertainty. The experience in this study is that siting these devices under marginal soil and subsurface conditions entails a substantial risk of early failure. Analysis of this experience resulted in development of a detailed set of site assessment guidelines for locating infiltration devices in the future to ensure that soil and subsurface conditions are appropriate for their implementation. It is important that these guidelines be implemented to insure that infiltration is used with adequate separation from groundwater and in soils with a favorable infiltration rate. In addition, loss of soil structure, clogging, and other changes that may occur during the life of the facility may be difficult to ameliorate. Nevertheless, infiltration devices are considered technically feasible at suitable sites and they were among the most cost-effective BMPs tested in this study.

Continuous Deflective Separators

Two CDS® units were successfully sited, constructed and monitored during the study. The devices were developed in Australia with the primary objective of gross pollutant (trash and litter) removal from stormwater runoff. The devices are considered technically feasible depending on site specific conditions. They were highly successful at removing gross pollutants, capturing an average of 88 percent, with bypass of this material occurring mainly when the flow capacity of the units was exceeded. Even though these two units were sited on elevated sections of freeways, 94 percent of the captured material by weight was vegetation. Consequently, the maintenance requirements may be excessive if these units are located in an area with a significant number of trees or other sources of vegetative material.

A secondary objective of the CDS® units is the capture of sediment and associated pollutants, particularly the larger size fractions. The average sediment concentration in the influent to the two systems was relatively low and no significant reduction was observed. Reductions in the concentrations of other constituents were also not significant. It should be noted that the specific fiberglass CDS units tested in this study are no longer offered by the manufacturer. CDS does manufacture similar concrete units that were not evaluated as a part of this study.

These devices maintain a permanent pool in their sumps and mosquito breeding was observed repeatedly at the two sites. The frequency of breeding was reduced by sealing the lids of the units and installing mosquito netting over the outlet. Other non-proprietary devices developed by Caltrans for litter control, which do not maintain a permanent pool, may be preferred to this technology to minimize vector concerns.

Drain Inlet Inserts

Two models of proprietary drain inlet inserts were evaluated. The data collected during this study indicate that they cannot be operated unattended because of hydraulic limitations that resulted in flooding on a number of occasions and clogging that caused bypass of untreated runoff. Their pollutant removal was also minimal. The absolute number of maintenance hours was not large; however, the timing of maintenance was critical, right before and during storm events. Because of their frequent maintenance requirements and safety considerations (access along active freeways and highways), implementation on roadsides would not be appropriate. Installation at maintenance stations might be considered safer; however, timely maintenance is often infeasible due to other maintenance activities required during storm events. In addition, they were only marginally effective, with constituent removal generally less than 10 percent. Consequently, these particular models were judged to be not technically feasible at the piloted locations.

The two types of inserts monitored in this study were carefully selected from the many types that were available at the start of the study based on an evaluation of their water quality improvement potential. There are many other types of proprietary drain inlet inserts on the market that were not evaluated and may perform better than the two evaluated here; however, until there is better independent documentation of their pollutant removal effectiveness as well as operation and maintenance requirements, this technology should not be routinely considered for implementation. The variety of drain inlet inserts on the market has increased since the beginning of the pilot program, and one of the inserts evaluated during this study is no longer being manufactured. Some newer insert types are now available but the results of this study should not be used to assess the expected feasibility and/or performance of these recently available technologies. It should be noted trash removal was not monitored as part of this study and certain types of drain inlet inserts may be effective for this purpose.

Oil-Water Separator

Although an oil-water separator (OWS) was successfully sited, constructed and monitored, the results indicate that this is not an applicable technology for the piloted location. Twenty-two maintenance stations were originally considered for implementation of this technology and the ten with the potential for higher concentrations of petroleum hydrocarbons in runoff were subject to further evaluation. Four of these were subsequently selected for monitoring and of these, only one site appeared to have concentrations that were sufficiently high to warrant installation of an oil-water separator. However, concentrations of free oil in stormwater runoff observed during the course of the study from this site were too low for effective operation of this technology. Runoff quality from three other maintenance stations was monitored during the study and concentrations of petroleum hydrocarbons at these sites were also below the threshold required for effective operation of the oil-water separator. Improved source-control measures at Caltrans maintenance stations have generally been effective in reducing hydrocarbon pollutant levels below that which OWS are effective in removing. In conclusion, none of the 25 maintenance stations in Districts 7 and 11 that were evaluated had sufficiently high concentrations of free oil for successful implementation of this technology. At these low levels, other conventional stormwater controls can provide better treatment of hydrocarbons, as well as other pollutants of concern in runoff; however, they may be appropriate in certain non-stormwater situations (e.g., where source controls cannot ensure low oil and grease concentrations).

Cost

The incurred costs of constructing and operating the BMPs in this pilot study were documented in detail. These costs reflect the requirements of stormwater retrofit in the highway environment in the urban areas of southern California and may not be representative of those that might be incurred in other settings. There has been extensive discussion among the parties involved in this study regarding whether these numbers accurately represent the costs that would be incurred in a more extensive (widespread) retrofit program. Many reasons have been suggested for possible differences including, among others: costs specific to pilot projects, the bidding climate at the time the contracts were advertised, the lack of standard competitive bidding, and the dispersed nature of the construction activities. While the parties disagree to some extent about the degree of departure from a normal scenario, both parties agree that there were pilot-specific costs incurred in this project that would not be replicated in a larger scale retrofit implementation program. A separate study commissioned by the retrofit parties suggested ways to reduce costs. Additional cost information from elsewhere in the nation is provided in Appendix C.

The actual construction costs were reviewed on a site-by-site basis by a technical workgroup that included water quality specialists, construction managers and design engineers. The goal of the workgroup was to develop 'generic' retrofit costs that could reasonably be applied to other Caltrans BMP retrofit projects. The costs were developed by (1) reviewing the specific construction items for each site; (2) eliminating those that were atypical; and (3) adjusting the costs that were considered to be outside of what would 'routinely' be encountered in a retrofit situation. Specific construction items that were reduced or eliminated from the realized costs are discussed in the individual device chapters. The average adjusted construction costs for each of the technologies are presented in Table 3.

The construction costs for each of the BMPs have been normalized by the water quality volume rather than by tributary area to account for the significant differences in design storm depth used for sizing the controls in different parts of the study area and for the differences in the runoff coefficient at each site. For the flow-through devices, such as swales, the cost per unit volume calculations used the water quality volume for the tributary area that would be used for BMP sizing if a capture-and-treat type device, such as a detention basin, were implemented at the site. Where more than one facility of the same type was constructed, the mean cost per water quality volume is reported.

Life-cycle costs were developed by adding the present value of normalized expected operation and maintenance cost to the normalized adjusted construction cost. The expected maintenance requirements were developed based on the recommended Operation and Maintenance Plan (Appendix D) and are also presented in Table 3. The present value calculation used a 20 year life-cycle and a 4 percent discount rate. There was a substantial range of values for the life-cycle cost of biofiltration strips and drain inlet inserts among the individual sites because the size of the devices was fixed, while the tributary areas varied greatly. Nevertheless, the average value observed in the study was used for computations in this table as it was for other devices.

The pilot program construction cost figures represented throughout this report are directly applicable only to Caltrans and its operations. The unique environment and constraints associated with retrofitting BMPs into the California Highway system makes comparison to other possible applications of the same BMPs difficult. Furthermore, even within the Caltrans system, information on construction costs will undoubtedly increase greatly as BMPs continue to be developed and implemented, such that the construction cost information in this report will be of limited value over time. It should be recognized that the Operation and Maintenance cost information was based partly upon estimates and projections of future needs.

The parties engaged the assistance of outside experts to review the costs experienced in the retrofit pilot program and to make suggestions for cost reductions and improvements in efficiency. Eventually these consultants prepared a report, which is appended to this report in Appendix C.

Table 3 Cost of BMP Technologies (1999 dollars)

BMP Type (No. of installations)	Avg. Adjusted Construction Cost	Adjusted Construction Cost/m³ of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m³	Life-Cycle [a] Cost/m³
Wet Basin (1)	$ 448,412	$ 1,731	$ 16,980	$ 452	$ 2,183
Multi-chambered Treatment Train (2)	$ 275,616	$ 1,875	$ 6,410	$ 171	$ 2,046
Oil-Water Separator (1)	$ 128,305	$ 1,970	$ 790	$ 21	$ 1,991
Delaware Sand Filter (1)	$ 230,145	$ 1,912	$ 2,910	$ 78	$ 1,990
Storm-Filter™ (1)	$ 305,355	$ 1,572	$ 7,620	$ 204	$ 1,776
Austin Sand Filter (5)	$ 242,799	$ 1,447	$ 2,910	$ 78	$ 1,525
Biofiltration Swale (6)	$ 57,818	$ 752	$2,750	$ 74	$ 826
Biofiltration Strip (3)	$ 63,037	$ 748	$2,750	$ 74	$ 822

BMP Type (No. of installations)	Avg. Adjusted Construction Cost	Adjusted Construction Cost/m^3 of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m^3	Life-Cycle [a] Cost/m^3
Infiltration Trench (2)	$ 146,154	$ 733	$ 2,660	$ 71	$ 804
Extended Detention Basin (5)	$172,737	$590	$ 3,120	$ 83	$ 673
Infiltration Basin (2)	$ 155,110	$ 369	$ 3,120	$ 81	$ 450
Drain Inlet Insert (6)	$ 370	$ 10	$1,100	$ 29	$ 39

[a] Present value of operation and maintenance unit cost (20 yr @ 4%) plus construction unit cost.

Despite the uncertainty in the projected costs of a wholesale BMP retrofit program, the cost data can be used to rank BMPs by life-cycle costs, which can serve as the first step in selecting the most cost-effective technology for a given site.

Recurring issues that strongly affected the capital cost of the devices were the discovery of unsuitable material in the subsurface and buried utilities at the sites selected for implementation of the devices. Unsuitable material included both natural and manmade objects that increased the cost of excavation. At several sites, large boulders had to be removed and the site over-excavated and backfilled. Other sites had been used as disposal areas, the extent of which was not realized until after construction began. Rarely did the as-built plans correctly identify the location of utilities, requiring their relocation or the repositioning of the BMP during construction. These types of conditions may be encountered fairly frequently in retrofit construction. Consequently, average published costs may be appropriate for planning purposes, but should not generally be used to estimate the cost for a particular site, unless supplemented with a detailed site assessment.

In addition to construction costs, it is also important to consider the operation and maintenance costs for each technology. An important element in selecting the most appropriate BMP for a site is an understanding of the amount and type of operation and maintenance required. BMPs that require less maintenance are preferred, other factors being equal.

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LIST OF APPENDICES

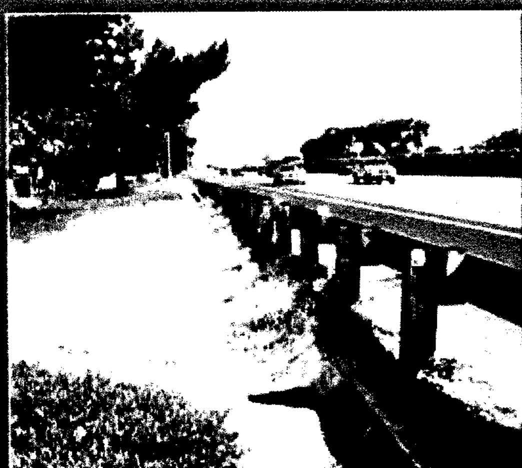
Note: The appendices to this final report are contained on two CD-ROMs attached to the inside back cover of this document. The CD-ROMs contain the following appendices:

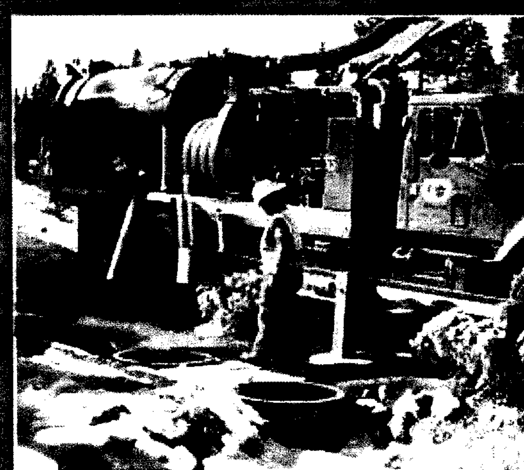
CD-ROM No. 1 :

CD-ROM No. 2:

Statewide Stormwater Management Plan (SWMP)

CTSW-RT-07-182-1.1





California Department of Transportation
Division of Environmental Analysis
1120 N Street
Sacramento, CA 95814
http://www.dot.ca.gov/hq/env/stormwater

Caltrans

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- **Project Engineer:** The Project Engineer (PE) is responsible for preparation of the PID and PA/ED documents during the planning phases and PS&E documents during the design phase. The Project Engineer is responsible for selecting and incorporating BMPs into project plans and specifications, and is responsible for determining whether a SWPPP is required for the project.

- **District/Regional Design Stormwater Coordinator:** The District/Regional Design Stormwater Coordinator is responsible for providing support to the DNC and District Design staff throughout all phases of the project planning and design process.

5.3 BMP Identification and Selection Procedures

BMPs are selected and designed to protect water quality and minimize life-cycle maintenance costs and resources, provide adequate site access and maximize worker and public safety. Design Pollution Prevention, Treatment, and Construction Site BMPs are incorporated into the plans and specifications. Construction, operating and maintenance costs are considered when selecting permanent project BMPs so adequate cost is projected and enough funding is allocated (B.9).

Project-specific BMP selection is an iterative process that begins with initial project planning activities. As the project moves into detailed design, the Department revisits the BMP selection process, and a detailed BMP selection and design commences together with detailed design of the highway and drainage facilities. MEP criteria such as economic, social, legal, or technological constraints may affect the feasibility and practicability of permanent BMPs. For example, some highway projects would necessitate extraordinary construction, plumbing, or features to collect and treat runoff. If the Department cannot implement permanent BMPs into a specific project, then the Department documents its findings in a technical report submitted to the RWQCB at PS&E or no later than when project is at Ready-to-List (RTL).

5.3.1 Incorporation of Design Pollution Prevention BMPs into Projects

The Project Engineer uses information gathered during the project planning and design to select appropriate Design Pollution Prevention BMPs. These BMPs are technology-based BMPs selected to reduce post-construction pollutant discharges.

If implementation of the project will result in an increased potential for downstream erosion or sedimentation in channels, the Department will implement Design Pollution Prevention BMPs. Examples include the following:

- Modifications to channel (both natural and man-made) lining materials, including vegetation, geotextile mats, and rock rip-rap;
- Energy dissipation devices at culvert outlets;
- Smoothing the transition between culvert outlets/headwalls/wing-walls and channels to reduce turbulence and scour;
- Incorporating retention and/or detention facilities to attenuate peak discharges, and;
- Use of pervious surface materials (B.4) to maximize water quality benefits
- Use of vegetative surfaces.

Table 5-1 lists the Design Pollution Prevention BMPs that have been approved by the Department for project-specific use statewide (B.4). For summary descriptions of the approved Design Prevention BMPs, see Appendix C.

Table 5-1. Design Pollution Prevention BMPs [1]

Consideration of Downstream Effects Related to Potentially Increased Flow
Peak Flow Attenuation Basins
Preservation of Existing Vegetation
Concentrated Flow Conveyance Systems
Ditches, Berms, Dikes and Swales
Overside Drains
Flared Culvert End Sections
Outlet Protection Velocity Dissipation Devices
Slope/Surface Protection Systems
Vegetated Surfaces
Hard Surfaces

[1]BMP lists and categories are dynamic. New and modified BMPs will be identified in the Annual Report.

The Department also designs vegetative surfaces on completed slope/surface areas to minimize erosion and provide permanent stabilization. These vegetative BMPs are designed to provide long-term sustainability consistent with site conditions and maintenance requirements (A.7).

To help ensure that the Department meets its goal to incorporate appropriate Design Pollution Prevention BMPs into its projects, the Department provides opportunities for comment from RWQCB staff during the project planning and design phases (see Section 5.4.1). Approved Design Pollution Prevention BMPs, as listed in Table 5-1, are incorporated into projects. However, Districts may propose incorporating a non-approved Design Pollution Prevention BMP as a pilot project (see Section 4.3). The appropriate Headquarters' (HQ) functional units must approve such proposals prior to incorporation of the proposed BMP as a pilot project.

5.3.2 Incorporation of Treatment BMPs into Projects

During the project planning and design process, the Project Engineer will incorporate treatment BMPs to the MEP for all projects subject to the statewide permit, and which meet the following criteria (A.8):

Table 5-2. Threshold for Implementation of Structural Treatment BMPs into Department Projects

Project Category	Threshold – Net Additional Impervious Area (2)
Non- Highway Facilities (Rest Areas and Vista Points, Park and Ride Lots, Maintenance and support facilities)	43,560 square feet (1 acre) or local SUSMP impervious area requirement.
Highways (1) (3)	43,560 square feet (1 acre)

(1) Pedestrian/bike path projects do not require treatment BMPs.

(2) If the net impervious area constitutes 50 percent or more of the original facility, then post-construction BMPs will be designed for the entire facility.

(3) Emergency projects are exempt from treatment BMPs based on the immediate need to provide service and protection for the public.

The Department may also have stand-alone projects to construct treatment BMPs to meet location specific pollution control requirements (see Section 13).

Table 5-3. Approved Treatment BMPs [1]

Biofiltration: Strips/Swales
Infiltration Devices
Detention Devices
Traction Sand Traps
Dry Weather Flow Diversion
Media filters
Multi-Chamber Treatment Trains
Wet Basins
Gross Solids Removal Devices

[1]BMP lists and categories are dynamic. New and modified BMPs will be identified in the Annual Report.

The approved treatment BMPs listed in Table 5-3 are fiscally reasonable and technically feasible when project site conditions are favorable. The Department's research program has generally determined these BMPs to be constructible, maintainable, and effective at removing pollutants to the MEP, provided the appropriate siting and design criteria are satisfied. For summary descriptions of the approved treatment BMPs, see Appendix C.

Typically, approved treatment BMPs as described herein are incorporated into projects. However, if project conditions prohibit the use of approved BMPs, then the District may propose incorporating a non-approved BMP as a pilot project (see Section 4.3). The appropriate Headquarters' (HQ) functional units must approve such proposals prior to incorporation of a non-approved BMP as a pilot project. The Department provides opportunities for comment from RWQCB staff by identifying the status of treatment control designs for the projects listed in the DWPs (See Section 16). If requested by the RWQCB staff, the Department reviews the projects with the RWQCB staff.

5.3.2.1 Sizing Treatment BMPs

For water quality treatment purposes, the volume of water to be treated is referred to as the Water Quality Volume (WQV), and the flow rate to be treated is the Water Quality Flow (WQF). The WQV of treatment BMPs are based on using any one of the following options:

INDIANA

Final Report

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ASSESSMENT AND SELECTION OF STORMWATER BEST MANAGEMENT PRACTICES FOR HIGHWAY CONSTRUCTION, RETROFITTING, AND MAINTENANCE

By

Lynn A. Corson
Director
Indiana Clean Manufacturing Technology and
Safe Materials Institute
School of Civil Engineering
Purdue University

Joint Transportation Research Program
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Conducted in Cooperation with the
Indiana Department of Transportation
and the U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Indiana Department of Transportation or the Federal Highway Administration at the time of publication. The report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, IN 47907
October 2006

In consideration of the types of projects that INDOT typically undertakes, BMPs were classified into linear and non-linear applications. Linear projects are those whose right-of-way is generally at or below standard clear zone requirements. Non-linear projects are those that require additional right-of-way to incorporate additional features (e.g. interchanges, rest stops, maintenance facilities). Linear and non-linear stormwater BMPs used during the Construction phase are further categorized by whether the water quality practice relies on the mechanism of erosion control or sediment control. The *Post-Construction BMP Selection Matrix* is a 3-step filtering process used to determine the most appropriate BMP, or group of BMPs to address Stormwater runoff. *Step 1* addresses physical feasibility factors and allows the designer to determine whether development site conditions such as area requirements, soils, terrain, depth to water table, drainage area, head, or whether the site is ultra-urban. Those BMPs that are not eliminated in *Step 1* are considered in *Step 2*, stormwater treatment suitability. Each remaining BMP is rated based on its effectiveness to provide water quantity and water quality benefits. BMPs that remain after *Step 2* are considered in *Step 3*. This final step considers community and environmental factors including construction costs, maintenance, community acceptance and benefit for wildlife habitat.

A BMP fact sheet was developed for each Construction and Post-Construction BMP identified. The fact sheets are intended to provide more detailed information about each BMP. Each Construction Phase BMP fact sheet includes quick reference bullet points that identify when to use, advantages,

A. CONSTRUCTION PHASE EROSION CONTROL BMP PRACTICES APPROPRIATE FOR LINEAR and NON-LINEAR PROJECTS

Suggested BMPs	Fact Sheet	Installation Cost	Maintenance	Water Quantity Benefit		Water Quality Benefit					
						Pollution Prevention Benefit		Pollutant Removal			
				Rate Control	Volume Reduction	Erosion Control	Sediment Control	TSS	P&N	Metals	Fecal Coliform
Grading	CEC-1	\$3.50-12.00/cys (3)	Medium	Varies	Varies	Primary	N/A	Some	Some	Some	No
Soil Roughening	CEC-2	\$0.10 – \$0.50/sy	Low	Some	No	Primary	N/A	No	No	No	No
Sequencing	CEC-3	Varies (4)	N/A	No	No	Primary	Primary	Some	Some	Some	No
Straw Bale Ditch Check	CEC-4	\$4.00-\$8.00/lf	High	Some	No	Primary	N/A	Yes	Some	Some	No
Fiber Wattle Roll Ditch Check	CEC-5	\$6.00-\$8.00/lf	Medium	Some	No	Primary	N/A	Yes	Some	Some	No
Straw Mulch	CEC-6	\$0.20 - \$0.40/sy	Low	Some	No	Primary	N/A	Some	Some	No	No
Bonded Fiber Matrix (BFM Mulch)	CEC-7	\$1.50 - \$2.50/sy	Low	Some	No	Primary	N/A	Some	Some	No	No
Erosion Control Blanket	CEC-8	\$1.00 - \$2.50/sy	Low	Some	No	Primary	N/A	Some	Some	No	No
Native Seeding (Temporary)	CEC-9	\$0.50-\$1.00/sy	Medium	Some	Some	Primary	N/A	Some	Some	No	No
Surface Water Diversion	CEC-10 CEC-11 CEC-12	Varies	Medium	No	No	Primary	N/A	No	No	No	No
Turbidity Curtain	CEC-13	\$15-25/sy	Medium	No	No	N/A	Primary	No	No	No	No
Riprap	CEC-14	Varies	Medium	No	No	Primary	Varies	No	No	No	No

TSS = Total Suspended Solids; P&N = Phosphorus & Nitrogen; Primary = Primary Design Benefit

B. CONSTRUCTION PHASE SEDIMENT CONTROL BMP PRACTICES APPROPRIATE FOR LINEAR PROJECTS

Suggested BMPs	Fact Sheet	Installation Cost	Maintenance	Water Quantity Benefit		Water Quality Benefit					
						Pollution Prevention Benefit		Pollutant Removal			
				Rate Control	Volume Reduction	Erosion Control	Sediment Control	TSS	P&N	Metals	Fecal Coliform
Vehicle Tracking Pads	CSC-1	$2000-4000/each[2]	High	No	No	Secondary	Primary	Some	Some	Some	No
Silt Fences	CSC-2	$1.00-3.00/lft	High	Some	No	N/A	Primary	No	No	No	No
Inlet Protection	CSC-3	$50-150/inlet	High	No	No	N/A	Primary	Yes	Some	Some	No
Sediment Trap	CSC-4	$1,000 - $1,500/per acre of drainage	High	Some	Some	N/A	Primary	Yes	Some	Some	No
Rock Check Dam	CSC-5	$20-40/ton	High	Some	Some	N/A	Primary	Yes	Some	Some	No

TSS = Total Suspended Solids; P&N = Phosphorus & Nitrogen; Primary = Primary Design Benefit

C. CONSTRUCTION PHASE SEDIMENT CONTROL BMP PRACTICES RESERVED FOR NON-LINEAR PROJECTS

Suggested BMPs	Fact Sheet	Installation Cost	Maintenance	Water Quantity Benefit		Water Quality Benefit					
						Pollution Prevention Benefit		Pollutant Removal			
				Rate Control	Volume Reduction	Erosion Control	Sediment Control	TSS	P&N	Metals	Fecal Coliform
Sediment Basin	CSC-6	$20-30/ton material removed	High	Some	Some	Primary	Primary	Yes	Some	Some	No

TSS = Total Suspended Solids; P&N = Phosphorus & Nitrogen; Primary = Primary Design Benefit

Notes:

(1) Adapted from the Minnesota Metropolitan Council's "Urban Small Sites Best Management Practice Manual" http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm
(2) Assumes 50-ft long entrance with 30-ft radii at main roadway, 3" No. 53 stone over 12" No 2 stone.
(3) Assumes earthwork is Common Excavation. Price would increase for factors such as wetness, or environmental contamination.
(4) Cost is usually not paid for directly, but hidden amongst the cost of various pay items. More detailed sequencing requirements will usually result in higher cost.

Overview of Common Post-Construction BMP Practices [1]

BMP Group	Fact Sheet(s)	Treatment Mechanism	Common Characteristics	Linear BMPs	Non-Linear BMPs	Effective Years of Life [3]
Detention Systems [2]	PSC-1 PSC-2 PSC-3 PSC-4	Particulate settling	Adequate hydrology and soils required	Dry Swale	Wet Pond Extended Detention Pond Dry Pond	Ponds: 20-50 Swale: 5-20
Constructed Wetlands [2]	PSC-5 PSC-6	Particulate settling Biological filtering	Adequate hydrology and soils required	Stormwater Wetland Wet Swale	Stormwater Wetland	Wetland: 20-50 Swale 5-20
Infiltration Systems	PSC-7 PSC-8	Adsorption Biodegradation Precipitation	Adequate soil media critical	Infiltration Trench	Infiltration Basin	5-15
Filtration Systems	PSC-9 PSC-10 PSC-11 PSC-12	Straining Adsorption Chemical transformation Microbial decomposition	Effective suspended solids removal	Bioretention Filter Strip Turf Reinforcement Mat (TRM) [4] Native Seeding (permanent) [4]	Bioretention Filter Strip Turf Reinforcement Mat (TRM) [4] Native Seeding (permanent) [4]	5-20
Water Quality Structures	PSC-13	Settling Buoyancy of oils & floatables	Pretreatment	Hydrodynamic Separators	Hydrodynamic Separators	50-100

(1) Adapted from "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring", Federal Highway Administration http://www.fhwa.dot.gov/environment/ultraurb/uubmp3p1.htm)
(2) Assumes pretreatment with a sediment forebay (ponds and wetlands)
(3) Assumes effective regular maintenance is performed
(4) Not a stand alone post-construction BMP. Can increase the effectiveness of other BMPs when incorporated into their design and construction.

THREE-STEP PROCESS FOR BMP SELECTION

The following outlines a process for selecting the best stormwater treatment BMP or group of BMPs to meet water quality and water quantity requirements as well as factors to consider for BMP placement. This outline guides the designer through a three step process adapted from Minnesota Metropolitan Council's "Urban Small Sites Best Management Practice Manual" and Maryland Department of the Environment's "Maryland Stormwater Design Manual". The steps progressively screen for:

- Physical Feasibility Factors
- Stormwater Treatment Suitability
- Community and Environmental Factors

The above noted reference documents are available online (as of November 2005) at the following web address links: http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm and http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Step 1: Physical Feasibility Factors

The first step addresses and allows the designer to determine whether development site conditions such as soils, terrain, depth to water table, drainage area, slope or head conditions, and area requirements will limit the use of a particular BMP.

<u>Area Requirements</u> – Linear or non-linear area requirements.
<u>Soils</u> – Evaluation of soils is based on USDA or NRCS hydrological soils group at the site.
<u>Water Table</u> – Indicates the minimum depth to the seasonally high water table from the bottom or floor of a BMP.
<u>Drainage Area</u> – Refers to the drainage area that is considered typical for the BMP.
<u>Head</u> – Estimate of the elevation difference needed at a site (from inflow to outflow).
<u>Ultra-Urban Sites</u> –BMPs that work well in urban environments, where space is limited and original soils have been disturbed.

Step 2: Stormwater Treatment Suitability:

Using those BMPs that are not eliminated in step one, identify BMPs effective at providing water quantity and water quality benefits. These include rate control, volume reduction, and percent removal of total suspended solids, phosphorus, nitrogen, metals, and fecal Coliform.

<u>Water Quantity</u> – Effectiveness of the BMP to control the rate and volume of stormwater runoff.
<u>Water Quality</u> – Indicates a BMPs ability to remove Total Suspended Solids (TSS), Phosphorus (P), Nitrogen (N), Metals, and fecal Coliform from stormwater runoff.
<u>Accept Hotspot Runoff</u> – Ability of the BMP to treat stormwater runoff from land uses that may produce highly polluted runoff (gas stations, maintenance facilities, salvage yards, and industrial sites).

Step 3: Community and Environmental Factors

The remaining BMPs are then filtered through the third step. This step considers: frequency and cost of maintenance, construction cost, community acceptance, and benefit to wildlife.

Construction Cost – Represents base capital costs for BMP installation to treat stormwater runoff from a 5 acre site.

Low = $0 - $10,000 for application of BMP on 5 acre site.
Medium = $10,001 - $20,000 for application of BMP on 5 acre site.
High = $20,000+ for application of BMP on 5 acre site.

Maintenance – Assesses the relative maintenance needed for a BMP based on frequency and cost of maintenance.
Community Acceptance – The community's acceptance of a BMP based on nuisance problems, visual orientation, and community preference surveys.
Wildlife Habitat – Ability to provide wildlife or wetland habitat based on size, water feature, wetland feature, and vegetative cover.

STEP 1 – PHYSICAL FEASIBILITY FACTORS

Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP?

BMP Group	Specific BMP	Area Requirements	Soil Groups	Terrain	Water Table[(1)] (ft)	Drainage Area[(2)] (acre)	Head[(2)] (ft)	Ultra Urban
Detention Systems	Wet Pond	Non-linear	C,D	Low lying areas (liner for karst areas)	3	>2	3-6	No
	Extended Detention Pond	Non-linear						
	Dry Pond	Non-linear	Any[(3)]	Low lying areas	3	>2	3-8	
	Dry Swale	Linear	Any	Moderate slope	3	2-4	2-6	
Constructed Wetlands	Stormwater Wetland	Linear	Any[(4)]	Low lying areas	0	>1	1-8	No
	Wet Swale	Linear	Any	Moderate slope	0	<4	2-3	
Infiltration Systems	Infiltration Trench	Linear	A,B	No karst areas	3	2-4	3-8	Sometimes
	Infiltration Basin	Non-linear	A,B	No karst areas	3	2-20	3-4	No
Filtration Systems	Bioretention	Linear	Any	Low lying areas	3	2-4	2-3	Yes
	Filter Strip	Linear	Any	Moderate slopes	3	<5	Negligible	No
	Turf Reinforcement Mat (TRM)[(5)]	Linear	Any	Any	N/A	N/A	N/A	Yes
	Native Seeding (permanent)[(5)]	Linear	Any	Moderate Slope	N/A	All	N/A	Yes
Water Quality Structures	Hydrodynamic Separators	Linear	Any	Any	>3	Varies[(6)]	Varies by vendor	Yes

(1) Recommended minimum elevation above water table. Special consideration should be given if anticipated pollutant includes bacteria or other harmful constituents to drinking water or groundwater

(2) Adapted from "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring", Federal Highway Administration http://www.fhwa.dot.gov/environment/ultraurb/uubmp3p1.htm)

(3) When dry ponds are installed in C or D type soils, the bottom of the basin should be sloped to allow for complete dewatering and avoid ponded areas. Perforated tile underdrains may also be installed for dewatering.

(4) Below water table.

(5) Not a stand alone post-construction BMP. Can increase the effectiveness of other BMPs when incorporated into their design and construction.

(6) Due to the increasing number of manufacturers of proprietary water quality structures, the upper limit of drainage area may vary from 2 to 300 acres.

STEP 2 – STORMWATER TREATMENT SUITABILITY

Do the BMP(s) from Step 1 provide needed water quantity and water quality benefit?

Suggested BMPs		Water Quantity Benefit		Water Quality Benefit[1] % Removed					Accept Hotspot Runoff
BMP Group	Specific BMP	Rate Control	Volume Reduction	TSS	P	N	Metals	Fecal Coliform	
Detention Systems	Wet Pond Extended Detention Pond	High	Low	46-98	20-94	28-50	24-89	N/A	Varies
	Dry Pond	High	Varies[2]	67-93	75-94	N/A	N/A	N/A	Varies
	Dry Swale	Medium	Low	30-90	20-85	0-50	0-90	N/A	Yes
Constructed Wetlands	Stormwater Wetland	High	Low	65	25	20	35-65	N/A	No
	Wet Swale	Low	Low	65	25	20	35-65	N/A	No
Infiltration Practices	Infiltration Trench	Medium	High	75-99	50-75	45-70	75-99	75-98	No
	Infiltration Basin	Medium	High	75-99	50-75	45-70	50-90	75-98	No
Filtration Systems	Bioretention	Medium	Medium	75	50	50	75-80	N/A	Yes
	Filter Strip	Medium	Medium	27-70	20-40	20-40	2-80	N/A	Yes
	Turf Reinforcement Mat (TRM)[5]	Low	Low	81[4]	9[4]	38[4]	42-71[4]	N/A	No
	Native Seeding (permanent)[5]	Low	Low	81[4]	9[4]	38[4]	42-71[4]	N/A	No
Proprietary Systems[3]	Hydrodynamic Separators	None	None	80-90	N/A	N/A	N/A	N/A	Yes

(1) Adapted from "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring", Federal Highway Administration http://www.fhwa.dot.gov/environment/ultraurb/uubmp3p1.htm)
(2) Dry pond volume reduction highly dependent on soil permeability.
(3) Not a stand alone post-construction BMP. Can increase the effectiveness of other BMPs when incorporated into their design and construction.
(4) Median percent removal for vegetates swales from United States Environmental Protection Agency Office of Water. EPA 832-F-99-006 Storm Water Technology Fact Sheet Vegetated Swales September 1999.
(5) Due to variability of units, refer to independent data supplied by manufacturer.

STEP 3 – COMMUNITY & ENVIRONMENTAL FACTORS

Are there important community or environmental factors that might influence the selection process of the remaining BMPs?

BMP Group	Specific BMP	Construction Cost (5-acre site)[1]	Maintenance		Community Acceptance	Wildlife Habitat
			Frequency	Annual Cost (based on Construction Cost)[1]		
Detention Systems	Wet Pond	Low	Annual	3-5%	Moderate	Medium
	Extended Detention Pond	Low	Annual	3-5%	Moderate	Medium
	Dry Pond	Low	Mowing Schedule	5-7%	Moderate	Low
	Dry Swale	Low	Annual	3-5%	Moderate	Low
Constructed Wetlands	Stormwater Wetland	Medium	Annual	5-7%	Moderate to High	High
	Wet Swale	Medium	Mowing Schedule	5-20%	Moderate	Medium
Infiltration Systems	Infiltration Trench	High	Biannual	5%-7%	Moderate to High	None
	Infiltration Basin	Medium	Biannual	5-20%	Moderate	Low
Filtration Systems	Bioretention	High	Mowing Schedule	5-7%	Moderate	Medium
	Filter Strip	Low	Mowing Schedule	5-7%	High	Medium
	Turf Reinforcement Mat (TRM)	Medium	Meeting Schedule	1-5%	High	Medium
	Native Seeding (permanent)	Low	Annual	1-5%	High	Medium
Water Quality Structures	Hydrodynamic Separators	High	Biannual	1-5%	High	None

1. United States Environmental Protection Agency, Office of Water. EPA-821-R-99-012: Preliminary Data Summary of Urban Storm Water Best Management Practices-Chapter 6: Costs and Benefits of Stormwater BMPs, August 1999.
2. United State Environmental Protection Agency, Office of Water. EPA-821-99-002: Stormwater Technology Fact Sheet Turf Reinforced Mats, September 1999

APPENDIX 4

POST-CONSTRUCTION BMP FACT SHEETS

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

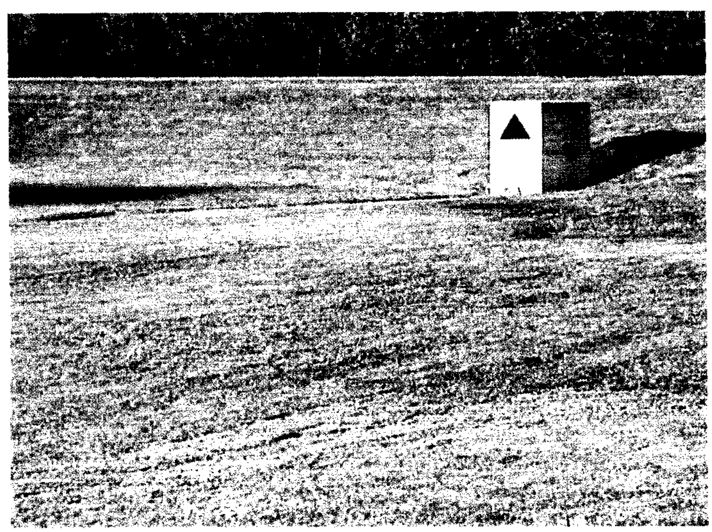
Dry Pond

When to use:
- In hydrologic soil types A and B or in C and D soil with sloped bottom or underdrains
- In low lying areas
- Water table is at least 3 feet below the pond bottom
- Drainage area of at least 2 acres
- Hydraulic head of 3 to 8 feet
- Not practical for use in ultra urban settings
- Cannot be placed on steep or unstable slopes

BMP Type:	Retention/Detention – Non-Linear
TSS Removal:	67-93%
Nitrogen Removal:	N/A
Phosphorous Removal:	75-94%
Metal Removal:	N/A
E. coli Removal:	N/A
Runoff Volume Control:	Varies
Runoff Rate Control:	High
Annual Maintenance Cost:	5-7%[1]
Relative Construction Cost:	Low
Effective Life:	20-50 years

[1] Reported as a percentage of Construction Cost

Advantages:
- Can achieve 80% TSS removal as a stand alone BMP
- Variable ability to accept pollutants from offsite hotspots
- Low construction cost
- Low to moderate maintenance costs
- Moderate community acceptance
- Provides water quantity benefit in the form of runoff rate control
- Long effective life
- Can act as sediment trap/basin during construction phase
- Excellent retrofit opportunity for existing dry ponds
- Typically requires less excavation than wet ponds


Virginia DCR, 1999

Limitations:
- Requires additional right-of-way beyond standard clear zone limits
- Removal rates vary widely depending on site conditions and storm events
- Low wildlife habitat benefit
- Minimum set-back from high water level required (see local codes)
- Heavy storms may resuspend sediments

Dry Pond

Description:

Dry ponds, also called "detention ponds," are stormwater basins that are designed to intercept a volume of stormwater runoff and temporarily impound the water for gradual release to the receiving stream or storm sewer system. Traditional dry pond designs do not provide much water quality benefit. However, with a few modifications, dry ponds can be very effective at removing pollutants. Extended detention dry ponds can be designed as two-stage facilities. In these cases, the upper stage stores and reduces flood peaks and the lower stage is designed for water quality control. The lower stage volume may be able to treat a certain depth of water over the impervious area, such as 0.5 inch or a design storm frequency, such as the 1-year 24-hour storm event. Following storm events, dewatering times typically range between 24 and 48 hours. This residence time may allow for greater than 90 percent removal of particulates through settling. A shallow marsh or wetland may be incorporated into the design to facilitate removal of nitrogen and phosphorus. The incorporation of a forebay, energy dissipator, or pretreatment facility before flow enters the pond from a channel or pipe is important to lessen the impact of sediment and grit on the pond and to facilitate pond maintenance. When dry ponds are installed in C or D type soils, the bottom of the basin should be sloped to allow for complete dewatering and avoid ponded areas. Perforated tile underdrains may also be installed for dewatering.

Drawings:

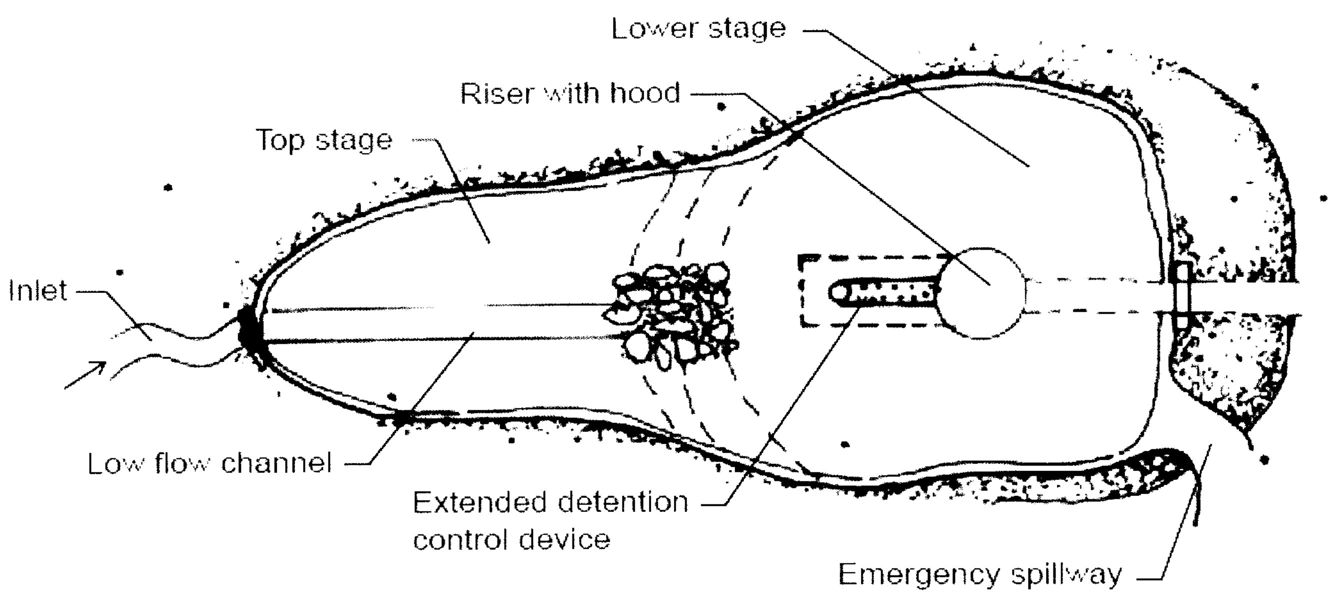


Figure 1: Dry Extended Detention Pond – Plan View
(NRCS, 2003)

Dry Pond

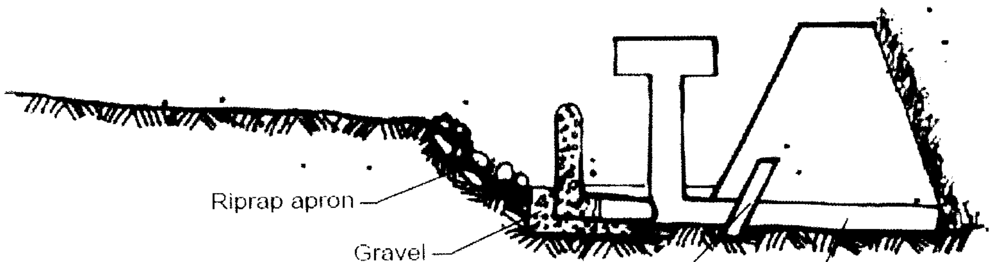


Figure 2: Dry Extended Detention Pond – Section View
(NRCS, 2003)

Reference:

NRCS, 2003. *Urban BMPs – Water Runoff Management.* NRCS Watershed Science Institute with Mississippi State University Center for Sustainable Design.
http://www.wsi.nrcs.usda.gov/products/UrbanBMPs/water.html

Virginia DCR, 1999. *Virginia Stormwater Management Handbook.* Commonwealth of Virginia, Department of Conservation and Recreation.
http://www.dcr.state.va.us/sw/stormwat.htm#handbook

Extended Detention Pond With Micropool

When to use:
- In hydrologic soil types C and D or with a clay liner
- In low lying areas
- Water table is at least 3 feet below the pond bottom
- Drainage area of at least 2 acres
- Hydraulic head of 3 to 6 feet
- Not practical for use in ultra urban settings
- Cannot be placed on steep or unstable slopes

Advantages:
- Can achieve 80% TSS removal as a stand alone BMP
- Variable ability to accept pollutants from hotspots
- Low construction cost
- Low to moderate maintenance cost
- Moderate community acceptance
- Medium wildlife habitat benefit
- Provides water quantity benefit in the form of runoff rate control
- Long effective life
- Can act as sediment trap/basin during construction phase
- Excellent retrofit opportunities for existing dry or wet ponds

Limitations:
- Requires additional right-of-way beyond standard clear zone limits
- Removal rates vary widely depending on site conditions and storm events
- Minimum set-back from high water level required (see local codes)
- Heavy storms may resuspend sediments
- Potential for mosquito breeding areas
- Adequate source of water needed to maintain permanent water pool areas year round
- Water can become stagnant
- Evaporation can concentrate levels of salt and algae
- Embankment may be regulated as a dam by IDNR

BMP Type:	Retention/Detention – Non-Linear
TSS Removal:	46-98%
Nitrogen Removal:	28-50%
Phosphorous Removal:	20-94%
Metal Removal:	N/A
E. coli Removal:	N/A
Runoff Volume Control:	Varies
Runoff Rate Control:	High
Annual Maintenance Cost:	5-7%[1]
Relative Construction Cost:	Low
Effective Life:	20-50 years

[1] Reported as a percentage of Construction Cost

Center for Watershed Protection, 2000

Extended Detention Pond With Micropool

Description:
Typical extended detention pond configurations include shallow wetlands or small ponding areas in combination with dry areas, along with the incorporation of a micropool at the outlet (Figure 1). Extended detention ponds with micropools incorporate a permanent pool component that is absent in dry ponds. However, they differ from wet ponds in the amount of the overall basin dedicated to the permanent pool. Runoff is treated by settling and algal uptake in the forebay and micropool. Pollutant removal occurs through settling, biological activity, and adsorption in the areas lateral to the permanent pool. If a shallow wetland is incorporated into the design, microbial breakdown of pollutants can be added to the list of pollutant removal mechanisms.

Drawings:

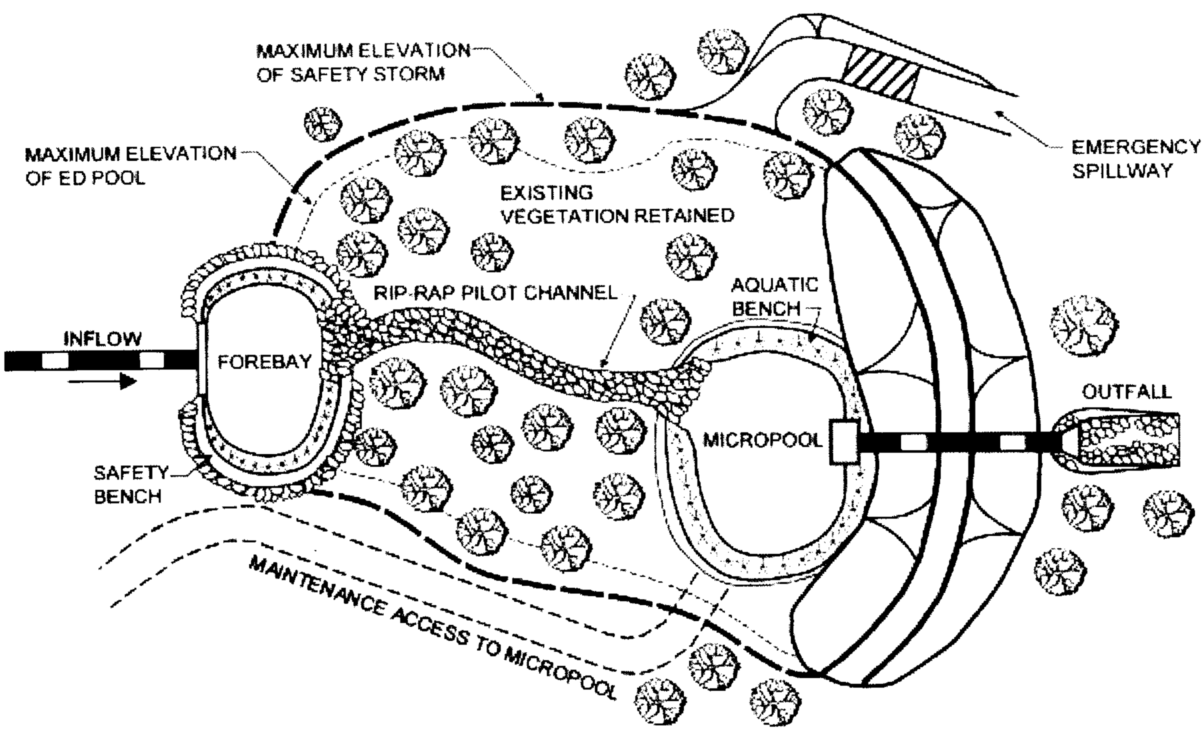


Figure 1: Typical Extended Wet Detention – Plan View
(with shallow wetland and micropool options)
(Georgia Stormwater Management Manual, 2001)

Extended Detention Pond With Micropool

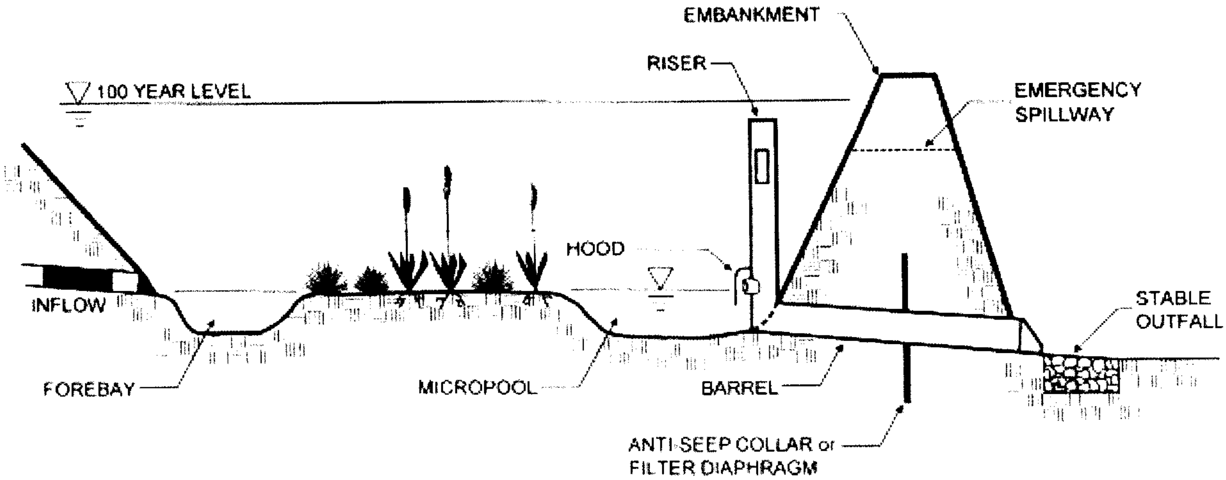


Figure 2: Typical Extended Wet Detention – Section View (with shallow wetland and micropool options)
(Modified from Georgia Stormwater Management Manual, 2001)

References:

Georgia Stormwater Management Manual, 2001. Volume 2, Section 3.2.1.
http://www.georgiastormwater.com/

Center for Watershed Protection, Stormwater Manager's Resources Center, 2000
http://www.stormwatercenter.net/

Wet Pond

When to use:

- In hydrologic soil types C and D or with clay liner
- In low lying areas
- Water table is at least 3 feet below the pond bottom
- Drainage area of at least 2 acres
- Hydraulic head of 3 to 6 feet
- Not practical for use in ultra urban settings
- Cannot be placed on steep or unstable slopes

Advantages:

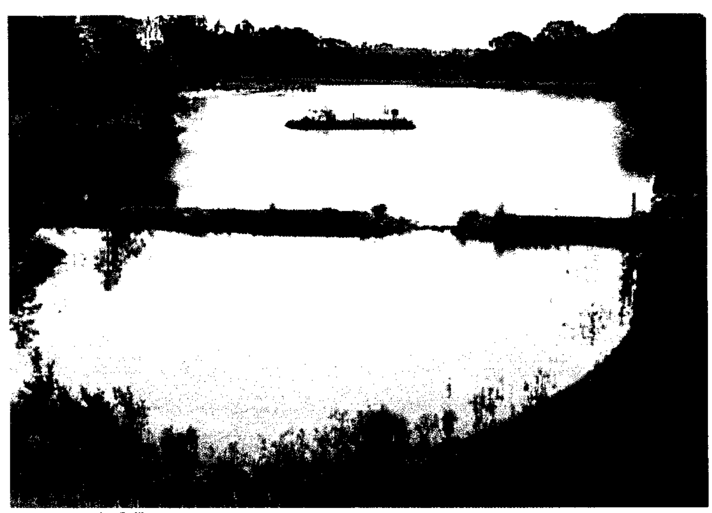
- Can achieve 80% TSS removal as a stand alone BMP
- Variable ability to accept pollutants from hotspots
- Low construction cost
- Low to moderate maintenance cost
- Moderate community acceptance
- Medium wildlife habitat benefit
- Provides water quantity benefit in the form of runoff rate control
- Long effective life
- Can act as sediment trap/basin during construction phase
- Retrofit opportunities for existing wet ponds
- Large sediment storage volume below water

Limitations:

- Requires additional right-of-way beyond standard clear zone limits
- Removal rates vary widely depending on site conditions and storm events
- Minimum set-back from high water level required (see local codes)
- Heavy storms may resuspend sediments
- Potential for mosquito breeding areas
- Adequate source of water needed to maintain permanent water pool areas year round
- Water can become stagnant
- Evaporation can concentrate levels of salt and algae
- Embankment may be regulated as a dam by IDNR

BMP Type:	Retention/ Detention – Non-Linear
TSS Removal:	46-98%
Nitrogen Removal:	28-50%
Phosphorous Removal:	20-94%
Metal Removal:	24-89%
E. coli Removal:	N/A
Runoff Volume Control:	Low
Runoff Rate Control:	High
Annual Maintenance Cost:	3-5%[1]
Relative Construction Cost:	Low
Effective Life:	20-50 years

[1] Reported as a percentage of Construction Cost



Virginia DCR, 1999

Wet Pond

Description:
The wet pond is a facility which removes sediment, organic nutrients, and trace metals from stormwater runoff. This is accomplished by slowing down stormwater using an in-line permanent pool or pond effecting settling of pollutants. The wet pond is similar to a dry pond, except that a permanent volume of water is incorporated into the design. 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.

The permanent pool is usually maintained at a depth between 6 and 8 ft. High pollutant removal efficiencies for sediment, phosphorus, and nitrogen are achievable when the volume of the permanent pool is at least three times the water quality volume (the volume to be treated). 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.

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 exfiltrate 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 geosynthetic or clay liner may be necessary.

Drawings:

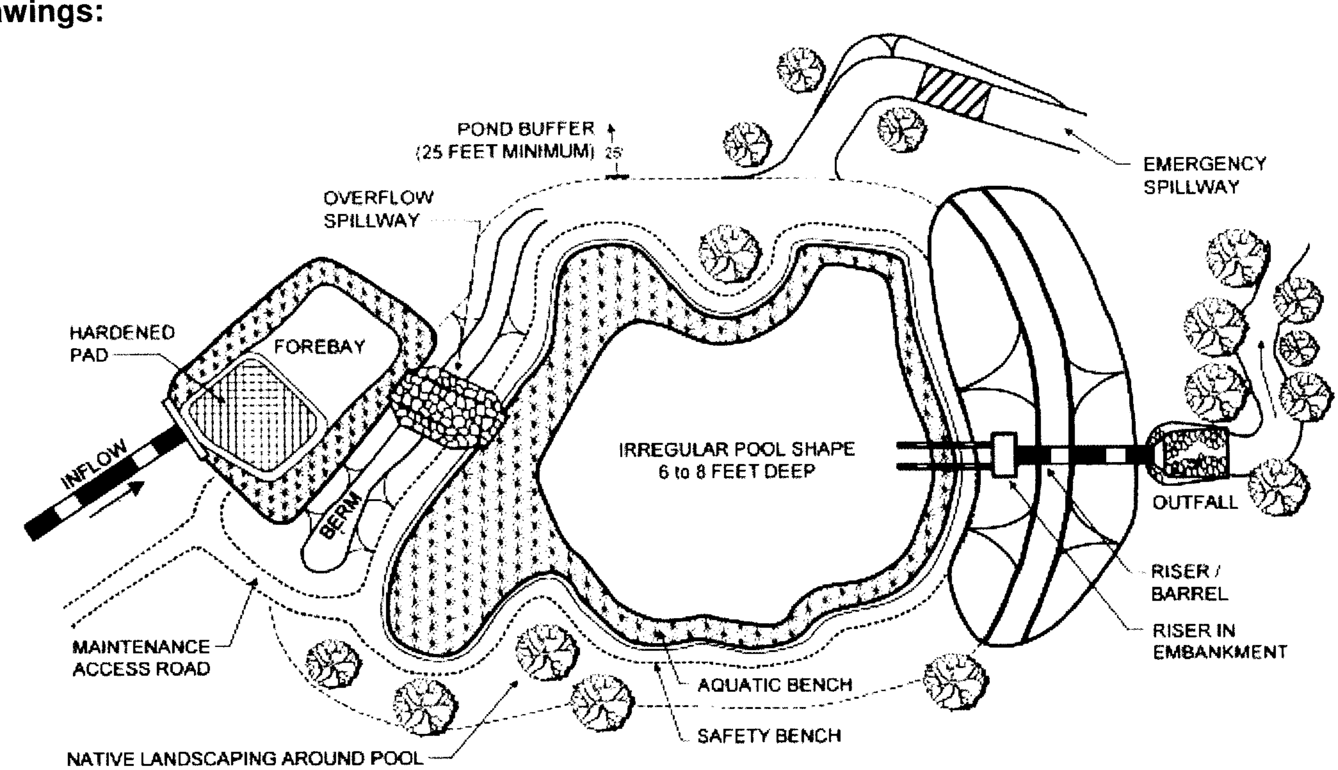


Figure 1: Typical Wet Pond with Wetland Perimeter – Plan View
(Georgia Stormwater Management Manual, 2001)

Wet Pond

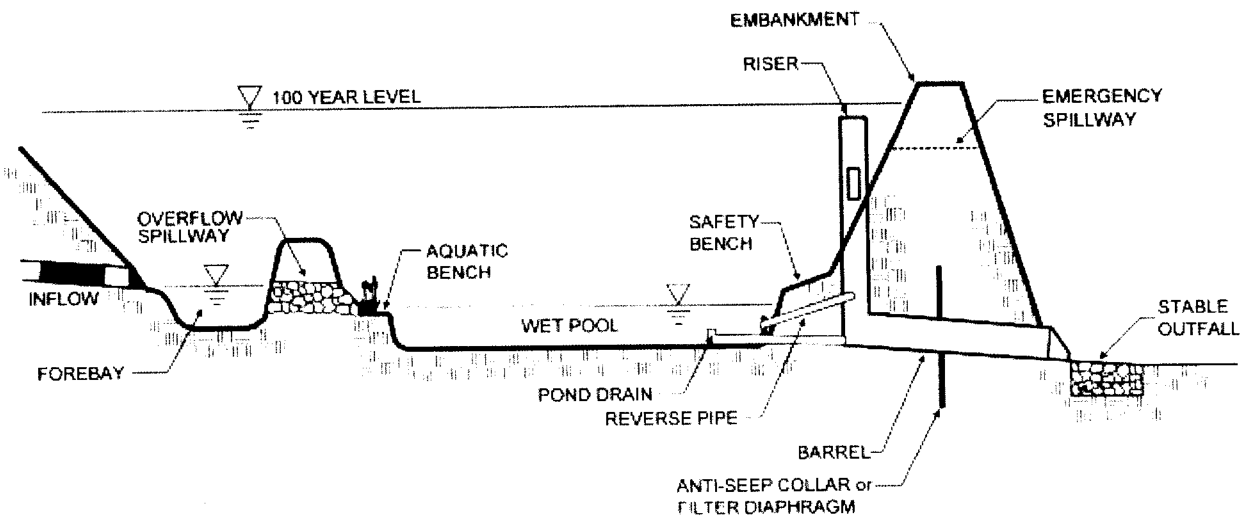


Figure 1: Typical Wet Pond – Section View
(Modified from Georgia Stormwater Management Manual, 2001)

References:

Georgia Stormwater Management Manual, 2001. Volume 2, Section 3.2.1.
http://www.georgiastormwater.com/

Virginia DCR, 1999. *Virginia Stormwater Management Handbook.* Commonwealth of Virginia, Department of Conservation and Recreation.
http://www.dcr.state.va.us/sw/stormwat.htm#handbook

PADEP, 2005. *Draft Pennsylvania Stormwater Management Manual, Section 6.* Pennsylvania Department of Environmental Protection.
http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section06-StructuralBMPs-part1.pdf

Dry Swale

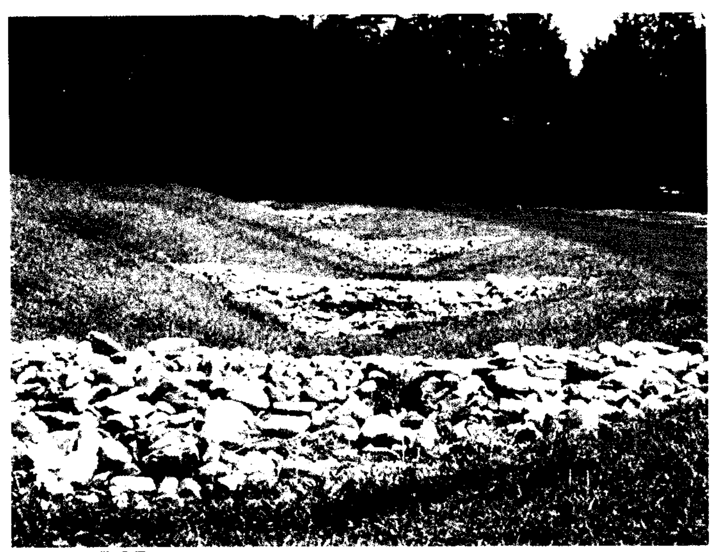
When to use:
- Any soil type
- Water table is at least 3 feet below the swale invert
- Drainage area of 2 to 4 acres
- Hydraulic head of 2 to 6 feet
- Not practical for use in ultra urban settings
- Cannot be placed on steep or unstable slopes

Advantages:
- Can achieve 80% TSS removal as a stand alone BMP
- Can accept pollutants from offsite hotspots
- Low construction cost
- Low maintenance cost
- Moderate community acceptance
- Relatively easy to design, install and maintain

Limitations:
- Removal rates vary widely depending on site conditions and storm events
- Minimum set-back from high water level required (see local codes)
- Heavy storms may resuspend sediments
- Potential for mosquito breeding areas
- Limited runoff quantity and rate control for small storm events
- Effective life may be reduced if not properly maintained
- Low wildlife habitat benefit
- Irrigation may be necessary to maintain vegetative cover

BMP Type:	Retention/ Detention - Linear
TSS Removal:	30-90%
Nitrogen Removal:	0-50%
Phosphorous Removal:	20-85%
Metal Removal:	0-90%
E. coli Removal:	N/A
Runoff Volume Control:	Low
Runoff Rate Control:	Medium
Annual Maintenance Cost:	3-5%[1]
Relative Construction Cost:	Low
Effective Life:	5-20 years

[1] Reported as a Percentage of Construction Cost


Virginia DCR, 1999

Dry Swale

Description:
Dry swales are engineered grassed channels that not only convey stormwater from a roadway but also provide water quality benefits. They can be sized to detain stormwater and address water quantity management needs. Dry swales are designed so that runoff infiltrates through the bottom of the swale into the ground below. The majority of the treatment is provided by the process of soil infiltration, which filters suspended solids and facilitates adsorption of dissolved pollutants. The subsoil must have appropriate permeability and infiltration rates. Treatment efficiency of dry swale designs is dependent on the gradient of the swale, the swale size, and the infiltration rate of the subsoils.

Swales are configured as on-line facilities. They provide effective treatment of small, frequent storms, but must still retain the ability to convey high runoff rates from the roadway when less frequent high-intensity storms occur. During these larger rainfall events, swales provide only marginal treatment of the high flow rates.

Drawings:

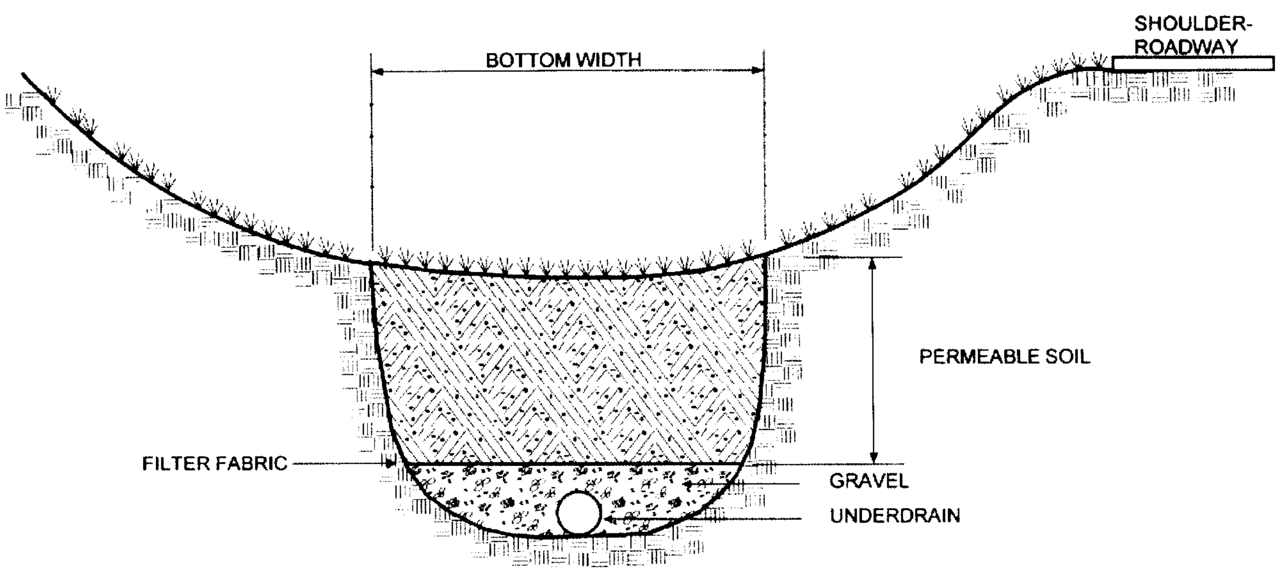


Figure 1: Typical Swale Configuration – Section View
(Modified From Center for Watershed Protection)

Dry Swale

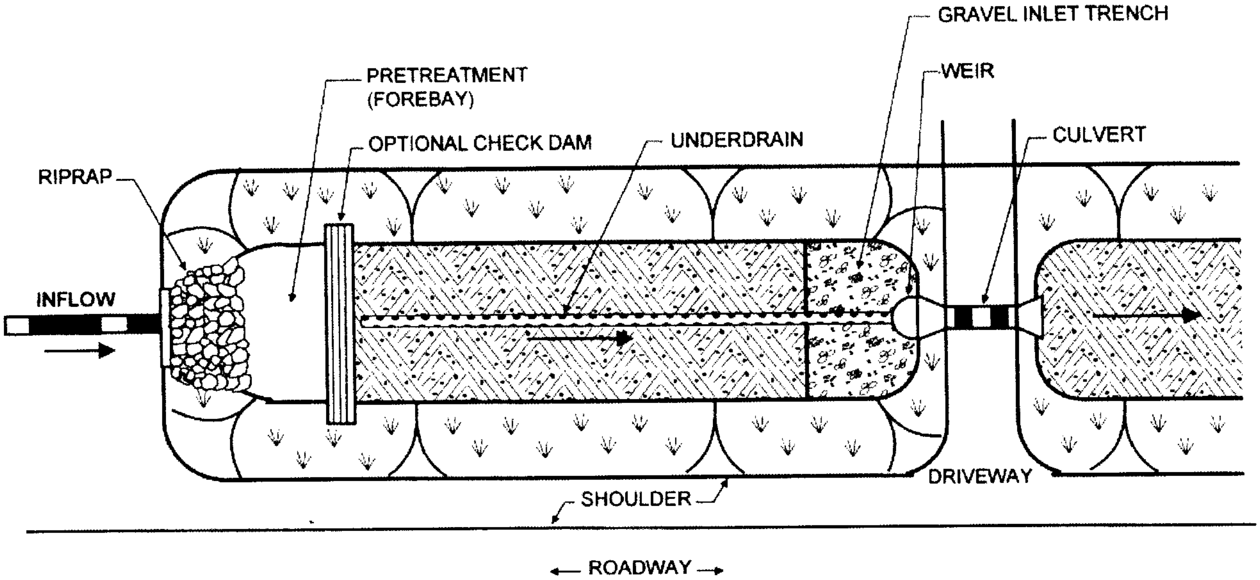


Figure 2: Typical Swale Configuration – Plan View
(Modified From Center for Watershed Protection)

References:

Center for Watershed Protection, Stormwater Manager's Resources Center, 2005, *Stormwater Management Fact Sheet, Grassed Channel.*
http://www.stormwatercenter.net/

Virginia DCR, 1999. *Virginia Stormwater Management Handbook*. Commonwealth of Virginia, Department of Conservation and Recreation.
http://www.dcr.state.va.us/sw/stormwat.htm#handbook

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Stormwater Wetland

When to use:
- Any soil type
- In low lying areas
- Water table at the surface of the proposed wetland bottom elevation.
- Drainage area a minimum of 1 acre.
- Hydraulic head of 1 to 8 feet.
- Not practical for use in ultra urban settings.

Advantages:
- Medium construction cost.
- Low to moderate maintenance cost.
- Moderate to high community acceptance.
- Provides water quantity benefit in the form of runoff rate control.
- High wildlife habitat benefit.
- Has long effective life.
- Can be used as a regional water quality facility.
- May be possible to use existing native seedbank (dormant seeds present in topsoil) in lieu of seeding

Limitations:
- Requires additional right-of-way beyond standard clear zone limits
- Does not achieve 80% TSS removal rates as a stand alone BMP but can be used in conjunction with other BMPs to achieve 80%
- Minimum set-back from high water level required (see local codes)
- Can not accept pollutants from offsite hotspots
- Can accumulate salts and scum which can be flushed out by large storm flows
- Maintenance, including plant harvesting, is required to provide nutrient removal
- Wetland may periodically become a nutrient source
- Hydrology must be adequate to sustain wetland vegetation.
- If native seedbank is inadequate, a qualified professional must select vegetation.

BMP Type:	Constructed Wetland - Linear
TSS Removal:	65%
Nitrogen Removal:	20%
Phosphorous Removal:	25%
Metal Removal:	35-65%
E. coli Removal:	N/A
Runoff Volume Control:	Low
Runoff Rate Control:	High
Annual Maintenance Cost:	5-7%[1]
Relative Construction Cost:	Medium
Effective Life:	20-50 years

[1] Reported as a percentage of Construction Cost

Virginia DCR, 1999

Stormwater Wetlands

Description:
Stormwater wetlands are constructed wetland systems designed to maximize the removal of pollutants from stormwater runoff via several mechanisms: microbial breakdown of pollutants, plant uptake, retention, settling and adsorption. Stormwater wetlands temporarily store runoff in shallow pools that support conditions suitable for the growth of wetland plants. Stormwater wetlands also promote the growth of microbial populations which can extract soluble carbon and nutrients and potentially reduce BOD and fecal coliform levels concentrations.

Stormwater quality wetlands differ from wetlands constructed for compensatory mitigation purposes and wetlands created for restoration. Typically, stormwater wetlands will not have the full range of ecological functions of natural wetlands; stormwater wetlands are designed specifically for flood control and water quality purposes. Similar to wet ponds, stormwater wetlands require relatively large contributing drainage areas and/or dry weather base flow.

Drawings:

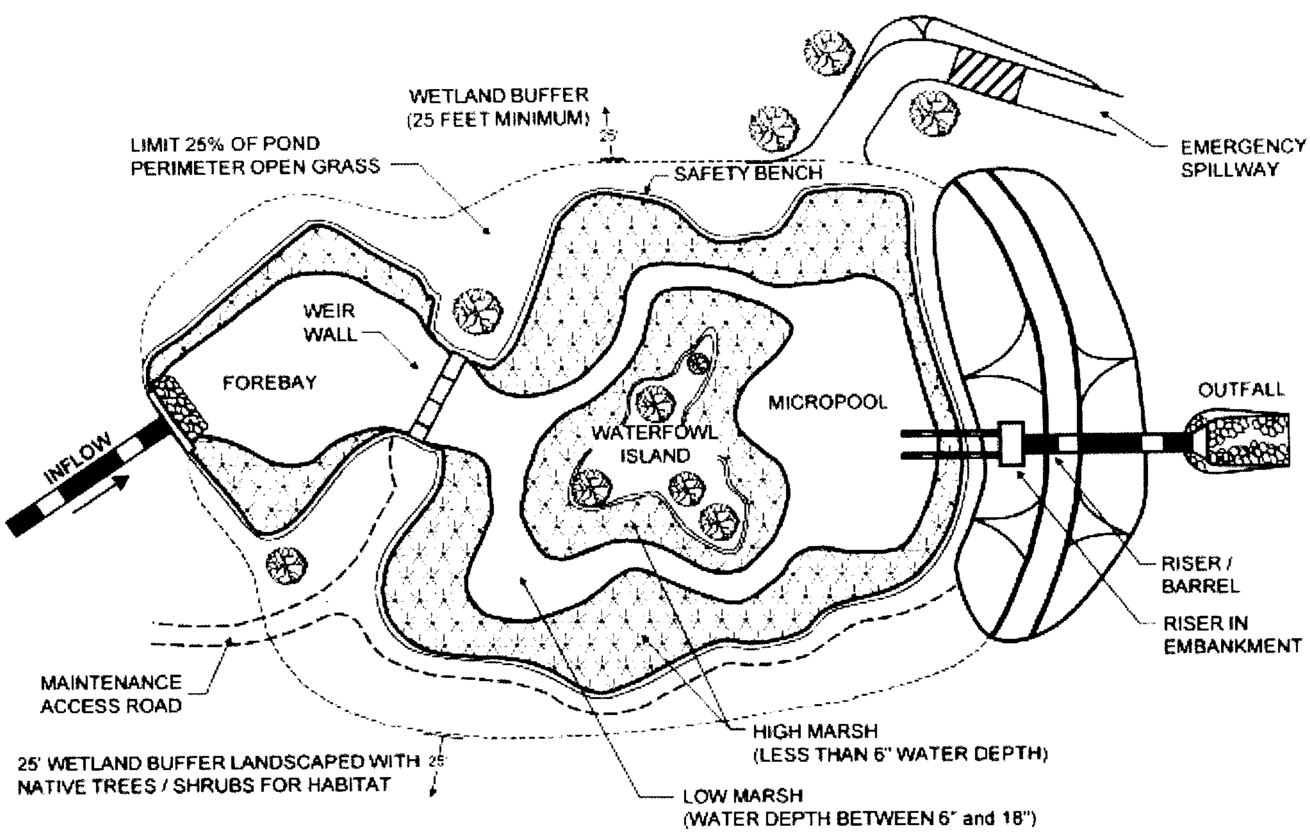


Figure 1: Constructed wetland plan view
(Georgia Stormwater Management Manual, 2001)

Stormwater Wetlands

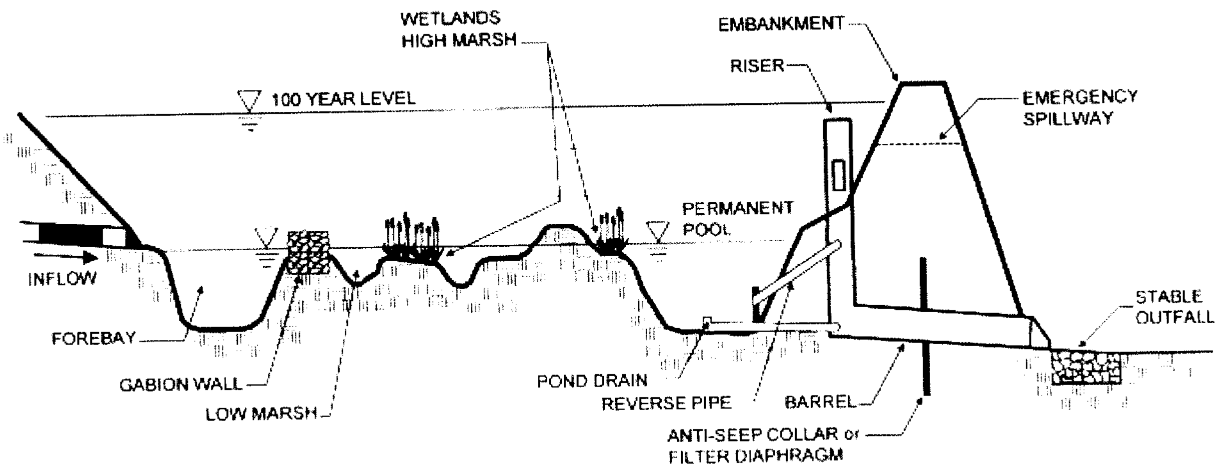


Figure 2: Constructed wetland section view
(Georgia Stormwater Management Manual, 2001)

References:

Georgia Stormwater Management Manual, 2001. Volume 2, Section 3.2.1.
http://www.georgiastormwater.com/

Metropolitan Council, 2001. *Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practices for Cold Climates.* Metropolitan Council Environmental Services.
http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm

Virginia DCR, 1999. *Virginia Stormwater Management Handbook.* Commonwealth of Virginia, Department of Conservation and Recreation.
http://www.dcr.state.va.us/sw/stormwat.htm#handbook

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Wet Swale

When to use:
- Any soil type
- Moderately sloping terrain
- Water table elevation is at the swale invert elevation
- Drainage area of 2 to 4 acres
- Hydraulic head of 2 to 3 feet
- Not practical for use in ultra urban settings

Advantages:
- Medium construction cost
- Moderate community acceptance
- Medium wildlife habitat benefit
- Relatively easy to design, install and maintain

Limitations:
- Does not achieve 80% TSS removal rates as a stand alone BMP but can be used in conjunction with other BMPs to achieve 80%
- Minimum set-back from high water level required (see local codes)
- Variable maintenance cost
- Can not handle pollutants from offsite hotspots
- Additional design criteria necessary to achieve runoff quantity control
- Can have a short effective life even with appropriate maintenance.
- Potential for mosquito breeding areas
- Not appropriate for pollutants toxic to vegetation
- Become less feasible as number of culvert crossing increase

BMP Type:	Constructed Wetland - Linear
TSS Removal:	65%
Nitrogen Removal:	20%
Phosphorous Removal:	25%
Metal Removal:	35-65%
E. coli Removal:	N/A
Runoff Volume Control:	Low
Runoff Rate Control:	Low
Annual Maintenance Cost:	5-20%[1]
Relative Construction Cost:	Medium
Effective Life:	5-20 years

[1] Reported as a percentage of Construction Cost

PA SW Management Manual, 2005

Wet Swale

Description:

Wet swales are engineered grassed channels that not only convey stormwater from a roadway but also provide water quality benefits. Wet swales are distinguished from the simple drainage/grassed channel by design features that maintain a saturated condition in soils at the bottom of the swale. The goal of a wet swale is to create an elongated wetland treatment system that treats stormwater through physical and biological action. Unlike dry swales, infiltration of stormwater is an undesirable condition in a wet swale because it would likely result in conditions detrimental to maintaining saturated soils to support wetland vegetation. Wet swales provide for stormwater treatment in wet soils where treatment may otherwise be nonexistent or negligible. Versatility with this practice allows for off-line placement of wetland cells, as well as the introduction of emergent wetland plant species to encourage creation of habitat. Wet swales can also be sized to detain stormwater and address water quantity management needs.

Drawings:

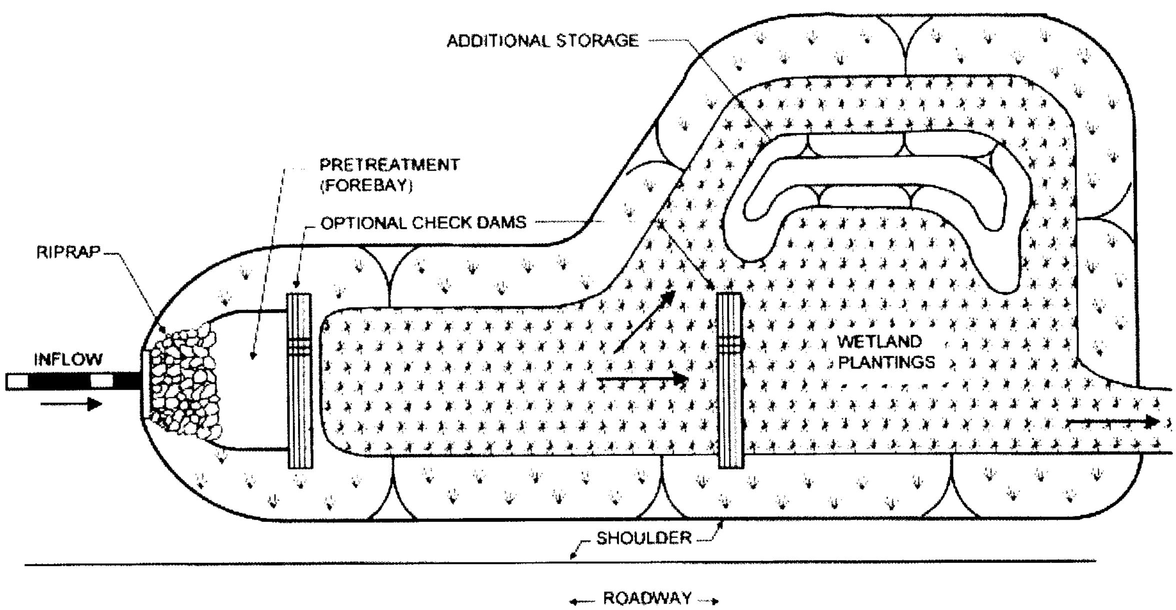


Figure 1: Plan View of a Wet Swale
(Center for Watershed Protection)

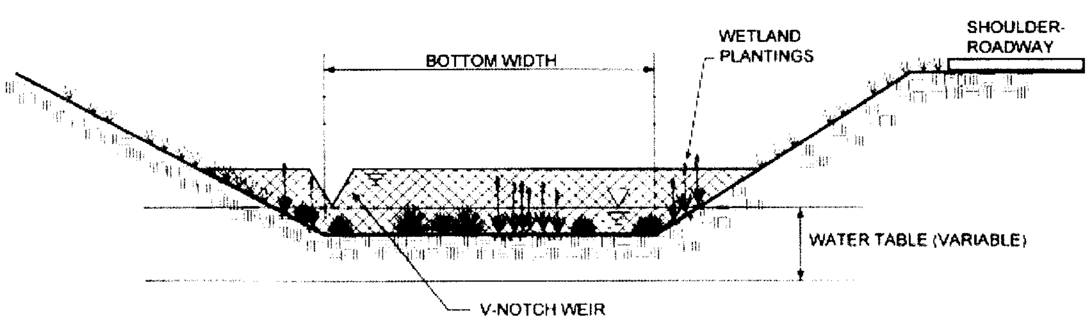


Figure 2: Section view of a wet swale with optional check dam
(Modified from Center for Watershed Protection)

Wet Swale

References:

Center for Watershed Protection, Stormwater Manager's Resources Center, 2005, *Stormwater Management Fact Sheet, Grassed Channel.*
http://www.stormwatercenter.net/

PADEP, 2005. *Draft Pennsylvania Stormwater Management Manual, Section 6.* Pennsylvania Department of Environmental Protection.
http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section06-StructuralBMPs-part1.pdf

Infiltration Trench

When to use:

- Should not used in karst areas
- In soil types A and B
- Water table is at least 3 feet below the trench
- Drainage area of 2 to 4 acres
- Hydraulic head of 3 to 8 feet
- Can be used in some ultra urban settings

Advantages:

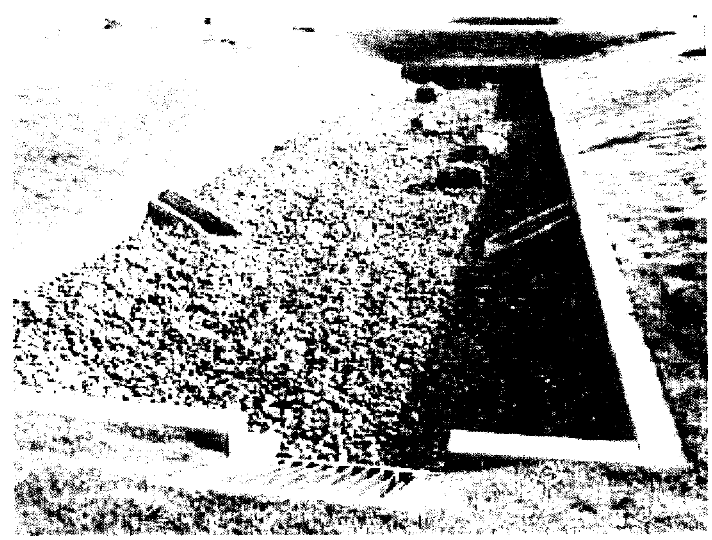
- Can achieve 80% TSS removal rates as a stand alone BMP
- Highly efficient removal of pollutants of concern
- Low to moderate maintenance cost
- Moderate to high community acceptance
- Provides water quantity benefit in the form of runoff volume control
- Provides groundwater recharge

Limitations:

- High construction cost
- Can not accept pollutants from offsite hotspots
- Can have a short effective life even with appropriate maintenance
- High failure rate due to clogging and high maintenance burden
- Low removal of dissolved pollutants in very coarse soils
- Groundwater monitoring may be needed due to risk of contamination in very coarse soils
- Metal and petroleum hydrocarbons can accumulate in soils to potentially toxic levels
- No wildlife habitat benefit
- Pretreatment of runoff is recommended to minimize sediment loading, avoid clogging. TSS removal

BMP Type:	Infiltration System - Linear
TSS Removal:	75-99%
Nitrogen Removal:	45-70%
Phosphorous Removal:	50-75%
Metal Removal:	75-99%
E. coli Removal:	75-98%
Runoff Volume Control:	High
Runoff Rate Control:	Medium
Annual Maintenance Cost:	5-7%[1]
Relative Construction Cost:	High
Effective Life:	5-15 years

[1] Reported as a percentage of Construction Cost



Portland, OR BMP Manual, 2004

Infiltration Trench

Description:
An infiltration trench is an excavated trench that has been lined and backfilled with stone to form a subsurface basin. Stormwater runoff is diverted into the trench and is stored until it can infiltrate into the soil, usually over a period of several days. Infiltration trenches are very adaptable BMPs, and the availability of many practical configurations make it ideal for small urban drainage areas, such as ultra-urban sites. Infiltration trenches can be either on-line or off-line systems. They are most effective and have a longer life cycle when some type of pretreatment to remove sediment is included in their design. Pretreatment may include techniques such as vegetated filter strips or grassed swales.

Infiltration trenches provide the majority of treatment by processes related to soil infiltration, which include sorption, precipitation, trapping, filtering, and bacterial degradation..

Drawings:

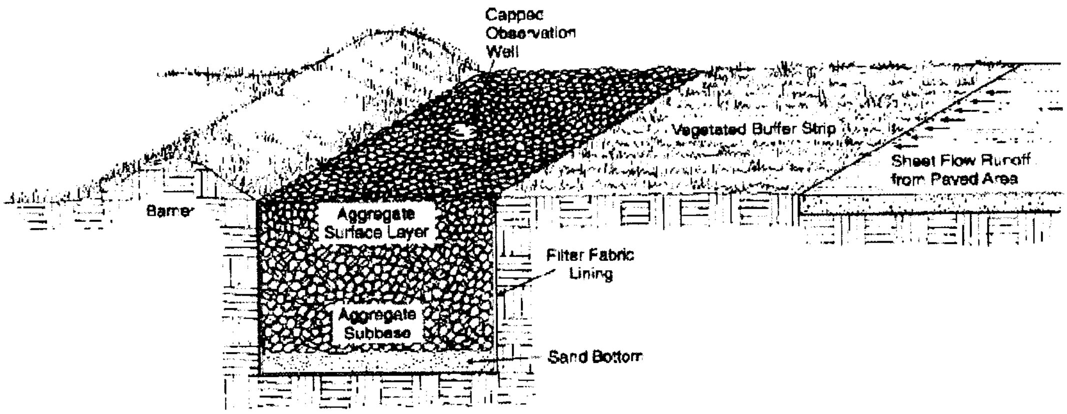


Figure 1: Typical Above Ground Infiltration trench Configuration
(Modified from Georgia Stormwater Management Manual, 2001

Infiltration Trench

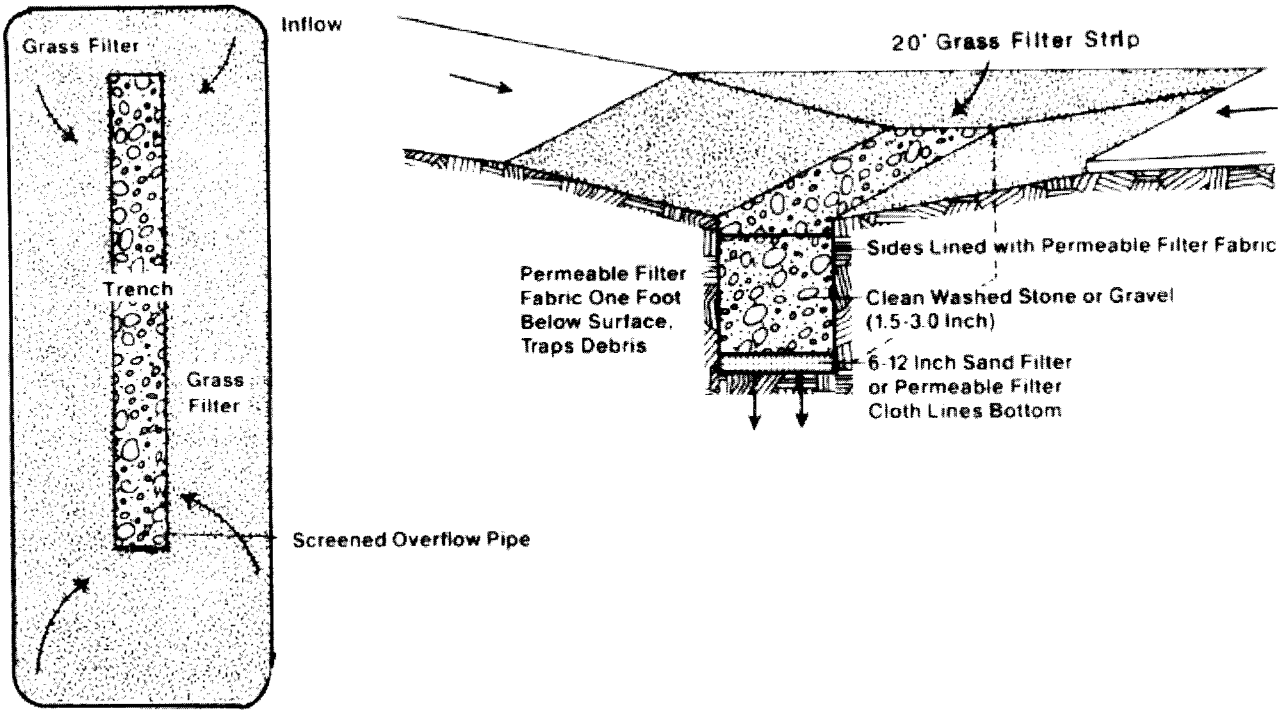


Figure 2: Infiltration Trench, Road Median Application – Plan and Section View (Metropolitan Council, 2001)

References:

Georgia Stormwater Management Manual, 2001. Volume 2, Section 3.2.1.
http://www.georgiastormwater.com/

Metropolitan Council, 2001. *Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practices for Cold Climates.* Metropolitan Council Environmental Services.
http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm

Portland, Oregon Bureau of Environmental Services, 2004, *Portland Stormwater Management Manual.*
http://www.portlandonline.com/bes/index.cfm

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Infiltration Basin

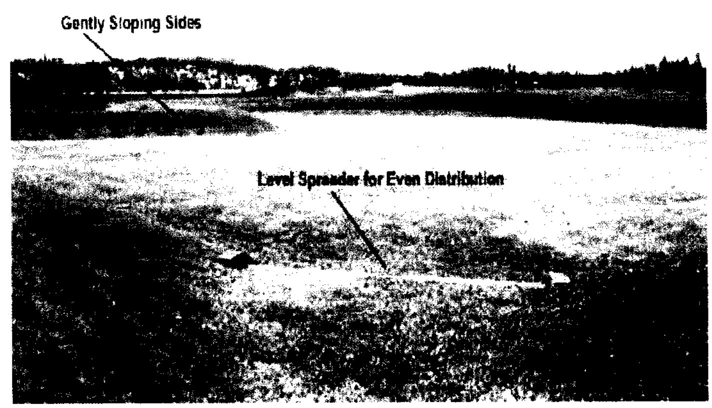
When to use:
- Should not be used in karst areas
- In soil types A and B
- Water table is at least 3 feet below the basin
- Drainage area of 2 to 20 acres
- Hydraulic head of 3 to 4 feet
- Not practical for use in ultra urban settings

Advantages:
- Can achieve 80% TSS removal rates as a stand alone BMP
- Highly efficient removal of pollutants of concern
- Medium construction cost
- Moderate community acceptance
- Provides water quantity benefit in the form of runoff volume control
- Provides groundwater recharge

Limitations:
- Requires additional right-of-way beyond standard clear zone limits
- Moderate to high maintenance cost
- Can not accept pollutants from offsite hotspots
- Can have a short effective life even with appropriate maintenance
- High failure rate due to clogging and high maintenance burden
- Low removal of dissolved pollutants in very coarse soils
- Groundwater monitoring may be needed due to risk of contamination in very coarse soils
- Metal and petroleum hydrocarbons can accumulate in soils to potentially toxic levels
- Requires relatively large amount of right-of-way compared to other measures
- Low wildlife habitat benefit unless vegetation with plantings other than turf grass

BMP Type:	Infiltration System – Non-Linear
TSS Removal:	75-99%
Nitrogen Removal:	45-70%
Phosphorous Removal:	50-75%
Metal Removal:	50-90%
E. coli Removal:	75-98%
Runoff Volume Control:	High
Runoff Rate Control:	Medium
Annual Maintenance Cost:	5-20%[1]
Relative Construction Cost:	Medium
Effective Life:	5-15 years

[1] Reported as a percentage of Construction Cost



PA SW Management Manual, 2005

Infiltration Basin

Description:
An infiltration basin is a surface pond which captures first-flush stormwater and treats it by allowing it to percolate into the ground through permeable soils. Physical, chemical, and biological processes occur within the soil column, 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 2 and 20 acres. For drainage areas less than 2 acres, an infiltration trench or other BMP may be more appropriate. For drainage areas greater than 20 acres, maintenance of an infiltration basin would be burdensome, and an dry extended 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.

Drawing:

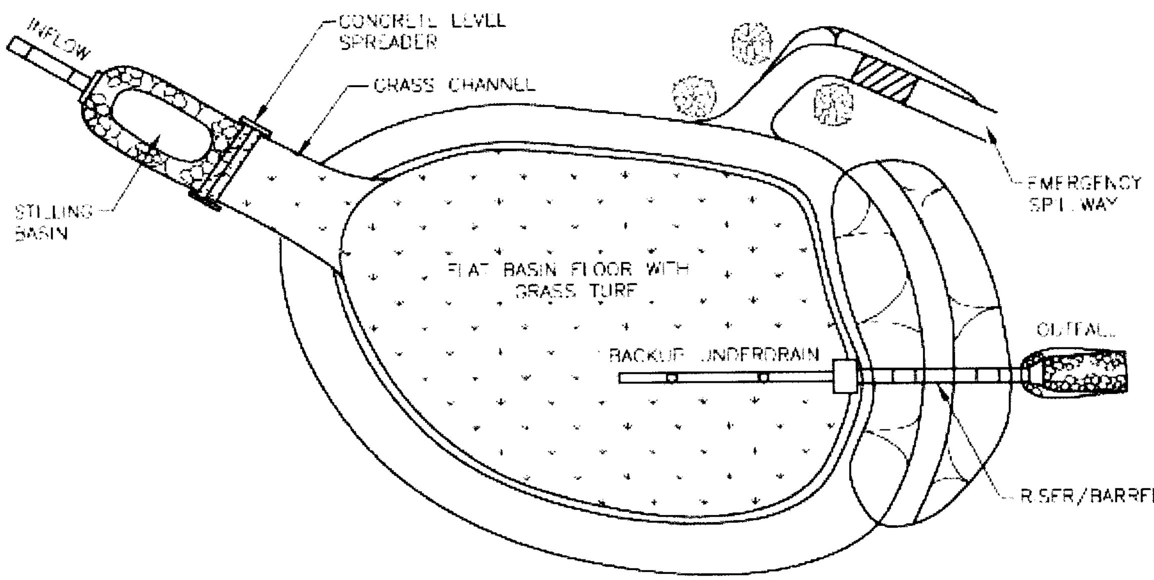


Figure 1 – Plan view of an infiltration basin
(PA SW Management Manual, 2005)

Reference:

PADEP, 2005. *Draft Pennsylvania Stormwater Management Manual, Section 6*. Pennsylvania Department of Environmental Protection.
http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section06-StructuralBMPs-part1.pdf

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Bioretention

When to use:

- Any soil type
- Low lying areas
- Water table is at least 3 feet below the swale invert
- Drainage area of 2 to 4 acres
- Hydraulic head of 2 to 3 feet
- Can be used in ultra urban settings

Advantages:

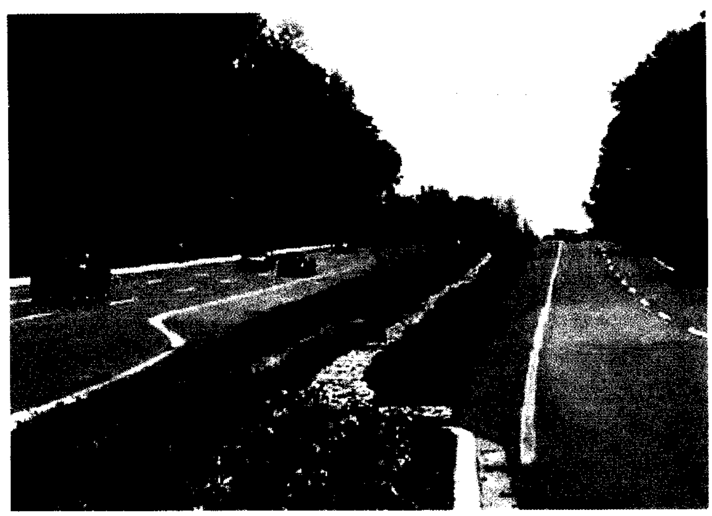
- Can accept pollutants from offsite hotspots
- Moderate maintenance cost
- Moderate community acceptance
- Medium wildlife habitat benefit
- Good metal removal rates
- Requires relatively little engineering design
- Provides groundwater recharge when runoff is allowed to infiltrate
- Also can serve as landscaping features

Limitations:

- Requires additional right-of-way beyond standard clear zone limits
- Does not achieve 80% TSS removal rate as a stand alone BMP but can be combined with other measures
- High construction cost
- Additional design criteria necessary to achieve runoff quantity control
- Can have a short effective life even with appropriate maintenance
- Low removal of nitrates
- Clogging may be a problem if the BMP receives runoff with high fine particle loads
- Maximum ponds depths may limit the amount of runoff that can be directed to the area
- Construction runoff should be diverted due to the clogging potential

BMP Type:	Filtration System – Linear
TSS Removal:	75%
Nitrogen Removal:	50%
Phosphorous Removal:	50%
Metal Removal:	75-80%
E. coli Removal:	N/A
Runoff Volume Control:	Medium
Runoff Rate Control:	Medium
Annual Maintenance Cost:	5-7%[1]
Relative Construction Cost:	High
Effective Life:	5-20 years

[1] Reported as a percentage of Construction Cost



PA SW Management Manual, 2005

Bioretention

Description:
Bioretention can be described as shallow, landscaped depressions commonly located in parking lot islands, medians, or within small pockets in residential areas. Stormwater flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition. Filtered runoff can either be allowed to infiltrate into the surrounding soil, or collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters. Infiltration components should not be incorporated into bioretention designs in karst areas. Runoff from larger storms is generally diverted past the area to the storm drain system.

Drawing:

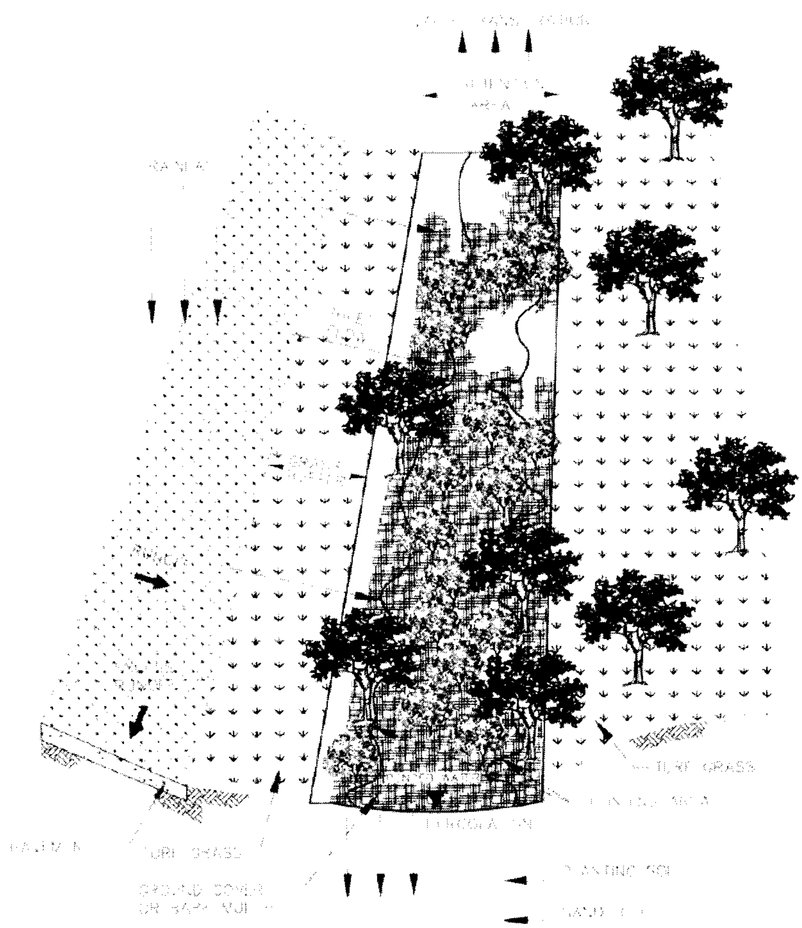


Figure 1: Bioretention Basin
(Virginia DCR, 1999)

References:

PADEP, 2005. *Draft Pennsylvania Stormwater Management Manual, Section 6.* Pennsylvania Department of Environmental Protection.
http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section06-StructuralBMPs-part1.pdf

Virginia DCR, 1999. *Virginia Stormwater Management Handbook.* Commonwealth of Virginia, Department of Conservation and Recreation.
http://www.dcr.state.va.us/sw/stormwat.htm#handbook

Filter Strip

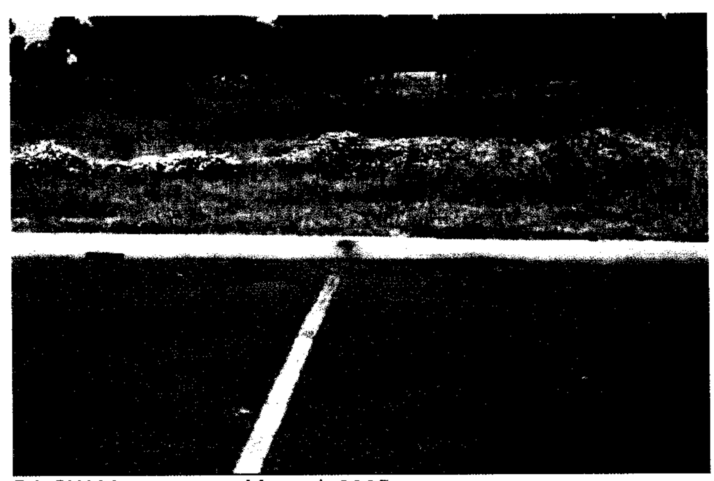
When to use:
- Any soil type
- Moderately sloping terrain
- Water table is at least 3 feet below the filter strip
- Drainage area of less than 5 acres
- Where sheet flow can be achieved
- Not practical for use in ultra urban settings

Advantages:
- Can accept pollutants from offsite hotspots
- Low construction cost
- Low to moderate maintenance cost
- High community acceptance
- Medium wildlife habitat benefit
- Slightly reduces watershed imperviousness
- Slightly contributes to groundwater recharge

Limitations:
- Can not accept concentrated flow. Concentrated flow must be distributed with a level spreader.
- Does not achieve 80% TSS removal rate as a stand alone BMP
- Additional measures necessary to achieve adequate runoff quantity control
- Removal rates vary widely depending on flow lengths
- Can have a short effective life even with appropriate maintenance
- Requires slopes less than 10%
- Requires low to fair permeability of natural subsoil
- Requires more right-of-way than other BMPs
- Effectiveness significantly reduced if flow becomes concentrated
- Pollutant removal is unreliable in urban settings

BMP Type:	Filtration System - Linear
TSS Removal:	27-70%
Nitrogen Removal:	20-40%
Phosphorous Removal:	20-40%
Metal Removal:	2-80%
E. coli Removal:	N/A
Runoff Volume Control:	Medium
Runoff Rate Control:	Medium
Annual Maintenance Cost:	5-7%[1]
Relative Construction Cost:	Low
Effective Life:	10-20 years

[1] Reported as a percentage of Construction Cost



PA SW Management Manual, 2005

Filter Strip

Description:
Vegetated filter strips, also known as vegetated buffer strips, are vegetated areas with low slopes, designed to accept runoff as overland sheet flow. When used as erosion and sediment control during construction, filter strips are generally not engineered or constructed but rather areas where existing vegetation is preserved. Runoff velocity is reduced by maintaining existing vegetative cover and/or, preserving a natural buffer strip around the lower perimeter of the disturbed land. However, a vegetated filter strip is not an effective control alone and must be combined with other post-construction BMPs.

This factsheet covers the use of engineered vegetated filter strips as a permanent control measure. Vegetated filter strips may range in form from grassland to forest, and are designed to intercept flow, lower flow velocity, and maintain sheet flow conditions. The dense vegetative cover facilitates conventional pollutant removal through detention, sedimentation, filtration by vegetation, and infiltration into soil. Existing vegetative buffers can be preserved during construction and function as post-construction BMPs.

Filter strips are most useful in contributing watershed areas where peak runoff velocities are low. In the ultra-urban environment, filter strips are limited due to the required flow length and are appropriate only where ample room exists for installation. There must be sufficient flow length and gradient to effectively treat the stormwater. The primary highway application for vegetative filter strips is along rural roadways where runoff that would otherwise discharge directly to a receiving water first passes through a filter strip before entering a conveyance system.

Drawings:

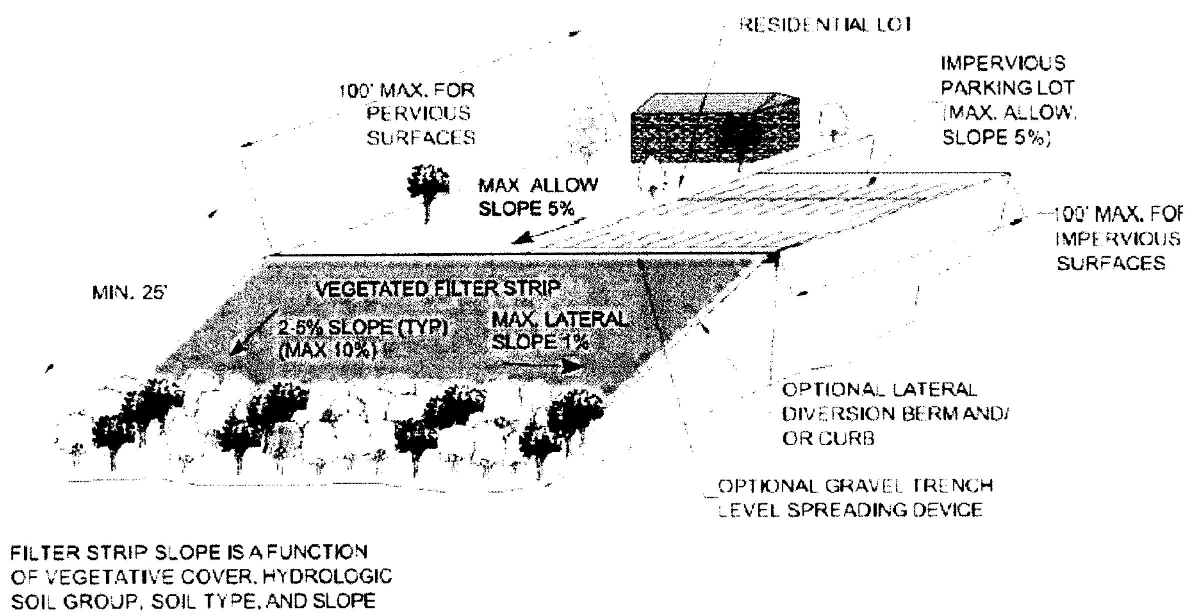


Figure 1: Filter Strip – Isometric View
(PA SW Management Manual, 2005)

Filter Strip

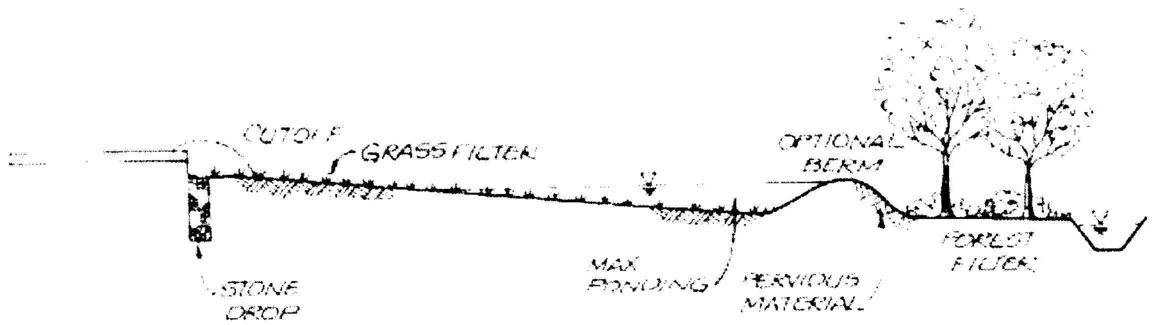


Figure 2: Filter Strip modified for quantity control
(Metropolitan Council, 2001)

References:

PADEP, 2005. *Draft Pennsylvania Stormwater Management Manual, Section 6.* Pennsylvania Department of Environmental Protection.
http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section06-StructuralBMPs-part1.pdf

Metropolitan Council, 2001. *Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practices for Cold Climates.* Metropolitan Council Environmental Services.
http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm

Turf Reinforcement Mat

When to use:
- Any soil type
- Moderately sloping terrain
- Along channel banks, on slopes, or as a lining on intermittent drainage ways
- Can be used in ultra urban settings

Advantages:
- Can accept pollutants from offsite hotspots
- Low construction cost
- Low maintenance cost
- Moderate community acceptance
- Can increase the effectiveness of other water quality measures

Limitations:
- Increased probability of failure if not installed properly
- Very steep or unstable streambanks require close examination of the underlying soils for stability. May be combined with other bioengineering practices
- Turf reinforcement mats (TRMs) should not be considered to be a stand alone post-construction BMPs. Installation of TRMs can be incorporated into other BMPs, such wet or dry swales.

BMP Type:	Filtration Systems - Linear
TSS Removal:	30-90%[1]
Nitrogen Removal:	0-50%[1]
Phosphorous Removal:	20-85%[1]
Metal Removal:	0-90%[1]
E. coli Removal:	N/A
Runoff Volume Control:	Low
Runoff Rate Control:	Medium
Annual Maintenance Cost:	3-5%[1,2]
Relative Construction Cost:	Low
Effective Life:	5-20 years

[1] Data reported as median percent removal of vegetated swales
[2] Reported as a Percentage of Construction Cost

North American Green, undated

Turf Reinforcement Mat

Description:
Turf reinforcement mats (TRMs) are three dimensional reinforcement matrices that provide sufficient thickness, strength and void space to permit soil filling and/or retention and the development of vegetation within the matrix. TRMs are composed of UV stabilized, non-degradable, synthetic fibers or nettings. Some TRMs also include a biodegradable component to promote vegetation growth. The medium of soil, vegetation, and fiber is designed for permanent and critical hydraulic applications where design discharges exert velocities and shear stresses that exceed the limits of mature, natural vegetation. TRMs should be designed based on allowable shear stress of the channel lining. The primary benefit of TRMs is they allow for infiltration and they can filter runoff from smaller rainfall events once vegetated.

Drawings:

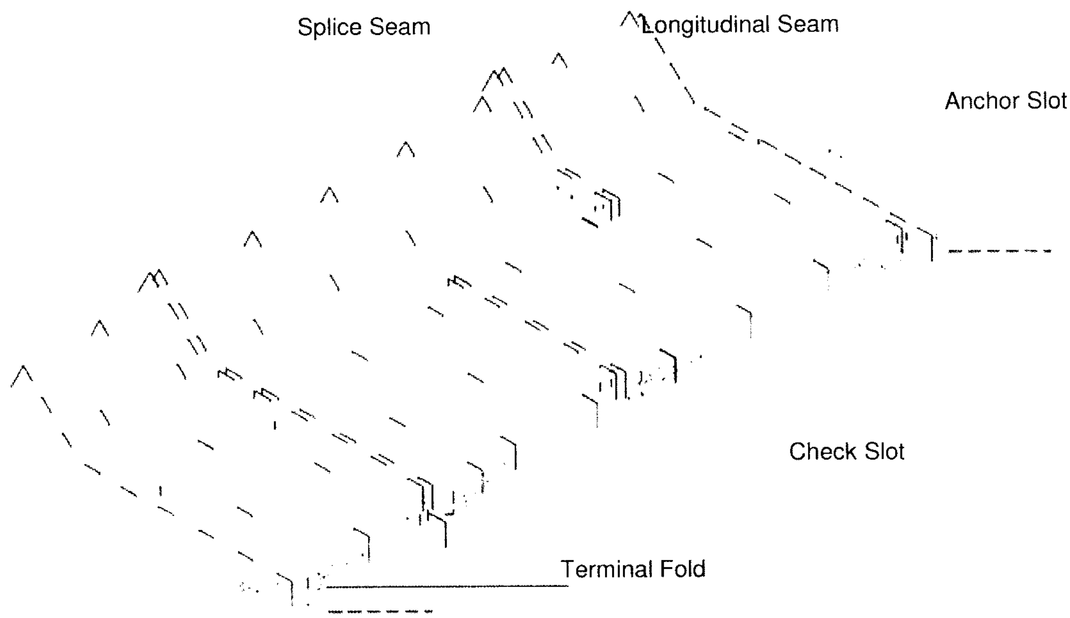


Figure 1: Channel Application
(TDOT, 2005)

References:

North American Green Image Library
http://www.nagreen.com/resources/imagelibrary/SC250/SC250_Slope_Unveg.jpg

TDOT, 2005. *Tennessee Department of Transportation Standard Drawings – Erosion Control and Landscaping*. Tennessee Department of Transportation Design Division.
http://www.tdot.state.tn.us/Chief_Engineer/engr_library/design/Std_Drwg_Eng.HTM

Native Vegetation – Permanent

When to use:
- For revegetation on completed construction jobs
- For landscaping
- For soil stabilization above the ordinary high water mark on channel banks and on slopes
- In combination with turf reinforcement mats and other bioengineering measures
- In combination with all other water quality measures that call for vegetative components

Advantages:
- Maintenance limited to reseeding sparse or bare areas
- Native vegetation is better adapted to local conditions than non-native
- Aesthetically pleasing
- Can increase the effectiveness of other water quality measures

Limitations:
- Very steep or unstable streambanks require close examination of the underlying soils for stability. May be combined with other bioengineering practices
- Native seeding should not be considered to be a stand alone post-construction BMPs. Native seeding can be incorporated into other BMPs, such wet or dry swales, or anywhere else that revegetation is required

BMP Type:	Retention/ Detention - Linear
TSS Removal:	30-90%[1]
Nitrogen Removal:	0-50%[1]
Phosphorous Removal:	20-85%[1]
Metal Removal:	0-90%[1]
E. coli Removal:	N/A
Runoff Volume Control:	Low
Runoff Rate Control:	Medium
Annual Maintenance Cost:	3-5%[1,2]
Relative Construction Cost:	Low
Effective Life:	5-20 years

[1] Data reported as median percent removal of vegetated swales
[2] Reported as a Percentage of Construction Cost

EPA, 2003

Native Vegetation – Permanent

Description:
Where possible, vegetative measures are preferred to engineered, structural, soil stabilization. On steeper slopes or flow paths, vegetation can be combined with turf reinforcement mats, fiber wattles, or other bioengineering techniques to aid in establishment and stability. The use of vegetative measures requires less maintenance and provides wildlife habitat.

Grasses introduced from Europe and Asia have traditionally been used to establish vegetative cover on construction sites in the Midwest. However, many designers are now specifying native grasses for revegetation, stabilization, and landscaping. Although slower to establish, native species require less maintenance in the long run than nonnative species. They are also better for water quality because they do not require the heavy fertilizer application that introduced species require.

Native grasses will grow on poor soils because they can gain access to nutrients and water that shallower-rooted grasses cannot reach. Therefore, native grasses are desirable for stabilizing soils. Cover crops such as oats or winter wheat should be seeded with native grasses to provide short-term erosion control while they are becoming established. Wildflowers could be added to the seed mixes on many projects. Because they develop very deep root systems, native grasses and wildflowers provide very good long-term erosion control.

References:

EPA Website, 2004. United States Environmental Protection Agency. *Great Lakes Environment, Greenacres, Natural Landscaping Tool Kit, THE NATURAL LANDSCAPING ALTERNATIVE: An Annotated Slide Collection - Slide 7*
http://www.epa.gov/greenacres/tooltestkit/gallary/TKSlide07.html

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Hydrodynamic Separators

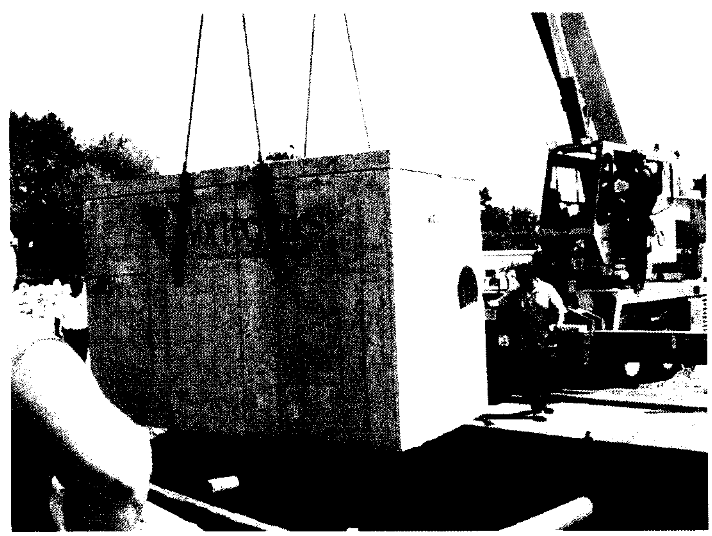
When to use:
- Any soil type
- Any terrain
- Water table greater than 3 feet below the structure
- Very practical for use in ultra urban settings
- Due to the increasing number of manufacturers of proprietary water quality structures, the upper limit of drainage area may vary from 2 to 300 acres.

BMP Type:	Proprietary System - Linear
TSS Removal:	80-90%
Nitrogen Removal:	N/A
Phosphorous Removal:	N/A
Metal Removal:	N/A
E. coli Removal:	N/A
Runoff Volume Control:	None
Runoff Rate Control:	None
Annual Maintenance Cost:	1-5%
Relative Construction Cost:	High
Effective Life:	>100 years

[1] Reported as a Percentage of Construction Cost

Advantages:
- Achieves 80% or greater TSS removal rate as a stand alone measure
- Can accept pollutants from offsite hotspots
- High construction cost
- Low maintenance cost
- High community acceptance
- Very long effective life
- Prefabricated for different standard storm drain designs
- Require minimal space to install

Limitations:
- Does not provide runoff volume or rate control
- Removal rates for pollutants other than TSS vary by manufacturer and often depend on accessories added to the structure
- No wildlife habitat benefit
- Some devices may be vulnerable to accumulated sediments being resuspended during heavy storms
- Can only handle limited amounts of sediment and debris
- Regular maintenance and inspection is required to assess sediment, floatable, and oil accumulation
- Sizing and analysis vary between vendors



CBBEL file, 2005

Hydrodynamic Separators

Description:
Installation of hydrodynamic separators can be grouped into in-line or off-line installations. Inline installations are typically only found on piped stormwater conveyance systems. Offline systems can be installed on closed stormwater systems or on open channels. Offline systems are often used to treat much larger flow rates than in-line systems. The flow to be treated is usually diverted to the stormwater treatment unit from the main conveyance system flow and then rejoins the main flow path once it is treated.

Hydrodynamic separators can be useful where space is limited or in areas susceptible to spills of petroleum products, such as gas stations. There are many manufacturers of hydrodynamic separators. The sizing and analysis methods used to demonstrate and verify the effectiveness of a unit varies widely among different manufacturers. The designer should establish a percent removal of a target particle size for the calculated water quality treatment rate. Figure 1 illustrates one of many different types of hydrodynamic separators.

Drawings:

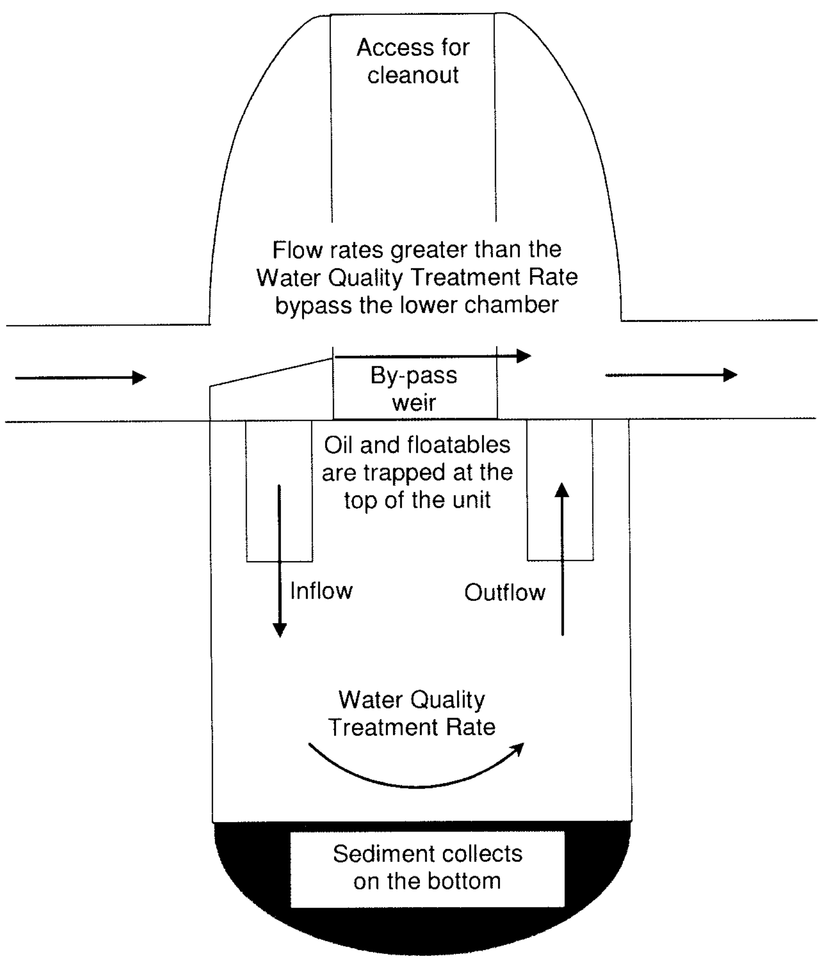


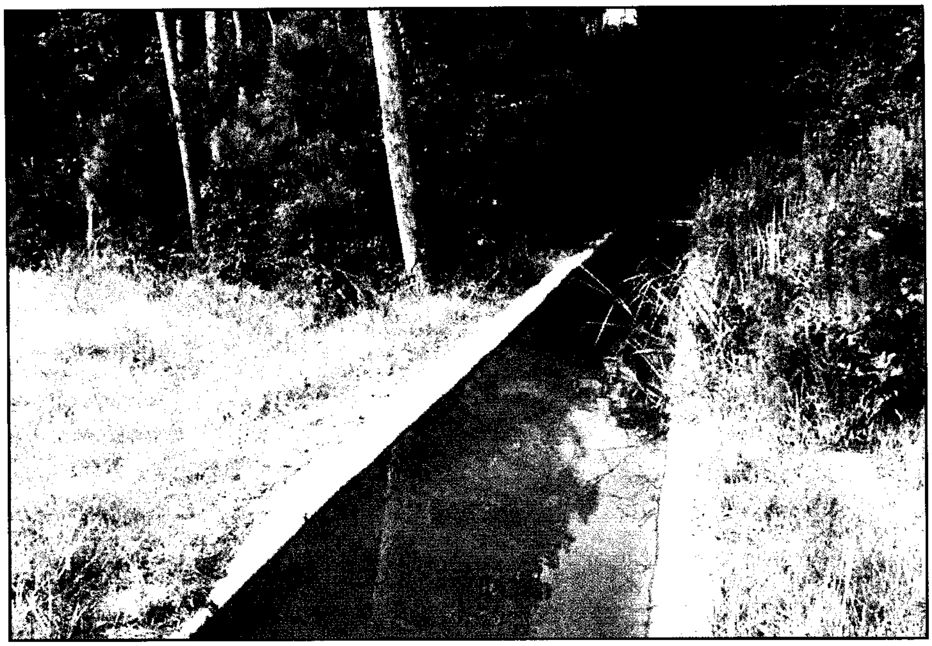
Figure 1: General Hydrodynamic
Separator Schematic (CBBEL, 2005)

References:

None

NORTH CAROLINA

CHAPTER 3 Level Spreader



OVERVIEW

A LEVEL SPREADER is a structural BMP that redistributes concentrated stormwater flow into diffuse flow.

PURPOSE AND DESCRIPTION

- A level spreader provides a nonerosive outlet for concentrated runoff by diffusing the water uniformly across a stable slope.
- A level spreader consists of a trough with a level nonerosive lip.

APPLICATIONS

- Level spreaders should be implemented only where uniform, diffuse flow can be achieved downgrade of the level spreader.
- Level spreaders are appropriate when concentrated runoff from a project area is conveyed by roadside ditches and/or storm pipes toward the buffer zone of a receiving water body.
- Level spreaders comply with NCDENR Riparian Buffer Protection Rules that restrict concentrated flow through buffer zones.
- Level spreaders are suitable for many highway applications, including interchanges, intersections, linear roadways, bridges, and facility areas.

WATER QUALITY BENEFITS

- Diffuse flow exiting a level spreader increases stormwater infiltration.
- Level spreaders mitigate downgrade erosion and ponding.
- Level spreaders reduce the water velocity, which allows larger particles to settle.

3.1 Description

The main components of a level spreader are the trough and the nonerosive lip. Runoff enters the trough of a level spreader via a conveyance system, such as a pipe or roadside ditch outlet, and exits the level spreader via the lip. The lip must be level to ensure uniform diffuse flow along the length of the level spreader as the water overflows the trough. The level spreader trough may be constructed using either concrete or vegetation.

The designer should consider reviewing soil survey maps before selecting a trough type.

An example of a level spreader and its components is shown in Figure 3-1.

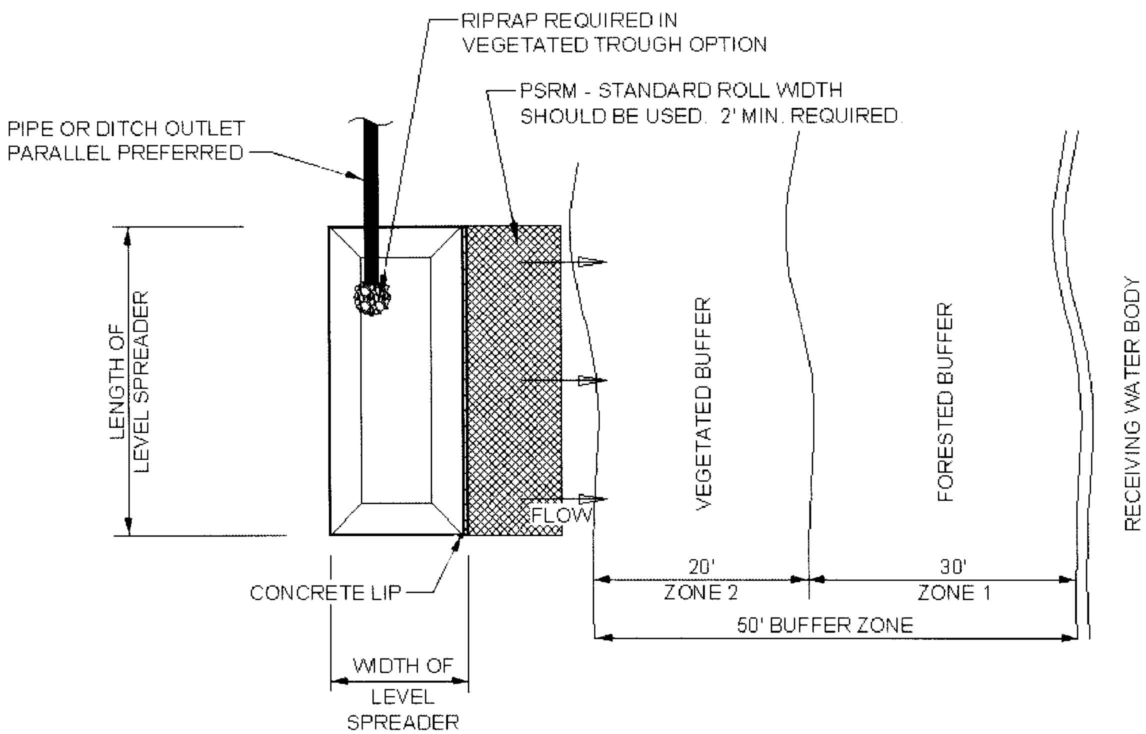


Figure 3-1. Typical level spreader layout and components

Concrete Trough

This level spreader type, illustrated in Figure 3-2, is constructed of concrete. Weep holes within level spreader troughs are optional at the discretion of the engineer. Weep holes are recommended where a water-filled trough is a safety concern, such as near parks where children play or in areas where mosquitoes breed. If weep holes are used to draw down water in the trough, they should discharge into a stone "dry cell." The dry cell should be wrapped in geotextile fabric and should run the entire length of the level spreader.

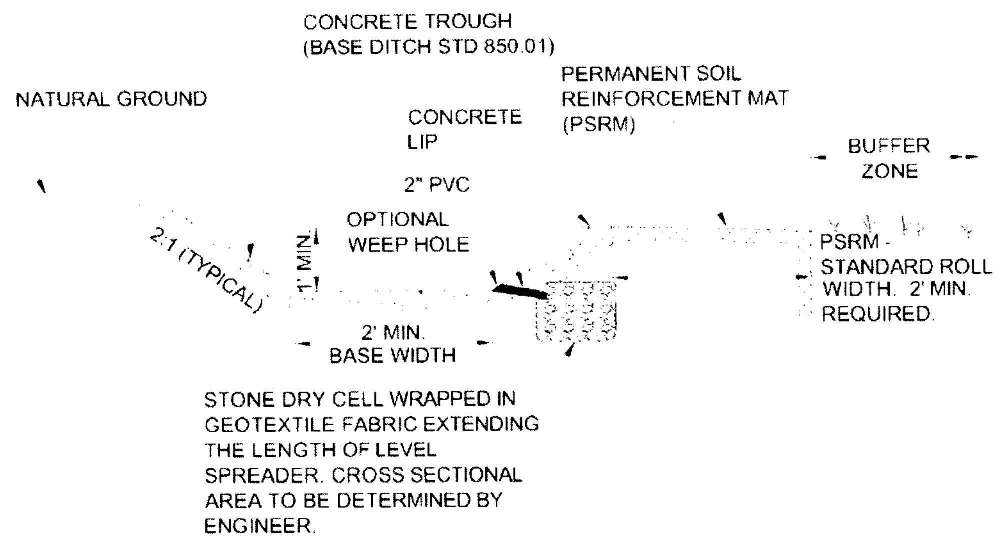


Figure 3-2. Level spreader with concrete trough

Vegetated Trough

Portions of the level spreader trough can be constructed using the existing vegetation cover or approved vegetation types. The vegetation should have a dense root mass and be easily maintained. Only the upstream slope and base of the trough should be constructed using the selected vegetation type. The lip of the level spreader must be made of concrete to prevent the lip from eroding. Figure 3-3 is an example of a level spreader with a vegetated trough.

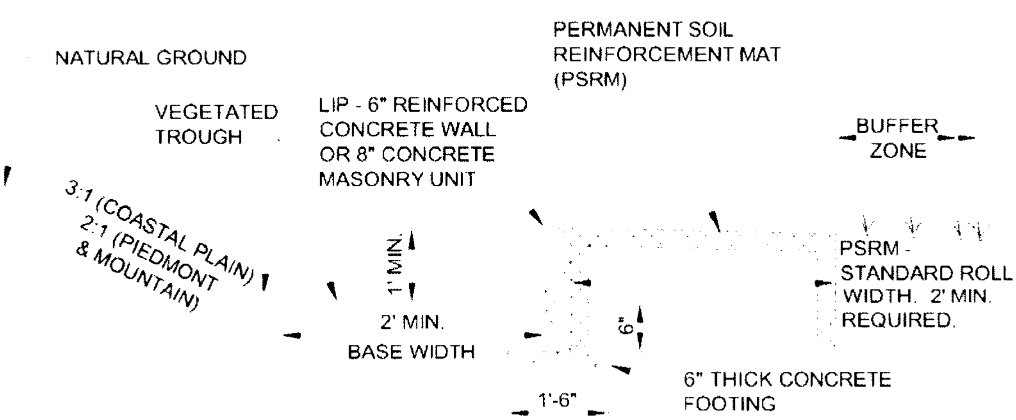


Figure 3-3. Level spreader with vegetated trough

3.2 Applications

The level spreader is applicable primarily when a concentrated flow is discharged upstream of a protected buffer. The release of concentrated flow in regulated buffer zones is restricted unless runoff is treated by acceptable practices. An example of a level spreader in a field setting is shown in Figure 3-4. Although level spreaders alone have been proven to provide stormwater treatment, they are often combined with existing buffers and/or other BMPs to enhance pollutant removal capabilities.

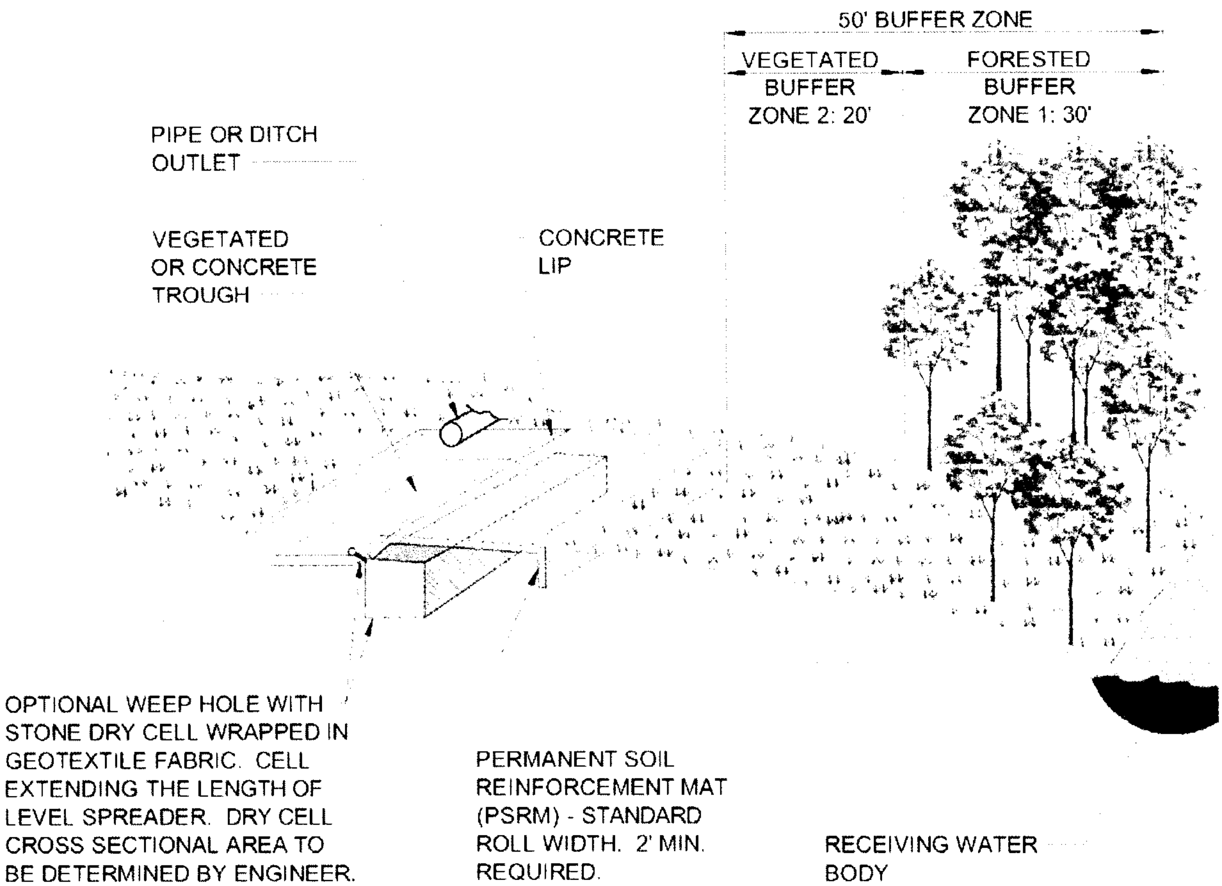


Figure 3-4. Typical level spreader with buffer

Level spreaders are commonly used on many highway facility types such as linear roadways, interchanges, intersections, bridges, and facility areas. The use of a level spreader may not be feasible in every linear highway application and will depend on site-specific constraints such as limited right-of-way or steep slopes.

3.3 Design

The entire level spreader system must pass a 10-year storm event without degrading the buffer or receiving stream. The designer must determine the contributing impervious drainage area and the Q_{10} discharge using the rational method. The rational method is described in more detail in Chapter 2.

When the Q_{10} is less than or equal to 10 cfs and the site is flat, a preformed scour hole may be a better treatment option than the level spreader to promote diffuse flow. Compared to level spreaders, preformed scour holes typically require a smaller construction area and are less expensive. Additional information on the design of this BMP can be found in Chapter 4.

Design criteria must consider watershed/contributing area, design storm event, and level spreader specifications. For a list of the required design criteria, see the Design Criteria Summary box.

DESIGN CRITERIA SUMMARY

- ❒ Contributing area to the outfall should be delineated to determine the water quality volume and Q_{10} discharge.
- ❒ The entire system must pass a 10-year storm event without degrading the buffer or receiving stream.
- ❒ Length of the level spreader should be a minimum of 10 feet and a maximum of 300 feet.
- ❒ Lip of the level spreader must be on a zero percent grade.
- ❒ The trough should have a minimum depth of 1 foot with a minimum base width of 2 feet.
- ❒ The trough should transition smoothly into the existing ground and have maximum side slopes of 2H:1V.
- ❒ Site selection will ensure that the hydraulic grade line does not propagate to the upstream drainage system or adjacent private properties.

The level spreader design flowchart provided in Figure 3.5 is intended to guide the designer to the most appropriate BMP option for a particular site. Although the flowchart is a support tool for determining the best design, the designer must still evaluate other design considerations addressed in this section.

CONVENTIONAL DESIGN OPTIONS

Conventional design options include a combination of the level spreader with existing buffer areas without the use of a bypass (Figure 3-6). The conventional design options must be capable of passing the entire Q_{10} discharge through the level spreader and buffer. Other design criteria are listed in the Conventional Design Options Summary.

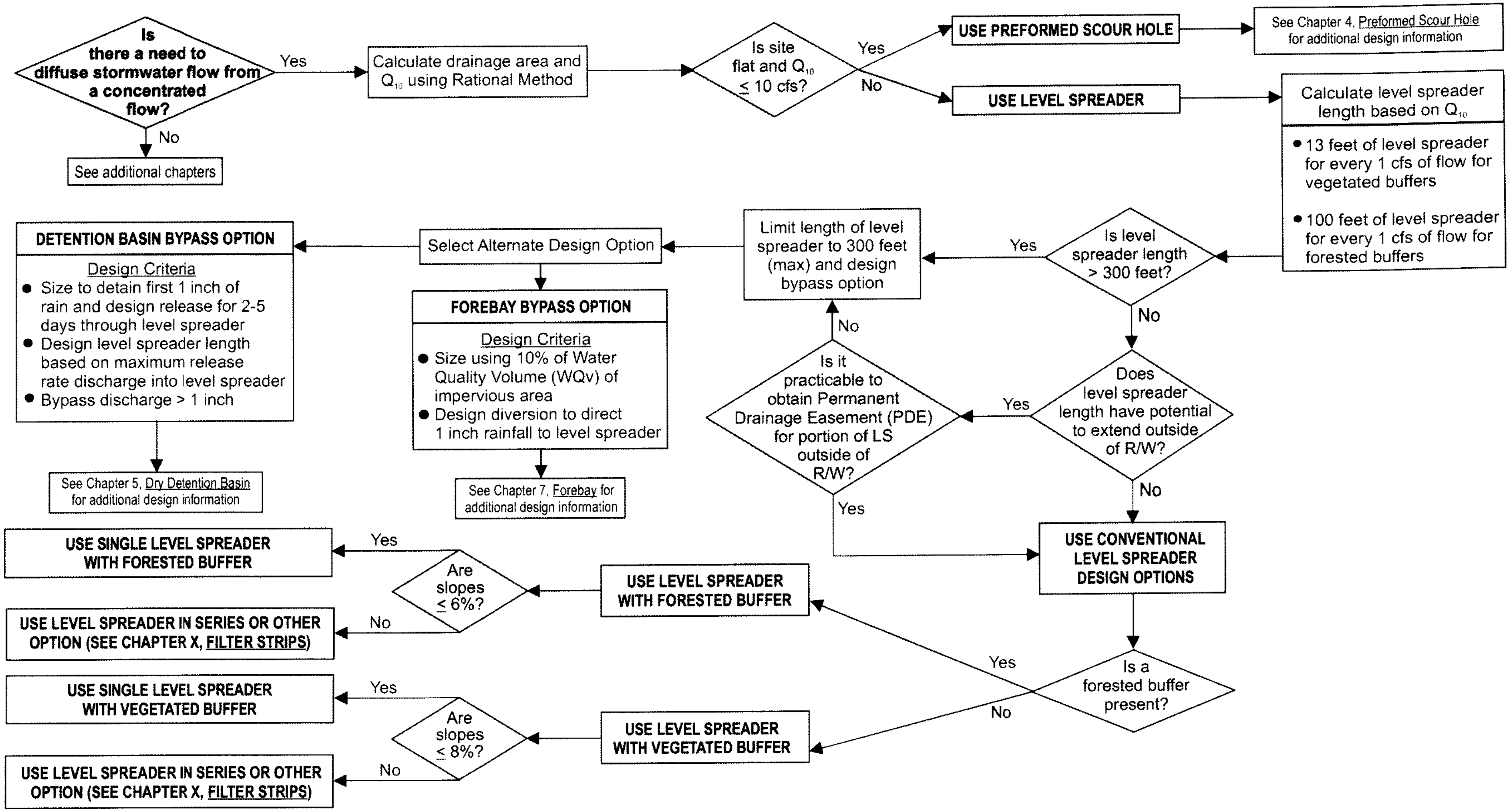


Figure 3-5. Level spreader design flowchart

Conventional Design Options Summary

Level Spreader with Vegetated Buffer

- ❒ Level spreader length is based on the Q_{10} discharge.
- ❒ 13 feet of level spreader is required for every 1 cfs.
- ❒ Level spreaders can be installed upstream of vegetated buffers where buffer slopes are 8% or less.

Level Spreader with Forested Buffer

- ❒ Level spreader length is based on the Q_{10} discharge.
- ❒ 100 feet of level spreader is required for every 1 cfs.
- ❒ Level spreaders can be installed upstream of forested buffers where buffer slopes are 6% or less.

Level Spreaders in Series

- ❒ Level spreader length is based on the Q_{10} discharge.
- ❒ Level spreaders in series can be used with vegetated buffers for buffer slopes between 8% and 25%.
- ❒ Level spreaders in series can be used with forested buffers for buffer slopes between 6% and 15%.
- ❒ Concrete level spreaders must be located outside of the buffer zones. Vegetated level spreaders with concrete lips are allowed in Zone 2.

Figure 3-6. Level spreader with mixed vegetated and forested buffers

Alternative Design Options

Conventional designs may not be capable of passing the Q_{10} discharge because of topography, size and imperviousness of the drainage area, limited right-of-way, or other site constraints. To meet the Q_{10} requirement, it may be necessary to implement an alternative level spreader design with bypass. Alternative designs include pairing a dry detention basin or a forebay with a level spreader. In both treatment trains, discharge events greater than the 1-inch storm bypass the BMPs through a pipe, a riprap-lined ditch, or a grassed swale.

According to the NCDWQ Riparian Buffer Protection Rules, these alternative design options are "allowable" activities for some protected buffers, pending North Carolina Division of Water Quality (NCDWQ) approval. As the Rules vary by watershed, confirmation of allowable activities in the buffer zone should be made before the alternative design is selected.

Bypass combinations described in the following box are used most frequently; however, other bypass options may be more appropriate, depending on site-specific conditions.

Alternative Design Options Summary

Level Spreader with Dry Detention Basin and Bypass

- ❐ Level spreader length is based on the maximum discharge release rate.
- ❐ For forested buffer, 100 feet of level spreader is required for every 1 cfs.
- ❐ For vegetated buffer, 13 feet of level spreader is required for every 1 cfs.
- ❐ Dry detention basin is sized to detain the first inch of rain using the water quality volume method. The water is then released over 2–5 days through the level spreader.
- ❐ Discharges greater than the 1-inch storm bypass the BMP through an overflow weir.

Level Spreader with Forebay and Bypass

- ❐ Level spreader length is based on the 1-inch-per-hour-intensity storm.
- ❐ For forested areas, 100 feet of level spreader is required for every 1 cfs.
- ❐ For grass or thick ground cover, 13 feet of level spreader is required for every 1 cfs.
- ❐ Forebay size is calculated by taking 10% of the water quality volume (WQv) based on the impervious area.
- ❐ Diversion pipe is sized to route the 1-inch-per-hour-intensity storm to the level spreader.
- ❐ Discharges greater than the 1-inch storm bypass the BMP through a conveyance system.

Level Spreader with Dry Detention Basin

A dry detention basin, when combined with a level spreader, should be sized to detain a 1-inch rain event and release the stormwater over 2–5 days through a level spreader. The basin should include an overflow device that allows the system to bypass storms greater than 1 inch. An overflow weir and channel are examples of bypass conveyance systems. Further information on dry detention basins can be found in Chapter 5.

Level Spreader with Forebay

Using a level spreader with a forebay is an option that is suitable for relatively small, impervious drainage areas, usually less than 5 acres. Typical sizing of the basin is calculated by taking 10 percent of the water quality volume (WQv) based on the impervious area. The WQv Method is discussed in Chapter 2. Additional information on forebay design is provided in Chapter 7.

In most designs, the forebay receives the point discharge directly and collects sediment. It is optional, however, for a diversion to be placed within or prior to the forebay. The diversion pipe directs the 1-inch storm to the level spreader. Discharges greater than the 1-inch storm are bypassed through a designed conveyance channel or pipe.

DESIGN AND CONSTRUCTION CONSIDERATIONS

The design of the level spreader must take into account the topography of the site. The designer must locate the level spreader so that ground contours are parallel to the lip, and the downgrade slope to the stream is smooth. The smooth transition from the level spreader to the stream will prevent diffuse flow from rechannelizing as stormwater makes its way through the buffer. If diffuse flow is not attainable based on site conditions, then a level spreader should not be used.

Additional design recommendations follow:

- Use proper energy dissipation (i.e., concrete trough or riprap) where perpendicular or angular inflows to the level spreader are necessary.
- Design the BMP to include components (i.e., berms, bypass systems) that prevent off-site flows from entering the BMP.
- Design the transition between the level spreader and other BMPs or buffers to avoid erosion once installation is complete.
- Place the level spreader outside of Zone 2.
- Ensure that the location of the BMP is outside of roadway clear recovery zones.
- Ensure safe ingress and egress of the level spreader for inspection and maintenance.
- Check the available right-of-way when determining the BMP footprint.
- Construct the level spreader on undisturbed soil.
- Install the level spreader and lip at zero percent grade.
- Determine whether weep holes are necessary.
- Position level spreader lip parallel to inflow device (perpendicular to direction of diffuse flow) if possible.

- Verify existing soil types using either soil survey maps or existing geotechnical reports when determining whether to use a vegetated trough.
- Include permanent soil reinforced mats (PSRMs) at the transition between the trough lip and buffers to prevent erosion at the interface.

3.4 Inspection and Maintenance

Periodic cleaning is required as a part of routine maintenance to prevent clogging of weep holes and to ensure the overall performance of the BMP. General inspection and maintenance recommendations are as follows:

- Inspection of level spreaders should be performed by experienced personnel.
- Until vegetation is established, the level spreader should be inspected frequently and after major rain events.
- Once vegetation is established, the level spreader should be inspected periodically.

3.5 Safety Considerations

Any BMP that has the potential for standing water presents a drowning hazard. Consider fencing the area to ensure safety. See NCDOT Specification 866 for fencing options.

CHAPTER 4 Preformed Scour Hole

OVERVIEW

A PREFORMED SCOUR HOLE is a structural BMP designed to dissipate energy and promote diffuse flow.

PURPOSE AND DESCRIPTION

- Preformed scour holes are riprap depressions constructed at the outlet of a point discharge.
- By providing a stable impact point for peak flows, a preformed scour hole dissipates energy and diffuses flow for specific applications.

APPLICATIONS

- Preformed scour holes can provide energy dissipation for a variety of drainage applications. When used to diffuse flow, preformed scour holes are applicable only for limited site conditions.
- If diffuse flow is a goal, preformed scour holes should be implemented for small drainage areas and flat outlet areas outside the clear recovery zone. If these site constraints cannot be met, a preformed scour hole should not be used.

WATER QUALITY BENEFITS

- Preformed scour holes reduce the amount of end-of-pipe erosion by eliminating unabated scour.
- By inducing diffuse flow conditions, preformed scour holes promote runoff infiltration and reduce downgrade erosion.

4.1 Description

Preformed scour holes are preshaped, riprap-lined basins located directly downgrade of an outfall (Figure 4-1). The man-made structure mimics the natural scour hole that would otherwise form at the conveyance outlet if no energy dissipation were provided. The basin is stabilized with filter fabric and riprap to absorb the impact of the discharge and to prevent additional erosion. Once flow has filled the shallow basin, it overtops the preformed scour hole and is redistributed as diffuse flow to the surrounding area.

To prevent erosion immediately downgrade of the preformed scour hole, an apron of permanent soil reinforcement matting (PSRM) is required downgrade of the BMP.

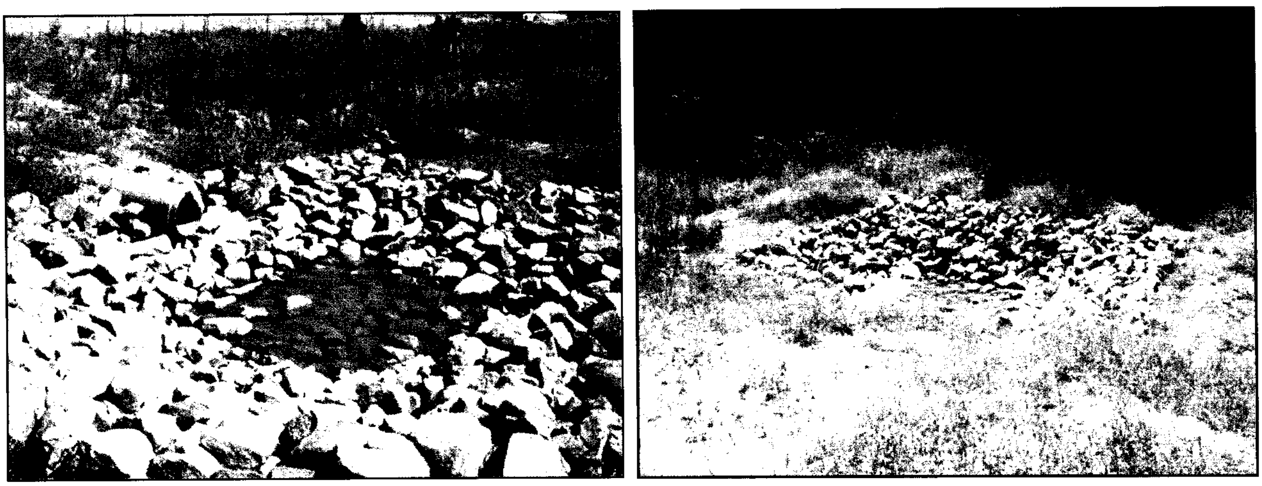


Figure 4-1. Preformed scour holes

Preformed scour holes absorb the impact of high velocities and reduce the potential for downgrade erosion from point discharges by reducing flow velocities. When preformed scour holes are implemented under small peak flow conditions and installed on level ground, the BMP redistributes concentrated inflow to diffuse outflow to adjacent land. By dispersing flow, the preformed scour hole provides a water quality benefit by

- Preventing scour at the pipe outfall,
- Promoting runoff infiltration, and
- Reducing soil erosion downgrade.

A typical example of a preformed scour hole layout and its components is shown in Figure 4-2. Figure 4-3 is a cross section of a typical preformed scour hole.

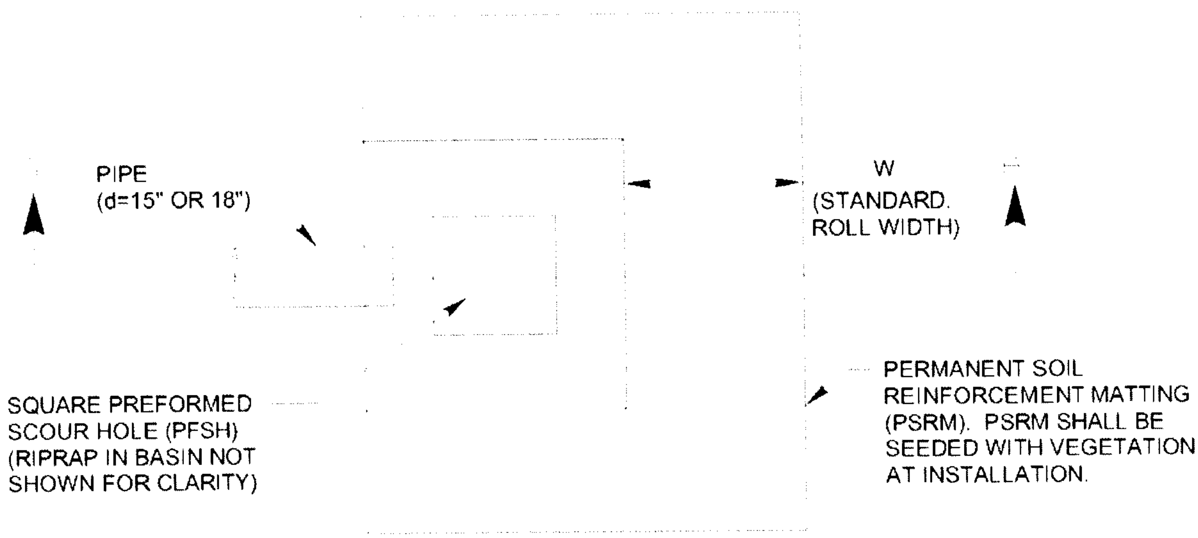


Figure 4-2. Typical preformed scour hole layout and components

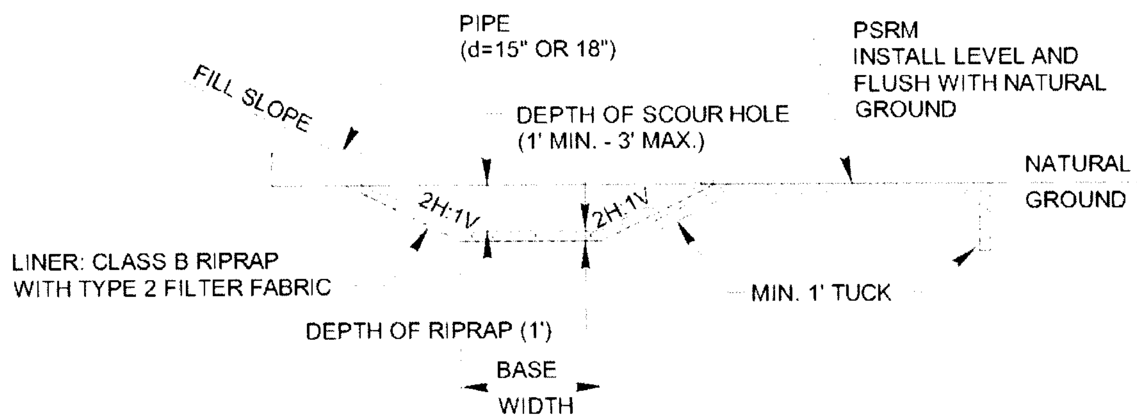


Figure 4-3. Preformed scour hole cross section

4.2 Applications

Preformed scour holes, sometimes referred to as riprap basins, can be used for energy dissipation in a variety of man-made conveyance systems. When the preformed scour hole is used for energy dissipation only, the runoff can exit the BMP either to a downgrade pipe or channel, or from less than three sides of the scour hole. Considerable guidance exists on the use of preformed scour holes (i.e., riprap basins) for energy dissipation purposes. However, this toolbox will focus on the specific application of the preformed scour hole to provide energy dissipation *and* diffuse flow to small drainage areas. For a preformed scour hole to perform both functions, specific conditions must exist.

Most importantly, the ground downgrade must be flat to prevent reconcentration of runoff. To redistribute runoff from channelized flow to diffuse flow, preformed scour holes should be implemented only for Q_{10} peak flows of 10 cfs or less. If these site and flow conditions exist and the BMP is designed and implemented in accordance with this toolbox, preformed scour holes can be used upgrade of protected buffer areas, outside of Zone 2.

If diffuse flow is required and either (1) the Q_{10} peak flow is greater than 10 cfs or (2) the site slope is not relatively flat, other BMPs should be considered instead of a preformed scour hole. Figure 4-4 shows a preformed scour hole in a linear highway application.

Figure 4-4. Preformed scour hole in a linear highway application

4.3 Design

For the purpose of diffusing flow, preformed scour holes can be used downgrade of 15-in. and 18-in. pipes.[1] For a preformed scour hole to be installed upgrade of riparian areas, the following requirements must be met:

- The outfall area must be flat.
- The BMP must be located outside of Zone 2 in buffer areas.
- The maximum allowable discharge for a 15-in. pipe is 6 cfs, based on the Q_{10} discharge.
- The maximum allowable discharge for an 18-in. pipe is 10 cfs, based on the Q_{10} discharge.

Once these site constraints are met, the size of the preformed scour hole is calculated based on the class of riprap used to line the hole and the diameter of the discharge pipe. For optimum

[1] If the discharge pipe is greater than 18 in. and/or diffuse flow is not a goal, the designer is directed to the Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 14 entitled *Hydraulic Design of Energy Dissipators for Culverts and Channels* (September 1983) for complete design procedures.

energy dissipation, the ratio of the scour hole depth (in.) to the midrange size of riprap (d_{50}, in.) should be greater than 2.0 and less than 4.0.

For 15-in. and 18-in. pipes, only Class B riprap (d_{50} = 8 in.) can be used to line the preformed scour hole. This specification is based on (1) empirical relationships between the area of the discharge pipe and the riprap d_{50} and (2) unsuccessful applications of smaller riprap sizes. Therefore, a d_{50} of 8 in. allows for a minimum scour hole depth of approximately 1 foot and a maximum scour hole depth of 3 feet. The minimum and maximum stone sizes for Class B riprap are 5 in. and 12 in., respectively.

Design Criteria

A summary of additional design information follows.

Design Criteria Summary

- ❒ The base of the scour hole is square. The width is calculated as follows:
  Base width = 3 × Discharge pipe size
  See Figure 4-3.
- ❒ Riprap must be Class B (d_{50} = 8 inches).
- ❒ Minimum width of the PSRM apron is the standard PSRM roll width.
- ❒ PSRM must be tucked a minimum of 1 foot underneath the filter fabric and natural ground around the perimeter of the scour hole. Refer to the preformed scour hole standard detail in Appendix B.
- ❒ Scour hole must be installed in flat areas.
- ❒ Side slope for all four sides of the scour hole is 2H:1V.
- ❒ Riprap thickness is equal to 1.5 times the midrange riprap stone size (d_{50}), or 1 foot for Class B riprap.
- ❒ Minimum depth of the scour hole is 1 foot.
- ❒ Maximum depth of the scour hole is 3 feet.

Design and Construction Considerations

Where diffuse flow is a primary goal, preformed scour holes must be installed level in relatively flat areas. To avoid shifting of the scour hole after installation, the BMP should be installed in undisturbed soil instead of in fill material.

Additional design recommendations follow:

- Ensure that the location of BMP is outside of clear recovery zones.
- Ensure that the location of BMP is outside of environmentally sensitive areas.
- Install performed scour holes after site stabilization.
- Check the available right-of-way when determining the BMP footprint and orientation.

- Ensure that the apron is flush with natural ground. The elevation of the top of the preformed scour hole should be the same as the elevation of the PSRM.
- Ensure that riprap consists of a well-graded mixture of stone. Smaller-size riprap stones should be used to fill voids between larger stones.
- Where practical, route off-site runoff away from the BMP.
- Immediately after construction, stabilize the exit areas with vegetation.
- Clear the area of all construction debris and check the exit areas for any potential obstructions that could promote channelized flow.

4.4 Inspection and Maintenance

Sediment, trash, and debris should be removed from the preformed scour hole periodically.

CHAPTER 5 Dry Detention Basin

OVERVIEW

A DRY DETENTION BASIN is a stormwater runoff quantity control BMP that attenuates stormwater flows, promotes settlement of suspended pollutants, and reduces erosive velocities downstream of the outlet structure.

PURPOSE AND DESCRIPTION

- Dry detention basins are structural BMPs designed to temporarily capture stormwater runoff and attenuate peak flows.
- Inflow to the BMP is retained and released from a primary outlet control device over a period of time.
- Dry detention basins are designed with a drawdown component that keeps the basin dry between storm events.

APPLICATIONS

- Dry detention basins are suitable for a variety of highway applications, provided there is adequate area for the basin.
- The recommended contributing drainage area is 75 acres or less.
- To maximize water quality benefits, dry detention basins can be included in a treatment train with other structural BMPs that target removal of solids and dissolved pollutants.

WATER QUALITY BENEFITS

- Dry detention basins promote sedimentation of suspended solids.
- By reducing peak discharges, dry detention basins prevent downstream erosion and hydrologic impacts to receiving water bodies.
- Incorporation of an underdrain system can maximize stormwater particle and particulate-bound pollutant removal.

5.1 Description

A dry detention basin is a permanent structural BMP with two or more outlet structures that capture, detain, and release stormwater runoff over a period of time. Dry detention basins provide water quality benefits through quantity control and the settling of suspended solids. By controlling the release of stormwater flows, dry detention basins mitigate the erosive impacts of frequent and/or intense storm events. When stormwater is temporarily detained in a dry detention basin, suspended solids are separated through sedimentation. Dry detention basins are designed to completely drain within 2–5 days after a storm event.

Figure 5-1. Typical dry detention basin during construction

The main components of a dry detention basin follow:

- Basin
- Outlet control structure
- Drawdown orifice
- Embankment
- Emergency spillway
- Underdrain system (optional)

Runoff enters a dry detention basin as diffuse flow, a point discharge from an open channel and/or conveyance pipe, or a discharge from a pretreatment BMP. Inflowing stormwater runoff fills the basin until it reaches the water quality volume elevation, defined by the height of the outlet control structure. For storm events less than or equal to the water quality volume (WQv), stormwater runoff is detained and the discharge is controlled through a combination of the drawdown orifice and soil infiltration. In Figure 5-1, the inflow structure with energy dissipator and riser structure are shown.

The embankment is an earthen dam over the barrel outlet pipe leading from the riser. The embankment allows the basin to temporarily detain volumes from storm events greater than the water quality volume. For larger storm events, an emergency spillway is necessary to minimize the potential for overtopping the basin and downstream flooding. The emergency spillway serves as an overflow structure that is typically constructed as a channel in natural ground.

Typical examples of a dry detention basin layout and its components are shown in Figures 5-2 and 5-3.

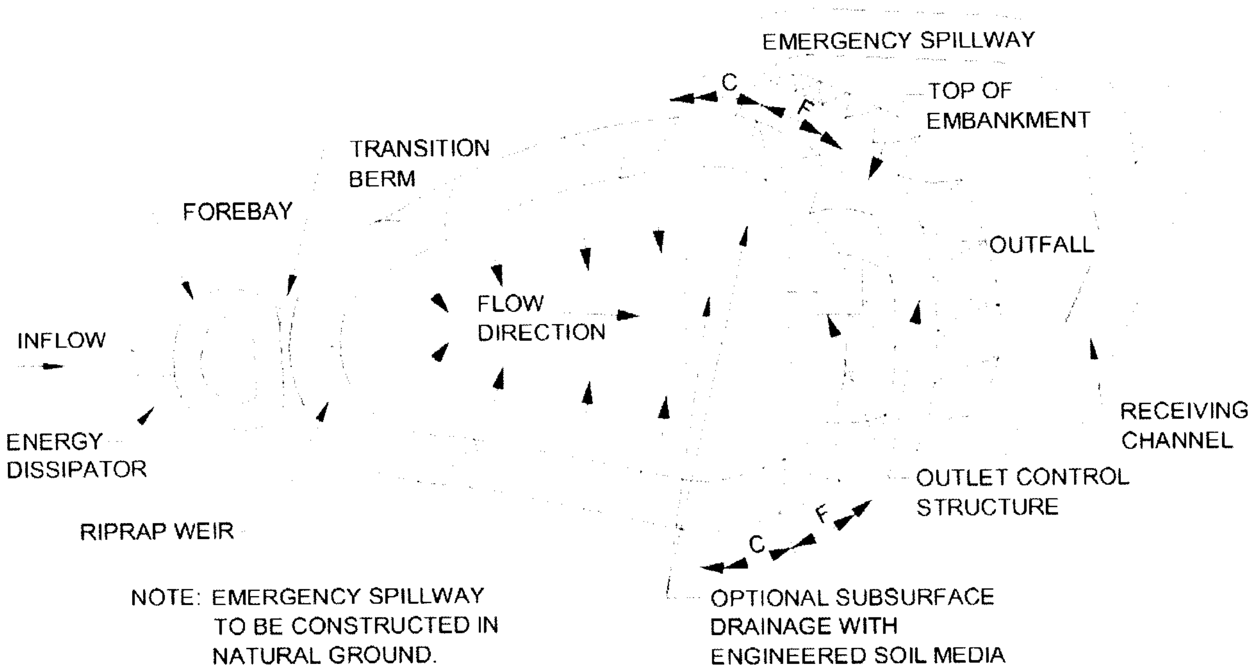


Figure 5-2. Typical dry detention basin layout and components

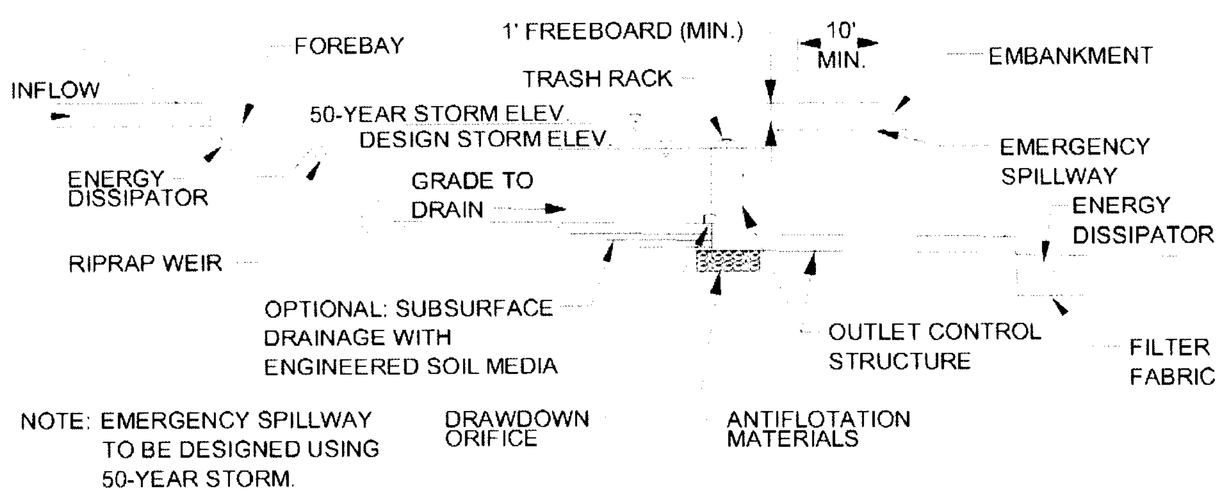


Figure 5-3. Dry detention basin cross section

5.2 Applications

Dry detention basins are suitable for collecting and detaining runoff from a variety of highway applications such as linear rights-of-way, facility areas, and interchanges. Compared to other structural BMPs, the basin footprint can be relatively large, making some linear right-of-way applications impractical.

The dry detention basin is applicable when the primary objective is controlling and reducing peak flow rates into receiving water bodies. Because stormwater is detained in the basin, the settling of particles and particulate-bound pollutants is the primary pollutant removal mechanism. Pollutant removal efficiencies are increased, especially for soluble pollutants, when significant infiltration occurs. Underdrain systems with engineered soil media can be used to improve infiltration rates. Dry detention basins can also be implemented in series with other structural BMPs, such as forebays, filter strips, or grass swales, to meet pollutant removal efficiency requirements.

5.3 Design

The design of the dry detention basin must account for the drainage area hydrology and the BMP component hydraulics. The inflow and outflow hydrographs for all design storms (e.g., 1-inch and 50-year storm events) must be determined and considered during design. Outlet structure hydraulics must also be evaluated. The routing procedure and hydrograph computation can be performed by a variety of methods and procedures contained in spreadsheets or modeling programs. The routing must be completed for each design storm under consideration to determine the water surface elevation of that storm as well as overall functionality of the system. More detailed information on hydrologic analysis and design methods is presented in Chapter 2.

This section provides guidance on designing dry detention basins for both water quantity and quality control. These design criteria may not apply if the sole purpose of the dry detention basin is to attenuate peak flow rates. In this case, the designer should consider both the appropriate design storms for detainment as well as downstream conditions when determining final design criteria.

BASIN SIZING CRITERIA

Dry detention basins are sized to temporarily store the volume of runoff from the first inch of rain, at a minimum. The height of the riser structure above the basin invert is determined by the required water quality volume (WQv) (refer to Chapter 2 for more information on WQv). A minimum of one foot of freeboard should be provided between the 50-year storm elevation and the top of the basin.

To improve the removal efficiency of solids using gravitational settling, the distance between the basin inlet and the outlet control structure should be maximized. The configuration of the basin can be determined by using the criteria outlined in the box entitled Basin Sizing Criteria Summary.

BASIN SIZING CRITERIA SUMMARY

- ❒ Basin should capture the runoff from the 1-inch storm and allow it to draw down over a period of 2–5 days.
- ❒ Minimum flow length-to-width ratio is 3:1 to prevent short-circuiting.
- ❒ Maximum contributing drainage area should not exceed 75 acres.
- ❒ Height of the embankment should not exceed 12 feet.
- ❒ Basin volume should not exceed 10 acre-feet.
- ❒ Basin side slopes should be 3H:1V or flatter. For steeper slopes, slope stabilization should be considered.
- ❒ A minimum of 1 foot of freeboard should be provided, measured from the top of the basin to the 50-year-storm water surface elevation.
- ❒ Basin should be located at a minimum of 2 feet above the seasonal high groundwater table.

BASIN COMPONENT DESIGN CRITERIA

Basin components include the outlet control structure, drawdown orifice, embankment, and emergency spillway.

Outlet Control Structure

The outlet control structure is composed of a riser and a discharge pipe (refer to Figure 5-3). The top of the riser should be set at a higher elevation than the basin floor to provide detention time for attenuation and delayed release of stormwater runoff peaks. The riser structure is typically made of concrete for durability. The material for the barrel or the pipe outlet structure is selected based on the outlet velocity and slope. The riser structure can consist of a drop inlet, an open-throat catch basin, or other acceptable control structure.

Drawdown Orifice

The orifice has small-diameter holes to allow for flow release and runoff infiltration. For drawdown purposes, it is preferable to use an orifice diameter between 2 and 3 inches. If a larger opening is required, then two or more orifice holes are recommended. The orifice should be designed to draw down the water quality volume within 2–5 days. Drawdown orifice size can be calculated using a routing spreadsheet or the orifice equation. The routing spreadsheet will include the changing head elevation; the equation alone should use an average height equal to one-half of the WQv depth.

Embankment

The height of the embankment is determined by providing a minimum of 1 foot of freeboard above the water surface elevation of the 50-year storm event. The top width of the embankment should be 10 feet to provide maintenance access.

Emergency Spillway

The emergency spillway is typically constructed in natural ground to serve as an overflow structure to safely discharge storm runoff flow during large storm events. The channel is typically designed to convey the discharge for the 50-year storm event. If there is not enough available right-of-way to construct the emergency spillway, an alternative design can be used.

Often the top of the riser is converted into an emergency overflow device, such as an open-throat riser. If the riser serves as the emergency spillway, it must be designed to pass the discharge from the 50-year storm. All alternative designs options are subject to review by the NCDOT Hydraulics Unit. Additional design criteria for basin components are provided in the Basin Component Design Criteria Summary.

Basin Component Design Criteria Summary

Outlet Control Structure

- Outlet control structure should be designed to handle the 1-inch storm if an emergency spillway channel is provided.
- Outlet control structure should be designed to handle the 50-year storm if an emergency spillway channel is not provided.
- An emergency sluice gate should be provided. The sluice gate invert should be set to the basin invert with a minimum opening of 8 inches.

Drawdown Orifice

- The preferred orifice size is between 2 and 3 inches.
- Drawdown orifice should be sized to provide a 2–5 day drawdown time of the WQv.

Embankment

- Height should be less than 12 feet.
- Embankment structure should have a minimum top width of 10 feet with side slopes of 3H:1V or flatter.
- Minimum of 1 foot of freeboard must be provided between the surface water elevation of the 50-year storm event and the top of the embankment.

Emergency Spillway

- Emergency spillway invert elevation should be set to safely convey the 50-year storm event and prevent flooding of the roadway.
- Emergency spillway liner material should be designed to meet the peak flow velocity from the 50-year storm discharge.

Design Options Criteria

Two design options that can improve the performance of the dry detention basin are a pretreatment forebay and an underdrain system with engineered soil media.

A pretreatment forebay removes some sediment and trash through energy dissipation before the runoff enters the detention basin. Incorporation of a forebay upstream of the basin decreases the incidence of drawdown orifice clogging, improves overall pollutant removal efficiencies, reduces the required frequency of maintenance, and extends the lifetime of the detention basin. The BMP should be sized using 10% of the water quality volume from the impervious area. The transition between the pretreatment BMP and the dry detention basin should be designed to prevent erosion. More information on forebays is provided in Chapter 7.

An underdrain system with engineered soil media can reduce pollutant loads by infiltrating a larger volume of runoff within the basin. Promoting runoff infiltration is recommended only at sites where contamination of surrounding groundwater is not a concern. The underdrain is a secondary drawdown device and is not intended to be the primary drawdown device.

DESIGN OPTIONS CRITERIA SUMMARY

Forebay

- ❒ Contributing drainage area should be delineated to determine the water quality volume (WQv) and Q_{10} discharge.
- ❒ Forebay should be sized for 10% of the WQv from the impervious area. Refer to Chapter 7 for more guidance.
- ❒ Forebay should have a minimum length-to-width ratio of 2:1 where practical to promote sedimentation, with a maximum ratio of 6:1.
- ❒ Depth of the forebay should be between 3 and 5 feet.
- ❒ Forebay side slopes should be flatter than or equal to 2H:1V.

Underdrain System

- ❒ The basin bottom should slope inward toward the underdrain pipes at a 1–2% grade as well as slope at a 1–2% grade in the direction of the outlet.
- ❒ Six-inch perforated pipes are recommended.
- ❒ The underdrain system should connect to the outlet control structure.

DESIGN AND CONSTRUCTION CONSIDERATIONS

When determining the location of a detention basin, the designer must take into account the topography and soils. The detention basin's shape will be subject to the contours of the site in some locations. The orientation should maximize the length-to-width ratio as much as 3:1.

Additional design and construction recommendations follow:

- Confirm the depth to the seasonally high groundwater table. Dry detention basins should not be placed where the water table is less than 2 feet below the bottom of the basin.
- Consider the consequences of groundwater interaction with runoff. If the site soils are highly permeable and pollutant concentrations are elevated, an impermeable liner can be used to prevent groundwater impacts.
- Verify soil types using soil survey maps or existing geotechnical reports.
- Use impermeable liners in regions with karst topography (southeastern coastal plain) to prevent collapse of underlying soils.
- Locate the BMP outside of clear recovery zones (30 ft).
- Check the available right-of-way when determining the BMP footprint and orientation.
- Place detention basins in undisturbed soil, not in fill material.
- Provide proper anchoring of the outlet control structure to prevent flotation as needed.

- Plant native grasses in the basin or cover in sod. Alternative vegetation, such as low weed species or riparian shrubs, can be planted as well, provided it can withstand both dry and ponding conditions.
- Consider whether bypass or diversion of off-site drainage is necessary based on site constraints. These options are useful in retrofit applications.
- Stabilize all basin system outfalls to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042.
- Provide a debris screen or trash rack over the drawdown inlet and riser structure to prevent clogging and human encroachment.
- Consider using baffles to increase the effective flow length in the basin.
- Include maintenance access to the BMP for cleanup and repair.

5.4 Inspection and Maintenance

Regular inspection and maintenance of the dry detention basin is critical to the life of the BMP and the prevention of flooding on the roadway.

General inspection and maintenance recommendations are as follows:

- Remove debris, trash, and sediment buildup from the basin as necessary to minimize outlet clogging and improve aesthetics.
- Repair and revegetate eroded areas as needed.
- Check inlets and outlets for structural repairs to ensure that they are operational.
- Mow as necessary to limit unwanted vegetation and remove clippings as practical.

5.5 Safety Considerations

Detention basins are typically large, so any standing water can present a drowning hazard, especially in residential or public areas. Trash racks and other structures should be designed to prevent entry by children. Consider fencing the area to ensure safety. Refer to NCDOT Standard Specifications, Section 866, for fencing options.

CHAPTER 6 Grass Swale

OVERVIEW

A GRASS SWALE is a vegetated channel designed to convey and treat runoff from small drainage areas.

PURPOSE AND DESCRIPTION

- Grass swales have trapezoidal or V-shaped cross sections with side slopes 3H:1V or flatter.
- The channel is sized to convey the Q_2 at low velocities and the Q_{10} at nonerosive velocities.

APPLICATION

- Grass swales are appropriate for linear highway, interchange, and facility applications.
- To maximize water quality benefits, grass swales are best suited for small drainage areas.
- Grass swales are often used in series or upstream of other BMPs.

WATER QUALITY BENEFITS

- By reducing flow velocity, grass swales promote infiltration and runoff attenuation.
- Grass swales remove suspended solids, metals, and nutrients through sedimentation, vegetated filtration, infiltration, and biological uptake.

6.1 Description

Grass swales are broad and shallow vegetated channels designed to convey and treat peak runoff from small drainage areas. The purpose of a grass swale, as opposed to traditional roadside ditches, is to decrease the velocity of runoff to promote infiltration and interaction between runoff and vegetation. To perform this function, grass swales typically have denser vegetation and flatter slopes than most drainage channels. When incorporated into roadway or facility design as part of the conveyance system, grass swales can provide water quality benefits and be aesthetically pleasing.

Grass swales treat runoff through physical filtration, infiltration, and biofiltration. As runoff moves through the grassed channel, suspended solids are filtered through the grass, improving water clarity and removing particulate-bound pollutants such as metals and nutrients. In sufficiently permeable soils, infiltration plays a significant role in reducing runoff volume. Finally, removal of metals, nitrogen, and phosphorus may occur through biological uptake.

Figure 6-1. Grass swale with water quality rock check

The main component of the grass swale is the vegetated channel. In some applications, water quality rock checks are incorporated to terrace the grass swale to maintain a flat effective slope and provide erosion control (Figure 6-1). An example of a grass swale and its components is shown in Figure 6-2. Figure 6-3 is a cross section of a grass swale.

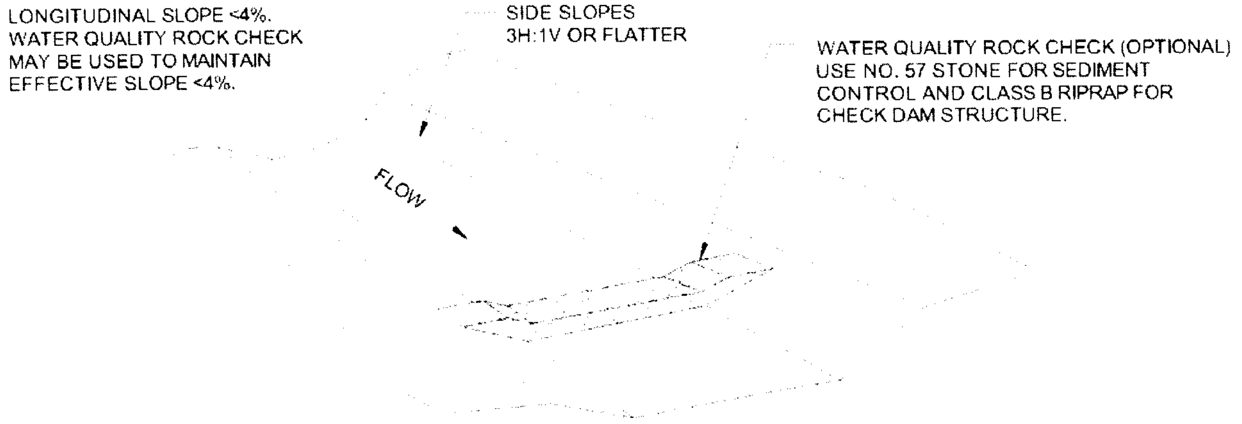


Figure 6-2. Isometric view of a grass swale with optional water quality rock check

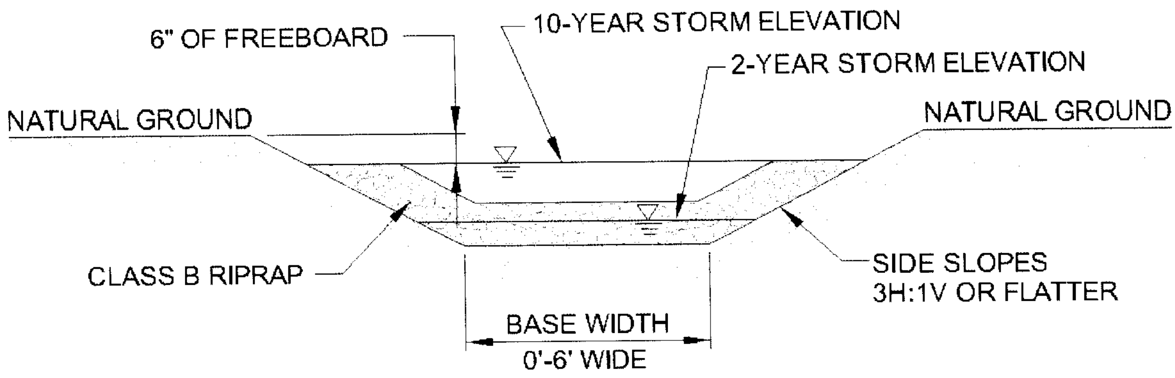


Figure 6-3. Grass swale cross section with optional water quality rock check

6.2 Applications

Grass swales are appropriate for a variety of transportation applications, including linear rights-of-way, highway interchanges, and NCDOT facilities. Grass swales are also well suited for secondary roadway applications because of the available pervious area along the roadside. In some instances, roadside ditches can be retrofitted to function as grass swales. Figure 6-4 shows grass swales in typical highway applications.

Grass swales significantly improve the water quality for drainage areas less than 20 acres. For larger drainage areas, grass swales are best implemented in series or in a treatment train of BMPs to maximize water quality benefits.

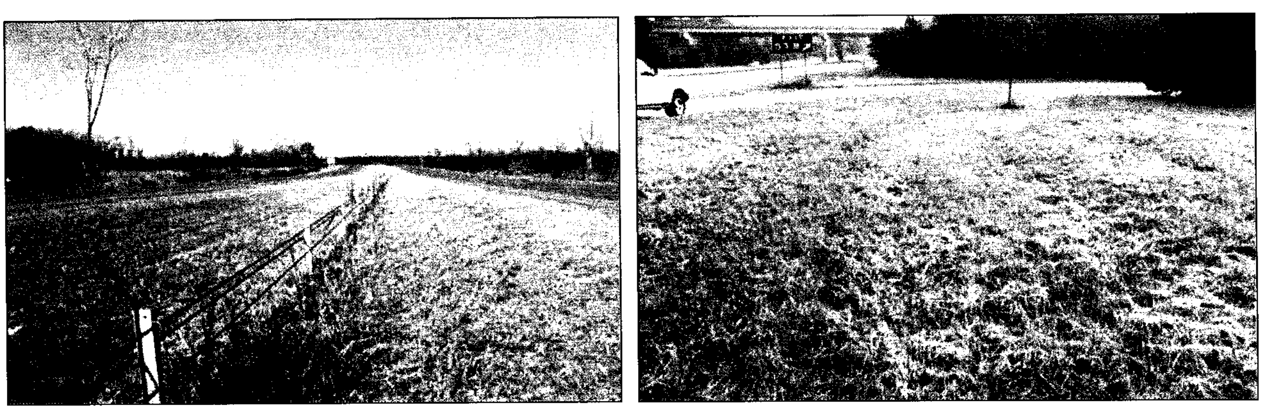


Figure 6-4. Linear highway applications of grass swales

6.3 Design

To maximize water quality benefits, grass swales are designed to reduce the flow velocity, increasing contact time between runoff and swale vegetation and promoting infiltration. Therefore, broad swales on relatively flat slopes with dense vegetation and permeable soil will be most effective at removing pollutants from stormwater.

The longitudinal slopes of the grass swale should be 4% or less. In addition, swale side slopes should be 3H:1V or flatter.

CONFIGURATION CRITERIA

Trapezoidal or V-shaped cross sections should be used in grass swale design.

SIZING CRITERIA

Grass swales are sized to (1) treat the runoff from the Q_2 and (2) safely convey the Q_{10} without overtopping the swale or eroding the swale lining. All discharges are calculated using the rational method. General design criteria are provided in the Design Criteria Summary. Additional criteria may be required for sensitive watersheds; the designer should consult regulatory requirements prior to grass swale design.

To maximize the treatment capacity of the grass swale, the maximum velocity for the Q_2 should be no greater than 2.0 fps. The grass swale should also be capable of conveying the Q_{10} at a velocity less than the permissible velocity and with 6 inches of freeboard. Permissible velocity is a function of the lining material. Most established grass linings have permissible velocities between 3.5 and 6.0 fps. For simplicity, 4.0 fps and less is considered a nonerosive velocity for grass-lined channels.

DESIGN CRITERIA SUMMARY

- ❒ Grass swales should be designed with longitudinal slopes between 0.3 and 4%.
- ❒ The maximum grass swale base width is 6 feet. Exact base width is determined by the desired flow depth.
- ❒ Grass swale side slopes should be 3H:1V or flatter.
- ❒ Grass swale length of 100 feet per contributing acre of drainage area is recommended.
- ❒ The maximum design velocity for the Q_2 is 2.0 fps.
- ❒ The permissible velocity for the Q_{10} is 4.0 fps for a channel with established vegetation.

The dimensions of the grass swale are determined using Manning's equation and the continuity equation. Complete guidance on stable channel design methods is provided in the NCDENR *Erosion and Sediment Control Planning and Design Manual,* Appendix 8.05.

VEGETATION CRITERIA

Vegetation used in grass swales should reasonably tolerate standing water, resist erosion, and resist bending when subject to runoff flows. To maximize treatment efficiency of the swale, the vegetation should be as dense as possible. Guidance on vegetative considerations, specifications for seeding mixtures, and a description of various grasses for use in each of North Carolina's physiographic regions is provided in the NCDENR *Erosion and Sediment Control Planning and Design Manual* (refer to Chapter 3, Chapter 6, and Appendix 8.02).

ALTERNATIVE DESIGN CRITERIA

If site constraints do not allow for the required longitudinal slopes or design storm velocities, water quality rock checks may be used as an alternative design. Water quality rock checks are permanent structures that reduce the effective slope of the grass swale and create small pools, dissipating the energy of flow. The rock checks should be used in series, with the toe of the upstream check at the same elevation as the top of the downstream check. Design criteria for water quality rock checks are provided in the accompanying Alternative Design Criteria Summary. For additional guidance, a detail drawing is provided in Appendix B.

ALTERNATIVE DESIGN CRITERIA SUMMARY (WATER QUALITY ROCK CHECK)

- ❐ Rock check should be 1 foot high along the wetted perimeter of the swale.
- ❐ Rock check should be constructed of Class B riprap.
- ❐ A 12-inch layer of No. 57 stone should be placed upstream of the Class B riprap to provide sediment control.
- ❐ Width of the check should be 4.5 feet in the direction of flow, including the layer of No. 57 stone.
- ❐ Toe of the upstream check should be the same as the top of the downstream check.

DESIGN AND CONSTRUCTION CONSIDERATIONS

Prior to the establishment of vegetation in the swale, significant erosion and scour can occur with bare soil. The exposed swale should be protected with a temporary erosion-resistant lining. Manning's n can typically be determined for various temporary liners from the manufacturer's specifications. Complete temporary erosion-resistant liner design procedures are provided in Appendix 8.05 of NCDENR's *Erosion and Sediment Control Planning and Design Manual,* as well as in FHWA's HEC-15 (FHWA, 2005). Figure 6-5 shows unvegetated grass swales.

Additional design and construction recommendations follow:

- Evaluate the impacts of ponded water in the grass swale. Ponded water and wetland vegetation may occur when longitudinal slopes are less than 1.0%.
- Evaluate the necessity for outlet protection at any discharge point from the grass swale to prevent scour.
- When applying the grass swale in a treatment train, design transitions to other devices to prevent short-circuiting.
- Where practical, route off-site runoff away from the grass swale.
- Consider alternative grasses or seeding mixtures in the event the selected vegetation is not effectively established.

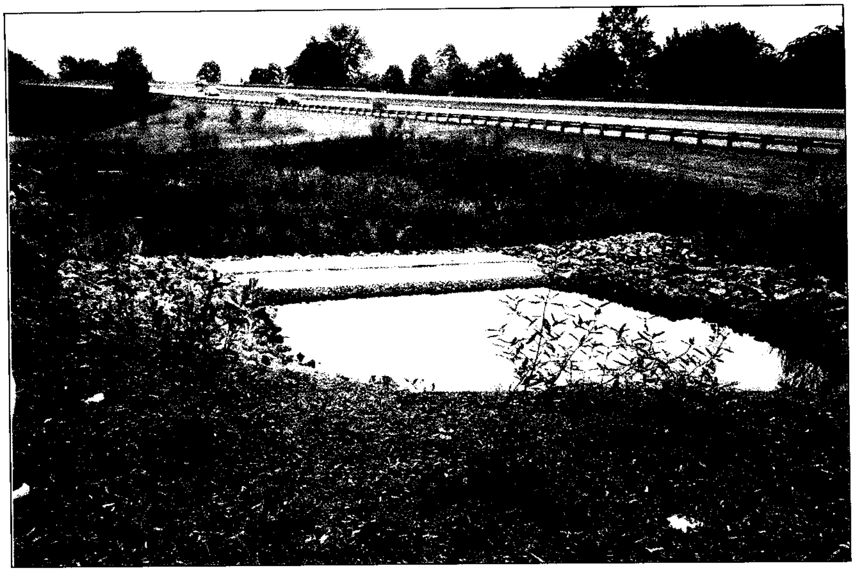

Figure 6-5. Grass swales without established vegetation

6.4 Inspection and Maintenance

Grass swale maintenance consists of mowing the vegetation and removing the deposited sediment. The height of the grass is important for proper functioning of the grass swale. Vegetation should be maintained at a height of approximately 5 inches. The maintenance schedule will depend on the type of vegetation selected. Additional inspection and maintenance recommendations follow:

- Remove sediment when it is 5 inches deep or approximately the height of vegetation. Dispose of residuals in accordance with local and state regulations.
- Periodically inspect the swale for the formation of rills, gullies, and bald patches. Correct as necessary.
- Remove trash and debris on a regular basis.

CHAPTER 7 Forebay



OVERVIEW

A **FOREBAY** is a pretreatment BMP to be used in conjunction with other BMPs designed to dissipate energy and capture sediment, trash, and debris.

PURPOSE AND DESCRIPTION

- A forebay is an excavated basin designed to dissipate the energy of concentrated flows and provide diffuse flow to a downgrade BMP.
- A forebay promotes sedimentation and captures trash and debris.

APPLICATIONS

- Forebays are pretreatment BMPs combined with other BMPs such as infiltration basins, dry detention basins, stormwater wetlands, bioretention basins, and level spreaders.
- Forebays are appropriate where concentrated runoff from a highway project is conveyed by roadside ditches and/or storm pipes to a receiving water body.

WATER QUALITY BENEFITS

- Forebays dissipate energy, thereby reducing the velocity of the flow to allow suspended particles to settle before discharging runoff into receiving water bodies.
- Forebays provide diffuse flow to downgrade BMPs.
- Forebays capture trash and debris.
- Forebays enhance the function of downgrade BMPs.

7.1 Description

A forebay is an essential component of most impoundment and infiltration BMPs, including infiltration basins, dry detention basins, stormwater wetlands, bioretention basins, and level spreaders (Figure 7.1). The forebay dissipates the energy of the flow from a point discharge, allowing suspended particles to settle and trapping trash and debris. This minimizes clogging of the downgrade outlet control device and prevents sedimentation in the receiving water body. The water exits the forebay through a nonerosive outlet control device.

The main components of a forebay follow:

- Excavated basin
- Liner material
- Outlet control device

The liner material should be selected by the engineer. Typical liner materials are riprap, grass, and concrete, although riprap with filter fabric is most commonly used. If riprap is used, the filter fabric acts as a barrier between the basin floor and the riprap. The outlet control device is generally a shallow weir. Forebays can be excavated basins or they can be constructed with earthen berms or riprap walls. Some forebays are a combination of both.

Figure 7-1. Riprap-lined forebay upgrade of a dry detention basin

A typical example of a forebay layout and components is presented in Figure 7-2. Figure 7-3 shows a forebay cross section.

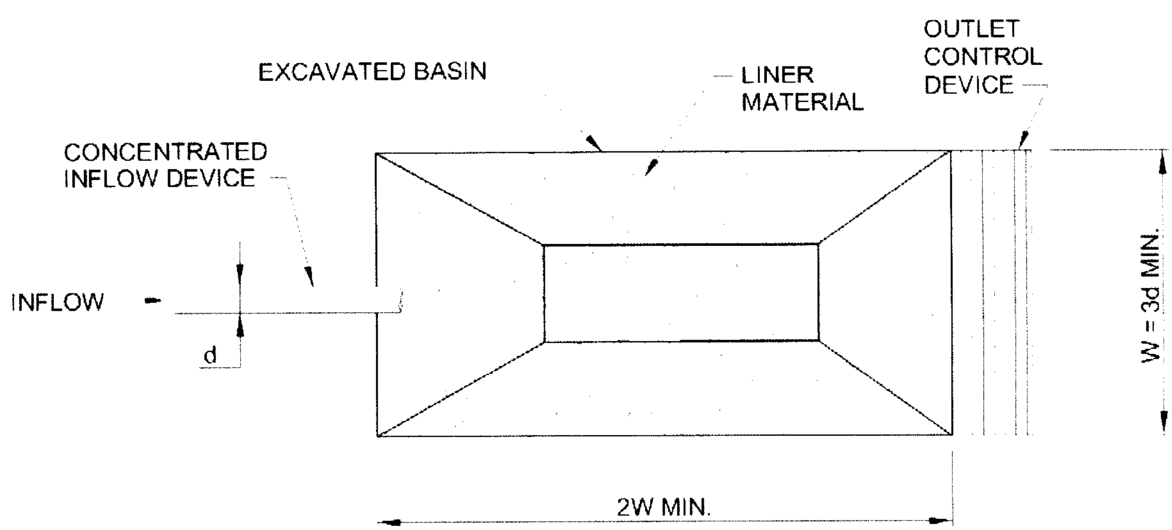


Figure 7-2. Typical forebay layout and components

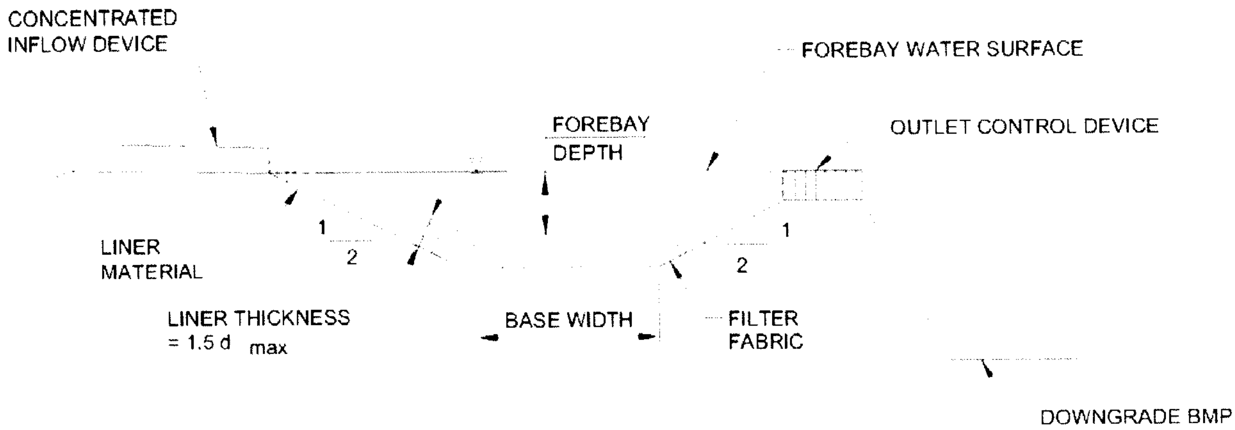


Figure 7-3. Forebay cross section

7.2 Applications

Forebays are suitable for many highway applications where the footprint space is available. Forebays are appropriate when concentrated highway runoff from a project is conveyed by roadside ditches and/or storm pipes to a downgrade BMP or water body. A forebay should be located at each inflow point, or the conveyance systems may be aligned to discharge into one forebay. A forebay typically serves as a pretreatment BMP for one or a series of BMPs. By trapping sediment and debris, a forebay enhances the performance and longevity of BMPs in series. BMPs that are typically combined with a forebay include, but are not limited to, infiltration basins, dry detention basins, stormwater wetlands, bioretention basins, and level spreaders. An example of a forebay used in combination with another BMP is shown in Figure 7-4.

Figure 7-4. Forebay with bioretention basin

7.3 Design

SIZING CRITERIA

The forebay size is determined by calculating 10% of the water quality volume (WQv) for the impervious drainage area. A good rule of thumb is to provide 345 cf of volume per impervious acre. Forebay volume can be estimated by applying the following equation,

$$V = 345\left(\text{ft}^3/\text{acre}\right) \times \text{IDA}\left(\text{acre}\right)$$

where V is the forebay volume (ft^3) and IDA is impervious drainage area (acre). More information about the WQv method is given in Chapter 2.

Design Criteria

The velocity of the flow entering the forebay will be reduced by the liner material to prevent scour and undermining. Outlet stabilization is necessary to absorb the impact of flow and reduce the velocity to nonerosive levels. The outlet stabilization material should line the forebay and be determined by the velocity produced by the Q_{10} discharge. It is recommended that the entire forebay bottom and side slopes be lined with the selected liner material. If riprap is used, it should consist of a well-graded mixture of field stone or quarry stone. The majority of the stone mix should consist of larger stones, with smaller stones filling the voids. The maximum stone diameter, d_{max}, should be no greater than 1.5 times the median size of the riprap, d_{50}.

The minimum thickness of the riprap should be 1.5 times d_{max}. The filter fabric is placed between the riprap and soil foundation to prevent soil movement through the openings of riprap. For requirements regarding the class and size distribution of riprap, see Table 1042-1 in Section 1042 of the NCDOT Standard Specifications. Design criteria for the forebay are summarized in the box.

Design Criteria Summary

- ❐ Contributing drainage area should be delineated to determine the Q_{10} discharge.
- ❐ Forebay should be sized to convey 10% of the WQv based on the impervious drainage area (IDA), as shown in Equation 1.
- ❐ Forebay should have a minimum length-to-width ratio of 2:1, where practical, to promote sedimentation, with a maximum ratio of 6:1.
- ❐ Depth of the forebay should be between 3 and 5 feet.
- ❐ Forebay side slopes should be flatter than or equal to 2H:1V.

Other design recommendations for a forebay and its components are as follows:

- The size of the riprap or liner material must be adequate for the forebay.
- Forebay outlet berms should have a minimum top width of 5 feet (in the direction of flow).
- Flow depth in the outlet control structure should be 6–12 inches above the end of the forebay for transition areas between the forebay and downstream BMPs.
- The transition berm between the forebay and the downgrade BMP should be made of a nonerodible material designed to minimize exit velocities and diffuse flow to the associated BMP.
- Forebays should be located at each inflow point. The conveyance system may be aligned to discharge into one forebay or several, as appropriate for the particular site.

Design Options

Forebays are often included in a series of BMPs. Regardless of whether a forebay is independent or is combined with other BMPs, the entire system must be capable of passing the Q_{10} discharge. Typical BMPs used downgrade of a forebay are as follows: infiltration basins, dry detention basins, stormwater wetlands, bioretention basins, and level spreaders.

Design and Construction Considerations

When selecting a forebay location, the designer must take into account topography. The forebay should be oriented to conform to the contours of the site. Typically, the forebay is placed adjacent to the invert of a highway drainage system outlet. When this is not practical, for instance, when there are steep slopes at an outfall, alternatives should be considered. Constructing a riprap-lined channel to connect the drainage system outlet pipe to the forebay is one means of solving this problem.

Additional design recommendations follow:

- Locate the BMP outside of clear recovery zones.
- Ensure that the forebay has easy access for maintenance.
- Check the available right-of-way when determining the BMP footprint and orientation.
- Direct off-site diffuse flow around or away from the forebay, where practical.

7.4 Inspection and Maintenance

In addition to accumulating sediment, forebays typically collect trash and other debris from the highway drainage system. This trapping feature allows subsequent BMPs in a series to function more efficiently, but it necessitates regular maintenance of the forebay. To ensure that the forebay maintains its trapping capability, periodic cleaning of the forebay inlet is required as a part of routine maintenance. Figure 7-5 illustrates the difference between a maintained forebay and a forebay in need of cleaning.


Figure 7-5. Maintained forebay (left) and forebay in need of sediment removal (right)

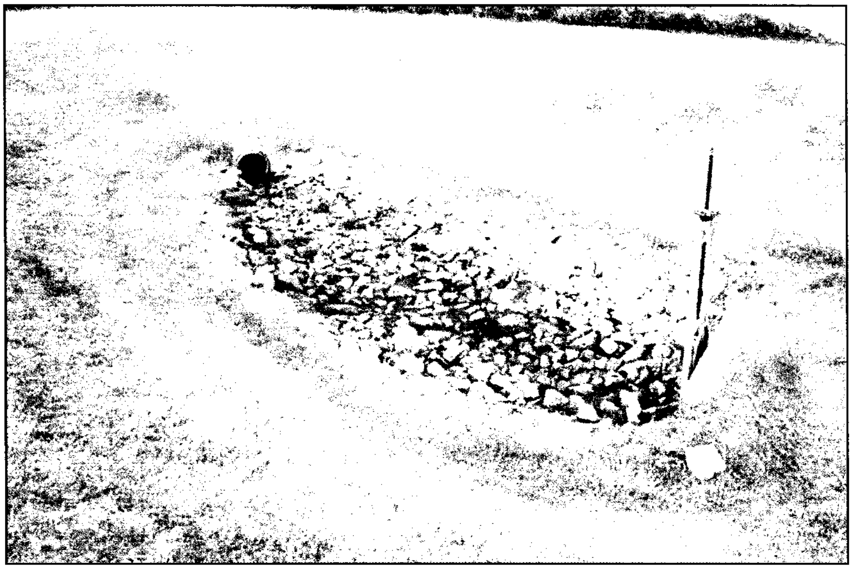
General inspection and maintenance recommendations are as follows:

- Trash and debris should be cleaned out periodically to maximize the performance of the BMP.
- If the sediment accumulates to the height of the forebay inlet, the sediment should be removed.
- If riprap is used to line the forebay, it should be replaced as necessary during cleanout.
- Filter fabric should be replaced as needed.

7.5 Safety Considerations

Forebays located in residential or public areas may present a drowning hazard. Consider fencing the area to ensure safety. Refer to Section 866 of the NCDOT Standard Specifications for fencing options.

CHAPTER 8 Hazardous Spill Basin



OVERVIEW

A HAZARDOUS SPILL BASIN is a BMP designed to protect surface water quality by retaining hazardous materials accidentally released on roadways near designated sensitive water supplies and concentrated truck usage areas.

PURPOSE AND DESCRIPTION

- Hazardous spill basins are structural BMPs designed to temporarily retain hazardous materials.
- Inflow to the basin is trapped by an outlet structure until emergency response activities are complete and the hazardous material is removed.
- Under normal operation, hazardous spill basins do not restrict the free flow of runoff.

APPLICATIONS

- Hazardous spill basins can be implemented at concentrated truck usage areas and along certain roadways.
- For linear highway applications, hazardous spill basins are provided at stream crossings on rural and urban arterials for specific classifications of streams.
- Hazardous spill basins can be included in a treatment train with other structural BMPs that target removal of solids and dissolved pollutants.

WATER QUALITY BENEFITS

Hazardous spill basins provide both a public safety and an environmental service by preventing the contamination of receiving waters.

8.1 Description

Hazardous materials are transported on North Carolina roadways to support various industries. To protect against the accidental release of hazardous material into receiving waters, hazardous spill basins are implemented at select locations. A hazardous spill basin (HSB) is a permanent structural BMP with an outlet structure capable of blocking the normal free flow of runoff to retain a spill of hazardous material. Hazardous spill basins provide surface water quality benefits by preventing the contamination of critical water supplies. Figure 8-1 is a photo of a typical hazardous spill basin.

Figure 8-1. Riprap-lined hazardous spill basin

Emergency response to hazardous spill releases is coordinated through the North Carolina Emergency Management Division (NCEMD). NCDOT supports NCEMD spill containment efforts involving vehicular accidents on state roads, right of ways, and adjacent properties when requested (NCDOT, 2000). Further, regional response teams are trained in various hazardous spill containment techniques and maintain portable equipment for that purpose. More information on emergency response can be found at the NCEMD website, www.dem.dcc.state.nc.us. Hazardous spill basins are intended to support NCEMD response efforts by acting as a secondary control when standard emergency response protocols are not adequate to contain a spill.

Hazardous spill basins have two or three main components:

- Basin
- Outlet structure
- Obstruction materials (optional)

Runoff and hazardous material typically enter a hazardous spill basin as a point discharge from the roadway or parking lot stormwater drainage system. However, runoff may enter the HSB as diffuse flow or as discharge from a pretreatment BMP. Hazardous spill basins are sized to contain the runoff volume from small, frequently occurring storm events plus additional volume to contain a spill. During normal operation, stormwater runoff flows through the system without detention or retention. In the event of a hazardous materials spill, the outlet pipe is obstructed by various mechanisms to prevent the release of hazardous material into a receiving stream.

Typical examples of a hazardous spill basin layout and its components are shown in Figures 8-2 and 8-3.

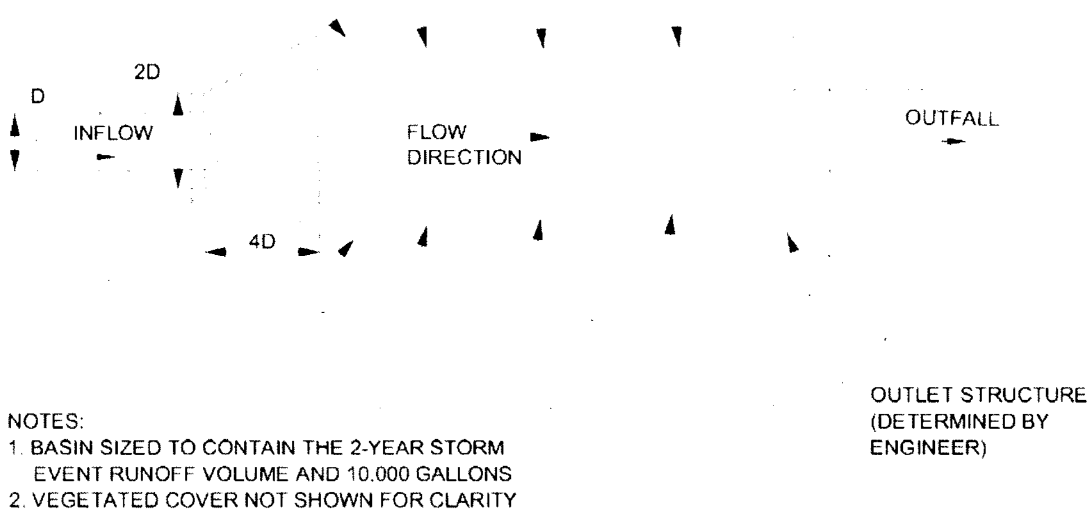


Figure 8-2. Typical hazardous spill basin layout and components

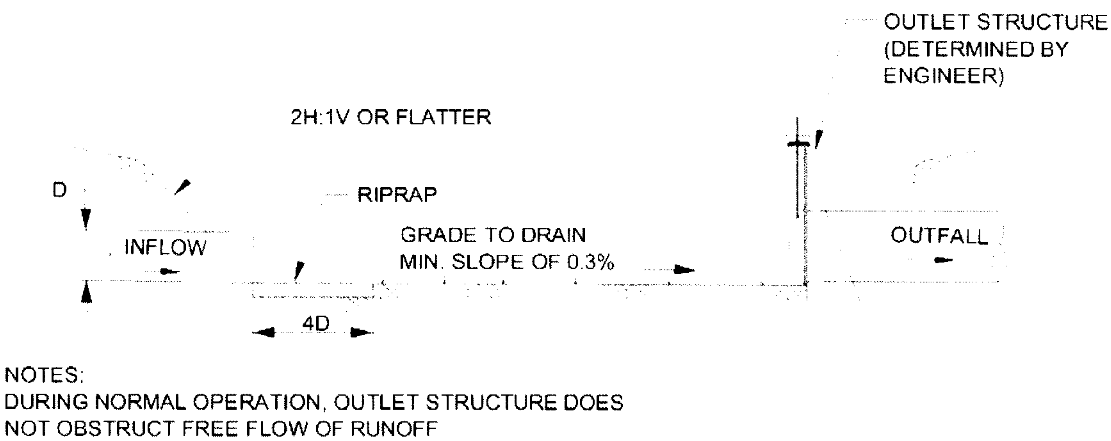


Figure 8-3. Hazardous spill basin cross section

8.2 Applications

Hazardous spill basins are applicable at NCDOT industrial facilities and in priority linear highway applications (see Figure 8-4). Hazardous spill basins have been implemented at weigh stations, runaway truck ramps, and rest area truck parking lots.

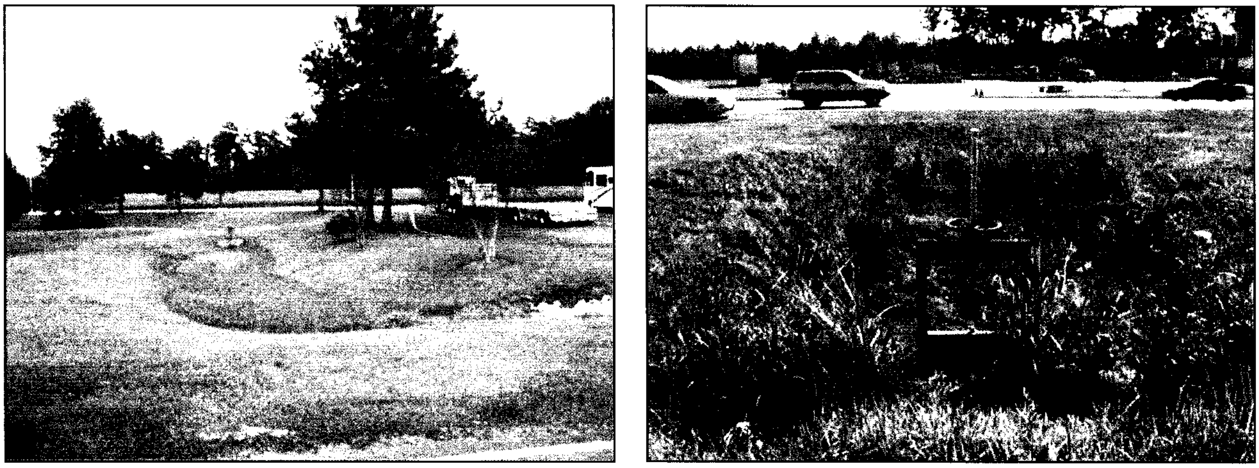


Figure 8-4. A hazardous spill basin at a rest area (left) and in a linear highway setting (right)

For linear highway applications, several factors determine whether a hazardous spill basin is appropriate including the functional roadway classification, the receiving stream classification, and highway geometrics. For new highway construction and major improvement projects, hazardous spill basins are applied at stream crossings on roadways classified as rural or urban arterials, **and**

- The stream is identified as an Outstanding Resource Water (ORW) or a WS-I water supply, or
- The stream crossing is within 1/2 mile of the critical area of a water supply source classified as WS-II, WS-III, or WS-IV. The critical area is defined as extending 1/2 mile from the normal pool elevation of a reservoir or 1/2 mile upstream of and draining to an intake. Therefore, hazardous spill basins are provided on stream crossings within 1 mile of the normal pool or upstream of an intake for applicable stream classifications.

The term *stream* is defined as a stream depicted as a solid or dashed blue line on 7-1/2 minute (1:24,000 scale) United States Geological Survey (USGS) quadrangle maps. The stream classifications ORW, WS-I, WS-II, WS-III, and WS-IV are discussed in detail in *BMPs for the Protection of Surface Waters* (2007 update). Surface water classifications and guidance on determining the classification of a waterbody can be found on the North Carolina Division of Water Quality website, http://h2o.enr.state.nc.us/csu/index.html. Finally, functional roadway classification maps can be obtained through NCDOT's Transportation Planning Branch.

Once it is determined that a hazardous spill basin is applicable due to the roadway classification and proximity to an applicable receiving stream, site-specific factors should be evaluated. For example, if a rural arterial does not support an adequate volume of tanker truck or other hazardous material transport vehicles to pose a significant risk of a hazardous spill, a hazardous spill basin may not be necessary. The accident-potential related to highway geometrics, ease of human access and egress to the basin, and the feasibility of basin construction should also be considered.

For Transportation Improvement Projects (TIPs), designers should consult the NCDOT TIP planning document for general recommendations on the use of hazardous spill basins.

8.3 Design

The hazardous spill basin comprises a naturally depressed or excavated basin and an outlet structure that can be closed during a hazardous spill event. Hazardous spill basins do not detain or retain stormwater and are not necessarily designed to remove suspended solids; therefore, the standard 3:1 length-to-width ratio for most stormwater BMP basins does not apply.

Basin Sizing Criteria

Hazardous spill basins are sized to temporarily store the runoff volume from the 2-year storm event plus an additional 10,000 gallons. In addition, a freeboard of one foot or greater should be incorporated into the design. Like most stormwater BMPs, the entire system should have the capacity to convey the 10-year storm event without system failure or degradation of the receiving stream. Depending on the size of the area draining to the hazardous spill basin, it may be necessary to consider using hazardous spill basins in parallel or a system bypass.

The actual shape of the basin is limited only by site-specific constraints. All efforts should be made to orient the hazardous spill basin to facilitate ease of operation and maintenance and to minimize the required right-of-way area. The basin design can be determined by using the criteria outlined in the box entitled Basin Sizing Criteria Summary.

Basin Design Criteria Summary

- ❐ The basin side slopes should be 2H:1V or flatter.
- ❐ The basin should be designed to contain the runoff volume from the 2-year storm event plus 10,000 gallons.
- ❐ At a minimum, the basin should be designed with 1 foot of freeboard.
- ❐ At a minimum, the basin should be capable of conveying the 10-year storm event without failure or downstream erosion.

OUTLET STRUCTURE DESIGN CRITERIA

Typically, the HSB outlet structure consists of an outlet pipe, a sluice gate, and a concrete head wall supporting the sluice gate. Any mechanical or nonmechanical means that stops and contains the flow within the basin can be implemented. The outlet structure should be designed to quickly and readily contain hazardous materials. Whether the hazardous spill basin will be under close scrutiny (i.e., at rest areas) or infrequently visited should be considered when choosing the outlet structure. Non-mechanical means of blocking the outlet pipe include the storage of an obstruction material, such as sandbags, near the hazardous spill basin.

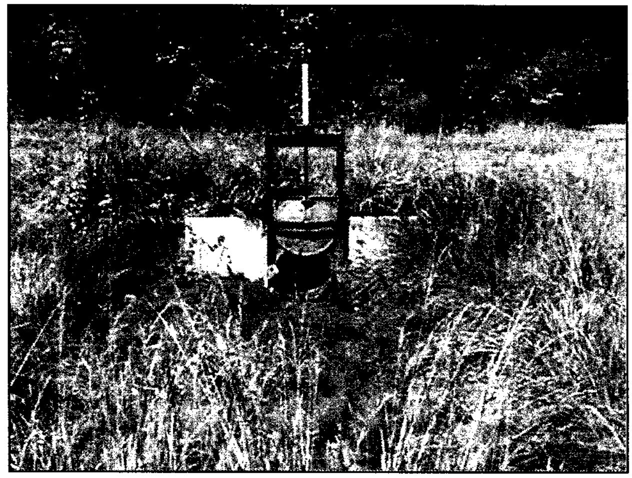


Figure 8-5. A sluice gate in a hazardous spill basin

The traditional sluice gate and concrete endwall option is discussed in this section. Examples of sluice gates in hazardous spill basin applications are shown in Figure 8-5. All alternative designs are subject to approval by the NCDOT Hydraulics Unit.

Outlet Pipe

The invert of the outlet pipe should be located as near the invert of the basin as possible to prevent the detention of runoff and the buildup of sediment. At a minimum, the outlet pipe should be sized to convey flow from the 10-year storm event. All riprap used for energy dissipation purposes should be placed beneath the pipe in accordance with NCDOT Standard Detail Drawing No. 876.02.

Sluice Gate

A sluice gate is a vertically sliding valve typically mounted to a concrete wall with anchor bolts. The purpose of the sluice gate is to stop the flow of runoff. The sluice gate is left open during normal operation. In the event of a spill, the gate is closed by the hazardous material transporter or an emergency responder. The sluice gate should form a watertight seal, as practical. Steel sluice gates are commonly applied in hazardous spill basins, although alternative materials can be considered. All sluice gates should be designed in accordance with NCDOT Standard Detail Drawing No. 838.02. Sluice gate dimensions, including gate diameter and frame height, are provided in the detail drawing as a function of the outlet pipe diameter. General design criteria are provided in the Outlet Structure Design Criteria Summary.

Concrete Endwall

The concrete endwall around the outlet pipe is constructed with Class B concrete to support the sluice gate. The design of concrete endwalls for use with sluice gates is also shown in NCDOT Standard Detail Drawing No. 838.02. The thickness of the base will vary as a function of the outlet pipe diameter.

Modification of the concrete endwall may be required, depending on the sluice gate dimensions and attachment method. The designer should consult the manufacturer's instructions for installation of the sluice gate before constructing the endwall.

OUTLET STRUCTURE DESIGN CRITERIA SUMMARY

Sluice Gate

- ❒ The sluice gate diameter should be a minimum of 7 inches larger than the outlet pipe diameter.
- ❒ The manufacturer's dimensions and specifications should be used to properly install the sluice gate.
- ❒ Refer to NCDOT Standard Detail Drawing No. 838.02.

Concrete Endwall

- ❒ Class B concrete should be used.
- ❒ The height of the concrete endwall should be 10 feet or less and is dependent on the pipe diameter.
- ❒ The concrete endwall should be chamfered 1 inch on all exterior corners.
- ❒ Refer to NCDOT Standard Detail Drawing No. 838.02.

DESIGN AND CONSTRUCTION CONSIDERATIONS

One measure of a successful hazardous spill basin application is the ease with which someone could locate and close the outlet device during an emergency. In addition, the hazardous spill basin should allow access for appropriate maintenance equipment. Alternative hazardous spill containment options should be considered if the basin cannot be accessed for operation and maintenance. Additional design and construction recommendations follow:

- Consider whether bypass or diversion of off-site drainage is necessary based on site constraints.
- Verify soil types using soil survey maps or existing geotechnical reports.
- Use impermeable liners in regions with karst topography (southeastern coastal plain) to prevent collapse of underlying soils.
- Locate the outlet structure outside of clear recovery zones (typically 30 ft).
- Check the available right-of-way when determining the basin footprint and orientation.
- Use proper energy dissipation where perpendicular or angular inflows to the hazardous spill basin are necessary.
- Protect the outlet structure from rust.
- Use forms to construct the bottom slab of the concrete endwall. When the base is poured separately, leave the concrete surface rough.
- Use proper energy dissipation where perpendicular or angular inflows to the hazardous spill basin are necessary. Stabilize all basin system outfalls to prevent scour and erosion. See NCDOT Standard Specifications, Section 1042, and NCDOT Standard Detail Drawing No. 876.02.

- Consider a flush-bottom sluice gate to prevent the buildup of debris beneath the gate.
- If a nonmechanical means is chosen to obstruct the outlet pipe, select materials that can be quickly moved into the basin without the aid of a shovel, such as sandbags. The materials should be relatively lightweight so they can be easily lifted by the average person.
- Consider covering obstruction materials with a tarp to prevent grass growth.
- Evaluate the impact that a fence will have on the ability to operate the hazardous spill basin in an emergency. At some sites, a fence may be necessary to prevent public access and vandalism. However, emergency responders and emergency equipment must be able to quickly access the hazardous spill basin.

8.4 Inspection and Maintenance

Hazardous spill basins must be maintained to be functional during an emergency spill. General inspection and maintenance recommendations are as follows:

- Remove debris, trash, and sediment buildup from the basin as necessary to minimize outlet clogging and improve aesthetics.
- Repair and revegetate eroded areas as needed.
- Check inlets and outlets to ensure that they are operational.
- If a sluice gate is used as part of the outlet structure, the gate should be closed and lubricated on a regular basis to prevent seizing. Nonfunctional sluice gates should be replaced. Consult the manufacturer's instructions for maintenance.
- If a blocking material is used, replace as needed.

Structural Stormwater Control Field Guide

This field guide is intended to assist the user in identifying different types of post-construction stormwater controls used by NCDOT. Post-construction stormwater controls treat stormwater runoff from roadway surfaces and other NCDOT facilities. The photos and descriptions provided represent typical examples of NCDOT structural controls and their identifying characteristics. However, each structural control will vary depending on site-specific conditions.

Filtration Basin

A SHALLOW BASIN WITH ENGINEERED OR AMENDED SOIL AND AN UNDERDRAIN SYSTEM

Filtration basins function by detaining stormwater in the basin. As stormwater infiltrates through the amended soil, sand, or engineered media, pollutants are filtered and adsorbed onto soil particles. Treated stormwater is directed to the receiving stream via the underdrain system.

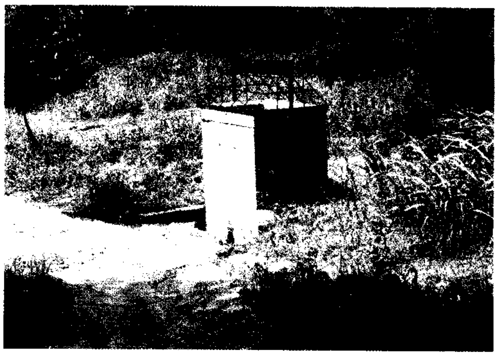
- Filtration basins may be shaped like ponds or channels.
- To improve pollutant removal, the basin may be covered with grass, wetland species, or landscaped vegetation (see Bioretention Basin).
- Sand filters are considered filtration basins.
- Filtration basins *may* have outlet control structures and emergency spillways. However, all filtration basins have underdrain systems.

Bioretention Basin

A TYPE OF FILTRATION BASIN WITH ENGINEERED MEDIA, AN UNDERDRAIN SYSTEM, AND LANDSCAPED VEGETATION

Bioretention basins use a landscaped mix of water-tolerant plants to improve pollutant removal. The vegetation is selected for its ability to physically filter and uptake stormwater pollutants. As with all filtration basins, stormwater is infiltrated through amended soil or an engineered media before it enters the underdrain system.

- Selected vegetation simulates various ecosystems such as forests, meadows, and hedgerows
- Bioretention basins are suited to drainage areas less than 1 acre.
- Bioretention basins may include outlet control structures and emergency spillways, but they will always have underdrain systems.



Dry Detention Basin

A SHALLOW, DRY BASIN WITH AN OUTLET PIPE OR ORIFICE AT THE INVERT OF THE BASIN

Dry detention basins temporarily detain runoff to promote sedimentation of solids and infiltration. Runoff is slowly released from an outlet control structure at a steady flow rate to increase detention time.

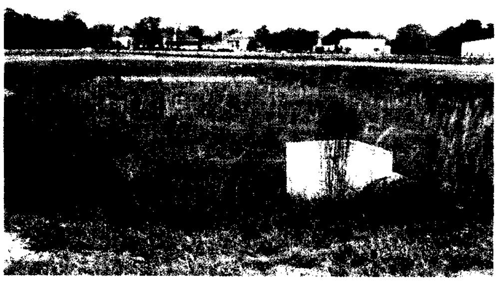
- Dry detention basins may be shaped like ponds or channels.
- The primary outlet control structure is located at the invert of the basin, allowing stormwater to drain slowly and completely between storm events.
- Dry detention basins are identified by the presence of an outlet control structure and an emergency spillway.

Wet Detention Basin

A SHALLOW BASIN THAT MAINTAINS A PERMANENT POOL OF WATER BY USING AN ELEVATED OUTLET CONTROL STRUCTURE

Wet detention basins treat stormwater through sedimentation and biological uptake of pollutants by plants, algae, and bacteria. Stormwater runoff in excess of the permanent pool is slowly released from the basin to prevent downstream erosion.

- Wet detention basins may be shaped like ponds or channels.
- The outlet control structure is elevated above the invert of the basin, allowing pollutant-laden solids to settle to the bottom and cleaner surface water to exit.
- The wet detention basin may have additional capacity for detaining and slowly releasing volumes greater than the permanent pool volume.
- Wet detention basins contain an emergency spillway to convey large events.
- Vegetation growing around the perimeter of the basin provides for biological uptake of nutrients from the water.



Infiltration Basin

A SHALLOW BASIN IN PERMEABLE SOILS THAT DETAINS AND INFILTRATES STORMWATER RUNOFF

Infiltration basins use porous soils to infiltrate stormwater. During infiltration, pollutants are physically filtered and adsorbed by the native soil. Infiltration basins provide total runoff volume control for all runoff equivalent to and smaller than the design storm and help to recharge groundwater.

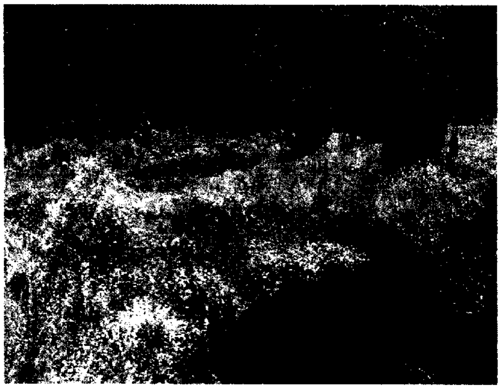
- Infiltration basins may be shaped like ponds or channels.
- Infiltration basins *may* have outlet control structures and emergency spillways.
- Infiltration basins rarely have underdrain systems. The purpose of the underdrain system in an infiltration basin is to facilitate maintenance.

Hazardous Spill Basin

A SHALLOW BASIN WITH AN OUTLET CONTROL STRUCTURE THAT CAN BLOCK THE ENTIRE CROSS-SECTIONAL AREA OF FLOW

Hazardous spill basins (HSBs) are designed to contain hazardous materials in the event of an accidental spill. During normal operation, stormwater runoff flows unimpeded through the basin. In the event of a spill, the outlet control structure is manually activated, preventing discharge from the basin.

- HSBs may be shaped like a pond or a channel.
- Sluice gates or sand bags are typically used to block the basin outlet.
- Some HSBs are marked by a sign with instructions to personnel on how to contain a spill.
- The HSB outlet control structure may be designed to provide detention in some applications.



Stormwater Wetland

AN ENGINEERED MARSH OR SWAMP WITH DENSE WETLAND VEGETATION

Stormwater wetlands mimic the water treatment ability of natural wetlands. Stormwater wetlands remove a variety of pollutants, primarily through biological uptake via plants and microorganisms.

- Stormwater wetlands, as opposed to naturally occurring wetlands, have distinct inlet and outlet structures.
- Vegetation grows throughout the wetland.
- Shallow pools of standing water are usually present, although some wetlands are designed for subsurface flow.
- Thick vegetative growth around the edges of the wetland aids in the biological uptake of pollutants.

Swale

A BROAD AND SHALLOW CHANNEL WITH DENSE VEGETATION

Swales convey and treat peak runoff from small drainage areas. Swales decrease runoff velocity to promote infiltration and physical filtration. Swales also increase contact time between runoff and vegetation to promote biological uptake of pollutants.

- Swales are shaped like channels and are designed based on target flow rates.
- Swales require nearly flat longitudinal slopes to function. Some applications use water quality rock checks to reduce the effective slope.
- Swales do not incorporate underdrain systems. Channel-shaped stormwater controls that use underdrain systems are filtration basins, not swales.

Level Spreader

A TROUGH AND LEVEL LIP USED TO REDISTRIBUTE CONCENTRATED STORMWATER AS DIFFUSE FLOW

Level spreaders provide a nonerosive outlet for concentrated runoff by diffusing the water uniformly across a stable slope.

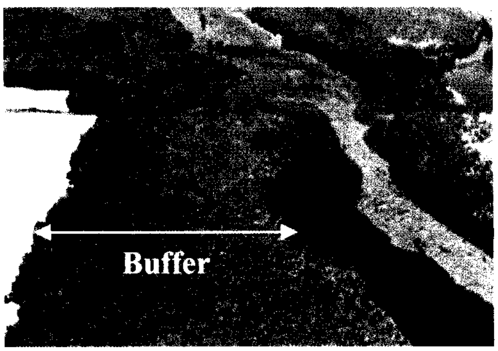
- Level spreaders are implemented upstream of buffers, swales, and basins to improve infiltration and biological uptake.
- Level spreaders are implemented downstream of stormwater controls to prevent stormwater from reconcentrating.
- Level spreaders are implemented on nearly flat grades to prevent reconcentration of runoff.
- The length of the level spreader trough will vary, depending on the stormwater discharge rate.

Filter Strip

A LINEAR SECTION OF LAND, EITHER GRASSED OR FORESTED, THAT PHYSICALLY FILTERS AND INFILTRATES STORMWATER.

Filter strips intercept perpendicular, diffuse flow, much the same way a buffer does. As runoff enters the filter strip, dense foliage and thick root mats physically filter out solids while reducing the peak flow rate.

- Runoff must be in the form of diffuse flow for filter strips to function. Filter strips are often located downstream of level spreaders and preformed scour holes.
- Filter strips may consist of tree stands, shrubs, grass, or a combination thereof.
- Filter strips may be located along the perimeter of a water bodies as well as nonriparian areas.
- Unlike buffers, filter strips are regularly managed through mowing, trimming, and replanting.



Bottom Photo: North Carolina Department of the Environment and Natural Resources (NCDENR)

Buffer

A SECTION OF DENSE WOODY OR GRASSY VEGETATION ALONG THE RIPARIAN CORRIDOR OF A WATER BODY

Buffers are constructed or natural strips of vegetation located along the banks of a water body. Buffers perform many of the same functions as filter strips. The buffer vegetation acts as a filter to remove pollutants from runoff and shallow groundwater.

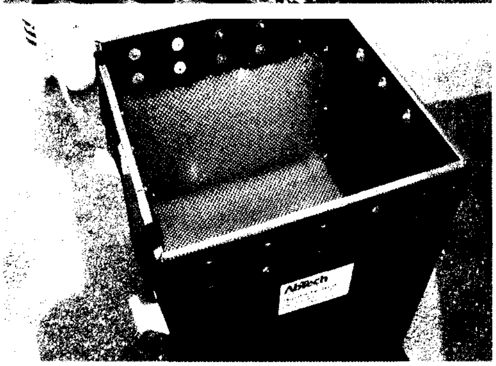
- Thin buffers provide bank stabilization, whereas wider buffers remove solids and uptake dissolved pollutants.
- Unlike filter strips, buffers should require little or no management.
- Buffers may be configured according to the two-zone or three-zone model. In these models, the areas closest to the stream bank are undisturbed forest. Landward areas are made up of shrubs or grass.
- In some watersheds, riparian buffers are subject to Riparian Area Protection Rules (i.e., buffer rules) that restrict development.

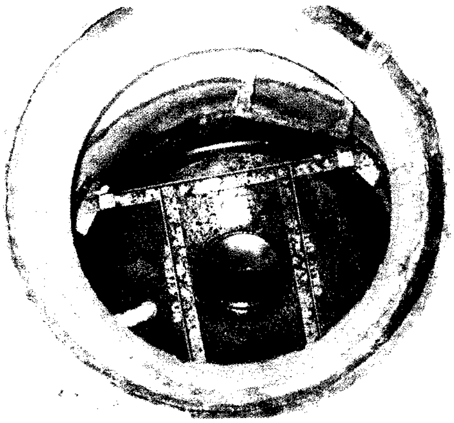
Preformed Scour Hole

A RIPRAP-LINED BASIN FORMED AT THE OUTLET OF A POINT DISCHARGE

By providing a stable impact point for peak flows, a preformed scour hole (PFSH) dissipates energy and diffuses flow. PFSHs prevent downgrade erosion and promote infiltration.

- The basins are reinforced with riprap to prevent erosion and scour.
- PFSH are used with pipe diameters of 18 inches or less.
- An apron of permanent soil reinforcement matting (PSRM) is required downgrade of PFSH to prevent scour.

 	**Forebay** A SMALL BASIN LOCATED UPSTREAM OF ANOTHER STORMWATER CONTROL Forebays are pretreatment devices designed to remove large stormwater particles. Forebays are important components of stormwater control systems because they improve the pollutant removal efficiency and extend the life of downstream controls. ▪ Forebays are always located upstream of other stormwater controls, generally controls in the basin family. ▪ Stormwater usually transitions from the forebay to the downstream control via a weir. ▪ Forebays are typically lined with riprap and filter fabric.
 	**Catch Basin Insert** A STORMWATER CONTROL THAT IS SUSPENDED FROM A CATCH BASIN AND THAT INTERCEPTS RUNOFF BEFORE IT ENTERS THE COLLECTION SYSTEM Catch basin inserts target various stormwater pollutants based on the configuration of the insert. As runoff enters the catch basin, solids are removed, depending on the size and distribution of the filter voids. Some inserts have materials with adsorptive properties that also remove dissolved pollutants. ▪ Inserts typically include a grate or curb inlet and a sump to collect coarse and gross solids. ▪ Inserts may incorporate filter fabric or media that trap or adsorb oil, grease, metals, and/or nutrients. ▪ Catch basin inserts are not as easy to locate as other controls because they come in a variety of configurations and are located underground. ▪ Many inserts are proprietary. The photos at left show the AbTech Ultra Urban catch basin insert.

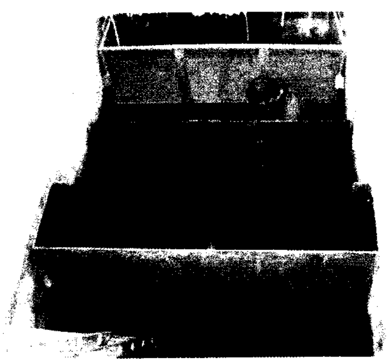


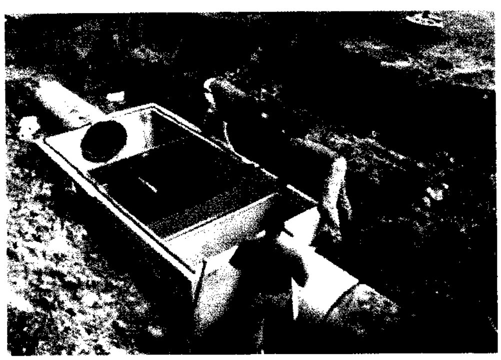
Swirl Concentrator

A CONTROL THAT USES VORTEX FLOW TO SEPARATE AND REMOVE SOLIDS FROM RUNOFF

The influent pipes of swirl concentrators are oriented tangentially to the concentrator to induce a swirling flow regime. Flow currents direct solids to the center and bottom of the unit, where they are held in a sump for removal. Some concentrators are configured to trap oil and floatables as well.

- Swirl concentrators may be incorporated both online and offline, but are usually underground.
- Swirl concentrators are designed based on a target flow rate, as opposed to a water quality volume.
- Many swirl concentrators are proprietary. The photo at left shows the Hydro International Downstream Defender.





Wet Vaults

A WET VAULT IS A CONTROL THAT MAINTAINS A PERMANENT POOL OF WATER WITHIN A BAFFLE BOX

Wet vaults function by slowing down the velocity of runoff within a collection system to allow solids to settle and floatables to rise to the top of the water column. Many wet vaults are self-contained stormwater control systems, incorporating trash baskets and sorbent media to capture gross solids and dissolved pollutants, respectively.

- Wet vaults maintain a permanent pool of water, regulated by baffles and tee pipes.
- Wet vaults may be designed based on a water quality volume or a flow rate, depending on their configuration.
- Wet vaults may be above or below ground.
- Many wet vaults are proprietary or contain proprietary components. The CrystalStream Technologies (CST) Water Quality Vault is pictured at left.

OHIO

LOCATION AND DESIGN

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

MANUAL

VOLUME TWO
DRAINAGE DESIGN

The OHIO DEPARTMENT of TRANSPORTATION

1113 Erosion Control at Bridge Ends

1113.1 General

For the purpose of reducing problems of erosion in the vicinity of bridge ends, details as shown on Standard Construction Drawing DM-4.1 shall be followed. At locations where the design flow exceeds 0.75 cubic feet per second, catch basins should generally be provided.

1113.2 Corner Cone

Item 670 Slope Erosion Protection shall be placed on all bridge approach embankment corner cones, beginning at the edge of the crushed aggregate or concrete slope protection.

1114 Temporary Sediment and Erosion Control

1114.1 General

Temporary sediment and erosion control is required on all projects that have Earth Disturbing Activities as outlined in Supplemental Specification 832. A Storm Water Pollution Prevention Plan (SWPPP) is required for all projects that require a NOI (See section 1112) The SWPPP requirements are outlined in Supplemental Specification 832.

1114.2 Cost Estimate for Temporary Sediment and Erosion Control

For all projects that require temporary sediment and erosion control furnish an amount to be encumbered in the project final package. Use the temporary sediment and erosion control estimator located in the Design Reference Resource Center to develop this amount. Furnish the calculations with the final plan package.

1115 Post Construction Storm Water Structural Best Management Practices

1115.1 General

Post Construction Storm Water Best Management Practices (BMP) are provided for perpetual management of runoff quality and quantity so that a receiving stream's physical, chemical and biological characteristics are protected and stream functions are maintained.

BMP are required for all projects within ODOT right-of-way that have ODOT maintenance responsibility and disturb 1 acre or more. Maintenance projects as outlined in section 1112.2 do not require BMP.

BMP are protected and located in accordance with Location and Design, Volume 1.

If discharging into a roadway ditch that conveys a captured stream, separate the drainage by using curbing or barrier. Treat impervious drainage areas with a BMP.

Furnish a drainage design that will reduce the need for bridge scuppers. If bridge scuppers are required, contact the Office of Structural Engineering, Hydraulic Section.

All Type A culverts will have stream protection per section 1105 Roadway Culverts.

1115.2 Land Disturbance Limits

Land disturbance (LD) is defined as an area of Earth Disturbing Activities (EDA) as outlined in Supplemental Specification 832 or an area where pavement is being removed to the sub-grade.

For non-maintenance projects with less than 1 acre of LD, BMP are not required but are recommended.

For non-maintenance projects with 1 acre or more but less than 5 acres of LD, BMP are required. Choose from the following list and maximize the design to the extent practicable:

- Exfiltration trench
- Manufactured systems
- Vegetated Biofilter
- Extended detention
- Retention Basin
- Bioretention Cell
- Infiltration Trench
- Infiltration Basin
- Constructed Wetlands

For all projects with five or more acres of LD or projects that are a part of a larger common plan of development which will have five or more acres of LD, BMP shall be incorporated into the permanent drainage system for the site. Choose from the following list:

- Exfiltration trench
- Manufactured systems
- Vegetated Biofilter
- Extended detention
- Retention Basin
- Bioretention Cell
- Infiltration Trench
- Infiltration Basin
- Constructed Wetlands

1115.3 Drainage Area

For projects that are located in multiple drainage areas, provide BMP based on the total acres of project LD.

For projects with drainage areas that are less than or equal to 0.25 acres when in a sump or at an intersection per figure 1116-1, a BMP is not required.

1116 Water Quality Volume

1116.1 Water Quality Volume Calculation

The following equation shall be used to calculate the water quality volume:

$$WQv = T(P*A*Cq)/12$$

Where,

WQv = Water Quality Volume (Ac-ft)

T= Treatment Percent (see 1116.2)

P = Precipitation (0.75 inches)

A = Contributing Drainage Area to an outfall (acres)

$Cq = 0.858i^3 - 0.78i^2 + 0.774i + 0.04$
(see figure 1116-2)

i=impervious area divided by the total area

Cq = 0.9 when all drainage area is impervious.

1116.2 Treatment Percent

A contributing drainage area to an outfall that has both existing and new impervious areas requires a weighted average calculation to determine the percent of treatment required. Existing impervious area requires treatment of 20% of the area. New impervious area requires treatment of 100% of the area. This percent is multiplied by the calculated WQv or the ExT length to determine the amount of treatment. Use the following equation to determine the percent of treatment:

Treatment = [(Aix * 20)+(Ain * 100)] / (Aix+Ain)

Where,

Treatment= Treatment percent (%)

Aix= Existing impervious area (acres)

Ain= New impervious area (acres)

1116.3 Structural BMP Using the WQv

The water quality volume (WQv) is the treatment volume required for post construction BMP. Use the WQv for the following BMP:

- Exfiltration Trench
- Vegetated Biofilter
- Extended Detention
- Retention Basin
- Bioretention Cell
- Infiltration Trench
- Infiltration Basin
- Constructed Wetlands

Once an area has been treated, remove this area from the next downstream WQv calculation.

1117 Water Quality Flow

1117.1 Water Quality Flow Calculation

The water quality flow (WQf) is the discharge that is produced by using an intensity of 0.65 in/hr in the rational equation (section 1101.2.2). Use the entire contributing drainage for the WQf calculation. Once an area has been treated, remove this area from the next downstream WQf calculation.

1117.2 Structural BMP Using the WQf

Use the WQf for the following BMP:

- Manufactured System

1118 BMP Toolbox

1118.1 Exfiltration Trench

An exfiltration trench (ExT) captures roadway drainage at the outside edge of shoulder through the use of a permeable concrete surface. The permeable concrete surface is placed parallel to the roadway within a concrete structure. The ExT is placed 15 feet (min) prior to any drainage inlet, pavement catch basin (see figure 1118-1), or curb cut. The ExT width is 8 inches wide and the length is determined by the following equation:

$$Lt = T(A*Cq)/68,900$$

Where,

T= Treatment Percent (1116.2)
Lt= Required Impervious Length of Trench (ft)
Use a minimum length of 4 feet
Length is in increments of 4 feet
A= Total Contributing Area (square feet) as determined by the Strip Method per section 1103.3.

$Cq = 0.858i^3 - 0.78i^2 + 0.774i + 0.04$
(see figure 1116-2)

i=impervious area divided by the total area

Storm water is filtered until it reaches a 4 inch perforated conduit connected to a 4 inch non-perforated outlet conduit. The 4 inch outlet conduit may discharge into a drainage structure or onto the slope using a reinforced concrete outlet. The following criteria are used for payment for the ExT:

- Payment for the ExT shall be: Item 835 - Exfiltration Trench, Type ___ – L.F.
  - Use a Type A for curb and gutter, Type 2.
  - Use a Type B for barrier and non-6 inch curb.
  - Use a Type C for 6 inch curb without gutter.
- Payment for the 4 inch perforated conduit is: 605 4 inch Shallow Pipe Underdrains 707.31.
- Payment for the 4 inch outlet conduit is: 603 4 inch conduit, Type B 707.33.
- Payment for the precast reinforced concrete outlet is Item 604 precast reinforced concrete outlet.

The following criteria are used for designing an ExT:

- Do not use the ExT in tapers, parking areas, on a radius, or within a driveway.
- Do not use the ExT on the high side of a super elevated roadway.
- Do not use the ExT with shoulder widths less than 2 feet.

1118.2 Manufactured Systems

Manufactured systems consist of underground structures that treat the WQf by removing particulate matter through settlement. Supplemental Specification 895 covers the material and performance criteria for these devices. They are placed in an off-line configuration with manholes to allow for routine maintenance procedures (see figure 1118-2).

Provide a No. 3 Manhole, With ___" Base ID and ___" Weir at this location. Furnish two lengths of 603, Type B Conduit placed perpendicular to the inflowing trunk sewer (see reserved area table for the total length required). Use the following table when placing a Manufactured System:

Manufactured Systems			
Type	**WQf (cfs)**	**No. 3 Manhole Base ID (inches)**	**603-Type B Conduit Diameter (inches)**
1	1	84	12
2	2	90	15
3	3	96	18
4	6	108	24

Reserve an area (as measured from the centerline of the No. 3 Manhole) according to the following table:

Reserved Area for Manufactured System				
Type	Width (feet)	Length (feet)	603-Type B Total Conduit Length (feet)	Weir Height (inches)
1	15	30	20	6
2	20	32	30	8
3	25	33	40	9
4	25	37	40	12

Center the length of the area at the No. 3 Manhole. If this area is not attainable, contact the Office of Structural Engineering, Hydraulics Section for further guidance. Ensure this area is void of all utilities and is accessible for routine cleanout and maintenance.

1118.3 Vegetated Biofilter

A Vegetated Biofilter (VBF) is a BMP treatment train that filters storm water through vegetation. The treatment train consists of the vegetated portion of the graded shoulder, vegetated slope, vegetated ditch, and an energy protection area.

When widening existing ditches, consider the following before purchasing new right-of-way:

- Reducing the foreslope of the ditch.
- Reducing the backslope of the ditch.
- Reducing the bench width to a minimum of 4 feet.

1118.3.1 Vegetated Ditch Design Process

For projects furnishing new ditches provide an outside ditch width located in fill sections according the following:

A. Calculate the width of the ditch according to section 1102 by one of the following:
1. Radius Ditch width equals the length of the arc
2. Rounding ditch width equals the rounding length
3. Trapezoid ditch width equals the bottom width

B. Calculate the Enhanced Bankfull Width (EBW) in feet using the following equation:

$$EBW = 5.4A^{0.356}$$

A= Total drainage area to the ditch (Ac)

C. Compare the ditch width found in Section 1118.3.1.A to the EBW found in Section 1118.3.1.B and determine the plan ditch width by choosing one of the following:

1. If the EBW is less than or equal to the width found in Section 1118.3.1.A, furnish Section 1118.3.1.A width in the plans.
2. If the EBW is greater than the width found in Section 1118.3.1.A and is less than or equal to 10 feet, furnish the EBW width in the plans.
3. If the EBW exceeds the width found in Section 1118.3.1.A and is more than 10 feet and the EBW will not require the purchase of additional right-of-way, furnish the EBW in the plans.
4. If the EBW exceeds the width found in Section 1118.3.1.A and is more than 10 feet and the EBW will require the purchase of additional right-of-way, furnish a Conveyance Ditch for Offsite Drainage Area according to Section 1118.3.2.

For projects using existing ditches where the EBW is greater than the existing ditch width as determined in Section 1118.3.1.A, maximize the existing ditch width to the extent that does not require the purchase of additional right-of-way.

Ditch width is to be calculated every 100 linear feet of ditch and at points where offsite runoff is accepted to provide the minimum required ditch width. Begin ditch width calculations at the outfall and move upstream through the drainage area.

1118.3.2 Conveyance Ditch for Offsite Drainage Area

A conveyance ditch is a 10 foot wide ditch with an earth berm (EB) that separates the conveyance of the roadway runoff from offsite runoff for the first flush flows. The EB is placed longitudinally in the ditch at a determined location.

Figures 1118-13 through 1118-18 detail common design scenarios for conveyance ditches. Calculate the conveyance ditch for the offsite drainage area using figures 1118-13 through 1118-18. If the offsite ditch design falls outside of the criteria used in figures 1118-13 through 1118-18, manually design the ditch using figure 1118-

19. A design example is detailed in figure 1118-4.

If the EB location is greater than 9 feet, contact the Office of Structural Engineering, Hydraulics Section.

Payment for the earth berm is per Item 203

1118.3.3 Energy Protection Area

An energy protection area provides energy reduction to the ditch flow prior to discharging into a water body. It is a constructed channel that has a 15 foot wide bottom with a layer of rock channel protection. The use of an EB is truncated at the upstream end of the energy protection area. Use the following criteria when providing an energy protection area:

A. Provi de 50 feet length (see figure 1118-5).

B. Provide a 12 inch thick layer of Item 601 RCP, Type D with filter or as required per section 1102 (if larger RCP is necessary).

C. Locate all energy protection areas in the outside roadway ditch.

D. The energy protection area is required on the upstream location of culverts. It is optional on the downstream location of culverts.

E. Provide energy protection areas as existing right-of-way permits for redevelopment projects. If any amount of right-of-way is purchased for the project, an energy protection area is required.

1118.4 Extended Detention

Extended detention is a method that captures storm water during rain events and slowly releases the captured volume over a period of time. The WQv is used to determine the storage volume of the detention basin. The WQv is discharged over a 48 hour time frame. Increase the WQv by 20% when sizing the BMP to allow for sedimentation to occur. Detention can be either above or below ground. Detention basins that are above ground are the preferred choice and should be used when feasible. However, when project site parameters dictate, an underground system may be the optimum choice.

1118.4.1 Detention Basin

A detention basin is a dry pond that detains storm water for quality and quantity. The following criteria apply when designing a detention basin:

A. Allow for 1 foot of freeboard above the storage volume.

B. Furnish a micro pool when feasible (see figure 1118-6)

C. Use side slopes of 4:1 (max).

D. Ensure the design check discharge will safely pass through the structure (section 1118.4.3).

E. Vegetate the sides of the basin with Item 670 Slope Erosion Protection.

F. Furnish a 6 inch layer of Item 601 Detention Basin Aggregate on the bottom of the basin.

G. Embankment work to create the impoundment will be constructed and paid for as Item 203 Embankment, Using Natural Soils, 703.16.A.

H. Consider vehicle access to the basin for periodic maintenance.

I. Do not locate on uncompacted fill or steep slopes (2:1 or more) or where infiltrating ground water could adversely impact slope stability.

J. Furnish an anti-seep collar around the outlet pipe.

K. Furnish gravel pack protection at the outlet structure (see SCD WQ1.1).

L. Place channel protection (RCP or Concrete Mat) at the entrance of the basin to minimize erosion and sediment resuspension.

M. Furnish a forebay that is approximately 7% of the total design volume.

N. Furnish a Water Quality Basin, Detention per section 1118.4.1.1

1118.4.1.1 Water Quality Basin and Weir

Furnish an outlet structure that fully drains the WQv within 48 hours or more. The outlet requires a flow control structure such as a perforated riser pipe to restrict the drainage discharge. Details of a perforated riser pipe outlet structure can be found on standard drawing WQ1.1.

Furnish a perforated riser pipe for detention basins. The outlet structure consists of a catch basin with a perforated riser pipe on the inlet side and a conduit on the outlet side. The perforated riser pipe is used for flow control to achieve the required discharge time. A gravel envelope surrounds the perforated riser pipe along the inlet side of the catch basin to prevent blockage of the orifice holes in the pipe. The catch basin and riser pipe are paid for as Item 604, Water Quality Basin, Detention.

Furnish a weir to allow the design check discharge to bypass the structure without damage to the detention basin or embankment of the basin. The design check discharge shall be determined per 1118.4.3.

The equation for a single orifice is:

$$Q = A \cdot C \cdot \sqrt{64.4H}$$

Where,

A = Area of orifice (ft^2)

H = Head on orifice as measured to the centerline of the orifice (ft)

C = Orifice coefficient

Orifice Coefficient Guidance

C	Description
0.66	Use for thin materials where the thickness is equal to or less than the orifice diameter.
0.80	Use when the material is thicker than the orifice diameter.

From CALTRANS, Storm Water Quality Handbooks, Project Planning and Design Guide, September 2002.

A hydrograph curve for the outlet will be required to calculate the discharge time of the WQv and the design check discharge (see 1118.4.3). The discharge time should correspond to the minimum of 48 hours.

Generally, it is easier to model the outlet structure and discharge time using software such as Pond Pak or HydroCad to develop the hydrograph.

1118.4.1.2 Anti-Seep Collar Design

An anti-seep collar shall be installed on conduits through earth fills where water is being detained. The following criteria applies to anti-seep collars:

A. Spacing between adjacent collars shall be 5 feet with the first collar being a minimum of 5 feet from the inlet.

B. Furnish a minimum of 2 collars per outlet conduit.

C. All anti-seep collars and their connections shall be watertight.

D. Minimum thickness shall be 6 inches.

E. Payment for the collar shall be Item 602 Concrete Masonry (see standard construction drawing WQ-1.2).

To determine the dimensions of the collar refer to the following:

Anti-Seep Collar Size

Maximum Water Depth	Collar Size (ftxft)
2	3x3
4	4x4
6	5x5

1118.4.2 Underground Detention

Underground detention areas are made up of a series of conduits. They range from an oversized storm sewer to a series of conduits that are specifically used for storm water detention. The following criteria apply when designing underground detention:

A. Ensure the Hydraulic Grade Line design of the storm sewer will pass through the structure and meet the requirements of 1104.4.2.

B. Consider access to the conduits for periodic maintenance.

C. If practical, provide pretreatment of the storm water with a vegetated strip.

D. Payment for the conduit shall be: Item 603 ____" Conduit, Type____, for underground detention.

1118.4.3 Design Check Discharge

A design check discharge with the frequency of a 10-year event shall be used as calculated by the Rational Equation. Use the entire drainage area that contributes to the BMP to calculate the design check discharge.

1118.5 Retention Basin

A retention basin is a "wet" pond that has a minimum water surface elevation between storms that is defined as the permanent pool. Above the permanent pool is a detention pool that provides storage for 75% of the WQv and discharges within 24 hours or more. The full storage water depth is typically between 3-6 feet and the volume is less than 15 Ac-ft. The permanent pool is sized to provide storage for 75% of the WQv. A retention basin is ideal for large tributaries, but it may require a large amount of space. Consider the following when designing a retention basin:

A. Use RCP at the inlet of the basin to provide energy dissipation and erosion control.

B. Allow for 1 foot freeboard above the WQv.

C. Use side slopes of 4:1 (max).

D. Ensure the design check discharge will safely pass through the structure (section 1118.4.3).

E. Use a length to width ratio of at least 3:1 to prevent short-circuiting.

F. Vegetate the sides of the basin with Item 670 Slope Erosion Protection.

G. Furnish a 6 inch layer of Item 601 Detention Basin Aggregate on the bottom of the basin.

H. Furnish a forebay (7-10% of the total retention volume) to extend the service life of the BMP when feasible.

I. Furnish an anti-seep collar around the outlet pipe (see section 1118.4.1.2).

J. Furnish a trash rack at the outlet structure.

K. The underlying soils should be compacted to prevent infiltration of the permanent pool or an impervious liner should be used.

L. Consider vehicle access to the basin for periodic maintenance.

M. Retention basin must be greater than 10,000 feet from a municipal airport runway.

N. Embankment work to create the impoundment will be constructed and paid for as Item 203 Embankment, Using Natural Soils, 703.16.A.

O. Furnish a Water Quality Basin, Retention per 1118.5.1.

1118.5.1 Water Quality Basin and Weir

A retention basin outlet structure is designed similar to the outlet structure for a detention basin. The difference is that 75% of the WQv should be discharged out of the basin in 24 hours or more. The outlet structures are of a similar type, except the openings will be set at a high enough elevation to maintain 0.75% of the WQv in the permanent pool (see standard construction drawing WQ-1.1). The catch basin and riser pipe is paid for as Item 604, Water Quality Basin, Retention.

1118.6 Bioretention Cell

Bioretention Cells consist of depressed low-lying areas that treat storm water through evapotranspiration and filtering through a planting soil. As the storm water passes through the soil it is filtered. An underlying perforated storm sewer or underdrain captures the treated storm water and carries it to an outlet. Extensive vegetation assists in the filtration of the storm water prior to filtering through the soil. Vegetation should consist of shrubs or grasses that are native to the area.

The existing soil must be removed and replaced when constructing a bioretention cell. The bioretention planting soil (plan note WQ101) should consist of a mixture of sand, topsoil, and compost.

A bioretention cell is sized to store the WQv prior to filtration. Total filtration should occur in 40 hours or more. Use the following equation to determine the minimum surface area of the bioretention invert:

$$A = \frac{WQv \cdot D}{3600 \cdot K \cdot T \cdot (h + D)}$$

Where,

WQv= Water quality volume (see section 1116) (Acre-feet)

T= Drain time of the cell, 40 hours

K= permeability of the planting soil (Use 3.3 x 10^-5 ft/sec)

A= Top surface area of the trench (Ac)

D= Depth of the planting soil (ft) (4.0 feet minimum)

h=Maximum depth of water above the cells top layer for the WQv (use 1 foot).

The following criteria apply when designing a bioretention BMP:

A. Do not place where snow may be stored.

B. Furnish 10 feet or less width between 4 inch underdrain laterals.

C. Furnish bypass or overflow for the design check discharge. Use a catch basin(s) in conjunction with an overflow weir as needed.

D. Furnish pretreatment of the storm water via vegetation.

E. Ensure the water table or bedrock is below the invert of the bioretention area.

F. Use side slopes of 4:1 (max).

G. Furnish a length to width ratio of 2:1 (min).

H. Use a minimum depth of 4 feet of planting soil. Provide at least 4 inches of depth deeper than the largest root ball.

I. Furnish an organic or mulching layer at the top of the planting soil.

J. Furnish a maximum depth of 1 foot to the riser pipe or catch basin outlet from the mulching layer for storage of the WQv.

K. Furnish a bioretention cell as Item 203-Special - Bioretention Cell.

1118.7 Infiltration

Infiltration techniques treat storm water through the interaction of a filtering substrate that consists of soil, sand, or gravel. This technique discharges the treated storm water into the ground water rather than into surface waters. Infiltration methods require an extensive investigation of the existing soils and geology to ensure success. The investigation should begin with a preliminary soil evaluation of the project site early in the design process. In situ testing is not anticipated during the preliminary evaluation process. Available soil and geology data found in the Soil and Water Conservation maps, United States Geological Survey (USGS), adjacent projects, or estimations from a geotechnical engineer should be used. Material property tables for infiltration, permeability, and porosity have been provided for the preliminary evaluation (table 1118-1 & 1118-2).

If the preliminary evaluation yields favorable results a more detailed evaluation should be performed. The detailed evaluation will require a geotechnical investigation of the underlying soils and geology. Soil borings should be performed to a maximum depth of 20 feet (or refusal) with samples taken every 5 feet for laboratory testing. The number and location of soil borings should correspond with the approximate size (as determined in the preliminary evaluation) of the infiltration BMP and should be recommended by the geotechnical engineer.

If the detailed evaluation yields favorable results, the ground water depth must be verified. The geotechnical engineer shall provide the seasonal high ground water depth. In some cases, observation wells may be installed and static water levels may be observed over a dry and wet season for verification.

The infiltration and permeability rate of the soil shall be tested in the detailed soil evaluation at the discretion of the geotechnical engineer. In some cases, insitu testing at the proposed location of the infiltration BMP may be required.

The following criteria apply to infiltration methods and must be met to be considered a feasible alternative:

A. Design using the WQv as per Section 1116.

B. Do not place infiltration BMP where snow may be stored.

C. The appropriate soil type must be present:

   1. Infiltration must be greater than 0.50 in/hr and no greater than 2.4 in/hr.

   2. Soils must have less than 30% clay or 40% of clay and silt combined.

D. The invert of the structure must be at least 4 feet above the seasonal high water table and any impervious layer.

E. Infiltration techniques are not suitable on fill soil, compacted soil, or steep slopes (greater than 4:1). Consideration should be given to the long term impacts upon hillside stability if applicable.

F. Pretreatment shall be provided to remove large debris, trash and suspended sediment to extend the service life. Examples of this may be the use of vegetated filter strip.

1118.7.1 Infiltration Trench

An infiltration trench is an excavated trench that has been lined with a geotextile fabric and backfilled with aggregate. The storm water is filtered through the aggregate and is stored within the pore volume of the backfill material. It is allowed to percolate through the sides and bottom of the trench. The drawdown time of the WQv is 24 hours or more. Consider the following when designing an Infiltration trench:

A. The minimum acceptable permeability of the surrounding soil is =6.5*10^-5 ft/sec (see table 1118-1).

B. Design using the WQv as per Section 1116.

C. Long and deep infiltration trenches are most efficient (3 feet bottom width and 3-6 feet deep).

D. Furnish a 6 inch layer of Item 601 Infiltration Basin Aggregate on the top of the trench.

E. The geometric shape of the trench is a trapezoid with sides at a 1:1 (H:V) slope due to constructability. The top width is calculated as:

Top Width = Bottom Width + (2 * Depth)

F. Pretreatment using a vegetated strip shall be provided to ensure longevity of the infiltration trench.

G. An observation well shall be provided to facilitate ground water level inspection.

H. Locate the infiltration trench at least 1,000 feet from any municipal water supply well and at least 100 feet from any private well, septic tank, or field tile drains.

I. Ensure the bottom of the trench is below the frost line (2.5 feet)

The length of the trench depends upon the depth and the bottom width. The required length is calculated by assuming a depth and bottom width. The length is calculated based upon the inflow (WQv) and the outflow (ground water recharge). The following equation calculates the required length in feet:

$$L_t = \frac{43560 \cdot WQv}{3600 \cdot K \cdot T \cdot (b + 2\ D) + 0.4 \left[D^2 + (b \cdot D)\right]}$$

Where,

WQv= Water quality volume (see section 1116) (Acre-feet)

T= Drain time through the sides of the trench, 24 hours

K= permeability of the surrounding soil (ft/sec) (table 1118-1)

D= Trench depth (ft)

b= Bottom width of the trench (ft)

Table 1118-1

Permeability of Soil (K)

Soil Type	Rate (K) (ft/sec)
Gravel	$3.3x10^{-3}$ to $3.3x10^{-1}$
Sand	$3.3x10^{-5}$ to $3.3x10^{-2}$
Silt	$3.3x10^{-9}$ to $3.3x10^{-5}$
Clay (saturated)	< $3.3x10^{-9}$
Till	$3.3x10^{-10}$ to $3.3x10^{-6}$

From Urban Runoff Quality Management WEF Manual of Practice No. 23, 1998, published jointly by the WEF and ASCE, chapter five

1118.7.2 Infiltration Basin

An infiltration basin is an open surface pond that uses infiltration into the ground as the release mechanism. It is designed to store the WQv.

Depending on the soil permeability, it may be used to treat from 5 to 50 acres. Lower permeable soils may require an underdrain system as an additional outlet. The drawdown time of the WQv should be between 24-48 hours. The following criteria apply when designing an infiltration basin:

A. Use an energy dissipater at the inlet.

B. Allow for 1 foot (min) freeboard above the WQv.

C. Vegetate the sides of the basin with Item 670 Slope Erosion Protection.

D. Furnish a 6 inch layer of Item 601 Infiltration Basin Aggregate on the bottom of the basin.

E. Use side slopes of 4:1 (max).

F. Use a length to width ratio of 3:1

G. Furnish bypass or overflow for the design check discharge (see section 1118.4.3).

H. Consider vehicle access to the basin for periodic maintenance.

I. Locate basin at least 1,000 feet from any municipal water supply well and at least 100 feet from any private well, septic tank, or drain field.

J. Furnish 10 feet or less width between 4 inch underdrain laterals (if used in the design).

K. Do not locate the basin where infiltrating ground water may adversely impact slope stability.

L. Ensure the invert of any underdrain in the basin is below the frost line (2.5 feet).

M. Embankment work to create the impoundment will be constructed and paid for as Item 203 Embankment, Using Natural Soils, 703.16.A.

The invert area of the infiltration basin can be calculated by the following equation:

$$A=(WQv * S.F. * 12)/(k * t)$$

Where,

A= area of invert of the basin (Acres)

WQv= Water Quality Volume (see section 1116) (Acre-feet)

S.F.= Safety Factor of 1.5
k= Infiltration Rate (in/hr) (table 1118-2)

t= Drawdown time of 48 hours

The required depth of the infiltration basin can be calculated by the following equation:

$$D= WQv/A$$

Where,

A= area of invert of the basin (Acres)

WQv= Water Quality Volume (Ac-ft)

D= Required depth of the basin (ft)

Table 1118-2

NRCS Soil Type (from soil maps)	HSG Classification	Rate (k)
		(in/hr)
Sand	A	8.0
Loamy Sand	A	2.0
Sandy Loam	B	1.0
Loam	B	0.5
Silt Loam	C	0.25
Sandy Clay Loam	C	0.15
Clay Loam & Silty Clay Loam	D	< 0.09
Clays	D	< 0.05

Infiltration Rate (k)

From Urban Runoff Quality Management WEF Manual of Practice No. 23, 1998, published jointly by the WEF and ASCE, chapter five

1118.8 Constructed Wetlands

Constructed wetlands treat storm water through bio-retention. They are depressed, heavily planted areas that are designed to maintain a dry weather flow depth ranging between 0.5 to 2 feet. The surface area required for a wetland is usually quite large due to the limited allowable depth. The area is usually on the magnitude of 1% of the entire drainage area. They are designed in a similar manner as a retention basin. The wetland is sized to provide storage for the WQv for a time frame of at least 24 hours (above the permanent pool) while providing a bypass or overflow for larger design check discharge (see section 1118.4.3). The water depth should be maintained by an outlet structure capable of providing the required water depth with the provision of a one foot freeboard. The following criteria apply when designing a wetland:

A. Do not place on a steep or unstable slope or at a location, which could induce short-term or long-term instability.

B. Wetlands must be greater than 10,000 feet from a municipal airport runway.

C. Base flow must be present to maintain the constant water depth (such as ground water).

D. Furnish a forebay that is 7% of the total required volume at a depth between 3-6 feet to settle out sediments.

E. Furnish side slopes of 4:1 (max).

F. Consider access for maintenance to the forebay and the outlet structure.

G. Vegetate the sides and bottom with grass

H. Furnish an impervious liner. Use a compacted clay bottom or a geotextile fabric to prevent infiltration of the storm water.

I. Furnish a length to width ratio of 3:1 (min) to prevent short-circuiting.

VIRGINIA

VIRGINIA DEPARTMENT OF TRANSPORTATION

LOCATION AND DESIGN DIVISION

INSTRUCTIONAL AND INFORMATIONAL MEMORANDUM

GENERAL SUBJECT: MANAGEMENT OF STORMWATER	NUMBER: IIM-LD-195.5
SPECIFIC SUBJECT: ENGINEERING AND PLAN PREPARATION	DATE: FEBRUARY 12, 2003
	SUPERSEDES: IIM-LD-195.4 DDM 2 (Drainage Manual)
DIVISION ADMINISTRATOR APPROVAL: Mohammad Mirshahi, PE	

CURRENT REVISION

- Guidelines for water quality and quantity control have been clarified in accordance with the Virginia Department of Conservation and Recreation's annual plan review process..
- Shading has been omitted from this memorandum.

EFFECTIVE DATE

- This memo is effective upon receipt.

BACKGROUND

- Acts of the General Assembly have resulted in the issuance of Virginia Stormwater Management (SWM) Regulations and Virginia Erosion and Sediment Control (ESC) Regulations. The general application to highway operations associated with these regulations is addressed in this memorandum. Additional information and instructions for the incorporation of the erosion and sediment details in plan assemblies are contained in the current version of IIM-LD-11.
- Additional details and examples of the engineering application of the Virginia SWM Regulations in the design of VDOT projects can be obtained from the VDOT Hydraulics Section in any of the various District offices or the Central Office in Richmond.

- Further information regarding the Virginia SWM Regulations or the Virginia ESC Regulations may be obtained from the Virginia Department of Conservation and Recreation (DCR) located at 203 Governor Street, Richmond, VA 23219 or at: http://www.dcr.state.va.us/sw/index.htm. Details may also be obtained from the Virginia SWM Handbook (Volume I and II) and the Virginia ESC Handbook published by DCR and available for reference in all VDOT Hydraulics Sections.

OBJECTIVE

Stormwater Management

- To inhibit the deterioration of the aquatic environment by instituting a stormwater management program that maintains both water quantity and quality post development runoff characteristics, as nearly as practicable, equal to or better than pre-development runoff characteristics.

Erosion and Sediment Control

- To effectively control soil erosion, sediment deposition, and post development runoff to minimize soil erosion and to prevent any sediment from escaping the project limits.

CRITERIA

General

- The runoff control provisions of both regulations are complementary and will be addressed under a single set of criteria. The information and instructions contained in this memorandum supersede all previous departmental documents. Where there are conflicts with previous instructions, this memorandum shall take precedence.

- For the applicability of the Virginia Erosion and Sediment Control Regulations see the latest version of IIM-LD-11.

- The Virginia Stormwater Management Regulations are applicable to all state agency projects.

- "State Agency Projects" are those land development activities wherein VDOT has funded any portion of the design, right of way acquisition, or construction including those constructed under the Public/Private Transportation Act (PPTA) and Design/Build projects. Projects, such as subdivision streets, industrial access roads, etc., which are designed and constructed by other parties and which are eligible for acceptance into the state roadway system for maintenance after completion of construction are not considered state agency projects and must conform to appropriate local regulations. Land development activities occurring within existing VDOT right of way, which are allowed by permit and which are designed, constructed, and funded by other parties, are not considered state agency projects and must conform to appropriate local regulations.

- "Land Development Project" is defined as a manmade change to the land surface that potentially changes its runoff characteristics as a permanent condition. The permanent condition should consider the effects of mature vegetative cover and should not be concerned with temporary changes due to construction activities. The temporary changes are addressed by the ESC regulations.

Water Quantity Control

- Water quantity control shall be governed by the Virginia ESC Regulation MS-19 that requires an adequate receiving channel for stormwater outflows.

- Receiving channels, pipes and storm sewers shall be reviewed for adequacy based upon the following criteria:

  - Natural channels shall be analyzed by the use of a 2-year storm to verify that stormwater will not overtop channel banks or cause erosion of the channel bed and banks.

  - All previously constructed manmade channels shall be analyzed by the use of a 10-year frequency storm to verify that the stormwater will not overtop the banks and analyzed by the use of a 2-year storm to verify that the stormwater will not cause erosion of the bed or banks.

  - Pipes and storm sewer systems shall be analyzed by the use of a 10-year frequency storm to verify that the stormwater will be contained within the pipe or storm sewer system. The receiving channel at the outlet of the pipe or storm sewer shall be analyzed for adequacy of the 2 year storm for natural channels or the 10 year storm for man made channels.

- Water quantity control for the 1 year storm (in lieu of the 2 year storm as required by ESC Regulation MS-19) may be needed if there are existing or anticipated erosion concerns downstream. Control of the 1 year storm requires detaining the volume of runoff from the entire drainage area and releasing that volume over a 24 hour period. The computations are similar to those used for detaining the Water Quality Volume

  (WQV) and releasing over a 30 hour period. See the DCR SWM Handbook pages 1-23 and 5-38 thru 5-41 for additional information. When the 1 year storm is detained for 24 hours there will be no need to provide additional or separate storage for the WQV if it can be demonstrated that the WQV will be detained for approximately 24 hours. The control of the 1 year storm may require a basin size that is 1.5 to 2 times larger than a basin used to control the increase in the discharge from a 2 year or a 10 year storm.

- Pre-development conditions shall be considered that which exist (or is anticipated to exist) at the time the road plans are approved for right of way acquisition. All land cover shall be assumed to be in good condition regardless of actual conditions existing at the time the analysis is done.

- Impounding structures (dams) that are not covered by the Virginia Dam Safety Regulations shall be checked for structural integrity and floodplain impacts for the 100-year storm event.

- Outflows from stormwater management facilities shall be discharged into an adequate receiving channel as defined by the ESC Regulation MS-19.

- Existing swales being utilized as natural outfall conveyances for pre-development run-off will be considered as channels and, if the swale satisfactorily meets the criteria contained in the ESC Regulation MS-19 for post-development run-off, it will be considered as an adequate receiving channel.

- Construction of stormwater management facilities should be avoided in floodplains. When this is unavoidable, a special examination to determine the adequacy of the proposed stormwater management facilities during the passage of the 10-year flood will be required. The purpose of this analysis is to ensure that the stormwater management facility will operate effectively. The stormwater management facility shall also be examined for structural stability during the passage of the 100-year flood event on the floodplain and shall be examined for any possible impacts caused by the basin on the 100-year flood characteristics of the floodplain. The construction of stormwater management facilities shall be in compliance with all applicable regulations under FEMA's National Flood Insurance Program.

- If it can be demonstrated that the total drainage area to the point of analysis within the receiving channel is 100 times greater than the contributing drainage area within the project site, the receiving channel may be considered adequate, with respect to the channel capacity and stability requirements of the ESC Regulations, without further computations.

- Construction of stormwater management facilities within a sinkhole is prohibited. If stormwater management facilities are required along the periphery of a sinkhole, the design of such facilities shall comply with the guidelines in IIM-LD-228 (Sinkholes) and DCR's Technical Bulletin #2 (Hydrologic Modeling and Design in Karst) and applicable sections of the DCR's SWM Handbook.

Water Quality Control

- A water quality control plan shall be developed for each outfall or watershed where one acre or more of land is disturbed and one acre or greater of impervious area is added.

- At outfalls or watersheds where one acre or more of land is disturbed but less than one acre of impervious area is added, an assessment based on specific site characteristics/limitations shall be made to determine what opportunities exist to enhance water quality.

- Where two or more outfalls flow directly into an adjacent natural or manmade receiving system, or where two or more outfalls converge into one system some distance downstream of the project, the combined additional impervious area of all affected outfalls shall be considered when determining the applicability of VDOT's Annual SWM Plan and the water quality requirements of the Virginia SWM Regulations. The presence of wetlands, perennial streams, natural channels, or other environmentally sensitive areas at the convergence of the outfalls will typically require that the outfall impervious areas be considered in total when assessing the project's water quality impacts. Multiple project outfalls can be considered individually only when the convergence (if applicable) of flows is sufficiently far from the outfalls so as to effectively disconnect the impact of the total combined project impervious area.

- The following comments represent the significant points of the current regulations (the page numbers referenced are those in the DCR SWM Handbook):

    1. BMP (Best Managenment Practice) requirements for quality control are "Technology Based" (4VAC-3-20-71). The type of BMP required is determined by the percent of area within the project site (right of way and permanent easement) with **new** impervious cover, per outfall. Table 1 shows the relationship of the new impervious cover to the type of BMP required.

TABLE 1*
BMP SELECTION TABLE

Water Quality BMP	Target Phosphorus Removal Efficiency	Percent Impervious Cover**
Vegetated filter strip Grassed swale	10% 15%	16-21%
Constructed wetlands Extended detention (2xWQV) Retention basin I (3xWQV)	30% 35% 40%	22-37%
Bioretention basin Bioretention filter Extended detention-enhanced Retention basin II (4xWQV) Infiltration (1xWQV)	50% 50% 50% 50% 50%	38-66%
Sand filter Infiltratration (2xWQV) Retention basin III (4xWQV with aquatic bench)	65% 65% 65%	67-100%

*Innovative or alternate BMPs not included in this table may be allowed at the discretion of DCR.

**Percent Impervious Cover: Relationship of the area of new impervious cover within the project site (right of way and permanent easement) to the total area of the project site (right of way and permanent easement), per outfall.

2. BMP requirements for flooding or quantity control are determined by the ESC Regulation MS-19 for adequate receiving channels.

3. Extended Detention Basins and Extended Detention Basins Enhanced require a Water Quality Volume (WQV) of 2 x the standard WQV or 1" of runoff from the new impervious area.

4. Extended Detention Basins and Extended Detention Basins Enhanced require a 30 hour drawdown time for the required WQV. The 3" minimum size water quality orifice previously allowed has been eliminated. If the required orifice size is found to be significantly less than 3", an alternative water quality BMP should be investigated for use, such as a linear facility that treats the first flush and allows larger storms to bypass. The calculation procedure for drawdown time and orifice sizing is shown on Pages 5-33 through 5-38 (SWM Handbook) and also in example problems available from VDOT.

5. Sediment Forebays should be used on Extended Detention Basins and Extended Detention Basins Enhanced. The volume of the Forebay should be 0.1" – 0.25" x the new impervious area or 10% of the required detention volume. See Pages 3.04-1 through 5 (SWM Handbook) for details. The overflow spillway shall be stabilized utilizing rip rap, concrete or other non-erodible material.

6. Suggested details for the Extended Detention Basin are shown on Pages 3.07-4 and 5 (SWM Handbook). The riprap lined low flow channel through the basin is not recommended due to maintenance concerns.

7. Suggested details for the Extended Detention Basin Enhanced are shown on Pages 3.07-6 and 7 (SWM Handbook). The geometric design will probably need to be more symmetrical than that shown in order to construct the basin to the dimensions needed.

8. Non-structural practices including, but not limited to, minimization of impervious areas and curbing requirements, open space acquisition, floodplain management, and protection of wetlands may be utilized as appropriate in order to at least partially satisfy the water quality requirements. Approval of such non-structural measures will be secured in advance from the Department of Conservation and Recreation.

MULTI-USE SWM BASINS

Quantity Control – Quality Control – Temporary Sediment Storage

- SWM basins may function as both quantity control and quality control facilities. Some basins may only be needed for quality control. Most swm basins are needed to serve as temporary sediment basins during the construction phase of the project and the design will need to address this dual function. The design that is needed for a permanent swm basin may need to be altered to provide additional temporary sediment storage volume that is in excess of the required WQV. For design purposes the two volumes (WQV and temporary sediment storage volume) should not be added together but rather the larger of the two should govern the basin design.

The additional volume needed for temporary sediment storage may be provided by excavating the bottom of the basin lower than that required for the WQV. The basin's permanent outlet control structure can be temporarily altered to serve as the control structure for the temporary sediment basin (See Standard SWM-DR of VDOT's Road and Bridge Standards and the DCR ESC Handbook). When the project is nearing completion and the basin is no longer needed for temporary sediment control, the basin can be readily converted to the permanent SWM basin by regarding (excavating and/or filling) and removing any temporary control structure appurtenances.

IMPLEMENTATION

Plan Preparation

- Standard and minimum plan projects shall show stormwater management and erosion control measures on the plans as directed in the latest version of IIM-LD-11 and the Road Design Manual.
- No-plan, SAAP and other types of projects (including maintenance) that do not have a "formal" plan assembly must conform to the requirements of the Virginia Stormwater Management Regulations. For the definition of these types of projects, and the procedures for addressing both the erosion and sediment control and stormwater management requirements on such projects, see the latest version of IIM-LD-11.

Foundation Data

- Foundation data (a soil boring) for the base of the dam should be requested for all stormwater management basins in order to determine if the native material will support the dam and not allow ponded water to seep under the dam. An additional boring near the center of the basin should also be requested if:

  1. Excavation from the basin may be used to construct the dam, or
  2. Rock may be encountered in the area of excavation, or
  3. A high water table is suspected that may alter the performance of the swm basin.

  For large basins, more than one boring for the dam and one boring for the area of the basin may be needed. The number and locations of the borings are to be determined by the Hydraulics Engineer and/or the Materials Engineer.

- The foundation data for the swm basin should be requested by the Hydraulics Engineer at the same time that the request for culvert foundation data is initiated.

Right of Way

- Permanent stormwater management facilities may be placed in fee right of way or in permanent easements. It is recommended that all permanent stormwater management facilities (dams, ponds, risers, etc.) be placed within fee right of way initially. Ditches and similar features may initially be placed in permanent easements. The final decision on right of way versus permanent easement should be made prior to the Right of Way Stage of the project development process based on information obtained at the Field Inspection meeting and/or the Design Public Hearing. The Department will generally be amenable to the desires of affected landowners in this matter. The multiple use of property for stormwater management and such features as utilities is permissible. The decision on the advisability of such actions must be made on an individual site basis.

Design Details

- The following details are to be incorporated into the design of VDOT stormwater management basins in order to be in compliance with the Virginia SWM Regulation Revisions of 1998 and the DCR SWM Handbook. These details address concerns with seepage through the dam and along the culvert due to the ponding of water in the basins being of longer duration than previous designs that used a minimum 3" water quality orifice.

    1. Foundation data for the dam is to be secured by the Materials Division in order to determine if the native material will support the dam and not allow ponded water to seep under the dam.

    2. The foundation material under the dam and the material used for the embankment of the dam should be an AASHTO Type A-4 or finer and/or meet the approval of the Materials Division. If the native material is not adequate, the foundation of the dam is to be undercut a minimum of 4' or the amount recommended by the Materials Division. The backfill and embankment material must meet the above soil classification or the design of the dam may incorporate a trench lined with a membrane (such as bentonite penetrated fabric or an HDPE or LDPE liner) and be approved by the Materials Division.

    3. The pipe culvert under or through the dam is to be reinforced concrete pipe with rubber gaskets. Pipe: Specifications Section 232 (AASHTO M170), Gasket: Specification Section 212 (ASTM C443)

    4. A concrete cradle is to be used under the pipe to prevent seepage through the dam. The concrete cradle is to begin at the riser or inlet end of the pipe and extend the full length of the pipe.

    5. If the height of the dam is greater than 15' or if the basin includes a permanent water pool, the design of the dam is to include a homogenous embankment with seepage controls or zoned embankment or similar design in accordance with the DCR SWM Handbook and recommendations of the Materials Division.

6. The top width of the dam should be 10' (3m) minimum to facilitate both construction and maintenance.

7. The side slopes of the basin should be no steeper than 3:1 to permit mowing and maintenance access.

8. The longitudinal bottom slope through the basin should be no more than 2% nor less than 0.5%.

9. The depth of the basin from bottom to the primary outflow point (top of riser, or invert of orifice or weir) should be no more than 3' (1m), if possible, in order to reduce the hazard potential. If the depth needs to be more than about 3' (1m), fencing of the basin site should be considered.

10. The primary control structure (riser or weir) should be designed to operate in weir flow conditions for the full range of design flows. Where this is not possible or feasible and the control structure will operate in orifice flow conditions at some point within the design flow range, an anti-vortex device, consistent with the design recommendations in the DCR SWM Handbook, shall be utilized.

11. The length to width ratio of the basin should be about 3:1 (wider at the outlet end). If the ratio is less than about 2:1, and if there is concern that the velocity of flow through the basin will be high, consideration should be given to using baffles within the basin to reduce velocity. Baffles should be constructed of "pervious" type material, such as snow fence, rather than earth berms that tend not to reduce the velocity.

Perimeter Controls

All SWM basins should be reviewed for the needs of fencing, barricades and no trespassing signs in accordance with the following guidelines:

- Fencing of SWM Basins

1. Fencing of stormwater management basins is normally <u>not required</u> and should not be considered for most basins due to:

   - <u>Insignificant Hazard</u> - Ponding of water in the basin should only occur with very heavy storms and be noticeable for only a few hours. The ponded depth will normally be no more than about 3' (1m). Ponds and lakes are almost never fenced, even though they may be located in subdivisions and have deep, permanent pools.

   - <u>Limits Maintenance</u> - Fencing will limit maintenance operations and could deter the frequency of maintenance. Fencing could become damaged during major maintenance operations.

2. Fencing of SWM basins may occasionally be needed and should be considered when:

- The basin is deep with ponded depth greater than about 3' (1m) and/or has steep side slopes with 2 or more sides steeper than 3:1, or

- The basin is in close proximity to schools, playgrounds or similar areas where children may be expected to frequent, or

- It is recommended on the Field Inspection Report, the Resident Engineer or the City/County (where City/County will take over maintenance responsibility.)

- Barricades

  A chain barricade (See Standard CR-1 of VDOT's Road and Bridge Standards) or gate may be needed on some basins to prohibit vehicular access if there is concern with illegal dumping or other undesirable access.

- Signs

  "No Trespassing" signs shall be considered for use on all basins, whether fenced or unfenced, and should be recommended, as needed, on the Field Inspection Report.

Regional Facilities

- There are many cases where it is more feasible to develop one major stormwater management facility to control a large watershed area rather than a number of small individual facilities controlling small drainage basins. The concept of regional stormwater management facilities is endorsed by VDOT provided that certain requirements are met.

- Development and use of regional stormwater management facilities must be a joint undertaking by VDOT and the local governing body. The site must be part of a master stormwater management plan developed and/or approved by the local governing body and any agreements related to these facilities must be consummated between VDOT and the local governing body. VDOT may enter into an agreement with a private individual or corporation provided the local governing body has a swm program that complies with the Virginia SWM Regulations and the proper agreements for maintenance and liability of the regional facility have been executed between the local governing body and the private individual or corporation.

- Where the roadway embankment serves as an impounding structure, the right of way line will normally be set at the inlet face of the drainage structure. The local government would be responsible for the maintenance and liabilities outside of the right of way and VDOT would accept the same responsibilities inside the right of way.

- Hydraulic design of regional stormwater management facilities must address any mitigation needed to meet the water quality and quantity requirements of the roadway project. Stormwater management facilities located upstream of the roadway project shall provide sufficient mitigation for the water quality and quantity impacts of run-off from the roadway project which may bypass the facility.

Maintenance

- Requirements for maintenance of stormwater management facilities, the recommended schedule of inspection and maintenance, and the identification of persons responsible for the maintenance will be addressed in VDOT's "Stormwater Management Annual Plan" as approved by DCR.

Future Reconstruction

- If a stormwater management facility is constructed to address the water quality and quantity requirements of a current project and, at some time in the future, is displaced to accommodate future roadway construction, the new stormwater management facility constructed at that time must address the water quality and quantity requirements due to the future construction <u>and</u> the water quality and quantity requirements that were mitigated by the original stormwater management facility.

Reporting

- VDOT is required to submit an annual report to the Department of Conservation and Recreation (DCR) that identifies the location, number and type of stormwater management facilities installed during the preceding year, their storage capacities, the affected water body, and a summary of any water quality monitoring data associated with the facility. A database has been established on the Hydraulics Section's telecommunication file system to record this type of data for all projects. It shall be the responsibility of the district drainage engineer and the hydraulic design engineers in the Central office to ensure that the required information is logged on the database for all stormwater management facilities that are designed for roadway projects. In order for the database to reflect those facilities constructed during the preceding year, it is recommended that the required information be logged at the time of the first submission of plans to the Construction Division. The reporting period will be from July 1 to June 30.

PLAN DETAILS

Stormwater Management Drainage Structure Standard SWM-1

- To be used at all applicable locations where a riser type of control structure is desired.

Stormwater Management Dam

- To be used at locations where a wall type control structure is desired (includes modifications to standard endwalls). Normally used for shallow depths of ponding.

- Details to be provided for individual locations.

Copies of the control structures other than those above shall be submitted to the office of the State Hydraulics Engineer to facilitate future development or modification of standard details.

Stormwater Management Details Standard SWM-DR

- Specify at each location requiring a water quality orifice and/or where modifications are required in order to provide for a temporary sediment basin during the construction phase of the project. The size opening for the water quality orifice or other required openings in the control structure shall be specified in the description for the control structure for each basin.

Access

- A means of access for inspection and maintenance personnel shall be provided at each SWM facility location. The Standard PE-1 details shown in VDOT's Road and Bridge Standards should be used for vehicular entrances.

- A turnaround should be provided on each vehicular entrance.

- Appropriate all weather surface material shall be provided for each vehicular entrance.

Method of Measurement – Basis of Payment

Stormwater Management Drainage Structure (SWM-1):

- Basis of payment to be linear feet (meters) measured from invert of structure to top of concrete.

Stormwater Management Dam:

- Basis of payment to be cubic yards (m^3) of Concrete Class A3 Miscellaneous and pounds (kilograms) of Reinforcing Steel.

Grading:

- Excavation for stormwater management basins will be measured and paid for as cubic yards (m^3) of Stormwater Management Basin Excavation.
- Fill material needed for dams or berms will be measured and paid for as cubic yards (m^3) of Regular Excavation, Borrow Excavation or Embankment.
- The Grading Diagram is to reflect how the cubic yards (m^3) of Stormwater Management Basin Excavation and cubic yards (m^3) of Embankment or Borrow is to be distributed.

Stormwater Management Summary

- All drainage items related to the construction of stormwater management facilities shall be summarized, by location, in the Drainage Summary for the project.
- All incidental items related to the construction of stormwater management facilities shall be summarized, by location, in the Incidental Summary for the project.
- Stormwater Management Excavation and Borrow or Embankment, if needed, is to be included in the totals on the Grading Diagram and Summary.

PAY ITEMS

The following pay items are established:

PAY ITEM	UNIT		ITEM CODE
	Metric	Imperial	
SWM Basin Excavation	m^3	Cu. Yds.	27545
SWM Drainage Structure (SWM-1)	m	Lin. Ft.	27550
For SWM Dam:			
Conc. Cl. A3 Misc.	m^3	Cu. Yds.	00525
Reinf. Steel	Kg.	Lbs.	00540

SPECIAL PROVISIONS

The current Special Provision/Copied Note for measurement and payment for stormwater management items is available for applicable projects as follows:

http://www.virginiadot.org/business/manuals-default.asp

INSERTABLE SHEETS

The following insertable sheets (English and Metric) are available on Falcon DMS, under the PPMS# eng-ser, Division, minsert and insert, for insertion into applicable plan assemblies:

- SWM Details – SD/MSD # 2209.
- SWM Drainage Structure (SWM-1) – SD/MSD # 2216.
- SWM Trash Rack – SD/MSD # 2216A

APPENDIX 4
REFERENCES

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STATE CONTACTS

OHIO
John P. Stains, P.E.
Ohio Department of Transportation
Roadway Hydraulics, Structural Engineering
1980 West Broad Street
Columbus, Ohio 43223
Phone: (614)728-1998
Fax: (614)752-4824
Email: john.stains@dot.state.oh.us
http://www.dot.state.oh.us/se/hy/LD2/LD2TOC.htm
Sections 1115 – 1118

VIRGINIA
Roy T. Mills
Virginia Department of Transportation
State Hydraulics Engineer
Phone: (804) 786-9013
Email: roy.mills@VDOT.Virginia.gov
http://www.extranet.vdot.state.va.us/locdes/electronic%20pubs/iim/IIM195.pdf

SOUTH CAROLINA
Ray Vaughn
South Carolina Department of Transportation
Phone: (803) 737-6378

FLORIDA
Larry Ritchie
Environmental Management Office
Florida Department of Transportation
Phone: (850) 414-5329
Fax: (850) 414-4443
E-mail: larry.ritchie@dot.state.fl.us

NORTH CAROLINA
Matthew (Matt) S. Lauffer, P.E.
NC Department of Transportation
Hydraulics Unit
Stormwater Management
Phone: (919) 250-4100
Email: mslauffer@dot.state.nc.us

GEORGIA
Brad Ehrman, P.E.
Design Group Manager
Georgia Department of Transportation
Office of Road Design
Phone: (404) 656-5409
Fax: (404) 657-0653
E-mail: bradley.ehrman@dot.state.ga.us

INDIANA
Rick Phillabaum
Indiana Department of Transportation
Phone: (317) 233-5151
Email: rphillabaum@indot.IN.gov
Website:
http://rebar.ecn.purdue.edu/JTRP_Completed_Project_Documents/SPR_2853/FinalReport/SPR_2853_Final/SPR_0605.pdf

OREGON
William Fletcher
Oregon Department of Transportation
Water Resources Program Coordinator
Phone: (503) 986-3509
Email: William.B.Fletcher@odot.state.or.us
Website:http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/docs/Erosion_Control_Manual_nav.pdf

KENTUCKY
Brooke Shireman
Environmental Technologist III
Kentucky Division of Water
14 Reilly Rd.
Frankfort, KY 40601
Phone: (502) 564-3410
Fax: (502) 564-9636
Email: brooke.shireman@ky.gov

Corrine Wells
Kentucky Division of Water
14 Reilly Rd.
Frankfort, KY 40601
Phone: (502) 564-2225
Fax: (502) 564-9636
Email: Corrine.wells@ky.gov

Shelby C. Jett, P. E.
Phone: (502) 564-7250

ARKANSAS
Jennifer Harman
Arkansas Department of Transportation
Phone: (501) 682-0627

Jennifer Bonner
City of Rogers
Phone: (479) 621-1117 ext. 1807
jbonner@rogersark.org