State of Tennessee
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER RESOURCES
William R. Snodgrass - Tennessee Tower
312 Rosa L. Parks Avenue, 11th Floor
Nashville, Tennessee 37243-1102

March 14, 2024

Mr. Trent Thomas, Team Lead
Tennessee Department of Transportation
Environmental Division \ Compliance Unit
James K. Polk Building, 9th Floor
505 Deaderick Street
Nashville, TN 37243
e-copy: trent.thomas@tn.gov

Subject: **Notice of Complete Permanent Stormwater Implementation Plan**
Transportation Separate Storm Sewer System (TS4) Program
National Pollutant Discharge Elimination System (NPDES)
Individual NPDES Permit Number TNS077585
Tennessee Department of Transportation (TDOT)
Statewide, Tennessee

Dear Mr. Thomas:

The Division of Water Resources acknowledges the receipt of a revised TDOT Permanent Stormwater Implementation Plan (enclosed) in our office on February 29, 2024. Our review of the revised plan showed that TDOT has submitted all the information required by the TS4 NPDES permit and Rule 0400-40-05-.15(1)(d). However, in the plan's table, under Permit Section 2.2.5. Timeframe – Milestones, it lists an "exemption." The permit does not provide an exemption. TDOT has 24 months from the effective date of the permit to fully update and implement Permit Section 2.2.5. Permanent Stormwater Management Program.

Additionally, given that TDOT has already provided comprehensive study results (please see documents enclosed) to both TDEC and the EPA under the previous permit cycle, we strongly urge TDOT to expedite the study phase under this permit and proceed with the implementation of stormwater control measures without further delay.

We value the ongoing collaboration with TDOT and look forward to the full implementation of your post-construction stormwater program. Should you require any additional information or clarification, please do not hesitate to contact me at (615) 687-7119 or by E-mail at Ann.Morbitt@tn.gov.

Sincerely,

Ann Morbitt
Division of Water Resources

Enclosures (6): 29FEB24 TDOT Permanent Stormwater Implementation Plan
Comprehensive Study Results Documents (5)

e-cc: Ms. Carma H. Smith, Tennessee Department of Transportation, carma.h.smith@tn.gov
Mr. Klint Rommel, Tennessee Department of Transportation (TDOT), klint.rommel@tn.gov
Ms. April Grippo, Division of Water Resources, april.grippo@tn.gov
Ms. Karina Bynum, Division of Water Resources, karina.bynum@tn.gov

Post-Construction/Permanent Stormwater Management Program

Revised Implementation Plan (Rev. 02/29/2024)

In accordance with TDOT's NPDES permit (TNS077585), the following revised implementation plan is being submitted to fulfill the requirements set forth in section 2.2.5 regarding the development of a permanent stormwater management program (PSMP).

Estimating timeframes and milestones for a program being developed from scratch and of this nature has proven to be impracticable in certain areas. Therefore, this implementation plan represents TDOT's best estimation of timeframes required to develop those necessary initial program elements and will no doubt require amending as the program development advances. As the program is developed, updates will be provided in TDOT's TS4 permit annual report.

As the implementation plan is reviewed, please keep in mind that TDOT's program will be unique in that it will be developed for the purpose of regulating projects being constructed by a single property owner. Unlike traditional MS4s, TDOT is not regulating businesses and/or developers within a political boundary but regulating its own activities within TDOT right-of-way and/or permanent easements across the state. Furthermore, TDOT does not have the legal authority to create ordinances and/or regulations.

Permit Section	Requirement	Comments	Timeframe - Milestones
2.2.5 Post-Construction/Permanent Stormwater Management in New Development and Redevelopment			
2.2.5	Permits issued to entities that operate a municipal separate storm sewer system (MS4) shall include the following effluent limitations to manage post-construction stormwater at all new development and redevelopment projects that disturb one or more acres of land, or less than one acre if part of a larger common plan of development, and discharge into the permittee's MS4.	As of the date of the issued permit, TDOT projects at or beyond the Stage Zero Footprint established in the Project Delivery Network (PDN) process and less than one acre of disturbance will be exempt from the post-construction requirements of the TDOT TS4 Permit.	Exemption August 1, 2023 to July 31, 2025

<table>
<tr><th colspan="4">2.2.5.1 Permanent Stormwater Management Program</th></tr>
<tr><td>2.2.5.1 (a)</td><td>The permittee shall develop and implement a permanent stormwater management program to reduce pollutants in stormwater discharges through management practices, control techniques, and systems, design, and engineering practices implemented to the maximum extent practicable (MEP).</td><td rowspan="3">TDOT will develop and implement a program of appropriate SCM maintenance procedures that sustain pollutant reduction-efficiency for the life of the new development or redevelopment project. All procedures, reports, and documented as part of the stormwater management program. The program will include at a minimum:

- The development and documentation of maintenance and inspection procedures and frequencies for approved SCMs which shall require all SCMs to be inspected at least once every five years by a licensed professional engineer, a licensed landscape architect, or other qualified professional familiar with applicable SCM design and maintenance requirements;
- The development and documentation of the procedure that will used to verify that SCMs are being inspected and maintained, including any written reports;
- The development and documentation of the procedure that will be used to ensure all inspection and maintenance information is included in the SCM tracking database.</td><td rowspan="3">TDOT will perform a literature review of other DOTs to determine the most effective SCMs to develop an initial SCM suite to pursue. It is anticipated that the initial suite of SCMs will be determined by June 2024.

Once the initial suite of SCMs is selected, it is anticipated that draft guidance for designers, contractors, and inspectors will be ready by March of 2025.

Training will be developed from the written guidance, and it is anticipated to be ready by June 2025.</td></tr>
<tr><td>2.2.5.1 (b)</td><td>The permanent stormwater management program shall include plans review, site inspections, and a means to ensure that permanent stormwater control measures (SCMs) are adequately operated and maintained.</td></tr>
<tr><td>2.2.5.1 (c)</td><td>The permittee must develop and implement, and modify as necessary, an ordinance or other regulatory mechanism to address permanent stormwater management at new development and redevelopment projects.</td></tr>
<tr><th colspan="4">2.2.5.2 Permanent Stormwater Standards</th></tr>
<tr><td>2.2.5.2 (a)</td><td>The permanent stormwater management program must require new development and redevelopment projects to be designed to reduce pollutants to the MEP, as set forth herein. Compliance with permanent stormwater standards for new development and redevelopment</td><td>TDOT will develop written design procedures which will describe the process by which all TDOT projects will be internally reviewed to determine if any component of the project will fall under the permanent stormwater requirements.</td><td>As noted above, design considerations will be developed once the initial suite of SCMs is selected. It is anticipated that design guidance will be ready by March 2025.</td></tr>
</table>

	projects is determined by designing and installing SCMs as established by Tennessee Rule 0400-40-05-.15 and complying with other requirements of Tennessee Rule 0400-40-05-.15. For design purposes, total suspended solids (TSS) may be used as the indicator for the reduction of pollutants.	TDOT will develop a list of structural SCM designs that may be used on TDOT projects. SCMs must be designed to provide full treatment capacity within 72 hours following the end of the preceding rain event for the life of the new development or redevelopment project. The water quality treatment design storm is based on the 1-year, 24-hour storm event as defined by Precipitation-Frequency Atlas of the United States. Atlas 14. Volume 2. Version 3.0. U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA), National Weather Service, Hydrometeorological Design Studies Center, Silver Springs, Maryland or its digital product equivalent. SCMs must be designed, at a minimum, to achieve an overall treatment efficiency of 80% TSS removal from the WQTV. The quantity of the WQTV depends on the type of treatment provided. TDOT will utilize the table referenced within the permit in the section (2.2.5.2 (c)) while developing SCMs.	
2.2.5.2 (b)	SCMs must be designed to provide full treatment capacity within 72 hours following the end of the preceding rain event for the life of the new development or redevelopment project. The permittee shall identify a suite of SCMs to be used in various situations. Information relevant to identified SCMs should be made readily available. Application of innovative SCMs is encouraged. If the permittee decides to significantly limit the number of SCM options, it must be documented as part of the stormwater management program how the performance standards of Tennessee Rule 0400-40-05-.15 can be met with the limited set of control measures that are allowed.		
2.2.5.2 (c)	Stormwater Control Measures (SCM)s must be designed, at a minimum, to achieve an overall treatment efficiency of 80% TSS removal from the Water Quality Treatment Volume (WQTV). SCMs must be designed, at a minimum, to achieve an overall treatment efficiency of 80% TSS removal from the WQTV.		
2.2.5.3. Stormwater Mitigation and Public Stormwater Fund			
2.2.5.3 (a)(b)	(a) A permittee may choose to develop an offsite mitigation program or payment in lieu into a public stormwater fund to offset the portion of the WQTV that cannot be treated on site to the MEP. The program must have a mitigation project approval procedure, and all projects must meet all requirements in this permit. Procedures and	TDOT will have the option of creating an internal (to TDOT) alternate post construction program comprising of a payment in lieu into a TDOT stormwater fund to offset the portion of the WQTV that cannot be treated on site to the TS4 MEP in accordance with Section	Procedures and requirements for the offsite mitigation and payment in lieu programs will be documented as part of the permanent stormwater management program and submitted for review and approval if it

	requirements in the offsite mitigation and payment in lieu programs should be documented as part of the stormwater management program and available for review. (b) If the permittee allows payment into a public stormwater fund, the permittee assumes responsibility to provide the required mitigation projects. The public stormwater fund should be used to fund public mitigation projects. The payment amount into a public stormwater fund must be sufficient to design, install, and maintain the stormwater mitigation measures.	2.2.5.3 of the TDOT TS4 Permit. The program would require TDOT to evaluate an alternate effort with a minimum funding of at least 1.5 times the cost of stormwater management for the portion of the WQTV not treated on site by the subject stormwater project. The program would have a mitigation project approval procedure, and all projects would meet all requirements in the TDOT TS4 Permit. The TDOT stormwater fund would be used to fund mitigation projects at TDOT facilities and other existing State owned installations with documented stormwater issues. The payment amount into the TDOT stormwater fund would be sufficient to design, install, and maintain the stormwater mitigation measures. Application of any of this payment in lieu alternative to a TDOT project would require a letter to TDEC stating the reasons and basis for the use of this process and the proposed mitigation action.	is determined one is needed.
2.2.5.4. Water Quality Riparian Buffers			
2.2.5.4	Permittees shall develop and implement a set of requirements to establish, protect, and maintain permanent water quality riparian buffers to provide additional water quality treatment in riparian areas of new development and redevelopment projects that contain streams, including wetlands, ponds, and lakes.	TDOT currently adheres to the Construction General Permit (CGP) requirements for buffer zones while designing and constructing projects. TDOT will review its current design considerations and make any necessary adjustment to meet the following requirements. - Stormwater discharges should enter the water quality riparian buffer as sheet flow, not as concentrated flow, where site conditions allow;	Any changes needed to TDOT's current design guidance for water quality riparian buffers, will be incorporated into the design guidance noted above which is anticipated to be ready by March 2025.

		- Water quality riparian buffers must have the minimum widths prescribed in the TS4 Permit, unless site-specific conditions necessitate alternative widths; and - Include a process to review proposed activities within buffers to ensure the pollutant removal function of the buffer will be retained.	
2.2.5.5. Codes and Ordinances Review and Update			
2.2.5.5 (b)	Current permittees shall continue to implement the existing permanent stormwater management program and update legal instruments according to the compliance schedule in subparagraph (1)(d) of Tennessee Rule 0400-40-05-.15.	With TDOT's PSMP being unique in that TDOT will not be regulating external entities (i.e., landowners), TDOT will integrate language into the design guidance documents and develop contract language to ensure compliance with the issued TS4 permit.	Guidance documents and/or contract language is anticipated to be ready by March 2025
2.2.5.6. Development Project Plan Review, Approval, and Enforcement			
2.2.5.6 (a)	Procedures for review and approval of development site plans, including inter-departmental consultations and a re-submittal process when modifications to the project require changes to an approved site development design plan;	As noted above. TDOT will integrate into its design guidance any procedures needed for approval and review of plans to ensure performance standards are being meet. Inspection protocols to ensure proper construction will also be integrated into the guidance documents.	Guidance documents for selected SCMs will be ready by March 2025.
2.2.5.6 (b)	A plans review process that requires SCMs to be properly designed, installed, and maintained to meet the performance standards established in Tennessee Rule 0400-40-05-.15. The process must also include incentives adopted by the permittee as authorized by paragraph (2) of Tennessee Rule 0400-40-05-.15, along with water quality buffers as required by paragraph (4) of Tennessee Rule 0400-40-05-.15 ; and		
2.2.5.6 (c)	A verification process to document that SCMs have been installed per design specifications within 90 days of installation. Verification shall include submission of as-built plans to the permittee, permittee		

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER RESOURCES
William R. Snodgrass – Tennessee Tower
312 Rosa L. Parks Avenue, 11th Floor
Nashville, Tennessee 37243-1102

December 11, 2020

Certified Mail Receipt
91 7199 9991 7032 7998 7354

Ms. Susannah Kniazewycz, P.E.
Director of Environmental Division
Tennessee Department of Transportation
James K. Polk Building Suite 900
505 Deaderick Street
Nashville, TN 37243

RE: Tennessee Department of Transportation - Municipal Separate Storm Sewer System National Pollutant Discharge Elimination System (NPDES) Permit TNS077585 Compliance Evaluation Inspection of Post-Construction Stormwater Management Program

Dear Ms. Kniazewycz,

On December 1, 2020, Karina Bynum, Ann Morbitt, Ariel Wessel-Fuss with the Division of Water Resources (Division) met virtually through Microsoft Teams with Christian Saxe, Carma Smith and Klint Rommel with the Tennessee Department of Transportation (TDOT), and TDOT contractor, Michael Cramer with ENSAFE, to evaluate compliance of TDOT's Post-Construction Stormwater Management Program with the requirements of NPDES permit number TNS077585. The inspection covered the period since the Division's September 2011 inspection.

On July 9, 2012, TDOT in response to the Division's 2011 inspection requested multiple permit and program modifications. On February 21, 2019, Division staff met with Christian Saxe, Barry Brown with TDOT and Mike Cramer with ENSAFE to review the request for modification and on June 10, 2019 issued a letter which addressed modification to the TDOT's program but did not address items requesting modification of the permit. The Division's June 10, 2019 letter stated: "*The remaining modifications listed in the July 9, 2012 letter (Permit section 2.1.1.1. A-E, 2.1.2. A–C, 2.1.3. A-D, 2.1.4. A-H, 2.1.5. A-G, 2.1.6.2 2.1.7, 2.2.1, and 2.2.2) pertain to permit re-issuance and are not addressed at this time.*" Section 2.1.5. including items A-G is covered in this inspection.

This compliance inspection found all items of TDOT's Post-Construction Stormwater Management Program completed and identified one measurable goal (under Management Measure

B) that was adjusted from the measurable goal described in the permit. No actions are required as result of this inspection.

Under Measurement Measure B: Tracking of installation and maintenance of structural post-construction storm water management BMPs, the measurable milestone mentions a GIS database layer for stormwater management BMPs. TDOT uses a geographic information system called TRIMS and a Maintenance Quality Assurance database which include information and tracking of various post-construction roadway elements including roadway structures, pavement, photo logs, drainage structures and maintenance information. Development and maintenance of a separate GIS database layer that is limited to only post-construction storm water management BMPs proved to be cost-prohibitive for TDOT when they issued a request for proposal (RFP) in 2012.

The Division issued the NPDES permit authorizing discharge of stormwater runoff from the Tennessee Department of Transportation storm sewer system on April 28, 2006 and it became effective on October 1, 2006. The permit expired on April 27, 2011 and has been administratively extended until a new permit is issued. TDOT operates all highways which are part of the federal interstate highway system under TDOT's control and state-numbered highways statewide, including all respective right-of-way areas totaling 15,091 road miles statewide and 191 facilities across the state as reported in the 2020 annual report. The Post-Construction Stormwater Management Program requirements, permit section 2.1.5 apply to TDOT's post-construction facilities including roadways, right-of–ways and appurtenances subject to stormwater runoff. The permit requirements and inspection findings for the Post-Construction Stormwater Management Program are summarized in Table 1 below.

Table 1
Permit section 2.1.5. Post-Construction Storm Water Management

Management Measure	Measurable Goal	Inspection Findings
A. Develop menu of BMPs	Develop menu of structural post-construction storm water BMPs that can be applied to new highways or upgrades of existing highways.	TDOT continues to produce regular updates to its Drainage Manual, including revisions to sections involving stormwater drainage and erosion prevention and sediment control. BMP Post-Construction Menu (2009) – document was provided and BMPs are implemented in the following: TDOT Drainage Manual https://www.tn.gov/tdot/roadway-design/design-standards/drainage-manual.html Standard Roadway Drawings https://www.tn.gov/tdot/roadway-design/standard-drawings-library/standard-roadway-drawings.html TDOT Design Guidelines https://www.tn.gov/tdot/roadway-design/design-standards/design-guidelines.html **COMPLETE**
	Develop menu of non-structural post-construction storm water BMPs that can be applied to new highways or upgrades of existing highways.	
	Update design standards to reflect the menu of structural BMPs for structural post-construction BMPs.	

B. Develop and implement a system to track the installation and maintenance of structural post construction storm water management BMPs.	Develop and maintain a GIS database layer identifying post construction storm water management BMPs	TDOT issued a RFP on 2/12/2012 for a web-based system for an Integrated Right-of- Way Information System that will compile information on all stormwater conveyance and structures, and track maintenance activities in a central database. The level of effort to map every swale, curb, inlet basin, detention pond, culvert, and other structures over 14,000 miles of highway was considered prohibitively expensive. The outfall mapping of just the urbanized areas cost TDOT over $4 million. Since 2016 TDOT has implemented an electronic system for inspections and to track maintenance activities in a Maintenance Quality Assurance database (MQA db). TDOT also supports the eTRIMS geodatabase. TRIMS is a single integrated linear referencing system database for State and local roadway structures, pavement, traffic, photo log, and crash data. TDOT is considering issuing a new RFP for Statewide Asset and Photolog Image Collection – proposed to include BMPs, however the bids may not come in at the level that can be funded. **COMPLETE** – with modified measurable goal due to infeasibility of separate GIS BMP database layer
C. Conduct random inspections of drainage systems to establish the overall condition of ditches in the district.	Conduct random inspections of statewide highway segments. Use the result of the overall condition of ditches as a tool in setting the annual maintenance priorities.	Centralized system database (MQA db) maintains the inspection and repair records for drainage structures within each of the TDOT Districts. Annual reports include number of drains, liner feet of drainpipes and trench drains cleaned, and lane miles of sweeping. Maintenance of post-construction drainage structures is performed on a district-by-district basis as part of routine ditch cleaning and drainage structure maintenance with priorities set by the Maintenance Quality Assurance rating based on the Maintenance Quality Assurance Program – Field Inspection Manual rev 2.1 2020. **COMPLETE**
D. TDOT shall review design standards for storm drain inlets to promote the use of grate spacing that	Documentation of the review shall be provided in the Annual report, with recommendations on developing a new standard if warranted	Report was completed in May 2009 with the following recommendation: "In lieu of revising current standards for grates on catch basin inlets, curb inlets, and other storm sewer system inlets, it is recommended that TDOT continue to

minimize the entry of trash, floatable and other debris into the storm drain system. Trash, floatable and other debris on the highways shall be handled by means other than flushing into storm drains. Where reduction in grate spacing would cause inadequate hydraulic performance, TDOT will pursue other management practices to minimize trash, floatable and large debris in storm runoff.		employ a wide range of BMPs to address storm water quality.” **COMPLETE**
E. Research BMPs.	Select four mature highway sites, with the approval of TDEC, where BMPs can be implemented on a semi-permanent basis for research evaluation. The purpose of this research is to measure storm water runoff quality at a storm drain outfall before and after BMP implementation and determine effectiveness. Develop and submit to the division for approval a study plan for each site which shall include: (1) A discussion of the basis for the selection of the site including its nature relative to typical highway design segments, its average daily traffic (ADT) and the percentage of non-TDOT drainage contributing (see Appendix C of Part II of the TDOT MS4 permit application), (2) A description of the BMP (either structural or non-structural) to be implemented and evaluated,	The Plan was originally submitted to TDEC in October 2007, TDEC’s written approval of the plan was received on April 21, 2008. Implementation of the plan began immediately after that date with design and installation of automated sampling stations at the four highway segments specified in the plan. A total of 297 storm water runoff samples were collected from all four approved sites between December 17, 2008 and May 31, 2011. Based on the original sampling results, TDOT pursued three follow-up evaluations to better understand the source and basis of the observed stormwater run-off characterizations. These evaluations included: - BMP implementation as required by permit section 2.1.5.E. BMPs evaluated included open-grade friction course paving and vegetated swales. - Focused evaluation on the source and nature of the observed nutrient contamination. - Focused evaluation on the source and nature of the observed pathogen contamination. In the debris and floatable study, the highest percentage of non-biological debris was at sites with relatively high amounts of average daily

	(3) A description of the site including the drainage area, portion impervious, portion pervious, type surface cover, and slopes, (4) List of pollutants for which analysis is to be made, (5) Description of equipment to be used to record rainfall events, measure runoff volume, provide first flush discrete samples and storm duration flow composited samples of storm water. Also collect and analyze any large solids, trash and floatables in the runoff that is not captured by conventional water sampling equipment.	traffic, relatively high flows or near a large residential area. Most likely non-biological debris were being thrown from vehicles traveling on the interstates or being washed from residential areas. The highest amount of biological debris was found at sites that were in rural areas or had large grassy areas surrounding the collection. **COMPLETE**
	Prior to implementing the selected BMP, TDOT shall conduct sampling at each site during a minimum of twelve months to determine background levels of pollutants. A written report of the findings shall be prepared and submitted to TDEC. Based on the findings, TDOT, with the approval of TDEC, shall implement the selected BMP at the site.	Preliminary data report (data 2009-2011) was submitted in 2012 with the final Highway Characterization Study submitted in 2013. **COMPLETE**
	Begin implementing plan. Following implementation of the BMP, TDOT shall conduct sampling at each site during a minimum of twelve months to evaluate the effectiveness of the BMP. TDOT will prepare a written report comparing the before and after analytical data and evaluating the effectiveness of the BMPs and the feasibility of implementation of this BMP at applicable highway sites.	The results of the Open Graded Friction Course and the stormwater swale investigations fulfilled the requirement of Section 2.1.5.E of the TDOT MS4 Permit to demonstrate the effectiveness of a specific BMP in mitigating the impact of contaminants of concern from TDOT highway stormwater runoff. The most significant observation from the swale investigation for TDOT at the SR-111 site was that the total flow volume infiltrated and evapotranspired by the swale was over twice the run-off volume that could have been generated by the impervious area within the study catchment. Similarly, at the I-40 site the total flow volume infiltrated and evapotranspired by the swale was over six times the run-off volume that could have been generated by the impervious area within the study catchment

		Nutrient contamination was found to be largely from atmospheric deposition. The source of pathogen contamination is still unclear. No other contaminants were found to be significant threats to water quality. Report of findings are still being finalized. Preliminary summary was provided on 24NOV20. With final Research Reports due in early 2021. **COMPLETE**
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.	Report titled "Post-Construction Stormwater Best Management Practices Research Report" was provided to the Division in 2007 and is also posted on the EPA's website at: http://www.epa.gov/npdes/pubs/tdot_bmp_report2007.pdf **COMPLETE**
G. Comprehensive maintenance manual, TDOT shall develop a comprehensive Right-of-Way Maintenance Manual integrating existing SOPs. The manual will contain information explaining how routine highway maintenance can impact storm water quality and what measures should be taken to minimize these impacts. The following subjects are to be included at a minimum: Report	Develop SOPs for the Maintenance Manual, at least 3 SOPs per permit year. Begin implementing each SOP after developing. Incorporate SOPs into training opportunities.	TDOT uses multiple comprehensive maintenance manuals, SOPs and SOGs. TDOT Integrated Vegetation Management Plan dated 01MAR16 is in TDEC online files and addresses 2, 6, 7. TDOT holds a permit coverage under the Pesticide GP and reports annually to the division. TDOT developed a Manual for Management of Storm Water Discharges Associated with Construction and Maintenance Activities in 2011 that focuses on erosion and sediment control. TDOT developed a comprehensive Maintenance Quality Assurance Program – Field Inspection Manual rev 2.1 2020 that addresses items 1, 4, 5, 9

on the SOPs created and training provided. 1. Road surface maintenance, 2. Landscaping (including flower beds), 3. Bridge repair, 4. Drainage system inspection and cleaning, 5. Right-of-way embankment stabilization, 6. Spraying of herbicides, 7. Vegetation control, cutting and removal, 8. Treatment system maintenance, and 9. Post construction BMP maintenance.		Item 8 – Treatment system maintenance is addressed through applicable SOPs (listed in the following section) Item 3 - Bridge repair is addressed in TDOT standard drawings: https://www.tn.gov/tdot/structures-/standard-structures-drawings/bridge-repair.html **COMPLETE**
	Report on the SOPs created, and training provided	List of SOPs developed to date: SOP 001 Spill Prevention and Response at TDOT Facilities SOP 002 Waste Accumulation Areas SOP 003 Aerosol Can Puncturing System SOP 004 Discarded Automotive Fuel Tanks SOP 005 Empty Container Management SOP 006 Highway Marking Operations SOP 007 Record-Keeping and Reporting for Special and Hazardous Waste SOP 008 Methamphetamine Lab Waste SOP 009 Parts Washer Units and Brake Washer Units SOP 010 Roll-Off Boxes for The Management of Wastes Found Along Highway Right-of-Ways and on Other TDOT-Maintained Properties SOP 011 Salt Handling and Salt Brine/Calcium Chloride/Liquid De-Icer Management SOP 012 Satellite Accumulation Areas SOP 013 Shipment and Disposal of Special, Non-Hazardous, and Hazardous Wastes SOP 014 Universal Waste Management SOP 015 Underground Storage Tanks SOP 016 Vehicle Wash Operations SOP 017 Used Oil Management SOP 018 Management of Material Stockpile SOP 020 SWPPP Management at Unstaffed Facilities SOP 021 Release of Captured Storm Water from Secondary Containment SOP 022 Management of Waste Tires SOP 023 Management of Scrap Metal SOP 024 Management of Environmental Records List of SOGs developed to date: SOG 401-1 Manual Spot Patching SOG 402-1 Crack Repair SOG 404-1 In-Place Asphalt SOG 405-1 Machine Milling SOG 406-1 Pavement and/or Sub-grade Replacement SOG 407-1 Pavement Preservation

		SOG 425-1 Grade Unpaved Surface SOG 426-1 Reshape Shoulder and Ditch SOG 430-1 Clean and Reshape Ditches SOG 435-1 Machine Mowing SOG 436-1 Slope Mowing SOG 438-1 Manual Brush Control SOG 440-1 Seeding the Mulch SOG 460-1 Plowing Snow and Ice SOG 461-1 Deicing (Rock Salt) SOG 462-1 Snow and Ice / Standby Stockpiling SOG 463-1 Anti-Icing (Salt Brine) SOG 477-1 Work Zone TTC Flagging and Mobile Operations SOG 495-1 Roadway Inspection- Special Litter (Road Patrol) Winter Operations SOG Vegetation Management SOG **COMPLETE**

The approach of TDOT stormwater management program over the years has been to develop science-based solutions that can be implemented with a reasonable respect for their cost and effectiveness. Much of the research lead to follow-up studies that concluded in 2020. The results from TDOT research conducted to date will be instrumental when the Division develops the next permit.

The Division appreciates the time and cooperation from the Department of Transportation Environmental Division extended during the inspection and during preparation for the inspection. The Division would like to thank your staff for their assistance with the retrieval of numerous documents. If you have any questions concerning this inspection, please contact Karina Bynum at (931) 520 - 6683 or at Karina.Bynum@tn.gov.

Sincerely,

Karina By

Karina Bynum, Ph.D., P. E,
Division of Water Resources

e-cc: Susannah Kniazewycz, P.E. - TDOT - Susannah.Kniazewycz@tn.gov
Carma Smith – TDOT- Carma.H.Smith @tn.gov
Christian Saxe – TDOT - Christian.Saxe@tn.gov
Klint Rommel – TDOT – Klint.Rommel@tn.gov
Jessica Murphy – DWR - Enforcement and Compliance - Jessica.Murphy@tn.gov
Ann Morbitt – DWR- Stormwater Manager - Ann.Morbitt@tn.gov
April Grippo – DWR - Deputy Director – April.Grippo@tn.gov
Ariel Wessel-Fuss – DWR - Permit Writer - Ariel.Wessel-Fuss@tn.gov

	inspection, or inspection by a qualified design professional. The verification process shall include enforcement procedures to bring noncompliant projects into compliance, which shall be detailed in the enforcement response plan. (see 2.4)		
2.2.5.7. Maintenance of Permanent Stormwater Control Measure Assets			
2.2.5.7(a)	Permanent SCMs, including SCMs used at mitigation projects, must be installed, implemented, and maintained to meet the performance standards of paragraph (2) of Tennessee Rule 0400-40-05-.15, and provide full treatment capacity within 72 hours following the end of the preceding rain event.	SCMs must be inspected on a regular basis. For each SCM installed as part of a TDOT project, a database will be developed/maintained which includes a description of the system components, a site map, documentation of ongoing site SCM inspection and maintenance activities, and the schedule of future inspections. Landscape plans should also be included for bioretention areas.	As guidance documents are being developed for the suite of SCMs, maintenance protocols will be addressed.
2.2.5.7 (b)	The permittee must develop and implement a program to require implementation of appropriate SCM maintenance procedures to sustain pollutant reduction-efficiency for the life of the new development or redevelopment project. All procedures, reports, and documented as part of the stormwater management program.		
2.2.5.8. Inventory and Tracking of Permanent Stormwater Control Measure Assets			
2.2.5.8	Continue to implement and maintain a system to inventory and track the status of all structural SCMs as required by section 2.2.5.8	All structural SCMs installed on TDOT projects will be included in a database/tracking mechanism with complete information, including: - A brief description of the type of SCM and basic design characteristics; - Inspection schedules; - A brief description of, or reference to, maintenance procedures and frequency; - Photographs of the installed SCMs; and - Maintenance and inspection records.	TDOT is currently using a program to track departmental assets along ROWs. Discussions have taken place to see if this program can be used to track installed SCMs. It is anticipated that by June 2024 TDOT will determine if this existing program can be used to track SCM assets. If TDOT's current tracking system proves to not be a viable option, other options will be researched and utilized to fulfill this requirement.

REVIEW OF STANDARD STORM DRAIN INLET GRATE SPACING

for

TDOT Go.

Tennessee Department of Transportation
Environmental Compliance Office

MAY 2009

Prepared by

SAIC
From Science to Solutions

Scientific Applications International Corporation

Oak Ridge, Tennessee

Purpose

This document summarizes a review of design standards for Tennessee Department of Transportation (TDOT) storm drain inlets as mandated by Section 2.1.5.D of Municipal Separate Storm Sewer System (MS4) Permit No. TNS077585, issued April 28, 2006 by the Tennessee Department of Environment and Conservation (TDEC). Section 2.1.5 mandates that TDOT "shall develop, implement and enforce a program to reduce pollutants in storm water from the post-construction facilities including roadways, right-of–ways and appurtenants subject to storm water runoff." More specifically, this program must include a review of grate spacing on storm drain inlets used by TDOT and its contractors. Subsection D states that current standards for grate spacing are to be evaluated with the following goal in mind: "minimize the entry of trash, floatable and other debris into the storm system."

Standards Review

Preliminary review focused on *Chapter 7: Storm Drainage Systems of* the TDOT Division Drainage Manual. Design guidelines in *Chapter 7* present methods to determine the spacing of inlet structures (e.g., the distance between two consecutive curb inlets), but the Drainage Manual does not specifically address grate spacing. Therefore, current TDOT standard drawings (shown in Table 1) were reviewed for spacing standards.

Field Review

In response to other requirements of the MS4 permit, TDOT is currently carrying out a multi-phase, statewide effort to map the locations and characteristics of all stormwater outfalls on TDOT right-of-way. At this time, the first two phases of mapping have been completed, encompassing almost 2180 miles of state roads in Eastern and Middle Tennessee. Two designated categories of outfalls include drop inlets (catch basins, bridge drops, and other openings not employing a curb) and curb inlets. The category of curb inlets includes two main groups: a vertical opening in a curb lacking any grate and a combination curb/catch basin, typically employing a metal grate in the horizontal direction with a vertical opening along the curb. Data accumulated through this project indicate wide variations between standards shown on TDOT drawings and existing storm water inlets.

Drop Inlets

A total of 9,569 outfalls have been characterized as drop inlets (some with grates, some without) in the stormwater outfall mapping project thus far. Of those drop inlets, 4,955 were labeled "no grate." Team members recorded the size and shape of openings for ungrated inlets as part of the standard process. When inlets did employ a grate, team members recorded the size of spaces within the grate. Some individuals also recorded the shape of the opening - round, rectangular, or square. If a drop inlet that would normally employ a grate was missing that grate, a notation of "grate missing" was placed in the data file.

Table 1. TDOT Storm Drain Grate Standard Drawings

Drawing	Revision Date	Description	Grate	Approximate Maximum Grate Opening
D-CB-38RB	9/05/2004	STANDARD PRECAST CIRCULAR NO. 38 CATCH BASIN	No. 38	4.5″ x 2′ 10″
D-CB-38S	7/29/2002	STANDARD 32" X 32" SQUARE CONCRETE NO.38 CATCH BASIN	No. 38	4.5″ x 2′ 10″
D-CB-38SB	9/05/2004	STANDARD 4' X 4' SQUARE CONCRETE NO.38 CATCH BASIN	No. 38	4.5″ x 2′ 10″
D-CB-38SC	9/05/2004	STANDARD 5'2" X 5'2" SQUARE CONCRETE NO. 38 CATCH BASIN	No. 38	4.5″ x 2′ 10″
D-CB-39RB	5/27/2001	STANDARD PRECAST CIRCULAR NO. 39 CATCH BASIN	No. 39	3.5″ x 4′ 2″
D-CB-39S	7/29/2002	STANDARD 4' X 4' SQUARE CONCRETE NO.39 CATCH BASIN	No. 39	3.5″ x 4′ 2″
D-CB-39SC		STANDARD 5'2" X 5'2" SQUARE CONCRETE NO. 39 CATCH BASIN	No. 39	3.5″ x 4′ 2″
D-CB-39SD	9/11/2002	STANDARD 7' X 7' SQUARE CONCRETE NO.39 CATCH BASIN	No. 39	3.5″ x 4′ 2″
D-CB-39SE	2/13/2004	STANDARD 9' X 9' SQUARE CONCRETE NO.39 CATCH BASIN	No. 39	3.5″ x 4′ 2″
D-CB-40S	7/29/2002	STANDARD 4' X 8' RECTANGULAR CONCRETE NO. 40 CATCH BASIN	No. 40	3.5″ x 4′ 2″
D-CB-40SE	5/05/2005	STANDARD 9' X 9' SQUARE CONCRETE NO.40 CATCH BASIN	No. 40	3.5″ x 4′ 2″
D-CBB-12A	5/27/2001	TYPE "B" CAST IRON FRAME, GRATE & NONMOUNTABLE INLET DETAILS FOR NOS. 10, 12, 14, 16, AND 17 TYPE CATCH BASINS		1.5″ x 19″
D-CBB-12B	5/27/2001	TYPE "B" CAST IRON FRAME, GRATE & 6" MOUNTABLE INLET DETAILS FOR NOS. 25, 26 AND 27 TYPE CATCH BASINS		1.5″ x 19″
D-CBB-12C	5/27/2001	TYPE "B" CAST IRON FRAME, GRATE & 4" MOUNTABLE INLET DETAILS FOR NOS. 28 AND 29 TYPE CATCH BASINS		1.5″ x 19″
D-CBB-13	5/27/2001	TYPE "B" CAST IRON FRAME, GRATE & NONM0UNTABLE INLET DETAILS FOR NO. 13 TYPE CATCH BASINS		1.5″ x 19″
D-CBB-31	5/27/2001	TYPE "B" CAST IRON FRAME, GRATE & INLET DETAILS FOR NOS. 31,41, 45, 46, & 51 TYPE CATCH BASINS		1.5″ x 19″
D-CBB-42	5/27/2001	CAST IRON GRATE DETAILS FOR NOS. 42, 43 & 44 TYPE CATCH BASINS		3.25″ x 3.25″
D-SLD-1 ; D-SLD-2 ; D-SLD-3	5/27/2001	SLOTTED DRAINS		1.75″ x 20′
D-TD-1		TRENCH DRAIN		1″ x 5.5″

Following are select findings from the stormwater outfall mapping project related to drop inlets:

- Bridges often contained multiple round openings with no grate, such as that shown in Photo 1. Most bridge drop openings (90% of those recorded) ranged from 2-4" in diameter. Occasional bridge drops measured six inches in diameter (261 total). Photo 1 displays a typical 4" diameter bridge drop located on State Route (SR) 170 above the Clinch River in Anderson County, Tennessee.

.

Photo 1.

- Drop inlets along the bottom of concrete barriers often do not employ a grate. For example, the drop inlet shown in Photo 2 is located on the side of a four lane highway (SR-116 north of Fraterville in Lake County, Tennessee); thirteen openings measure 5" x 28" each and drain directly to the terrain below.

Photo 2.

- A 30” x 60”catch basin along Interstate 75 near Lake City, Tennessee, is shown in Photo 3. This is one example of the 27 drop inlets recorded with the notation “grate missing.”

Photo 3.

- Occasional odd instances of homemade inlets were encountered, such as those shown in Photos 4 and 5. Both photos were taken along a stretch of SR-34 in Johnson City, Tennessee.

Photo 4.

Photo 5.

Curb Inlets

Another potential area of concern is curb inlet openings. To date, 3,568 curbs have been included in stormwater outfall data. Of the curbs marked with measurements, back openings ranged from 1” to 9” in height; the longest curb opening was recorded as 72” wide.   Photos 6 and 7 show typical curb openings encountered during the outfall mapping project.

Photo 6.

 **Photo 7.**

Debris

Types of debris often observed along roadways and in storm sewer systems are summarized in Table 2 below. Stormwater best management practice (BMP) research conducted by SAIC during 2008 and 2009 involved trash collection at three storm water outfalls in the East Tennessee region. Two of these outfalls lie adjacent to an interstate interchange with high average daily traffic (ADT). The third outfall is a six-foot-diameter pipe which serves as the primary discharge for a storm sewer system along SR-62 in the city of Clinton, Tennessee. Leaves, grass clippings, and cigarette butts comprised the bulk of debris collected on a regular basis at these sites.

Table 2. Examples of Common Solid Debris.

Common Debris	Average Size	Will pass through which TDOT grates?
Aluminum can	height = 4.8” diameter = 2.5”	Unlikely to pass through unless damaged.
20 oz. plastic bottle	height = 8.5” diameter = 2.5”	Unlikely to pass through unless damaged.
Wood chips / mulch	varies; up to 2” x 3”	Potentially all.
Candy wrapper	varies; average 2” x 6”	Potentially all, especially when torn or crumpled.
Disposable cups	varies; up to 5” x 8”	Potentially all; especially when torn or crumpled.
Leaves	varies; up to 4” x 4”	Potentially all, especially when torn or

		crumpled.
Miscellaneous paper products	varies; up to 8.5 x 11”	Potentially all; especially when torn or crumpled.
Grass Clippings	<0.25” x 1-2”	Likely to pass through all grates.
Cigarette Butts	0.25” x 1” (dry)	Likely to pass through all grates.

What Others Have Done

In 2005-2006, the City of Los Angeles carried out a pilot study to investigate the effectiveness of catch basin opening screen covers in preventing trash from entering the storm sewer system. Twenty-four catch basin screens were installed within the Westlake area. These covers were constructed from hot dipped galvanized expanded metal with diamond shaped openings, approximately 1” in length. Covers spanned the entire length and height of curb openings, and were designed to open when sufficient flow mobilized floatable trash in the area and pushed the screen open.

Data collection and measurements were made after four separate storm events exceeding 0.25 inch. A previous study of 30 catch basins in 2004 had resulted in characterization of collected waste as 85% plastic material and paper greater than one inch. Therefore, during dry weather, it was assumed that 85% of material previously entering the catch basin was blocked by the newly installed screen. Further analysis of materials collected after rain events in the 2005-2006 study yielded an effective rate of trash removal (for all trash greater than one inch) of 86%.[1] The increase of 1% was primarily attributed to those times when storm water opened the screen and previously collected trash and debris were admitted to the system in lieu of causing stormwater to pond on the road.

“Full capture” of trash under the Los Angeles Regional Water Control Board (LA RWQCB) requires retaining all particles larger than 5 mm throughout events up to and including the peak flow resulting from a one-year, one-hour storm. Retrofitting existing stormdrains can be very expensive, so use of a variety of BMPs to control trash has been implemented in both the City and County of Los Angeles. These BMPs include:

- Catch basin opening covers (as described above)
- Catch basin inserts
- Hydrodynamic separators/vortex separators
- Screening, netting and basket devices at the end of pipes
- Litter booms
- Anti-littering enforcement
- Bans or fees on specific products that often become litter
- Taxes on businesses that are the source of litter
- Public clean-ups

[1] Technical Report: Assessment of Catch Basin Opening Screen Covers. June 2006. City of Los Angeles, Watershed Protection Division.

- Trash receptacles
- Street sweeping
- Open channel clean-ups
- Raising public awareness through methods such as catch basin stenciling[2]

Conclusions

Catch basins are not ideally designed to capture sediment, pollutants, and other debris. Sumps will collect some portion of suspended pollutants and non-floatable debris, but without regular maintenance, sumps eventually fill and no longer offer any significant treatment to incoming storm water. Performance of the sump with respect to sediment collection and non-floatable debris continues to lessen, even before the sump is full, each time additional sediment and/or debris is deposited. In addition, small floating debris and pollutants such as oil and grease freely enter grate openings and pass through into the storm sewer system.

A reduction in grate spacing might seem a reasonable option at first glance, especially for those grates with the larger openings, such as reflected in standard drawings D-CB-38x, -39x, and -40x. However, even if TDOT standards were revised, it would likely be years before a significant number of grates in the field reflected these new standards. As the stormwater outfall mapping data shows, standard drawings do not necessarily reflect what exists in the field. In addition, although some reductions of grate sizing might prove beneficial for capturing large debris, the majority of debris entering storm sewer systems is quite small.

In lieu of revising current standards for grates on catch basin inlets, curb inlets, and other storm sewer system inlets, it is recommended that TDOT continue to employ a wide range of BMPs to address storm water quality. Current technology offers some structural measures, such as inlet screens and hydrodynamic separators, capable of effectively capturing debris in storm water flow. In high density areas known or found to contribute large amounts of debris, increased maintenance efforts and public awareness campaigns can reduce the amount of trash and debris coming into contact with storm water runoff in the first place.

[2] Municipal Best Management Practices for Controlling Trash and Debris in Stormwater and Urban Runoff,

TDOT MS4 Permit Post-Construction Stormwater Management Evaluations

1.0 Permit Section 2.1.5.E Post Construction Storm Water Management
The TDOT MS4 Permit (No. TNS077585) requires TDOT to design and implement a research program where BMPs for post-construction stormwater management can be implemented on a semi-permanent basis for research evaluation. Specifically, the permit required TDOT to:

> *"Select four mature highway sites, with the approval of TDEC, where BMPs can be implemented on a semi-permanent basis for research evaluation. The purpose of this research is to measure storm water runoff quality at a storm drain outfall before and after BMP implementation and determine effectiveness… Prior to implementing the selected BMP, TDOT will conduct sampling at each site during a minimum of twelve months to determine background levels of pollutants*."

Selection of the four sites was based on:

(a) nature relative to typical highway design segments,
(b) average daily traffic (ADT), and
(c) the percentage of non-TDOT drainage contributing to the runoff.

The TDEC approved *TDOT Best Management Practice Study Plan* details sampling methods, parameters to be analyzed, and project objectives. A total of 297 storm water runoff samples were collected from all four approved sites between December 17, 2008 and May 31, 2011. Samples included grab samples acquired as soon as the flow and rainfall criteria were achieved; and flow-weighted composites taken over the duration of a storm event.

Samples were evaluated for the following parameters:

- total and dissolved metals (cadmium, copper, lead, zinc),
- chemical oxygen demand (COD),
- Nitrogen as total kjeldahl nitrogen (TKN), Nitrate/Nitrite, and ammonia (NH3),
- total phosphorus, and ortho-phosphate,
- total suspended solids (TSS),
- total dissolved solids (TDS),
- diesel range petroleum hydrocarbons (TN EPH),
- gasoline range petroleum hydrocarbons (TPH-GRO),
- chloride, and
- total and fecal coliform (including E. coli).

Because there are no promulgated regulatory standards (e.g., numeric criteria applicable to highway stormwater outfalls), and/or guidelines regarding the acceptable level of contaminants in stormwater runoff associated with TDOT highways and right-of–way activities applicable in Tennessee, or which set limits or standards on the quality of stormwater discharged from the TDOT ROW, stormwater screening levels (SWSLs) were developed for this project to provide criteria upon which to evaluate the observed analytical results. Regulations, and permit benchmark values applied to other regulated stormwater run-off sources were the primary source of standards used to determine the SWSLs.

TDOT Stormwater Screening Levels

Laboratory Analyses	Laboratory Detection Limit	Project Specific Stormwater Screening Levels	Source
Conventional			
Chloride	1 mg/l	1200 mg/l	TDOT MS4 Permit Facilities Monitoring Plan
TSS	1 mg/l	150 mg/l	TDOT MS4 Permit Facilities Monitoring Plan
TDS	1 mg/l	500 mg/l	U.S. EPA National Drinking Water Regulations
COD	1 mg/l	120 mg/l	TDOT MS4 Permit Facilities Monitoring Plan
TN EPH	0.10 mg/l	10.0 mg/l	No promulgated Federal or State Regulations found for water or stormwater. Based on criteria established for oil and grease in TDOT MS4 Permit Facilities Monitoring Plan
TPH	0.10 mg/l	1.0 mg/l	TDEC Division of Underground Storage Tanks, Technical Guidance Document -011
pH	N/A	5.0-9.0	Tennessee Storm Water Multi-Sector General Permit
Total Hardness	25 mg/l	60-120 mg/l	US Geological Survey National Stream Quality Data
Microbial			
Total Coliform	N/A	1000 CFU/100 ml	TDEC Total Maximum Daily Load risk assessment based on Tennessee General Water Quality Criteria
Fecal Coliform	N/A	1000 CFU/100 ml	TDEC Total Maximum Daily Load risk assessment based on Tennessee General Water Quality Criteria
E. Coli	N/A	941 CFU/100 ml	TDEC Total Maximum Daily Load risk assessment based on Tennessee General Water Quality Criteria
Nutrients			
TKN	0.3 mg/l	0.68 mg/l	Tennessee Storm Water Multi-Sector General Permit
NH3	0.3 mg/l	4.0 mg/l	Tennessee Storm Water Multi-Sector General Permit
Total	0.05 mg/l	2.0 mg/L	Tennessee Storm Water Multi-Sector General Permit
Ortho-	0.05 mg/l	2.0 mg/l	Tennessee Storm Water Multi-Sector General Permit
Nitrate +	0.1 mg/l	0.68 mg/l	Tennessee Storm Water Multi-Sector General Permit
Total Metals			
Cd (cadmium)	0.0002 mg/l	0.0021 mg/l	Tennessee Storm Water Multi-Sector General Permit
Pb (lead)	0.001 mg/l	0.156 mg/l	Tennessee Storm Water Multi-Sector General Permit
Cu (copper)	0.001 mg/l	0.018 mg/l	Tennessee Storm Water Multi-Sector General Permit
Zn (zinc)	0.001 mg/l	0.395 mg/l	Tennessee Storm Water Multi-Sector General Permit
Dissolved Metals			
Cd (cadmium)	0.0002 mg/l	0.0020 mg/l	Converted from Tennessee Storm Water Multi-Sector General Permit Benchmark for Total Metals
Pb (lead)	0.001 mg/l	0.123 mg/l	Converted from Tennessee Storm Water Multi-Sector General Permit Benchmark for Total Metals
Cu (copper)	0.001 mg/l	0.017 mg/l	Converted from Tennessee Storm Water Multi-Sector General Permit Benchmark for Total Metals
Zn (zinc)	0.001 mg/l	0.386 mg/l	Converted from Tennessee Storm Water Multi-Sector General Permit Benchmark for Total Metals

Of the 22 priority pollutants, analytical results from only four parameters exceeded their SWSLs in at least 10% of the samples evaluated:

- total kjeldahl nitrogen (exceeded SWSL in 77% of samples),
- Nitrate/Nitrite (45% exceeded SWSL),

- total coliform (98% exceeded SWSL) and
- fecal coliform (60% exceeded SWSL).
- COD exceeded its SWSL in slightly less than 10% of the samples evaluated for that parameter
- TSS exceeded its SWSL in slightly more than 5% of the samples evaluated for that parameter
- TDS exceeded its SWSL in slightly more than 7% of the samples evaluated for that parameter
- total copper exceeded its SWSL in slightly less than 7% of the samples evaluated for that parameter

All other parameters exceeded their respective SWSLs in less than 1% of the samples evaluated for that parameter. Only nutrients and pathogens appeared to be present in the TDOT stormwater runoff at significant concentrations.

2.0 Follow-up Evaluations

Based on the original sampling results, TDOT pursued three follow-up evaluations to better understand the source and basis of the observed stormwater run-off characterizations. These evaluations included:

- BMP implementation as required by permit section 2.1.5.E. BMPs evaluated included open-grade friction course paving and vegetated swales.
- Focused evaluation on the source and nature of the observed nutrient contamination.
- Focused evaluation on the source and nature of the observed pathogen contamination.

2.1. BMP Implementation

Permit Section 2.1.5.E continues:

> "Prior to implementing the selected BMP, TDOT shall conduct sampling at each site during a minimum of twelve months to determine background levels of pollutants. Based on the findings, TDOT shall implement the selected BMP at the site."

Because the results of the stormwater sampling showed contaminants that were not easily managed by conventional BMPs, TDOT decided to evaluate two stormwater management methods already in use by TDOT for their effectiveness in managing the observed contamination, open-grade friction course paving and vegetated swales.

2.1.1 Open-Grade Friction Course Paving

Open-Grade Friction Course (OGFC) is an open-graded Hot Mix Asphalt (HMA) mixture with interconnecting voids that provides improved surface drainage during rainfall. The rainwater drains vertically through the OGFC to an impermeable underlying layer and then laterally to the daylighted edge of the OGFC. OGFC has a narrowly-graded coarse aggregate and a high asphalt content that includes a larger percentage of air voids than typical asphalt paving. With the safety of Tennessee motorists as a priority, OGFC has been gaining interest with TDOT pavement engineers. The back spray from vehicles in fast-moving traffic is drastically reduced by using this strong, stable, porous mix that allows water to travel through the pavement to the edge of the road and down the side instead of collecting on top of it. OGFC mixtures have long been noted for reduction in back spray, prevention of hydroplaning, improved wet-weather visibility of traffic stripes, and reduced headlight glare. These mixes are also gaining wide appeal due to noise reduction characteristics. Studies have also indicated the use of OGFC may also have environmental benefits in that the concentration of some contaminants in the stormwater runoff from the roadway may be significantly reduced. Since 2005, TDOT has been placing OGFC pavements on interstates and other select routes as a measure to reduce wet-weather crashes. This special type of asphalt mixture is designed to be porous and allow for rainwater to drain towards the shoulder underneath the riding surface as opposed to the typical "dense-graded" asphalts that require water to drain on top. In June 2015, TDOT re-paved the entire length of I-275 in Knoxville, Tennessee, with OGFC. The TDOT ECO saw this as a unique opportunity to evaluate the stormwater contaminant reduction by characterizing the highway runoff at multiple locations both immediately before and after the application of OGFC. Previous studies by other state DOTs have typically only been able to characterize the stormwater runoff after the application of OGFC and then compare the contaminant concentration levels to those from other locations and/or to generic values of highway stormwater runoff.

In this evaluation, four sampling locations were identified along I-275 in Knoxville and stormwater samples were taken from these same four locations while the highway was paved with standard non-porous asphalt as well as after the application of OGFC. Stormwater sampling locations for this project were about 1.5 to 4 miles south of the Merchants Drive and I-75 interchange site used for other ongoing TDOT-sponsored highway run-off monitoring investigations. The evaluation was conducted in three phases: Phase 1 was the baseline case prior to the re-paving with OGFC. This phase began on March 27, 2015 and was completed on June 9, 2015, immediately before the OGFC re-paving work began. A total of 31 samples were acquired from 9 rainfall events during Phase 1. Phase 2 began on July 24, 2015, immediately after the completion of re-paving with OGFC, and was completed on July 29, 2016 to provide a full 12 months of sampling results with the intent to observe any seasonal variations that might occur in the sampling results. A total of 63 samples were acquired from 21 rainfall events. Phase 3 (see Table 4) includes long-term monitoring to determine if the impact of the OGFC on stormwater quality may change as the paving material matures. This phase began on August 18, 2017, and continued through February 21, 2019. A total of 40 samples were acquired from 13 rainfall events. Each full sample was analyzed for concentrations of Escherichia coli (E. Coli); Total Dissolved Solids (TDS); Total Suspended Solids (TSS); Volatile Suspended Solids (VSS); Nitrogen [Ammonia, Nitrate-Nitrite, and Total Kjeldahl Nitrogen (TKN)]; Total Phosphorus; Orthophosphate; Total Metals [Cadmium, Copper, Lead, and Zinc], Dissolved Metals [Cadmium, Copper, Lead, and Zinc]; and Extractable Petroleum Hydrocarbons (EPH).

Results from the sampling showed significant reductions in most of the measured parameters. Both the Phase 2 and Phase 3 results showed significant reduction in TSS levels after the installation of the OGFC pavement. Reductions in both phases consistently exceeded 90 percent over the entire sampling period. TSS levels during Phase 3 were found to be less than those in Phase 2, indicating that that the OGFC effect on TSS levels did not lesson over time. The significant reduction in the TSS of over 90% is by far the most significant observation produced by this investigation, as TSS is postulated to be the driving mechanism for the transport of most of the other contaminants observed in stormwater runoff. The reduction seen in the metals and nutrients are most likely just a result of their dependence on suspended sediments for mobility from the highway surface to the stormwater discharge.

Conversely, the average E.coli values for all Phase 2 samples was 3,675 CFU/100 ml, which is a 76.4% increase over the Phase 1 (i.e., pre-paving) results. While comparison of results within each location showed a significant increase at all sampling sites from Phase 1 to Phase 2, but levels decreased at three sampling sites during Phase 3. Summary of the results are presented in the table below.

OGFC Study Results Summary

Parameter	**Phase 1 Average**	**Phase 2 Average**	**Phase 3 Average**	**Percent Change From Phase 1 to Phase 2**	**Percent Change From Phase 1 to Phase 3**	**Percent Change From Phase 2 to Phase 3**
E.coli (MPN/100 ml)	2,084	3,675	3, 970	+76.4	+90.5	+8.0
TSS (mg/l)	478	38	14	-92.1	-97.0	-61.7
TDS (mg/l)	328	1,078	262	+229	-20.0	-75.7
Ammonia (mg/l)	0.213	0.183	0.183	-14.1	-14.0	+0.13
Nitrate-Nitrite (mg/l)	0.639	0.323	0.355	-49.5	-44.5	+9.9
Total Phosphorous (mg/l)	0.539	0.149	0.067	-72.3	-87.6	-55.3
Orthophosphate (mg/l)	0.255	0.031	0.042	-87.8	-83.7	+34.4
TKN (mg/l)	2.281	1.395	0.847	-38.8	-62.9	-39.3
Total Copper (mg/l)	0.1189	0.0242	0.0147	-79.6	-87.7	-39.3
Dissolved Copper (mg/l)	0.0269	0.0131	0.0127	-51.3	-52.7	-2.98
Total Lead (mg/l)	0.0521	0.0078	0.0013	-85.1	-97.4	-82.8
Total Zinc (mg/l)	0.6373	0.1315	0.1540	-79.4	-75.8	17.1
EPH (mg/l)	3.52	3.35	2.26	-4.95	-35.8	-32.4

Based on this initial evaluation, OGFC appears to have significant potential to reduce the key contaminant levels observed in highway stormwater run-off.

2.1.2 Vegetated Swale Evaluation

Vegetated swales are commonly used by TDOT to convey runoff from the roadway to an acceptable outlet point in a simple and aesthetically pleasing way. The nature and fate of runoff from TDOT ROW is somewhat different from that of typical urban stormwater runoff from municipalities. Within municipalities, runoff mostly originates from surfaces that drain directly into piped storm drains and is discharged to a surface waterbody. On the other hand, highway runoff frequently discharges to vegetated areas that can potentially infiltrate all or a portion of the stormwater and potentially function as infiltration basins. The swales can therefore result in runoff reduction and in lowering the peak flow during a storm event. However, existing TDOT swales have never been evaluated for infiltration and runoff reduction capacity. Current estimates are that over 55% of the TDOT roadways may discharge to vegetated swales and ditches (approximately 7700 highway miles) and thus the ROW could include as much as 19,000 acres of vegetated swales state-wide. However, this is a very rough estimate and one goal of the current swale evaluation efforts is to develop a more accurate and defensible version of these values based on existing GIS and Lidar mapping data.

The ability of vegetated swales to function as stormwater management structures likely depends on multiple factors, such as their design parameters (channel slope, channel length and width etc.) and contributing drainage area characteristics (roadway area, swale area, average daily traffic volume, number of lanes, etc.), however, quantitative data on the role of these various factors is limited Two sites were selected for the initial evaluations, one is a swale along I-40 west of Cookeville and the other is a swale on SR-111 north of Cookeville. The highway vegetated swale sections selected for this evaluation were isolated so that the potential rainfall and subsequent runoff from the adjacent highway could be clearly and accurately quantified. The discharge from that section of swale was monitored to determine what percentage of the total potential runoff (i.e. rainfall and run-on from the highway) is actually retained and infiltrated, evaporated and/or transpired. The SR-111 vegetated swale site had a mild cross-sectional slope of 5-10%, a total length of 650 feet, and an average width of 54 feet, yielding a total area of 1.9 acres. The I-40 site had a steep slope of 15-30%, a total length of 1,140 feet, and an average width of 90 feet, yielding a total area of 2.4 acres. The layout and elevations of the swale sites were evaluated both through conventional land surveying techniques and through a LiDAR drone survey. The discharge flow from the catchment areas were channeled without restriction or ponding through a 36-inch HDPE pipe and the flow through that pipe was monitored by a Teledyne ISCO TIENet 360 LaserFlow™ non-contact flow sensor.

Flow, soil and meteorological data were collected from 132 storm events at the SR 111 site over a 14 month period from 12/20/2018 through 2/24/202. Data was collected from 88 storm events at the I-40 site over the 11 month period from 5/22/2019 through 3/28/2020. Preliminary results found that the SR-111 experienced an overall runoff reduction of 49% over the entire 14 month period when considering the entire catchment area (i.e. total of impervious and pervious areas). However, the total flow volume infiltrated and evapotranspirated by the swale was over twice the run-off volume that could have been generated by the impervious area within the study catchment. The analysis of the\ I-40 site was more complex because it also received upstream run-on from a culvert which drained an area not included in the surveyed catchmnent area. An overall runoff reduction of 30% was observed over the study catchment area when considering the upstream inflow in the calculations and a runoff reduction of 56% was observed when the upstream flow was excluded from the calculations. For this site the total flow volume infiltrated and evapotranspirated by the swale was over six times the run-off volume that could have been generated by the impervious area within the study catchment. At both sites the effect of seasonal evapotranspiration appeared to be significant, with runoff reduction capacity increasing by 30% to 50% during the spring and summer months when vegetation was more prominent.

2.2 Focused Nutrient Evaluation

The original TDOT TOW stormwater sampling (Section 1.0, above) found that nutrients were one of the contaminant types that exceed the program's SWSLs and a supplement focused study of nutrient contamination was implemented to understand the nature and source of these results. The goal of this focused nutrient evaluation was to identify the sources of nitrogen concentrations in TDOT MS4 stormwater runoff, as well as to understand the land use and meteorological influences on the concentrations. In order to accomplish the goal, three objectives were developed:

(1) determine the contribution of atmospheric deposition to the loading of NO2¬-+NO3- in TDOT MS4 stormwater runoff;
(2) evaluate the potential of land use as a source or sink for nutrient loading into stormwater runoff from the TDOT ROW, and
(3) establish and implement stable isotope source-tracking techniques to identify sources of nitrogen in TDOT MS4 discharges.

Three locations representing peri-urban (Putnam County), rural (Sumner County) and urban (Knox County) land uses distributed throughout Tennessee were selected for the evaluation. Stormwater and wet atmospheric deposition samples, as well as meteorological data were collected and analyzed for 138 rainfall events over 25 months. A total of 933 stormwater samples were evaluated during this study, as well as 153 atmospheric deposition samples. The original (2008-2011) TDOT stormwater sampling program evaluated 297 samples. TTU also performed a dual stable isotopic analysis to determine the potential sources of nitrogen (specifically NO_3^- and NH_3) in stormwater runoff and atmospheric deposition samples. A total of 106 stable isotopic analyses were performed.

Results indicate that the primary contributor of nitrogen in stormwater runoff at the Putnam County site was NO3- and NH3 in rain/precipitation, whereas that of the Sumner County site it was NH3 in fertilizer and rain. Both the Knox County sites showed soil as a primary source of nitrogen in stormwater runoff, which may have resulted from the vegetated swale and the sediment accumulation occurring in the culvert where samples were taken. Overall, this study demonstrated that when TDOT ROW is largely pervious and well-maintained, devoid of land use influences outside of the ROW, dominant nitrogen source in stormwater runoff is atmospheric deposition or rain/precipitation. However, when the ROW and drainage area are influenced by surrounding land use or not maintained regularly, the nitrogen source shifts to soil.

Comparison of Current Pollutant Concentrations Results with the 2008-2011 TDOT Stormwater Characterization Study

	pH	**TSS (mg/L)**	**TDS (mg/L)**	**Chloride (mg/L)**	**SRP (mg P/L)**	**TP (mg P/L)**	**TN (mg N/L)**	**NH_3 (mg N/L)**	**NO_3^- (mg N/L)**	**NO_2^- (mg N/L)**	**TKN (mg N/L)**
Current Nutrient Study (All sites)											
Mean	7.85	86.7	183.5	61.3	0.037	0.18	0.86	0.14	0.29	0.013	0.56
Standard Deviation	0.55	122.86	725.86	385.49	0.08	0.20	0.77	0.22	0.38	0.043	0.58
Previous TDOT 2008-2011 Study (All sites)											
Mean	7.70	43.7	196.1	45.6	0.255	0.381	NA	0.251	0.744		1.58
Standard Deviation	0.77	73.9	207.2	108.7	0.322	0.458	NA	0.271	0.538		2.14
TDOT Stormwater Screening Levels	**5.0-9.0**	**150.0**	**500.0**	**1200.0**	**2.0**	**2.0**	**---**	**4.0**	**0.68**		**0.68**

Overall, TDOT ROW stormwater run-off nutrient values observed during this evaluation were significantly lower than the results observed in the original TDOT MS4 Permit mandated stormwater sampling, which was performed from 2008 to 2011. The current results would not have exceeded the SWSL developed to evaluate the significance of the original sampling data.

2.3. Focused Pathogen Evaluation

TDOT has also sponsored a focused evaluation of pathogens in its stormwater run-off performed by the University of Tennessee – Knoxville (UTK). The UTK team sampled stormwater discharges from the TDOT ROW and pathogen impaired stream segments upstream and downstream from the TDOT stormwater discharge points. These samples were evaluated using bacterial source tracking methods at the UTK laboratories for E. coli and other water quality parameters. Preliminary results from the UTK study came to the following conclusion:

> *"The separation of roadway runoff samples from stream samples indicates that the microbial community composition in the stormwater runoff was significantly different from that of the stream water, suggesting that the receiving stream was not impacted significantly by the stormwater runoff from the roadways. These results are in support of previous observations that the roadway stormwater runoff was not a primary contributor of pollutant loading to the stream."*

The detection of microbial indicators such as *E. coli* is typically assumed to be indicative of recent fecal contamination and the potential presence of bacterial pathogens. However, the original TDOT stormwater sampling found evidence suggesting the presence of naturally occurring microbial indicators in its stormwater discharges. Th findings from these additional evaluations further suggest that the presence of indicator organisms in the original TDOT stormwater sampling could not necessarily be attributed to fecal contamination with public health implications.

3.0 Conclusions and Recommendations for Further Investigation

3.1 Open-Grade Friction Course Paving Findings

The results of the OGFC investigation fulfilled the requirement of Section 2.1.5.E of the TDOT MS4 Permit to demonstrate the effectiveness of a specific BMP in mitigating the impact of contaminants of concern from TDOT highway stormwater runoff. Overall, the OGFC pavement has shown encouraging indications that it can be a very valuable tool for TDOT in meeting future stormwater permit requirements. Achieving TSS reductions of over 80% will qualify it as a BMP that would meet the runoff reduction requirements now being imposed on Tennessee municipalities under their MS4 permits. Other state DOTs (e.g. Texas DOT) have produced similar data in their evaluations of the environmental benefits of OGFC. However, before OGFC can be accepted as a BMP meeting the runoff reduction requirements, additional data will likely be required at other Tennessee sites to demonstrate that the results described above can be consistently replicated in highway runoff situations. The implications of the observed pathogen results must also be further delineated. As TDOT continues to repave Tennessee highways with OGFC, similar investigations should be performed to verify the results of the I-275 study.

3.2 Vegetated Swales Investigation Findings

The most significant observation from the swale investigation for TDOT at the SR-111 site was that the total flow volume infiltrated and evapotranspirated by the swale was over twice the run-off volume that could have been generated by the impervious area within the study catchment. Similarly, at the I-40 site the total flow volume infiltrated and evapotranspirated by the swale was over six times the run-off volume that could have been generated by the impervious area within the study catchment. This result indicates that TDOT highways discharging stormwater to vegetated swales would be in compliance with the current TDEC MS4 Permit runoff reduction requirements being imposed on municipalities. Current rough estimates are that 75% of non-urbanized area highway miles (7,240 miles) discharge stormwater to vegetated swales and10% of urbanized area highway miles (450 miles) discharge stormwater to vegetated swales. The total highway miles that discharge stormwater to vegetated swales would then be approximately 7,700 miles. Assumeing that, on average, each highway mile discharges to a 10 ft. wide vegetated swale on each side of the roadway (not including medians). Thus TDOT has approximately 811,852,800 sq.ft. (18,638 acres) of vegetated swales in place.

At both sites the effect of seasonal evapotranspiration appeared to be significant, with runoff reduction capacity increasing by 30% to 50% during the spring and summer months when vegetation was more prominent.

To build on the success of the swale project and further demonstrate that TDOT is likely already in compliance with the runoff reduction requirements currently being imposed on Tennessee municipalities several follow-up investigations are recommended.

1. Continuing monitoring the two existing sites with some actions to see if we can improve the infiltration and evapotranspiration capability of the swales through some simple actions such as mechanically aerating the soil, adding soil amendments to increase permeability (Maryland DOT is doing this), reduce mowing frequency, and introducing new ground cover plants that would increase evapotranspiration.

2. Identify 2 or 3 new swale locations and move the existing equipment there. Monitor the sites for at least 12 months as we did with the last iteration. Again, this would be a relatively low cost option since there would be no need to purchase any new equipment, just relocating the existing systems. However, LiDAR drone surveys of the new sites would have to be performed.

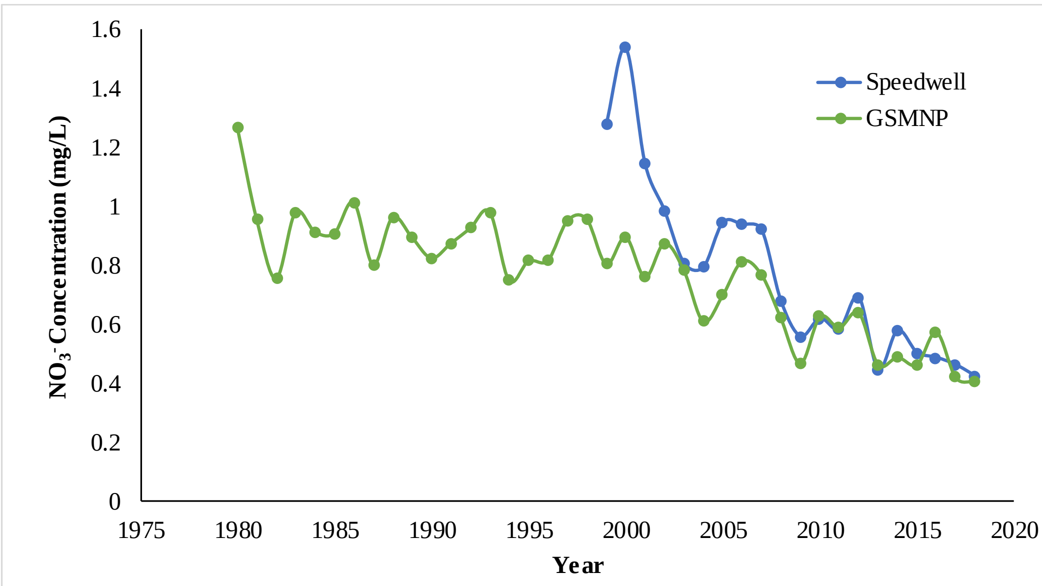
3. Set up the high resolution flow monitoring equipment at the existing I-75 site in Knoxville and the SR-136 interchange in Cookeville to evaluate the runoff reduction created by the large vegetated areas at these interchanges. The cost of this project would

be dependent on whether it is possible to adapt the existing equipment to these sites or new LaserFlow sensors and supporting equipment had to be purchased.

4. Apply the existing GV-SWTH model to additional Tennessee counties to develop a more defensible estimate for the area of vegetated swales in the TDOT ROW. Counties would be selected to be representative of the entire state (i.e. in East, Middle and West Tennessee) and represent urban versus rural distribution of highways.

3.3 Focused Nutrient Evaluation Findings

Overall, TDOT ROW stormwater run-off nutrient values observed during this evaluation were significantly lower than the results observed in the original TDOT MS4 Permit mandated stormwater sampling. This decline in nutrient levels is consistent with the values observed in atmospheric deposition over the last ten years.



NO_3^- concentration each year at Tennessee Sites from the National Atmospheric Deposition Program

Since atmospheric deposition is a principal source for nutrients in TDOT ROW stormwater discharges, the decline in the TDOT stormwater results would be expected. Based on the lower nutrient levels in the stormwater results and the large size of the recent database, there appears to be no need for additional investigations into nutrient contamination in TDOT highway runoff. At some point, these results will need to be translated into actual stream loadings for verification of TMDL compliance, but those calculations will require a better understanding of the number and typical flow volumes from TDOT stormwater management systems and outfalls to waters of the state.

3.4 Focused Pathogen Evaluation Findings

TDOT has sponsored research by the University of Tennessee – Knoxville (UTK) to sample stormwater discharges from the TDOT TSCS (MS4) and pathogen impaired stream segments upstream and downstream from the TDOT stormwater discharge points. These samples were evaluated using bacterial source tracking methods at the UTK laboratories for E. coli and other water quality parameters. Preliminary results from the UTK study came to the following conclusion:

> *"The separation of roadway runoff samples from stream samples indicates that the microbial community composition in the stormwater runoff was significantly different from that of the **stream water,** suggesting that the receiving stream was not impacted significantly by the stormwater runoff*

from the roadways. These results are in support of previous observations that the roadway stormwater runoff was not a primary contributor of pollutant loading to the stream."

UTK has continued to investigate the use of indicator organisms (such as E.coli) to evaluate the presence of human fecal pollution in stormwater runoff. Organisms previously assumed to be specifically associated with fecal materials have been found to survive and grow in non-fecal environments. Therefore, it is problematic to use the detection of indicator organisms as a tool to evaluate fecal contamination of stormwater runoff. To overcome this problem, the composition of all bacterial constituents in stormwater samples (i.e. community fingerprints) were used as a collective marker. The community fingerprints of stormwater samplers were compared with those representative of human fecal materials (i.e. sewage) to determine the potential contribution of human fecal sources to the microbial loading in runoff from the TDOT right-of-way (ROW). Preliminary findings from the use of the microbial fingerprinting techniques at existing TDOT ROW runoff sampling sites and receiving streams suggest that the presence of indicator organisms in TDOT MS4 stormwater could not necessarily be attributes to fecal contamination with public health implication. These studies have strongly indicated that the presence of pathogens in TDOT stormwater runoff is not a significant contributor to surface water contamination and thus there appears to be no need for additional investigations into pathogen contamination in TDOT highway runoff. At some point, these results will need to be translated into actual stream loadings for verification of TMDL compliance, but those calculations will require a better understanding of the number and typical flow volumes from TDOT stormwater management systems and outfalls to waters of the state.

MENU OF POST-CONSTRUCTION
STORM WATER CONTROL
BEST MANAGEMENT PRACTICES

MAY 2009

Tennessee Department of Transportation

Environmental Compliance Office

Prepared by

Scientific Applications International Corporation

Oak Ridge, Tennessee

Table of Contents

TABLES

ACRONYMS

BMP	Best Management Practice
DDDM	Design Division Drainage Manual
DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
ODOT	Ohio Department of Transportation
PCBMP	Post-Construction Best Management Practice
SAIC	Scientific Applications International Corporation
SSWMP	Statewide Storm Water Management Plan
TDEC	Tennessee Department of Environment and Conservation
TDOT	Tennessee Department of Transportation

1.0 INTRODUCTION

This document provides a menu of post-construction best management practices (PCBMPs) to be used by the Tennessee Department of Transportation (TDOT) and its contractors in compliance with Section 2.1.5.A of the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Permit No. TNS077585, issued April 28, 2006 by the Tennessee Department of Environment and Conservation (TDEC). Section 2.1.5 requires TDOT to:

> "Develop, implement and enforce a program to reduce pollutants in storm water from the post-construction facilities including roadways, right-of–ways and appurtenants subject to storm water runoff."

Subsection A, for which this document was developed, requires that in the third year of coverage under the current MS4 permit referenced above, TDOT is to develop:

- a menu of structural post-construction storm water BMPs that can be applied to new highways or upgrades of existing highways; and
- a menu of nonstructural post-construction storm water BMPs that can be applied to new highways or upgrades of existing highways.

This document presents the requested menu of post-construction best management practices, both structural and non-structural) and discussion of each selected measure, including additional sources of in-depth information for the use of individuals responsible for design, implementation, and maintenance of these measures.

2.0 BACKGROUND

2.1 Post Construction Runoff Control

MS4 operators such as TDOT are required to meet the Post Construction Runoff Control minimum control measure [40 CFR 122.34(b)(5)] in areas of new development or redevelopment. There are two primary impacts from post-construction runoff: (1) increased storm water volume, and (2) an increase in both the types and amounts of pollutants in storm water runoff. Increased storm water volume most often results from an increase in impervious area, but can also be caused by altered drainage patterns. Increased pollution is a common result of development; developed areas often contain such pollutants as oil and grease, heavy metals, pesticides, nutrients such as nitrogen and phosphorus, and immobilized sediment.

2.2 Previous Research, Pilot Studies, and Current Standards

TDOT has developed and implemented a Statewide Storm Water Management Plan (SSWMP), which includes measures used to minimize storm water impacts during the construction process in compliance with the NPDES construction permit. The U.S. Environmental Protection Agency (EPA) recommends development of construction and post-construction storm water plans be done in tandem, due to the similar nature of construction and post-construction best management practices (BMPs) and overall storm water related goals. Therefore, during the development of this menu of PCBMPs, all existing TDOT methods, whether designed for temporary or permanent use either during or after construction, were kept in mind and are appropriately referenced throughout this document.

2.2.1 Post-Construction Storm Water Research

In 2007, TDOT solicited research on what other state departments of transportation (DOTs) have done to address post-construction storm water. A review of ten DOTs (Arkansas, California, Florida, Georgia, Indiana, Kentucky, North Carolina, Ohio, South Carolina, and Virginia) followed the requirements outlined in Section 2.1.5.F of the current MS4 permit:

> "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."

Information obtained in these research efforts was summarized in a report titled *Post-Construction Storm Water Best Management Practices Research Report* (TriAD, 2007). This report included more than twenty structural and six nonstructural PCBMPs adopted for standard use by the subject DOTs. In lieu of recommending individual measures for adoption by TDOT, the TriAD report offered standard sets of structural PCBMPs for eight scenarios. These eight scenarios and possible structural PCBMPs are summarized in Table 1. These BMPs include: catch basin with a manufactured system, in-line storage, grassed swale, pond, bioswale, constructed wetland, infiltration trench, gross solid removal device (GSRD), dry weather flow diversion, level spreader, energy protection area, porous pavement, vegetated filter strip, oil/water separator, and bioretention cell. Each of the measures proposed by TriAD in 2007 has been included within the TDOT Post-Construction Menu of Storm Water Control BMPs except two.

In-line storage systems use storage located within a storm drain system to detain peak flow during heavy rain events; however, they offer no water quality treatment and only limited protection of downstream channels. For these reasons, the EPA does not recommend the use of in-line storage systems in many circumstances. Due to the large number of available PCBMPs, in-line storage has not been included in the final TDOT Menu of PCBMPs.

Dry weather flow diversions, the use of which is well documented in California, act to divert urban runoff (non-stormwater runoff from activities such as irrigation or car washing) to sanitary sewer systems and/or sewer treatment plants during periods of dry weather. However, during rain events, stormwater is directed through its "original" flow path in the storm sewer system. Therefore, PCBMPs aimed at stormwater control would be required to the same extent whether a dry weather flow diversion was in place or not. The only clear benefit of a dry weather flow diversion would be to pass off responsibility for minimal non-stormwater runoff between rain events to another entity. It is unlikely that the municipalities TDOT interacts with would be interested in this scenario.

2.2.2 Manufactured Systems Pilot Study

In 2002, TDOT initiated a pilot study of manufactured systems at TDOT facilities. Three units - an Advanced Drainage Systems (ADS) Water Quality Unit, Royal Environmental Eco Sep Oil and Water Separator, and BaySaver Separation System - were installed at the Nashville facility; a Continuous Deflective Separation (CDS) system had been installed in 2001 as part of a facility addition. The Knoxville facility received a Crystalstream (PBM) Oil/Grit Separator and Aquaswirl Concentrator, and a Baysaver Separation System was installed at the Smith County I-40 East Rest Area.

Table 1. 2007 "Standard Scenario" Recommendations.

Scenario	Recommended BMPs
Interstate with multiple lanes and center concrete divider	• Catch basin with a manufactured system • In-line storage[1] • Grassed swale • Retention Pond
Divided highway with grass medians	• Bioswale • Constructed wetland • Retention Pond • Infiltration trench
Multiple lane road with curb drains	• Catch basin with a manufactured system • Gross solid removal device (GSRD) • Dry weather flow diversion[1]
Multiple lane road, drains to shoulders	• Bioswale • Constructed wetland • Retention Pond • Level spreader
Narrow two-lane road, steep slopes on both sides	• Energy Protection Area[2] • Bioswale • Retention Pond
Narrow two-lane road, flat vegetated surroundings	• Grassed Swale • Wetland • Energy Protection Area[2] • Retention Pond
TDOT facility with large drainage area	• Wetland • Porous Pavement • Vegetated Filter Strip • Oil/Water Separator
TDOT facility with small drainage area	• Wetland • Porous Pavement • Bioretention Cell • Oil/Water Separator

1. This BMP has not been included in the TDOT Menu of PCBMPs.
2. Discussed as part of Better Site Design in Section 3.2.1.A.

By the end of 2007, three additional treatment units had been installed. The Knoxville facility and Nashville Floating Maintenance each acquired a Baysaver Separation System, and an Aquaswirl Concentrator was installed at the Smith County I-40 West Rest Area. A summary of the units installed to date at TDOT Facilities is shown in Table 2. Additional information on these manufactured systems, including installation specifics, performance, and lessons learned during the pilot study, is included in Appendix A.

Table 2. BMPs Installed at TDOT Facilities.

Location	Product	Installation Date	Description	Treated Flow Capacity	Floatables Storage Capacity
Nashville outfall 0-2	ADS	Oct. 2002	89 ft. long, 60 in I.D HDPE pipe with weir near midpoint to trap sediment and baffle over outlet to capture floatables	18.5 cfs	4000 gal.
Nashville outfall 0-3	CDS (Australian through Sherman-Dixie)	July 2001	Consists of three circular precast concrete chambers stacked on top of each other. The upper chamber provides initial separation, the middle chamber includes filter baskets for solids separation and the lower chamber is a collection sump.	2.8 cfs	400 gal.
Nashville outfall 0-4	BaySaver	Sep. 2002	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device. (10K Unit)	21.8 cfs	1110 gal.
Nashville outfall 0-6	Ecosep	Aug. 2002	Three separate precast concrete manholes, first chamber is grit chamber for solids separation, other two are oil separators.	2.72 cfs	1200 gal.
Nashville Floating Maintenance	BaySaver	Jan 2004	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device. (5K Unit)	11.1 cfs	630 gal
Knoxville outfall SW0-3	PBM	July 2002	Precast concrete box using baffles to control flow and increase gravity separation. Trash basket on front end for debris and adjustable weir with "oil bucket" to skim off floating oil.	6.2 cfs	200 gal.
Knoxville outfall SWO-2	Aqua-Swirl	Sept. 2002	Single HDPE tank using vortex action and baffle to separate solids and floatables.	14 cfs	1000 gal
Knoxville SWO-1	BaySaver	March 2006	Custom designed unit consisting of two rectangular precast concrete chambers using a trapezoidal weir in the primary chamber as an oil separation device.	27 cfs	1650 gal.
I-40 Smith County Rest Area East	Baysaver	Sept. 2003	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device. (5K Unit)	11.1 cfs	630 gal
I-40 Smith County Rest Area West	Aqua-Swirl	June 2007	Single HDPE tank using vortex action and baffle to separate solids and floatables.	14 cfs	1000 gal

2.2.3 Current TDOT Standards

Chapter 10 of the TDOT Design Division Drainage Manual (DDDM) (May 2008) discusses TDOT's current approach toward controlling the effects of storm water on TDOT projects. The majority of the control measures discussed in Chapter 10 aim to minimize erosion and sedimentation through implementation of temporary structural measures during the construction process. Only a few permanent structures are identified within Chapter 10: riprap energy dissipaters, riprap apron outlet protection, level spreaders, and permanent detention/retention basins. A review of TDOT standard roadway drawings revealed one additional permanent structural measure already in use by TDOT and its contractors: a concrete flume. It can be argued that since dissipaters, apron outlet protection, and flumes all function with a primary goal of erosion prevention, they do not meet the criteria of a post-construction BMP with respect to storm water volume or quality. However, dissipators, apron outlet protection, and flumes have been included in this menu of PCBMPs as any change in water velocity caused by development may negatively impact water quality. In addition, any reduction in storm water velocity delays some quantity of water from its impact further downstream, thereby impacting the discharge rate of storm water from the project site. Dissipators, apron outlet protection, and flumes are further discussed in Section 3.2.1.A – Flow Control.

3.0 POST-CONSTRUCTION BEST MANAGEMENT PRACTICES

PCBMPs are intended to address either: (1) increased storm water volume; or (2) an increase in both the types and amounts of pollutants in storm water runoff; after construction activities have been concluded. Structural PCBMPs aim to reduce one or both of these issues on a site specific basis. Nonstructural PCBMPs focus on eliminating storm water pollution at the source and/or maintaining storm water volumes at pre-construction levels. Nonstructural PCBMPs are not necessarily site specific, and may involve intangible aspects such as raising awareness of storm water concerns, better planning and management of new construction, and maintenance of structural PCBMPs. Most projects will gain maximum benefits from a combination of both structural and nonstructural PCBMPs.

Fifteen structural measures and twelve non-structural practices have been selected for inclusion in the TDOT Menu of Post-Construction Storm Water Control BMPs, shown in Table 3. Three additional BMPS not well-suited for linear roadway projects have been included in a category labeled *Facility*.

Table 3. TDOT Menu of Post-Construction Stormwater Control Best Management Practices.

Classification	Group	Practice
Structural	Ponds	“Dry” Extended Detention Pond
		“Wet” Retention Pond
	Infiltration	Infiltration Basin
		Infiltration Trench
		Exfiltration Trench
	Filtration	Bioretention Cell
		Sand Filters
		Organic Filters
		Underground Sand Filters
	Vegetation	Constructed Wetlands
		Grassed Swales
		Grassed Filter Strips
	Manufactured Systems	Oil/Water Separators
		Gross Solid Removal Devices
		Catch Basin Inserts
Non-Structural	Better Site Design	
	Flow Control	Level Spreader
		Paved Flume
		Rock Outlet Protection
		Plunge Pools
	Buffer Zones	
	Treatment Trains	
	Alternative Materials	
	Vegetative Control	
	Maintenance	Roadway and Bridge Maintenance
		Street Sweeping
		BMP Inspection and Maintenance
Facility	Alternative Turnarounds	
	Green Parking	
	Green Roofs	

3.1 Structural PCBMPs

Structural PCBMPs aim to reduce: (1) the volume of storm water; and/or (2) the types and amounts of pollutants in the storm water; discharged from the post-construction site.

Effectiveness

The effectiveness of a structural PCBMP is influenced by a number of factors: (a) size, type, and design of the control measure; (b) number and types of pollutants present; (c) site geology, soil type, and topology; (d) watershed characteristics; (e) climate; and (f) rainfall duration, intensity, and the time between rain events.

Considerations

The majority of structural PCBMPs must be anticipated during the initial roadway design process. Often these measures will require additional right-of-way or easements not otherwise necessary for the construction project. On both existing and new roadways, permanent structures such as ponds, trenches, and grassed swales may prove challenging due to right-of-way limitations.

Mechanisms

Table 4 lists the various processes most commonly employed by structural PCBMPs to reduce selected pollutants in storm water. Key terms are defined below:

- During **sedimentation**, particles previously suspended in storm water settle out due to the force of gravity.

- **Filtration** occurs when storm water passes through a porous medium and particulates are trapped within void spaces.

- Both adsorption and absorption are types of **sorption**, a process in which one material is taken up and held by another.

- **Oxidation** refers to a chemical reaction in which atoms of an element lose one or more electrons.

- Conversion of a pollutant into a vapor or gas occurs during the process known as **volatilization**.

- **Precipitation** is a chemical reaction in which a pollutant in solution is converted to a solid state.

- Bacteria in soil and water form nitrates and nitrates from ammonia during **biological nitrification**.

- **Microbial decomposition** occurs when microorganisms feed on organic compounds, breaking them down into various chemical components.

- **Phytoremediation** uses green plants to remove pollutants from storm water and render them harmless to the environment, either by changing their chemical makeup or immobilization.

Table 4. Mechanisms Employed for Various Pollutants.

Pollutant	Effective Mechanisms
BOD (biological oxygen demand)	Sedimentation, Filtration, Microbial Decomposition
COD (chemical oxygen demand)	Sedimentation, Filtration, Oxidation, Microbial Decomposition
Hydrocarbons	Phytoremediation
Metals	Sedimentation, Filtration, Sorption, Precipitation
Nitrogen	Sedimentation, Filtration, Biological Nitrification, Phytoremediation
Pathogens	Sedimentation
Petroleum Hydrocarbons	Oxidation, Volatilization, Microbial Decomposition
Phosphorus	Sedimentation, Filtration, Sorption, Precipitation, Phytoremediation
Solids	Sedimentation, Filtration
Synthetic Organics	Sorption, Oxidation, Volatilization, Microbial Decomposition

Descriptions

Each of the selected structural BMPS is described within the following pages. Each description is accompanied by the following figure:

Volume	Quality

Boxes shaded in green indicate what concern(s) the selected BMP addresses. For example, a constructed wetland will treat both primary areas of concern: this BMP reduces the volume of storm water leaving the site during and immediately following a precipitation event by detaining a large volume of runoff. Storm water quality is improved through vegetative removal of sediment, heavy metals, toxic materials, oil and grease, and other pollutants.

Each description offers a brief summary of the measure, information regarding its applicability, and considerations specific to the measure. Specific sources of additional information for each measure are referenced for those interested in further details or design assistance. To avoid overwhelming the general reader, references within descriptions have been limited to the following:

- EPA *Fact Sheets* from the National Menu of Best Management Practices (Appendix B);
- Federal Highway Administration (FHWA) *Fact Sheets* for Stormwater Best Management Practices in an Ultra-Urban Setting (Appendix C);
- Ohio Department of Transportation (ODOT) guidance from *Location and Design, Volume 2 (Drainage Design);*
- Altanta Regional Commission guidance from *Georgia Stormwater Management Manual Volume 2: Technical Handbook;* and
- TDOT guidance from standard drawings and DDDM.

3.1.1 Ponds

Ponds (also referred to as basins) may serve multiple uses in addition to storm water control and treatment. Typically, a pond requires significant land area, which can pose a challenge for linear highway projects. Both detention and retention ponds are discussed in DDDM Section 10.08.3.4; however, no standard drawings exist since each pond must be designed to fit specific site hydrology. DDDM Chapter 8 offers detailed information on the planning and design of these permanent structures.

A. “Dry” Extended Detention Pond

Volume	Quality

Description: A “dry” or extended detention pond fills with storm water in response to a precipitation event. Between rain events, there is no permanent pool of water; typically water collected from a rain event fully discharges in 24-48 hours. Dry ponds may be used in drainage areas of up to 75 acres.

Application: The primary use for an extended detention pond is to reduce downstream water *quantity* impacts. When properly designed, dry ponds can provide downstream overbank channel protection and may offer area flood protection during severe storms. An extended detention pond requires a large area and may be impractical for many linear roadway projects.

Primary Mechanism: Sedimentation.

Considerations: Since water is only held for a short time before being released downstream, dry ponds offer little significant improvement to water quality. Any particles that do settle in the basin during the storm water detention period are likely to be re-mobilized during the first flush of the next rain event. Therefore, extended detention ponds are best implemented in conjunction with other PCBMPs.

For More Information:

- Appendix B: U.S EPA Fact Sheet: Dry Detention Ponds.
- Appendix C: FHWA Fact Sheet: Detention Ponds.
- Chapter 8, TDOT DDDM.
- Detention Basin, Section 1117.4, Location and Design Manual, Volume 2 (Drainage Design), ODOT.
- Dry Detention/Dry ED Basins, Section 3.4.1, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

B. "Wet" Retention Pond

Volume	Quality

Description: A "wet" or retention pond maintains a permanent pool of water even during dry weather. During storm events, remaining storage capacity fills with runoff. This temporary storage zone drains slowly over the following 24-48 hours, allowing sediment and other pollutant particles to settle through the permanent pool, therefore improving the quality of water released downstream. Establishment of a vegetative buffer around the permanent pool may offer additional treatment to storm water entering the retention basin.

Application: Wet ponds are not recommended for drainage areas smaller than 25 acres. Wet ponds can provide downstream overbank channel protection and may offer area flood protection during severe storms. A retention pond requires a large area and may be impractical for many linear roadway projects.

Primary Mechanism: Sedimentation.

Considerations: Water held in a retention pond may have a significantly higher temperature than water found downstream due to the effects of solar radiation during the holding period. Therefore, caution must be exercised when placing a retention pond upstream of high quality waters, such as trout streams, that may be negatively impacted by this temperature difference.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Wet Ponds.
- Chapter 8, TDOT DDDM.
- Retention Basin, Section 1117.5, Location and Design Manual, Volume 2 (Drainage Design), ODOT.
- Stormwater Ponds, Section 3.2.1, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

3.1.2 Infiltration

Infiltration PCBMPs take advantage of the natural chemical, biological, and physical processes that occur between soil and storm water to filter out pollutants. As discussed in Section 1.0, development typically involves an increase in the amount of impervious surfaces, reducing the quantity of storm water able to enter the ground water system within the project site. Infiltration BMPs provide a pathway for some of that storm water to enter into the groundwater system while simultaneously receiving water quality treatment.

A. Infiltration Basin

Volume	Quality

Description: An infiltration basin is a shallow depression that captures storm water runoff and discharges it into the ground. The captured storm water infiltrates the soil subsurface and receives water quality treatment via absorption, straining, and bacterial degredation as it infiltrates the soil subsurface and enters the groundwater system.

Application: Infiltration basins are normally fed by a significant impervious drainage area, such as that found at an interchange or along a stretch of highway that drains to a single location. These basins can be any shape, but typically cover an area roughly 2 to 4% of that of the upstream impervious area.

Primary Mechanisms: Filtration, sorption, microbial decomposition.

Considerations: The type of soil situated beneath the infiltration basin plays a key role in determining the effectiveness of water quality treatment. In areas of low-infiltration soil types, the required surface area of the basin may make this BMP impractical.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Infiltration Basin.
- Appendix C: FHWA Fact Sheet: Infiltration Basin.
- Infiltration Basin, Section 1117.7.2, Location and Design Manual, Volume 2 (Drainage Design), ODOT.

B. Infiltration Trench

Volume	Quality

Description: Infiltration trenches offer a bit more flexibility with regard to placement than infiltration basins, but operate on a similar principle. An excavated trench is lined and backfilled with stone to the original surface level. Storm water drains through the rock layers into surrounding and underlying soil. In areas of impermeable soils or those with a confining soil layer, a partial trench may utilize a pipe to discharge excess storm water to an outlet.

Application: Subsurface infiltration trenches may be used underneath pavement or grating. Surface trenches are normally combined with additional treatment options, such as grassed swales, and therefore require more surface area.

Primary Mechanisms: Filtration, sorption, microbial decomposition.

Considerations: Depth of bedrock and infiltration characteristics of native soil layers are primary considerations in the use of an infiltration trench. Small infiltration trenches may be used to treat first flush storm water, while larger units can also limit flooding during heavy storm events.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Infiltration Trench
- Appendix C: FHWA Fact Sheet: Infiltration Trench.
- Infiltration Trench, Section 1117.7.1, Location and Design Manual, Volume 2 (Drainage Design), ODOT.
- Infiltration Trenches, Section 3.2.5, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

C. ExFiltration Trench

Volume	Quality

Description: An exfiltration trench consists of a perferated pipe surrounded by a bed of filter materials, normally coarse aggregate. Storm water runoff enters the pipe either via a catch basin or through a horizontal slot at the top of the pipe. Storm water filters out from the pipe into the surrounding bed materials and then downward into the groundwater system.

Application: Exfiltration trenches may be employed along the shoulder of roads as stand-alone units or connected to other catch basins to form a complete drainage network. As with other filtration/infiltration methods, pretreatment BMPs are recommended upstream to prevent the filter material from clogging with accumulated sediment.

Primary Mechanisms: Sedimentation, filtration, infiltration.

Considerations: Groundwater contamination may occur with any infiltration method; therefore, exfiltration trenches should not be placed near any areas of high pollutant concern, such as gas stations. Areas with a high water table may require addition of filter fabric or other barrier methods to prevent native soil fines from entering the filter bed during reverse flow conditions.

For More Information:

- Exfiltration Trench, Section 1117.1, Location and Design Manual, Volume 2 (Drainage Design), ODOT.

3.1.3 Filtration

Filtration measures act primarily by straining out fine particulates suspended in storm water runoff. Often these measures are located downstream from at least one other BMP which removes large grain materials so that the filtration measure does not become clogged and ineffective. Filtration measures are available in a range of designs to address small and medium drainage areas. A filtration practice typically takes up two to three percent of the drainage area being served and therefore is well suited for use along roadways or other confined spaces.

A. Bioretention Cell

Volume	Quality

Description: Bioretention cells (also referred to as rain gardens) are shallow depressions planted with vegetation overlying various layers of filtration materials. Storm water is treated through natural vegetative processes and until discharged into the groundwater system or into the atmosphere through evapotranspiration.

Application: This measure is ideal for storm water runoff from large impervious areas and is often employed in parking lot islands and medians. Bioretention cells should not be located in areas with a high water table or unstable soil layers.

Primary Mechanisms: Sedimentation, filtration, sorption, microbial decomposition, phytoremediation.

Considerations: Areas surrounding the bioretention cell should be properly graded to promote sheet flow into the vegetated area and avoid erosive conditions that may result in heavy sediment loading.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Bioretention (Rain Gardens
- Appendix C: FHWA Fact Sheet: Bioretention.
- Bioretention Areas, Section 3.2.3, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).
- Bioretention Cell, Section 1117.6, Location and Design Manual, Volume 2 (Drainage Design), ODOT.

B. Sand Filters

Volume	Quality

Description: Variations on surface sand filters range from those that simply collect storm water in a shallow basin lined with sand or other filter materials, to the Austin version, which employs a bypass chamber, sedimentation chamber, flow distribution cell, and sand filter bed. In all variations, the primary mechanism is the filtration of storm water through a layer of sand.

Application: Sand filters may be used in watersheds up to 100 acres, although additional BMPs are recommended with use in large drainage areas. Care must be taken to direct storm water into the filter area without encouraging erosive flow, which can clog the filter material. Because sand filters do not discharge into groundwater, they can provide a good option for areas of karst topography.

Primary Mechanisms: Sedimentation, filtration.

Considerations: Some designs maintain a permanent pool, between rain events offering a breeding site for mosquitoes and other pests. Sand filters require significant head (four to eight feet) in order to induce the flow of storm water through filter material and should be located at least two feet above the water table.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Sand and Organic Filters.
- Appendix C: FHWA Fact Sheet: Surface Sand Filters.
- Sand Filter, Section 3.2.4, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

C. Organic Filters

Volume	Quality

Description: Organic filters employ organic materials such as peat and leaf compost to filter storm water. Designs are otherwise very similar to those of sand filters.

Application: Organic filters are normally used in high-density areas up to 10 acres with high levels of contaminants such as hydrocarbons, metals, and other organic chemicals.

Primary Mechanisms: Filtration, sorption, microbial decomposition.

Considerations: Organic media has a higher risk of becoming clogged than sand filters, so organic filters are often employed "off-line." Only a certain volume of storm water flow is diverted to the organic filter; excess volume must be treated by other methods if treatment of all volumes is deemed necessary.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Sand and Organic Filters.
- Appendix C: FHWA Fact Sheet: Organic Media Filters.
- Organic Filter, Section 3.2.3, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

D. Undergound Sand Filters

Volume	Quality

Description: Underground sand filters of the D.C. version are three-chambered measures. Storm water enters a settling basin where large particles filter out and then continues through a second chamber filled with sand or other filter material. The third chamber captures overflow and discharges the treated storm water. The Delaware version (also referred to as a perimeter sand filter) is well suited for use along the edge of roadways or parking lots.

Application: This measure is best suited for small watersheds (1 acre or less), although it may be used in drainage areas up to 5 acres. Because sand filters do not discharge into groundwater, they may provide a good option for areas of karst topography.

Primary Mechanisms: Sedimentation, filtration.

Considerations: Maintenance requirements of underground sand filters are higher than those of other PCBMPs. In addition, designs which maintain a permanent pool of water may provide breeding grounds for mosquitoes and other pests.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Sand and Organic Filters.
- Appendix C: FHWA Fact Sheet: Underground Sand Filters.
- Underground Sand Filter, Section 3.3.4, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

3.1.4 Vegetated Systems

Vegetated systems employ green plants to filter storm water pollutants through a variety of processes.

A. Constructed Wetlands

Volume	Quality

Description: Constructed wetlands are wet ponds which incorporate wetland vegetation such as cattails, rushes, and sedges. These wetlands normally have less biodiversity (both in plants and animals) than natural wetlands. Constructed wetlands treat storm water through biological and naturally occurring chemical processes of the ecological system.

Application: Like ponds, constructed wetlands require significant area of drainage and significant room for placement. Pocket wetlands normally require a minimum 5 acres of drainage; continuous baseflow and a drainage area of 25 acres or more is required for typical constructed wetlands.

Primary Mechanisms: Sedimention, filtration, sorption, oxidation, biological nitrification, microbial decomposition, phytoremediation.

Considerations: In karst topography, constructed wetlands should be lined with an impermeable material to preserve the permanent pool and prevent sinkhole formation.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Stormwater Wetland.
- Constructed Wetlands, Section 1117.8, Location and Design Manual, Volume 2 (Drainage Design), ODOT.
- Appendix C: FHWA Fact Sheet: Wetlands and Shallow Marsh Systems.
- Stormwater Wetlands, Section 3.2.2, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

B. Grassed Swales

Volume	Quality

Description: Grassed swales are open, vegetated channels that reduce storm water velocity and provide water quality treatment through filtration and/or infiltration. Dry swales incorporate a filter bed of soil and an underdrain system. Wet swales maintain marshy conditions and act as a shallow wetland treatment system.

Application: Swales are well-suited for use along highways or other roads due to their linear design. Since dry swales do not retain water, they may be used upstream of temperature-sensitive streams.

Primary Mechanisms: Sedimentation, filtration, infiltration, phytoremediation.

Considerations: Swales should not be employed in slopes greater than 4% and must be able to convey flow from design storms without incurring erosion. Pretreatment at the swale inlet should be included in any design to trap incoming sediments. Wet swales require either a high water table or poorly drained soils to retain a shallow pool of water.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Grassed Swales.
- Appendix C: FHWA Fact Sheet: Dry and Wet Vegetated Swales.
- Enhanced Swales, Section 3.2.6, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

C. Filter Strips

Volume	Quality

Description: Filter strips are densely vegetated sections of land designed to treat sheet flow through vegetative filtration and soil infiltration.

Application: Filter strips are typically employed as pretreatment in conjunction with other BMPs. Longer flow lengths will yield greater results, so available space is an issue to consider. Along highways, filter strips may be used to treat stormwater runoff before it enters a stream or other body of water.

Primary Mechanisms: Filtration, infiltration, phytoremediation.

Considerations: Uniform grading must be maintained so that water does not concentrate and bypass the filtration mechanism. This BMP is recommended on slopes ranging from 2 to 6%; flatter slopes may encourage pooling of storm water.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Vegetated Filter Strips.
- Appendix C: FHWA Fact Sheet: Filter Strips.
- Filter Strip, Section 3.3.1, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

3.1.5 Manufactured Systems

Manufactured systems is a broad term that encompasses a range of commercial products engineered to remove pollutants from storm water.

A. Oil/Grit Separators

Volume	Quality

Description: An oil/grit separator (OGS), also referred to as a gravity separator, is designed to remove oil and grease, debris, floatables, and solids through gravitational settling.

Application: OGSs are best employed at locations were a high degree of petroleum contamination is expected in storm water runoff or as pretreatment in high-density locations. Gravity separators are recommended for drainage areas under 1 acre, but may be used in drainages of up to 5 acres.

Primary Mechanisms: Sedimentation, filtration.

Considerations: Gravity separators are not effective at removing dissolved or emulsified pollutants like coolants and lubricants. Maintenance requirements are high for these units, as trapped pollutants must be removed or risk being resuspended during future storm events.

For More Information:

- Appendix A.
- Appendix C: FHWA Fact Sheet: Oil/Grit Separator Units.
- Gravity (Oil/Grit) Separator, Section 3.3.6, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

B. Gross Solid Removal Device

Volume	Quality

Description: Gross solid removal devices, also called hydrodynamic separators or swirl concentrators, are modifications of traditional OGS units. Separation of solids and suspended particulates from the storm water runoff may be assisted by a vortex, or swirl. These units may be specifically designed to prevent the resuspension of removed materials.

Application: Like OGS units, GSRDs are normally employed in high-density areas where runoff becomes contaminated crossing impervious surfaces such as high-travelled roads or parking lots. Structural components are installed underground and may be retrofitted to existing storm sewers or replace a proposed hole in a new system.

Primary Mechanisms: Sedimentation, filtration.

Considerations: Like OGS units, GSRDs have a high maintenance requirement. Due to the wide range of individual units available on the commercial market, a GSRD must be individually selected to meet the individual characteristics and expected pollutants at a given site; these units are not "one size fits all."

For More Information:

- Appendix A.
- Appendix C: FHWA Fact Sheet: Manufactured Systems.
- Manufactured Systems, Section 1117.2, Location and Design Manual, Volume 2 (Drainage Design), ODOT.

C. Catch Basin Inserts

Volume	Quality

Description: Catch basin inserts (CBIs) are designed for placement within the catch basin structure, where they filter large sediment and debris from incoming storm water. Some CBIs also absorb oil and grease through use of media filters.

Application: Catch basin inserts may be appropriate for unpaved areas that contribute coarse material to storm water runoff; however, they do not offer significant treatment of fine particles so runoff from impervious areas is unlikely to benefit much from their use. CBIs are primarily most effectively employed in areas affected by high levels of debris.

Primary Mechanisms: Sedimentation, filtration, sorption.

Considerations: Catch basin themselves serve as a sedimentation mechanism for storm water during normal rain events, as the water trapped within the sump deposits heavy debris and large sediment particles. Addition of a catch basin insert will increase maintenance requirements, since clogged inserts may result in street flooding. In addition, collected sediments must receive appropriate disposal.

For More Information:

- Appendix B: U.S. EPA Fact Sheet: Catch Basin Inserts.
- Appendix C: FHWA Fact Sheet: Catch Basin Inserts.

3.2 Non-Structural PCBMPs

Nonstructural PCBMPs aim to control the source of storm water pollution concerns. Nonstructural PCBMPs do not require extensive construction efforts as structural measures often do; however, as stated earlier, nonstructural measures still must receive careful consideration during the design process. In fact, better site design is a prime example of a nonstructural PCBMP. Other nonstructural measures include reduction of impervious areas, materials management, maintenance, and public education.

Nonstructural PCBMPs are often referred to as pollution prevention practices. These practices prevent pollution by: (1) reducing or capturing pollutants at their source; and (2) by capturing and disposing of storm water at its source. The distinction between structural and nonstructural PCBMPs can be unclear at times, so classification of individual measures may differ among reference materials.

3.2.1 Better Site Design

Better site design may incorporate a number of structural PCBMPs in addition to other nonstructural measures discussed in this document. Significant environmental features may be left undisturbed, while minimizing cut and fill slopes will greatly impact post-construction drainage. Post-construction storm water control must be in the forefront of the designer's mind throughout the design process in order to most effectively control costs, use available space, and maintain or even improve pre-construction storm water quality and volumes.

A. Flow Control

Highway construction can drastically alter the flow of storm water runoff. The conversion of land to impervious area and addition of cut/fill slopes can significantly increase both the volume and velocity of storm water runoff. During the construction process, temporary measures such as slope drains and check dams can adequately address these issues. However, permanent flow control must be considered during the initial design process and prove adequate to address post-construction storm water rates.

A.1 Level Spreader

A level spreader converts a small volume of concentrated flow into sheet flow, minimizing the potential for erosion and the resultant increased storm water sediment load. Level spreaders may be employed in drainage areas up to 5 acres. TDOT Standard Drawing EC-STR-61 provides additional information on both temporary and permanent use of level spreaders.

A.2 Paved Flume

Paved flumes are concrete channels used on highway cuts and fills to convey concentrated flow down steep slopes. Paved flumes do not slow storm water velocity, and should therefore be combined with outlet protection to prevent scouring at the receiving channel. TDOT Standard Drawing D-FLU-1 provides details on flume design; baffles may be included at the base of these structures to check storm water velocity.

A.3 Outlet Protection

Storm water outlets often carry a risk of high-velocity concentrated flow scouring the discharge location, contributing sediment to storm water runoff and harming the stability of the receiving channel. Properly designed outlet protection reduces storm water velocity and provides an effective barrier between the storm water flow and underlying soils in the receiving channel. Two methods of outlet protection are already widely in use by TDOT throughout Tennessee:

- Permanent Energy RipRap Dissipator (TDOT Standard Drawing EC-STR-21); and
- Riprap Apron Outlet Protection (Section 10.08.3.2 TDOT DDDM).

A.4 Plunge Pools

Plunge pools form naturally when high-velocity concentrated flow scours out a depression beneath a waterfall or outlet structure. Manmade plunge pools have occasionally been used as alternatives to hard-armour outlet protection when the required size of an apron proves prohibitive. When properly designed, plunge pools do not experience continued scouring and may even recede in size until a hydrologic equilibrium is reached. Plunge pools provide habitat for aquatic life and may incorporate vegetation as well.

B. Buffer Zones

Some references use the terms filter strip and buffer zones simultaneously. However, within this menu of PCBMPs, filter strip refers to a densely vegetated section of land intended to treat storm water runoff as discussed in Section 3.1.4.C. Buffer zones, on the other hand, are naturally occurring zones of vegetation that separate areas of development from adjacent property and/or waters of the state. Buffer zones should be left undisturbed during construction or redevelopment whenever possible.

C. Treatment Trains

The term “treatment train” refers to the combination of multiple BMPs employed in series to provide more effective and comprehensive storm water treatment than would be possible with use of only one measure. For example, each set of recommended BMPs for the eight scenarios listed in Table 2.2 comprise a treatment train. The goal of a treatment train is to maximize the number of treatment options available without needless duplication.

3.2.2 Alternative Materials

The goal in use of most alternative materials is to reduce the amount of pollutants entering the storm water system. Selected materials may contain fewer toxic chemicals, consist of natural alternatives, or eliminate compounds known to leach into storm water runoff. Alternative products may also help offset the increased storm water volume encountered in most developed areas.

Porous Pavement and Pavers

Porous pavements replace traditional asphalt and concrete materials with technologies designed to support vehicle traffic yet simultaneously allow an increased percentage of storm water to permeate downward through the roadbed. Porous pavers are hollow blocks either poured-in-place or set in a grid system.

Generally, porous pavements are used in parking areas and areas of low traffic volume, such as road shoulders, vehicle crossovers on divided highways, and emergency stopping areas. Porous pavements are not recommended for areas of high traffic volume or heavy loadings. Porous pavements should not be installed in close proximity to potential sources of high pollutants, such as gas stations and industrial sites, as the risk of contaminants entering groundwater is greatly increased. In addition, porous pavements should be located an appropriate distance from building foundations and drinking water wells.

Additional information on alternative pavement and porous pavers is available in the following documents:

- Appendix B: U.S. EPA Fact Sheet: Alternative Pavers.
- Appendix B: U.S. Fact Sheet: Porous Pavement.
- Appendix C: FHWA Fact Sheet: Porous Pavements.
- Modular Porous Paver Systems, Section 3.3.8, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).
- Porous Concrete, Section 3.2.7, Georgia Stormwater Management Manual, Volume 2 (Technical Handbook).

3.2.3 Vegetation Control

Vegetation control includes planting low-maintenance vegetation when possible, careful application of chemical fertilizers and pesticides, and proper disposal of clippings and cuttings after mowing and other maintenance activities. Grass clippings contribute nutrients such as nitrogen and phosphorus to stormwater runoff, promoting algae growth in receiving lakes and streams. Clippings may be left in place on vegetated areas of low velocity sheet flow, but should be kept off paved surfaces where they may be carried into the storm sewer system during wet weather. In addition, areas immediately surrounding catch basins in grass medians and interchanges should be kept free from grass clippings when mowing is performed.

3.2.4 Maintenance

The importance of maintenance in storm water control cannot be overstated. BMPs cannot function to their fullest capacity without receiving proper maintenance. When kept properly maintained, roadways and bridges are likely to last longer before contributions to storm water pollution become excessive. Finally, activities like street sweeping are simple, yet very effective ways to keep debris and pollutants from being captured by stormwater in the first place.

A. Roadway and Bridge Maintenance

Roads break down over time, exposing subsurface materials and increasing the number of suspended solids swept along by storm water runoff. Salting and sanding are well-known practices with negative impacts to storm water runoff; improved application techniques can prevent wasteful over-applications and minimize the levels of these pollutants. Paving operations should be completed only during dry weather conditions to reduce the risk of contaminating runoff. Pothole repairs can be completed using porous pavement, which will assist local groundwater recharge.

Bridge maintenance should be accompanied by the proper environmental precautions, such as tarps and vacuums to contain and remove paint scrapings and rust. Bridge scupper drains, common in TDOT designs, allow storm water runoff to drop directly onto the terrain below, often waters of the state. These drains pose two significant storm water pollution concerns. First, they convey high levels of pollutants directly from the roadway to waters below. Secondly, scupper drains have the potential to become blocked with debris and sediment if not cleaned on a regular basis, increasing the volume of storm water on the roadway.

B. Street Sweeping

Street sweeping may be appropriate for highway shoulders, rest stops, and TDOT maintenance facilities. Removing sediment, debris, and other solid materials from the roadway before a storm prevents these materials from requiring removal via another BMP downstream. Further information on street sweeping is available in Appendix C: FHWA Fact Sheet: Street Sweeping.

C. BMP Inspection and Maintenance

All structural post-construction BMPs require maintenance in order to perform their intended function, at minimum on an annual basis. Annual maintenance costs can range up to 20% of the initial installation cost; therefore, inspection and maintenance should be taken seriously during initial selection of BMPs. Maintenance information on specific BMPs is included in the reference material cited for each structural measure contained in this document. However, a few key notes bear mentioning here.

Inspectors should be given a checklist of items to review, specific to the measure undergoing inspection. Documentation of the inspection results should include not only any needed maintenance, but also notes on the effectiveness of the BMP to help TDOT select appropriate measures for similar sites in the future.

Routine repairs for many BMPs require common items, such as mowing machines, fertilizer, and replacement filters. However, emergency repairs may be necessary at times, and advance preparation for emergency response is necessary to reduce the risk of harm to human safety or significant environmental damage. A clogged inlet filter may not seem to pose much of a hazard, but a clogged outlet pipe in a large detention pond adjacent to a heavily traveled roadway could cause flooding and serious injury to passing motorists.

3.3 Facility PCBMPs

A number of PCBMPs employed by municipalities and commercial enterprises have been considered unlikely to provide effective storm water control on TDOT projects. Typically, these BMPs are better suited for implementation at a new or renovated TDOT facility. For example, an *alternative turnaround*, which provides a circular drive for cars to turn around with a center vegetated island, is unsuited for linear state highways; however, an alternative turn-around may be considered in lieu of a traditional cul-de-sac at a TDOT facility. (See Appendix B: U.S. EPA Fact Sheet: Alternative Turnarounds for further information.)

Other potential facility PCBMPs include:

- *Green parking* refers to a group of techniques aimed at reducing the impervious surface area of a parking lot. Some techniques are non-structural, such as the encouragement of carpools or use of public transportation that can translate into fewer needed parking spaces and shared parking lots, where two or more entities with alternate peak parking hours use the same space. If redesign of an existing TDOT facility is proposed, structural PCBMPS such as a bioretention cell may be employed. Alternative pavement and the use of above-ground or under-ground parking garages to minimize the footprint of the parking area are also green parking practices. See Appendix B: U.S. EPA Fact Sheet: Green Parking for additional information.

- *Green Roofs* can be applied to new construction, or retro-fitted to existing structures. Aimed at capturing stormwater and releasing it back into the atmosphere through evapotranspiration, green roofs offer garden settings in an unexpected location. See Appendix B: U.S. EPA Fact Sheet: Green Parking for additional information.

One other popular storm water control measure employed in urban areas is a return to *narrower roadways*. This concept was given consideration during the compilation of this menu, but eventually rejected for inclusion due to the very nature of TDOT business – building and maintaining roads – which requires large trucks and equipment at every facility.

4.0 REFERENCES

Atlanta Regional Commision. (2001). *Georgia Stormwater Management Manual Volume 2: Technical Handbook.* Atlanta Regional Commission. http://www.georgiastorm water.com

Federak Highway Administration. (2000). *Storm water Best Managemnet Practices in an Ultra-Urban Setting: Selection and Monitoring.* U.S. Department of Transportation, Washington, D.C. http://www.fhwa.dot.gov/environment/ultraurb/index.htm

Maryland Department of the Environment (MDE). (2000). *Maryland Storm water Design Manual Volumes I & II.* Center for Watershed Protection and Maryland Department of the Environment, Baltimore, MD. http://www.mde.maryland.gov/Programs/WaterPrograms/SedimentandStorm water/storm water_design/index.asp

Muthukrishnan, S., et al. (2004). *The Use of Best Management Practices (BMPs) in Urban Watersheds*. Washington, D.C. http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf

Northern Virginia Planning District Commission (NVPDC). (1996). *Nonstructural Urban BMP Handbook: A guide to nonpoint source pollution prevention and control through nonstructural measures.* Annandale, VA. http://www.novaregion.org/index.aspx?nid=250

Northern Virginia Planning District Commission (NVPDC). (1992). *Northern Virginia BMP Handbook: A guide to planning and designing best management practices in northern Virginia*. Annandale, VA. http://www.novaregion.org/index.aspx?nid=250

Ohio Department of Transportation. (2009) *Location and Design Manual Volume 2: Drainage Design*. Columbus, OH. http://www.dot.state.oh.us/storm water/Pages/default.aspx

Tennessee Department of Transportation (TDOT). (2008). *Design Division Drainage Manual*. Nasvhille, TN. http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/DrainManChap%20 1-10.htm

TriAD Environmental Consultants. (2007). *Post Construction Storm water Best Management Practices Research Report*. Prepared for Tennessee Department of Transporation (TDOT). Nashville, TN.

United States Environmental Protection Agency (U.S. EPA). (2001). *National Menu of Best Management Practices.* Washington, D.C. http://cfpub.epa.gov/npdes/storm water/menuofbmps/index.cfm?action=browse

Appendix A: Lessons Learned from Installation and Operation of Structural BMPs at TDOT Regional Facilities

Evaluating Structural BMP's at TDOT Regional Facilities with Reference to the Phase II Storm Water Regulations

Ronnie Bowers[1], Mike Cramer, P.E[2].; Dr. Vincent Neary, P.E.[3] and JJ Hollars[2]

ABSTRACT

The purpose of this paper is to provide preliminary information on a project initiated by the Tennessee Department of Transportation (TDOT) to evaluate commercially available stormwater treatment systems regarding their capability to function as structural Best Management Practices (BMP's) to support future TDOT stormwater regulatory compliance needs. The paper will describe the units that have been installed to date, provide preliminary information from the completed installations, and outline the plans for evaluation of the units and other future work planned to be performed.

INTRODUCTION

Compliance with the impending Phase II Stormwater regulations will require significant upgrades to stormwater systems across the state. Near term actions will be required by many municipalities with separate stormwater sewers; construction sites disturbing greater than 1 acre in size, and state controlled roadways in certain urbanized areas, to develop and file a stormwater discharge permit application with the Tennessee Department of Environment and Conservation (TDEC) by March of 2003. The March 10th compliance deadline for permit application includes a requirement for a stormwater management plan that outlines what actions will be taken to improve discharge standards. One of the components of many stormwater management plans will be the use of structural BMP's to treat stormwater prior to discharge to surface water. TDOT and its consultant, Science Applications International Corporation (SAIC), is working with TDEC, US EPA, the University of Tennessee (Knoxville and Jackson) and Tennessee Technological University to evaluate, select, install and test structural BMP units at TDOT's four regional facilities in Knoxville, Chattanooga, Nashville and Jackson.

Each of the selected units will be evaluated for treatment effectiveness, cost effectiveness, ease of installation, treatment capacity, applicability to actual and projected site conditions at TDOT facilities, and cost of operation and maintenance. To date, five units have been installed as a part of this project, three at the Nashville regional facility and two at the Knoxville facility. The selected units were retrofitted to capture and treat the discharge from the existing stormwater drainage systems existing at each of the TDOT facilities. A sixth unit that was previously installed at the Nashville facility will also be evaluated during the project.

1 Tennessee Department of Transportation

2 Science Applications International Corporation

3 Tennessee Technology University

BMP STORMWATER TREATMENT UNITS

The stormwater treatment currently units installed at the Nashville TDOT facility include:

- Advanced Drainage Systems (ADS) Water Quality Unit[1];
- Royal Environmental Eco Sep Oil and Water Separator[2];
- Baysaver Separation System[3]; and
- Continuous Deflective Separation (CDS)[2].

The CDS system had been installed prior to the initiation of this project as part of stormwater management for a recent addition to the TDOT facility.

The units installed at the Knoxville TDOT facility include:

- Crystalstream (PBM) Oil/Grit Separator[4]; and
- Aquaswirl Concentrator[5].

All of the units were purchased by TDOT from the local distributor and installed by SAIC and its construction subcontractor with technical guidance and assistance from the distributor and/or manufacturer. Detailed documentation of the installation process for each unit was maintained by SAIC and an evaluation and comparison of the installation requirements for each unit will be part of the project final report.

Treatment Unit Selection

At the initiation of the project an extensive literature and internet search was conducted to identify all of the commercially available systems that had potential application to TDOT stormwater management needs. Over fifty potential vendors and stormwater treatment unit designs were originally examined. Criteria for selection of the units included:

- suitability for given stormwater flow conditions – since all of the installations were retrofit conditions, the in-flow rate and potential contaminants could not be controlled and the unit must have been able to adapt to the situation. The requirement for the treated flow rate was based on a rainfall intensity of 2.54 inches/hour over the drainage area;
- suitability for site physical conditions – the units were installed at an existing stormwater outfall, thus the units had to be able to be installed at a given location regardless of elevation differences between inlet and outlet, depth to existing stormwater pipe, distance from paved access, depth to groundwater, and presence of hazards (eg. overhead power lines, buried pipelines);
- uniqueness of system design and construction - the selection process attempted to identify units which were representative of the major design philosophies and materials of construction currently available; and
- cost – cost of the units was not a primary consideration, but if two units represented essentially the same design and materials of construction, the less expensive unit was selected.

A summary of the units installed is provided in Table 1.

Units Distributed by:
1 Advanced Drainage Systems, Franklin, TN
2 Sherman-Dixie Concrete Industries, Hermitage, TN
3 Viking Products, Mt. Juliet, TN
4 Practical Best Management Inc., Stone Mountain, GA
5 AquaShield, Inc., Hixson, TN

TABLE 1 TDOT STORMWATER TREATMENT SYSTEMS

Location	Unit	Installation Date	Description	Treated Flow Capacity	Floatables Storage Capacity	Capital and Installation Cost
Nashville outfall 0-2	ADS	Oct. 2002	89 ft. long, 60 in I.D HDPE pipe with weir near midpoint to trap sediment and baffle over outlet to capture floatables	18.5 cfs	4000 gal.	$77,586
Nashville outfall 0-3	CDS	July 2001	Consists of three circular precast concrete chambers stacked on top of each other. The upper chamber provides initial separation, the middle chamber includes filter baskets for solids separation and the lower chamber is a collection sump.	2.8 cfs	400 gal.	Not Available
Nashville outfall 0-4	BaySaver	Sep. 2002	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device.	22 cfs	1110 gal.	$68,623
Nashville outfall 0-6	Ecosep	Aug. 2002	Three separate precast concrete manholes, first chamber is grit chamber for solids separation, other two are oil separators.	2.72	1200 gal.	$68,385
Knoxville outfall SW0-3	PBM	July 2002	Precast concrete box using baffles to control flow and increase gravity separation. Trash basket on front end for debris and adjustable weir with "oil bucket" to skim off floating oil.	6.2 cfs	200 gal.	$25,353
Knoxville outfall SWO-2	Aqua-Swirl	Sept. 2002	Single HDPE tank using vortex action and baffle to separate solids and floatable	14 cfs	1000 gal	$46,833

SAMPLING AND ANALYSIS PROGRAM

The primary objective of this sampling and analysis program is the collection of monitoring data to support TDOT's evaluation of stormwater runoff treatment devices for their potential future use in meeting environmental compliance program requirements. The secondary objective is to provide site-specific performance data on a variety of BMPs whose long-term use can yield significant environmental benefits to receiving waters of the State.

Specific questions that will be addressed in the data analysis include the following:

- How does the BMPs efficiency, performance and effectiveness compare to other BMPs tested?
- Does the BMP help achieve compliance with water quality standards?
- Does the BMP cause an improvement in or protect downstream biotic communities?
- Does the BMP have potential downstream negative impacts?
- What degree of pollution control does the BMP provide under typical operating conditions?
- How does effectiveness vary from pollutant to pollutant?
- How does effectiveness vary with various input concentrations?
- How does effectiveness vary with storm characteristics such as rainfall amount, rainfall intensity, and antecedent dry conditions?

Questions not addressed in this analysis include:

- How do design variables affect performance?
- How does effectiveness vary with different operational and/or maintenance approaches?
- Does effectiveness improve, decay, or remain stable over time?

Site Characteristics

Common characteristics of the Regional facilities include the presence of large impervious (paved) areas for vehicle traffic and parking, vehicle maintenance operations such as fueling, vehicle cleaning, painting and repair, and road maintenance functions, such as salt, sand and gravel storage, sign painting, and road-striping. A higher stormwater runoff flow rate (i.e., high runoff coefficient) is expected from parking lots and other the impervious areas than from vegetated areas at these sites. Common potential pollutants for all sites include petroleum products (oil & grease), heavy metals, sediment, bacteria and eroded sediment. The regional facilities may have additional pollutants characteristic of vehicle maintenance, including solvents and other synthetic organic compounds.

Storm Events to be Monitored

Storm events will be selected to yield the best quality data for the technology evaluation. A qualifying storm event will be one where the pollutant concentrations are measurable, the composite sample is representative of the complete runoff hydrograph, and the difference in the influent and effluent EMC and EML can be calculated for each site-related pollutant. Qualifying storm events must meet the following criteria:

a. the storm event must be >0.1 inches in magnitude.

b. the storm event must occur at least 7 day (168 hours) after the previously measured (>0.1inch) storm event.

Ideally, there would be an opportunity to obtain samples from 15 qualifying storm events for each technology tested. However, considering the probable practical limitations for the duration of evaluation, it is unlikely that each monitoring site will have 15 storm events resulting in completed sampling and analysis.

The results of this field demonstration and evaluation project will be used to aid in the selection and design of structural BMPs for future new construction and potential retrofits at the existing stormwater outfalls along the highways in “urbanized” areas, as well as other facilities and locations impacted by the Phase II regulatory requirements.

DATA ANALYSIS

Validated stormwater monitoring data will be analyzed to determine the efficiency of each technology in removing pollutants from stormwater runoff at TDOT facilities. Both the reduction in stormwater runoff pollutant concentrations and the reduction in loading (pollutant mass) are relevant to this evaluation. Samples will be collected using flow-proportional composite sampling to allow calculation of the Event Mean Concentration (EMC) and Event Mass Load (EML) for each pollutant and each storm event.

The EMC is the arithmetic average concentration of a specific pollutant in the total runoff volume from each storm event. The EML is the total constituent mass of a specific pollutant transported during a particular storm event. The EML is calculated for each pollutant using the measured EMC and the total runoff volume for the event.

Pollutant Load and Event Mean Concentration

The mid-sample method (Charbeneau & Barrett 1998) will be employed to derive the volume to be associated with each aliquot concentration, where load and event mean concentration (EMC) are calculated as

$$L = \sum_i C_i V_i \tag{1}$$

$$EMC = \frac{\sum_i C_i V_i}{\sum V_i} \tag{2}$$

and C_i is the concentration of the i^{th} sample and V_i is the storm volume associated with the i^{th} sample. The EMC, calculated using the mid-sample method, should be within 20% of the concentration of the composite sample.

First Flush Response (Influent Aliquot Samples Only)

The general assumption that the first part of the runoff is the most polluted will be evaluated by plotting curves of cumulative influent load versus cumulative influent volume for each constituent. A first flush event has occurred, at least qualitatively, if the cumulative load curve falls above the 45^o slope. The cumulative load curve can also be used to determine whether a quantitative criteria first flush has been met. For example, Saget et al. (1995) have proposed the 30/80 rule; the criteria that the first 30% of runoff transports at least 80% of the total event load. Parameters like antecedent dry days, intensity, and catchment area and slope are known to be important factors that affect the degree of first flush response.

BMP Removal Efficiency

Two methods for evaluating BMP removal efficiency will be employed: *The Efficiency Ratio Method* and *The Effluent Probability Method*.

The Efficiency Ratio Method is the most commonly used method for evaluating BMP removal efficiency. The Efficiency Ratio is defined in terms of the average EMC of pollutants over some time period,

$$ER = 1 - \frac{\text{average outlet EMC}}{\text{average inlet EMC}} = \frac{\text{average inlet EMC - average outlet EMC}}{\text{average inlet EMC}}$$

Where the arithmetic average EMC is calculated as,

$$\text{average EMC} = \frac{\sum_{j=1}^{m} EMC_j}{\text{number of events measured}}$$

This method weights EMCs from all events equally regardless of the relative magnitude of the storm. A high concentration/high volume event has equal weight in the average EMC as a low concentration/low volume event. However, for the purpose of comparing removal efficiencies among several BMPs it is a valid method

The Effluent Probability Method is the method recommended by EPA-ASCE (EPA-ASCE 2002) for evaluating BMP removal performance because it provides a statistical measure of influent and effluent quality. In this method, a normal probability plot (Frequency of Occurrence vs. EMC) will be generated of the log transform of both influent and effluent EMCs for all events. If the log transformed data deviates significantly from normality, other transforms will be explored to determine if a better distribution exists. Probability plots will be supplemented with standard statistical tests that determine if the data is normally distributed; including the Kolmogorov-Smirnov one-sample test and the chi-square goodness of fit test. These are paired tests comparing the data points from the best-fitted normal curve to the observed data.

REFERENCES

Charbeneau, R.J. and Barrett, M.E. (1998). "Evaluation of methods for estimating stormwater pollutant loads." *Water Environment Research*, 70-1296.

Saget, A., Chebbo, G. and Bertrand-Krajewski, K. (1995). "The first flush in sewer systems." In Proceedings *International Conference On Sewer Solids Characteristics, Movement, Effects and Control*, Dundee, U.K., pp. 58-65.

U.S. Environmental Protection Agency (EPA) & American Society of Civil Engineers (ASCE) (2002). Urban Stormwater BMP Performance Monitoring. A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. EPA-821-B-02--001.

Lessons Learned from Installation and Operation of Structural BMP's at TDOT Regional Facilities

To date, six stormwater treatment units have been installed at TDOT facilities, three at the Nashville regional facility, two at the Knoxville regional facility, and one at the I-40 Rest Area in Smith County. The selected units were installed to capture and treat the discharge from the existing stormwater drainage systems existing at each of the facilities. A seventh unit that was previously installed at the Nashville facility (as part of a separate construction project) has also been observed and evaluated during this project.

All of the units were installed as retrofits to existing stormwater collection and management system. Typically, the units were installed immediately downstream from the discharge outfall pipe and were permanently connected to the stormwater conveyance system. For those drainage areas that did not discharge into an underground pipe system, a standard stormwater catchbasin was installed at the discharge point and the catchbasin then fed the treatment system.

Since most of the units have been installed for close to a year, a retrospective review of the installation process and the perceived advantages and disadvantages of each unit would appear to be in order. The report summarizes the all the significant observations and lessoned learned during the installation of the units. The information is presented largely in tabular form to facilitate review of the relatively large number of observations and other data. The tables include:

- Table 1 TDOT Stormwater Treatment System Descriptions (pages 3-4)
- Table 2 Treatment System Cost per Treated Flow Capacity (page 5)
- Table 3 Significant Observations During Installation (pages 6-9)
- Table 4 Observed Advantages and Disadvantages of Each Treatment Units (pages 10-11)
- Table 5 Common Design and Construction Related Issues (pages 12-13)
- Table 6 Other Stormwater Treatment Units not Selected for Installation (pages 14-15)

General conclusions from the installation experience are also provided.

The stormwater treatment currently units installed at the Nashville TDOT facility include:

- Advanced Drainage Systems (ADS) Water Quality Unit[1];
- Royal Environmental Eco Sep Oil and Water Separator[2];
- BaySaver Separation System[3]; and
- Continuous Deflective Separation (CDS)[2].

The CDS system had been installed prior to the initiation of this project as part of stormwater management for a recent addition to the TDOT facility.

The units installed at the Knoxville TDOT facility include:

- Crystalstream (PBM) Oil/Grit Separator[4]; and
- Aquaswirl Concentrator[5].

A BaySaver Separation System[3] has been installed at the Smith County Rest Area

Photographs and design drawings from the installation of each unit are provided in Appendix A.

At the initiation of the project an extensive literature and internet search was conducted to identify all of the commercially available systems that had potential application to TDOT stormwater management needs. Over fifty potential vendors and stormwater treatment unit designs were originally examined. Criteria for selection of the units included:

- suitability for given stormwater flow conditions – since all of the installations were retrofit conditions, the in-flow rate and potential contaminants could not be controlled and the unit must have been able to adapt to the situation. The requirement for the treated flow rate was based on a rainfall intensity of 2.54 inches/hour over the drainage area;
- suitability for site physical conditions – the units were installed at an existing stormwater outfall, thus the units had to be able to be installed at a given location regardless of elevation differences between inlet and outlet, depth to existing stormwater pipe, distance from paved access, depth to groundwater, and presence of hazards (eg. overhead power lines, buried pipelines);
- uniqueness of system design and construction - the selection process attempted to identify units which were representative of the major design philosophies and materials of construction currently available; and
- cost – cost of the units was not a primary consideration, but if two units represented essentially the same design and materials of construction, the less expensive unit was selected.

A summary description of the units installed is provided in Table 1.

TABLE 1 TDOT Stormwater Treatment System Descriptions

Location	Unit	Installation Date	Description	Treated Flow Capacity	Floatables Storage Capacity	Labor and Equipment Cost for Installation	Material Cost for Installation
Nashville outfall 0-2	ADS	Oct. 2002	89 ft. long, 60 in I.D HDPE pipe with weir near midpoint to trap sediment and baffle over outlet to capture floatables	18.5 cfs	4000 gal.	$44,188	19,165
Nashville outfall 0-3	CDS	July 2001	Consists of three circular precast concrete chambers stacked on top of each other. The upper chamber provides initial separation, the middle chamber includes filter baskets for solids separation and the lower chamber is a collection sump.	2.8 cfs	400 gal.	Not Available	$16,500
Nashville outfall 0-4	BaySaver	Sep. 2002	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device.	22 cfs	1110 gal.	$27,939	$40,446
Nashville outfall 0-6	Eco-Sep	Aug. 2002	Three separate precast concrete manholes, first chamber is grit chamber for solids separation, other two are oil separators.	2.72	1200 gal.	$13,383	$53,397

TABLE 1 (continued) TDOT STORMWATER TREATMENT SYSTEMS

Location	Unit	Installation Date	Description	Treated Flow Capacity	Floatables Storage Capacity	Labor and Equipment Cost for Installation	Treatment System Material Cost for Installation
Knoxville outfall SW0-3	PBM	July 2002	Precast concrete box using baffles to control flow and increase gravity separation. Trash basket on front end for debris and adjustable weir with "oil bucket" to skim off floating oil.	6.2 cfs	200 gal.	$11,428	$13,925
Knoxville outfall SWO-2	Aqua-Swirl	Sept. 2002	Single HDPE tank using vortex action and baffle to separate solids and floatable	14 cfs	1000 gal	$14,132	$34,977
Smith County Rest Area	Bay Saver	Sept. 2003	Two separate cylindrical chambers of precast concrete using a trapezoidal weir in the primary chamber as an oil separation device.	7.8 cfs	430 gal	$34,218	$12,405

The labor and equipment cost category includes all subcontract labor costs, heavy equipment rental, safety equipment rental, gravel, erosion and sediment control measures, riprap, topsoil, and any other miscellaneous construction related costs for the installation. The treatment system material cost category includes the cost of the stormwater unit, any manholes, diversion structures, and piping that were necessary parts of the treatment system.

All of the units were purchased by TDOT from the local distributor and installed by SAIC and its construction subcontractor (Viking Products) with technical guidance and assistance from the distributor and/or manufacturer. Detailed documentation of the installation process for each unit was maintained by SAIC. In the case of the Eco-Sep system, much of the actual installation of the treatment system was performed by the vendor. Only the excavation, site prep, and backfilling were performed by SAIC and Viking. Thus, for this unit some of the installation costs are included in the lump sum treatment system material cost, and could not be accurately backed out. However, for all other systems all installation work was performed by SAIC and Viking with no physical support from the vendors. The level and quality of vendor technical support varied greatly among the different units.

Direct comparison of the installation and material costs must consider that the units were sized according to the area drained by the pre-existing stormwater collection system. Table 2 correlates the construction cost relative to the treated flow capacity of each unit.

Table 2   Treatment System Cost per Treated Flow Capacity

Unit	Labor Cost ($) / Treated Flow (cfs)	Material Cost ($) / Treated Flow (cfs)	Total Cost ($) / Treated Flow (cfs)
ADS	2389	1036	3425
CDS	Not Available	5893	Not Available
BaySaver (Nashville)	1270	1839	3109
Eco-Sep	4920	19631	24551
PBM	1843	2246	4089
Aqua-Swirl	1009	2498	3507
Bay Saver (Smith Co.)	4214	1567	5981

OBSERVATIONS FROM THIS COMPARISON INCLUDE THAT THE LARGER UNITS APPEAR TO BE MORE ECONOMICAL TO INSTALL ON A TREATED FLOW BASIS (NOTE THE DIFFERENCE BETWEEN THE SMALLER SMITH COUNTY BAYSAVER AND THE LARGER NASHVILLE BAYSAVER). HOWEVER, LABOR COSTS WERE INCREASED AT THE SMITH COUNTY SITE BECAUSE IT WAS IMMEDIATELY ADJACENT TO THE CANEY FORK RIVER AND SIGNIFICANT EFFORT WAS PUT INTO ENSURING THAT SEDIMENT AND EROSION CONTROL MEASURES WERE ADEQUATE AND MAINTAINED. MATERIAL COSTS PER TREATED FLOW CAPACITY WERE QUITE SIMILAR EXCEPT FOR THE CDS (WHICH WASN'T INSTALLED AS PART OF THIS PROJECT) AND THE ECO-SEP WHERE MATERIAL COSTS ALSO INCLUDED SIGNIFICANT INSTALLATION LABOR. THE ECO-SEP VALUES ARE ALSO EFFECTED BY ITS RELATIVELY LOW TREATED FLOW CAPACITY RELATIVE TO MOST OF THE OTHER UNITS. LABOR COSTS FOR THE ADS UNIT WHERE IMPACTED BY THE NEED TO REMOVE SIGNIFICANT ROCK DURING INSTALLATION.

To help the treatment system selection process for future application, and to support future installation efforts for these units, Table 3 summarizes the significant observations during the installation of each unit and provides lessons learned for the next installation.

Table 3 Summary of Significant Observations During Installation

Unit	Significant Observations During Installation	Lessons Learned
ADS	1) Presence of underground gas line required change in unit location from original design. Gas line was not shown on any facility drawings and was not well marked.	1) Unit installation design must include thorough site reconnaissance performed well before the start of installation activities
	2) Rock and water inflow encountered during excavation significantly increased construction time and cost	2) Unit installation design must include review of geologic maps of the area to verify depth to groundwater and bedrock.
	3) Limit room for storage of rock and dirt from excavation caused continuing logistical problems and increased installation time and cost.	3) Installation design must include estimate of volume of material to be excavated and specific plan for its storage and handling. In this case the need for a significant last minute change to the design due to utility interference contributed to this lack of planning.
	4) Large sections of plastic pipe difficult to connect with both section flush and secure.	4) Alignment of plastic pipe is very important. Each section must be carefully aligned and then fully bedded with gravel to half its diameter to secure alignment before installing next section. If sections are not secure, pressure from installing subsequent sections can cause minor changes in alignment that impact seal quality. One person should be inside pipe to verify alignment.
	5) Difficulty in sealing joints between pipe sections.	5) Water tight seals should be used at all connections regardless of manufactures recommendations. At least six inches of clearance should be available under each pipe to allow insertion of external seal. MarMac bands should be tightened initially and then left uncovered and retightened after all sections installed. Internal seals should be installed on all major connections. The internal seals should be installed as each section is connected and before the pipe is covered to beyond half its diameter to prevent distortion of the pipe at the joint.
	6) Received repeated questions on sediment and erosion control around site	6) Sediment and erosion control should be used around all disturbed soil areas even if not required by regulations.

Table 3 Summary of Significant Observations During Installation (con't)

Unit	Significant Observations During Installation	Lessons Learned
CDS	CDS unit was not installed as part of this project but was inspected and monitored frequently 1) Unit was observed not to fill with water during significant rainfall event. Water appeared to be coming in through the wall and not the entry port.	1) Unit was installed during construction of nearby building and parking lot. The manhole and piping was damaged, probably due heavy equipment use over the site during construction. Any units that are installed in a traffic area should be surrounded by bollards or other traffic restriction device to prevent damage.
BaySaver (Nashville)	1) Hit rock at bottom of hole about 6 inches above design bottom. Repositioned BaySaver manhole location so installation could be completed without excavating rock. 2) Ten foot inside diameter manholes were heavy, awkward and difficult to position with crane. Some accessibility problems with crane 3) Holes in primary manhole were 4 inches higher than design. 4) Difficulty in placing BaySaver unit in primary manhole. Unit was difficult to support and position accurately. 5) Frequent afternoon thunderstorms filled excavation with water, delaying work 6) Manholes were observed not to hold water after installation is complete. Manufacturer came to site and sealed internal surface over bottom 12 inches of manholes with an epoxy based grout.	1) Design needs to anticipate minor changes and include contingencies for repositioning manholes to conform to actual conditions. 2) Design needs to ensure practical access to excavation for crane and crane needs to be of sufficient size and capacity to place manholes. A better system to accurately guide and position large manholes needs to be found 3) Must have accurate design drawings from concrete manhole manufacturer prior to completion of design. When practical, procure manhole with no holes and have concrete cutter come out and drill holes after manhole placement. 4) Recommended to BaySaver that they construct unit with multiple attachment points for sling or rope connection. Must backfill up to bottom of BaySaver position to provide support prior to grouting. 5) When storms are likely system to divert water around excavation or drain it quickly must be included in the design. 6) All concrete manhole joints that will be below the normal water level must be sealed with two runs of tar between the sections and the external and internal joints grouted prior to completion of installation. Internal and external sealing should include all pipe penetrations.

Table 3 Summary of Significant Observations During Installation (con't)

Unit	Significant Observations During Installation	Lessons Learned
Eco-Sep	1) Manholes (7 ft. inside diameter) were delivered with wrong hole orientation, and were 4 inches shorter than design 2) Precise placement of large concrete manholes was very difficult even though a crane of sufficient size and capacity was used and installation was performed by experienced vendor. 3) Catch basin in roadway at head of system was displaced, apparently by heavy truck traffic	1) Must have accurate design drawings from concrete manhole manufacturer prior to completion of design. When practical, procure manhole with no holes and have concrete cutter come out and drill holes after manhole placement. 2) Design of layout of multiple large concrete manholes must be flexible to reduce need for precise placement. Much easier to place manholes at approximate positions and adjust connections. Use of HDPE manholes should be considered when practical. 3) Any units that are installed in a traffic area should either be designed and installed to tolerate extreme loads or surrounded by bollards or other traffic restriction device to prevent damage.
PBM	1) Difficulty in locating underground electrical line suspected to be in excavation area. Drawings were unreliable and utility had difficulty in tracing line. 2) Attempted to place unit directly from truck into excavation because site was immediately adjacent to roadway. Unit was placed successfully but clearly at limits of delivery truck mounted crane	1) Facility drawings are unreliable source of utility information. Utility clearances should be obtained before design is completed. 2) Truck mounted cranes should not be used for unit placement. Design needs to ensure practical access to excavation for crane and crane needs to be of sufficient size and capacity to place manholes.
Aqua-Swirl	1) Utility line was almost 6 ft. from position indicated by drawings and utility clearance. 2) Large diameter (10 ft. I.D.) HDPE unit was much easier to set in place than similar sized concrete unit.	1) Design should stay has far away as possible from underground utilities. When forced to excavated with 10 ft. of underground utility locations, digging should proceed slowly with multiple spotters watching for signs of utilities. 2) Use of HDPE should be considered for incorporation into all designs of all units.

Table 3 Summary of Significant Observations During Installation (con't)

Unit	Significant Observations During Installation	Lessons Learned
Bay Saver (Smith Co.)	1) Poorly compacted bedding material around original storm sewer installation led to unplanned exposure of water line and removal of more section of storm sewer pipe than was originally planned. 2) Precise alignment of concrete manholes (5 ft. I.D.) was difficult due to layout of site and orientation of existing stormsewer. 3) Pipes from primary manhole to storage manhole were dislodged during backfilling 4) Storage manhole was observed not to be holding water immediately after installation.	1) Excavations should begin at farthest point from existing storm sewer and work towards the potential problems with soil conditions evaluated continuously by qualified individual. 2) Methods to handle and adjust large concrete manholes must be improved to allow easier alignment. Design flexibility should reduce need for precise emplacement. 3) Are under BaySaver unit and piping to storage manhole must be carefully bedded prior to emplacement to provide sufficient and complete support along their full lengths to these components prior to mechanical backfilling. 4) Connections to piping from primary manhole were probably damaged during backfilling. All concrete manhole joints and pipe penetrations that will be below the normal water level must be sealed at the external and internal connection points by grouting prior to completion of installation.

Installing these units was a learning experience for all involved, including most of the vendors. Typically these units have been installed only for new construction, and installation as a retrofit to an existing stormwater management system is apparently an unusual application for these devises. By far the most significant lessons learned from these experiences was to perform a thorough site reconnaissance prior to the design (not just immediately prior to construction) to be aware of and incorporate geologic and man-made features of the site into the installation design; and to have sufficient flexibility in the installation design to allow minor adjustments to unit locations and positioning be made as adverse conditions are encountered without having to make major changes in the overall layout.

Based on the installation experience, and the operation of the units over the past year, the perceived advantages and disadvantages of each unit are summarized in Table 4.

Table 4 Summary of Observed Advantages and Disadvantages of Each Treatment Units

Unit	Original Rationale for Selection	Observed Advantages of System	Observed Disadvantages of System	General Comments
ADS	1) HDPE construction with low horizontal profile to reduce excavation depth; 2) Unique design, no other similar systems on market; 3) Oil and sediment separation methods very technically sound	1) HDPE allows easy handling of components; 2) Capital cost of system is relatively low	1) Length of system requires a lot of room and excavation 2) Multiple sections produce many joints subject to leakage 3) Connecting large diameter pipe more difficult than it appears and definitely requires experienced installers 4) Requires high flow diversion structure 5) Poor vendor support	1) System should be considered where depth of excavation needs to be minimized but there is sufficient areal space. 2) Connection and seal design between pipe sections needs improvement. 3) Installation should only be attempted by experienced crew.
CDS	System was installed prior to this project, rationale unknown	1) Technically well developed design 2) Good vendor support	1) Single manhole design raises concerns of captured contaminants being remobilized during peak storm events 2) Cost of unit appears relatively high	This is a system that definitely needs performance monitoring to verify that it functions to a level that justifies its price
BaySaver	1) Unique design, no similar systems on market 2) High treated flow capacity	1) Two manhole design prevents remobilization of captured contaminants 2) Does not require high flow diversion structure 3) Reasonably priced 4) Good vendor support	1) Use of large concrete manholes makes installation difficult 2) Relatively large depth and width of excavation	1) System should be considered where high treated flow capacity is needed, but space and depth of excavation are not a problem 2) Need to consider developing unit design which eliminates concrete manholes and goes to all HDPE construction

Table 4 Summary of Observed Advantages and Disadvantages of Each Treatment Units

Unit	Original Rationale for Selection	Observed Advantages of System	Observed Disadvantages of System	General Comments
Eco-Sep	1) Unique design, no similar systems on market 2) Oil recovery system design technically advanced	1) Oil recovery good 2) Good vendor support	1) Small treated flow capacity 2) Use of large concrete manholes makes installation difficult 3) Oil collection system easily clogged by vegetation 4) Cost of unit appears relatively high	1) System should only be considered where there is high spill potential and/or high level oil recovery is needed 2) Installation should only be attempted by experienced crew.
PBM	1) Considered representative example of common baffle box design used by many vendors	1) Easy installation 2) Excavation depth and width requirements relatively small 3) Does not require high flow diversion structure 4) Reasonably priced 5) Good vendor support	1) Single structure design raises concerns of captured contaminants being remobilized during peak storm events 2) Low oil storage capacity relative to other units 3) Complicated baffle and weir system may require increased maintenance and monitoring	1) This is a system that definitely needs performance monitoring to verify that its contaminant removal and retention levels are acceptable. 2) Evaluated other baffle box designs and vendors and this appears to be the best
Aqua-Swirl	1) Unique design, no similar systems on market 2) All HDPE construction	1) HDPE allows easy handling of components and ease of installation 2) Simple internal design should allow easy cleanout 3) Good vendor support	1) Single structure design raises concerns of captured contaminants being remobilized during peak storm events 2) Requires high flow diversion structure	This is a system that definitely needs performance monitoring to verify that its contaminant removal and retention levels are acceptable.

Many design and construction issues arose that were common to all installations. Table 5 summarizes these issues and the lessons learned.

Table 5 Summary of Common Design and Construction Related Issues

Construction Issue	Description of Problem or Concern	Lessons Learned
Sediment and Erosion Control	Although treatment unit installations do not disturb a sufficient soil area to trigger stormwater regulations regarding soil and erosion control, concerns were expressed that the installation jobs did not comply with regulations	All treatment unit installations will install basic sediment and erosion control structures around disturbed areas and soil piles.
ARAP Permitting	Treatment unit installations can be performed under an ARAP general permit that does not require documentation or notification of TDEC, however concerns were expressed that the installation jobs did not comply with regulations	A design package should be developed and distributed prior to the start of installation. This package should include a discussion of plans for sediment and erosion control and include a copy of the ARAP General Permit that will be followed for the installation
Pre-Design Site Reconnaissance	Site conditions were frequently very different then indicated by available information. Most facilities were built on fill, but conditions would change radically after excavations reached depths below the surface fill.	A site reconnaissance of the proposed treatment unit installation location should be conducted prior to selection of the type of unit and completion of the design. The review should include utility clearances and review of geologic maps and any subsurface information that might be available to quantify probable conditions. Test excavations should be performed where a potential for a significant problem is identified or where there is no reliable information on subsurface conditions
Utility Interferences	Facility drawings and utility clearances were unreliable in identifying the actual location of underground utilities	Installation design should stay has far away as possible from underground utilities. When forced to excavated with 10 ft. of underground utility locations, digging should proceed slowly with multiple spotters watching for signs of utilities.

Table 5 Summary of Common Design and Construction Related Issues (con't)

Construction Issue	Description of Problem or Concern	Lessons Learned
Soil and Rock Conditions	Unexpected conditions such as shallow bedrock, unstable soils, groundwater intrusion, and underground utilities were encountered at almost all of the installations	When difficult site conditions hinder installation, consideration should be given to reorienting the unit away from the problem or extending the storm sewer pipe to a better installation location
Concrete Manhole Dimensions	Dimensions of concrete manholes frequently differed from what was anticipated from the design.	Manholes drawings with full dimensions need to be provided by the manhole vendor prior to completion of the design
Confined Space Entry	Entrance into a treatment unit is not a permit required confined space entry under OSHA regulations, however concerns were expressed that the installation jobs did not comply with regulations	For any installations that may require a confined space entry situation, the design package will include a discussion of the requirements and the approach that will be taken to ensure safe practice.
General Health and Safety Concerns	There have been no OSHA reportable injuries or lost time accidents on any of the installation efforts, however were some "close calls" that raised health and safety concerns	A health and safety plan should be prepared for each installation identifying the major hazards and steps to prevent problems. The plan should be reviewed with all installation personnel.
Off-loading of Concrete Manholes	At many of the installations the concrete manholes were off-loaded from the delivery truck using a Trachoe or truck mounted crane and the lifting capacity of the equipment appeared to close to being exceeded	The concrete manhole supplier should provide actual weights of the components along with the design drawing. Knowing this weight during the design phase should allow an informed decision as to whether it will be necessary to have a crane on-site and if so, the capacity of the crane.

Prior to the selection of the units for installation, many other vendors were contacted for a review of their products. Table 6 identifies all of the other units that were evaluated and discusses why they were not selected for use in this set of installations.

Table 6 Summary of Other Stormwater Treatment Units not Selected for Installation

Product	Description	Max. Flow or Area Treated	Reason Not Selected for Installation
Downstream Defender	Single precast concrete cylindrical vessel, with conical bottom for sediment collection. Tangential inlet pipe produces rotational flow. Floatables are collected in central shaft unit.	13 cfs	1) Technically similar to other units 2) Single structure design raises concerns of captured contaminants being remobilized during peak storm events 3) Concern about access for cleaning
Stormwater Management StormFilter	Precast concrete box with multiple filtration canisters	Modular – depends on length	1) Treated flow capacity to low for most TDOT applications 2) Treated flow capacity low relative to physical size of unit 3) Requires separate high flow diversion structure 4) Contaminant removal capabilities greatly exceed that needed for most TDOT applications
StormGate Separator	Single precast concrete box with three internal settling chambers and baffles	4.1	5) Treated flow capacity to low for most TDOT applications 6) Requires separate high flow diversion structure 3) Single structure design raises concerns of captured contaminants being remobilized during peak inflow
Suntree Technologies Baffle Box	Rectangular precast concrete vault with multiple internal baffles and trash screen	42 cfs	1) Technically similar to other units 2) Limited oil collection capacity 3) Significantly more expensive than other similar units
Vortechnics	Precast or cast in place concrete box with internal cylindrical grit chamber to settle solids and baffles to separate oil/floatables	25 cfs	Technically interesting but could not justify cost

Table 6 Summary of Other Stormwater Treatment Units not Selected for Installation (con't)

Product	Description	Max. Flow or Area Treated	Reason Not Selected for Installation
V2B1	Two separate cylindrical chambers of precast concrete with the initial chamber using a vortex action to collect floatables and baffled second chamber to separate solids.	25 cfs	Contacted vendor with regard to use on future product but had difficulty coming to a mutually agreeable design
Stormceptor	Single precast concrete or fiberglass cylindrical vessel with three internal chambers.	2.5 cfs	1) Treated flow capacity low relative to physical size of unit 2) Single structure design raises concerns of captured contaminants being remobilized during peak storm events 3) Concern about access for cleaning
Stormvault	Rectangular precast concrete vault with multiple internal baffles and trash screen	Modular – depends on length	Technically similar to other units
GPRS Separator	Single precast concrete manhole with internal swirl concentrator	Not Specified	Developmental unit without widespread application
Highland Interceptor Tank	Cylindrical steel tank with internal baffles	11 cfs	Technically similar to other units

There are a number of other manufacturers that produce a wide variety of catch basin treatment systems. This class of treatment system was not reviewed extensively because of their limited flow capacity and need for frequent maintenance limited their general applicability to TDOT facility conditions. Additional types of treatment units are coming on to the market on a regular basis and this survey should be updated several times per year.

CONCLUSIONS

1. **One size does not fit all**: Vendors will be glad to sell you their unit for any application and show you reams of information as to why there system is the best, but every type of unit has its advantage and disadvantages and will work well in some places and poorly in others. Many organizations (e.g. EPA, ASTM) are trying to establish testing standards to introduce some controls and consistency into the evaluation of these devices, but currently there is little information that is wholly reliable, except information aquired from direct experience by a reliable source.

2. **Every site is the same and every site is different:** Although most stormsewer systems are essentially the same, and most TDOT facilities house fairly similar operations, each application will have unique features that will impact the system to be used and the installation methodology. A thorough pre-design site evaluation is essential. Encountering unexpected site conditions should be factored into all planning. Installation personnel must have sufficient training and experience to be able to respond and adapt to unexpected conditions.

3. **Know what you need and know what you are getting:** The stormwater treatment industry is very young and there are no universal standards for design specifications and nomenclature. Information on system design basis and specifications from vendors must be carefully reviewed to verify that they have not slanted the data on such things as drainage area, design basis rain event data, or treated flow rate to be more favaorable to their units capabilities. Vendors will frequently try to sell you a smaller unit then you need to appear more price competitive. Most vendors will offer to perform an installation design for their product based on your site specifications, but you must do your own independent design to verify their findings.

4. **Experience is the Best Teacher:** Installation of these stormwater treatments units, especially in a retrofit situation, will invariably present some unique and challenging problems. Most vendor information is heavy on marketing and light on coldly accurate data. Few installations will actually be completed exactly as planned and problems will arise (both substantive problems and perceptual problems from outside observers). The only way to evaluate and really understand the utility of these units is to actually perform or observe an installation and monitor the system's operation.

APPENDIX A

PHOTOGRAPHS AND DESIGN DRAWINGS OF EACH UNIT

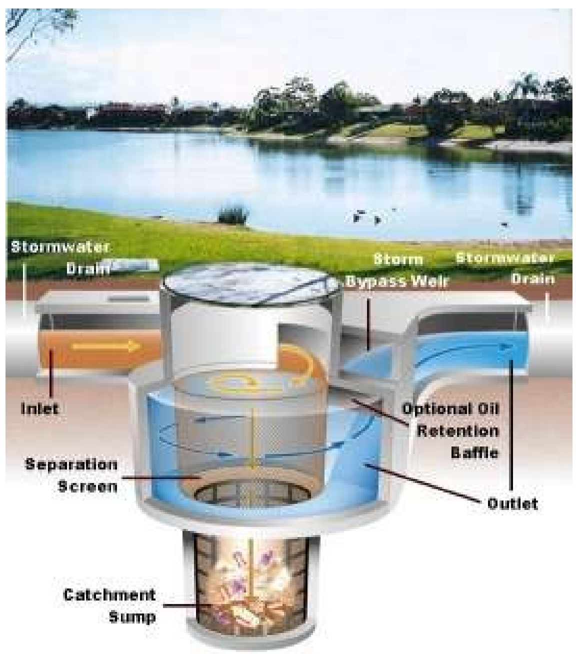
Advanced Drainage Systems (ADS) Water Quality Unit

Royal Environmental Eco Sep Oil and Water Separator

BaySaver Separation System (Nashville)

Continuous Deflective Separation (CDS)


CLEARWATER
CDS
TECHNOLOGIES
5-25-01
SD
CDS
PSW-50-50
CLEARWATER
PATENT NO
5,788,848


Stormwater
Drain
Storm
Bypass Weir
Stormwater
Drain
Inlet
Optional Oil
Retention
Baffle
Separation
Screen
Outlet
Catchment
Sump

Crystalstream (PBM) Oil/Grit Separator

Aquaswirl Concentrator


PC200LC

BaySaver Separation System (Smith Co.)


SDC1-1
SD


VIKING
BAY-1A
9-03-03

Appendix B: U.S. EPA Fact Sheets

(Provided in alphabetical order by BMP)

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Alternative Pavers

Click here to comment on this fact sheet

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

Subcategory: Innovative BMPs for Site Plans

Description

Alternative pavers are permeable surfaces that can replace asphalt and concrete and can be used for driveways, parking lots, and walkways. From a stormwater perspective, this is important because alternative pavers can replace impervious surfaces, creating less storm-water runoff. The two broad categories of alternative pavers are paving blocks and other surfaces, including gravel, cobbles, wood, mulch, brick, and natural stone. While porous pavement is an alternative paver, as an engineered stormwater management practice it is discussed in detail in the Porous Pavement fact sheet.

One type of alternative paver consists of a concrete lattice structure for support with grass growing in the void spaces (Source: Lo Gioco Landscaping, Inc., no date)

Paving Blocks

Paving blocks are concrete or plastic grids with gaps between them. Paving blocks make the surface more rigid and gravel or grass planted inside the holes allows for infiltration. Depending on the use and soil types, a gravel layer can be added underneath to prevent settling and allow further infiltration.

Other Alternative Surfaces

Gravel, cobbles, wood, and mulch also allow varying degrees of infiltration. Brick and natural stone arranged in a loose configuration allow for some infiltration through the gaps. Gravel and cobbles can be used as driveway material, and wood and mulch can be used to provide walking trails.

Applicability

Alternative pavers can replace conventional asphalt or concrete in parking lots, driveways, and walkways. At the same time, traffic volume and type can limit application. For this reason, alternative pavers for parking are recommended only for overflow areas. In residential areas, alternative surfaces can be used for driveways and walkways, but are not ideal for areas that require handicap accessibility.

Siting and Design Criteria

Accessibility, climate, soil type, traffic volume, and long-term performance should be considered, along with costs and stormwater quality controls, when choosing paving materials. Use of alternative pavers in cold climates will require special consideration, as snow shovels are not practical for many of these surfaces. Sand is particularly troublesome if used with paving blocks, as the sand that ends up between the blocks cannot effectively wash away or be removed. In addition, salt used to de-ice can also infiltrate directly into the soil and cause potential ground water pollution.

Soil types will affect the infiltration rates and should be considered when using alternative pavers. Clayey soils (D soils) will limit the infiltration on a site. If ground water pollution is a concern, use of alternative pavers with porous soils should be carefully considered.

The durability and maintenance cost of alternative pavers also limits use to low-traffic-volume areas. At the same time, alternative pavers can abate stormwater management costs. Used in combination with other better-site-design techniques, the cumulative effect on stormwater can be dramatic.

Limitations

Alternative pavers are not recommended for high-traffic volumes for durability reasons. Access for wheelchairs is limited with alternative pavers. In addition, snow removal is difficult since plows cannot be used, sand can cause the system to clog, and salt can be a potential pollutant.

Maintenance Considerations

Alternative pavers require periodic maintenance, and costs increase when the permeable surface must be restored.

Effectiveness

The most obvious benefit of utilizing alternative pavers includes reduction or elimination of other stormwater management techniques. Applied in combination with other techniques such as bioretention and green parking, pollutant removal and stormwater management can be further improved. (see Bioretention (Rain Gardens) and Green Parking fact sheets for more information.)

Alternative pavers provide better water quality improvement than conventional asphalt or concrete, and the range of improvement depends on the type of paver used. Table 1 provides a list of pavers and the range of water quality improvement achievable by different types of alternative pavers.

Table 1. Water quality improvement of various pavers (Source: BASMAA, 1997)

Material	Water Quality Effectiveness
Conventional Asphalt/ Concrete	Low
Brick (in a loose configuration)	Medium
Natural Stone	Medium

Gravel	High
Wood Mulch	High
Cobbles	Medium

Cost Considerations

The range of installation and maintenance costs of various pavers is provided in Table 2. Depending on the material used, installation costs can be higher or lower for alternative pavers than for conventional asphalt or concrete, but maintenance costs are almost always higher.

Table 2. Installation and maintenance costs for various pavers (Source: BASMAA, 1997)

Material	Installation Cost	Maintenance Cost
Conventional Asphalt/Concrete	Medium	Low
Brick (in a loose configuration)	High	Medium
Natural Stone	High	Medium
Gravel	Low	Medium
Wood Mulch	Low	Medium
Cobbles	Low	Medium

Reference

Bay Area Stormwater Management Agencies Association (BASMAA). January 1997. *Start at the Source: Residential Site Planning and Design Guidance Manual for Stormwater Quality Protection*. BASMAA, San Francisco, CA.

Information Sources

Brown, W.E., D.S. Caraco, R.A. Claytor, P.M. Hinkle, H.Y. Kwon, and T.R. Schueler. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection, Inc., Ellicott City, MD.

Schueler, T.R. *1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R. 1983. *Urban Runoff in the Washington Metropolitan Area*. Metropolitan Washington Council of Governments, Washington, DC.

Smith, D.R. 1981. *Life Cycle and Energy Comparison of Grass Pavement and Asphalt Based on Data and Experience from the Green Parking Lot*. The Heritage Conservation and Recreation Service.

Smith, D.R., and D.A. Sholtis. 1981. *An Experimental Installation of Grass Pavement*. The Heritage Conservation and Recreation Service.

Click here to comment on this fact sheet

Last updated on May 24, 2006

URL:http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Alternative Turnarounds

Click here to comment on this fact sheet

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

Subcategory: Innovative BMPs for Site Plans

Description

Rather than having a fully paved cul-de-sac bulb, site designers can incorporate pervious circles with vegetation that reduce the site's overall impervious area

Alternative turnarounds are end-of-street vehicle turnarounds that reduce impervious cover in neighborhoods by replacing cul-de-sacs. Cul-de-sacs are local access streets with closed circular ends that allow for vehicle turnarounds. Many cul-de-sacs have radiuses of more than 40-feet. From a stormwater perspective, cul-de-sacs create a huge bulb of impervious cover that increases the amount of stormwater runoff. Reducing the size of cul-de-sacs, either though the use of alternative turnarounds or by eliminating them altogether, can reduce the amount of impervious cover created at the site.

There are numerous alternatives to the traditional 40-foot cul-de-sac, all of which reduce impervious cover. One alternative reduces cul-de-sacs to a 30-foot radius. Others create hammerheads, loop roads, and pervious islands in the cul-de-sac's center.

Applicability

Alternative turnarounds can be applied in the design of residential, commercial, and mixed-use developments. Combined with alternative pavers, green parking, curb elimination, bioretention, and other techniques, the total reduction to site impervious cover can be dramatic, reducing the amount of stormwater runoff from the site. With proper designs, much of the remaining stormwater can be treated on site. For instance, a rain garden can be placed in a pervious island. Doing so will reduce impervious cover and treat stormwater from neighboring impervious areas.

Implementation

Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering into the cul-de-sac should be considered. Fire trucks, service vehicles, and school buses are often cited as examples for increased turning radii. However, research shows that some fire trucks are designed for smaller turning radii. In addition, many new larger service vehicles are designed using a tri-axle, and school buses usually do not enter individual cul-de-sacs.

Implementation of alternative turnarounds will also have to address local regulations and marketing issues. Communities may have specific design criteria for cul-de-sacs and other alternative turnarounds. Also, although cul-de-sacs are often featured as highly marketable, actual research on market preference is not widely available.

Limitations

Local regulations often dictate requirements for turnaround dimensions, and local codes may not allow some of the alternatives. In addition, marketing perceptions may also dictate designs, particularly in residential areas. While changing local codes is no small effort, by initiating a local site-planning roundtable, communities can change some of these regulations through a cluster ordinance or through a collective effort to review local codes to promote better site design.

Maintenance Considerations

If islands are constructed as part of a turnaround, they will need to be maintained. Kept as a natural area, the costs could be minimal. Bioretention areas will also require maintenance. The other options create less asphalt to repave, and maintenance will remain the same and cost less.

Effectiveness

Comparisons of several types of turnarounds found that hammerheads create the least amount of impervious cover, as shown in Table 1.

Table 1. Impervious cover created by each turnaround option (Schueler, 1995)

Turnaround Option	Impervious Area (square feet)
40-foot radius	5,024
40-foot radius with island	4,397
30-foot radius	2,826
30-foot radius with island	2,512
Hammerhead	1,250

Costs

Alternative turnarounds reduce impervious cover. Consequently, they also reduce construction costs (asphalt alone costs $0.50-$1.00 per square foot). At an estimated $6.40 per cubic foot, bioretention costs more than providing naturally vegetated areas, but it can help reduce overall stormwater management costs.

Information Resources

American Society of Civil Engineers, National Association of Home Builders, and Urban Land Institute. 1990. *Residential Streets* (2nd edition). Urban Land Institute, Washington, DC.

Brown, W.E., D.S. Caraco, R.A. Claytor, P.M. Hinkle, H.Y. Kwon, and T.R. Schueler. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection, Inc., Ellicott City, MD.

Bucks County Planning Commission. 1980. *Performance Streets: A Concept and Model Standards for Residential Streets*. Bucks County Planning Commission, Doylestown, PA.

Institute of Transportation Engineers. 1993. *Guidelines for Residential Subdivision Street Design*. Institute of Transportation Engineers, Washington, DC.

Schueler, T. 1995. *Site Planning for Urban Stream Protection*. Metropolitan Washington Council of Governments, Washington, DC.

Click here to comment on this fact sheet

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

Bioretention (Rain Gardens)

Click here to comment on this fact sheet

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

Subcategory: Filtration

Description

Bioretention areas can be used in parking areas to collect and treat stormwater (Source: University of Maryland, 2000)

Bioretention areas, or rain gardens, are landscaping features adapted to provide on-site treatment of stormwater runoff. They are commonly located in parking lot islands or within small pockets of residential land uses. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. During storms, runoff ponds above the mulch and soil in the system. Runoff from larger storms is generally diverted past the facility to the storm drain system. The remaining runoff filters through the mulch and prepared soil mix. The filtered runoff can be collected in a perforated underdrain and returned to the storm drain system.

Applicability

Bioretention systems are generally applied to small sites and in a highly urbanized setting. Bioretention can be applied in many climatological and geologic situations, with some minor design modifications.

Regional Applicability

Bioretention systems are applicable almost everywhere in the United States. In arid or cold climates, however, some minor design modifications may be needed.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Bioretention facilities are ideally suited to many ultra-urban areas, such as parking lots. While they consume a fairly large amount of space (approximately 5 percent of the area that drains to them), they can be fit into existing parking lot islands or other landscaped areas.


Bioretention area in a residential subdivision

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 or convenience store parking lot. Bioretention areas can be used to treat stormwater hot spots as long as an impermeable liner is used at the bottom of the filter bed.

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. Bioretention can be used as a stormwater retrofit, by modifying existing landscaped areas, or if a parking lot is being resurfaced. In highly urbanized areas, this is one of the few retrofit options that can be employed. However, it is expensive to retrofit an entire watershed or subwatershed using stormwater management practices designed to treat small sites.

Cold Water (Trout) Streams

Some species in cold water streams, notably trout, are extremely sensitive to changes in temperature. In order to protect these resources, designers should avoid treatment practices that increase the temperature of the stormwater runoff they treat. Bioretention is a good option in cold water streams because water ponds in them for only a short time, decreasing the potential for stream warming. Furthermore, bioretention cells have been shown to decrease the temperature of runoff from certain land uses, such as parking lots.

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

Some considerations for selecting a stormwater management practice are the drainage area the practice will need to treat, the slopes both at the location of the practice and the drainage area, soil and subsurface conditions, and the depth of the seasonably high ground water table. Bioretention can be applied on many sites, with its primary restriction being the need to apply the practice on small sites.

<u>Drainage Area</u>

Bioretention areas should usually be used on small sites (i.e., 5 acres or less). When used to treat larger areas, they tend to clog. In addition, it is difficult to convey flow from a large area to a bioretention area.

Slope

Bioretention areas are best applied to relatively shallow slopes (usually about 5 percent). However, sufficient slope is needed at the site to ensure that water that enters the bioretention area can be connected with the storm drain system. These stormwater management practices are most often applied to parking lots or residential landscaped areas, which generally have shallow slopes.

Soils/Topography

Bioretention areas can be applied in almost any soils or topography, since runoff percolates through a man-made soil bed and is returned to the stormwater system.

Ground Water

Bioretention should be separated somewhat from the ground water to ensure that the ground water table never intersects with the bed of the bioretention facility. This design consideration prevents possible ground water contamination.

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 bioretention area designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment refers to features of a management practice that cause coarse sediment particles and their associated pollutants to settle. Incorporating pretreatment helps to reduce the maintenance burden of bioretention and reduces the likelihood that the soil bed will clog over time. Several different mechanisms can be used to provide pretreatment in bioretention facilities. Often, runoff is directed to a grass channel or filter strip to filter out coarse materials before the runoff flows into the filter bed of the bioretention area. Other features may include a pea gravel diaphragm, which acts to spread flow evenly and drop out larger particles.

Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. Several basic features should be incorporated into bioretention designs to enhance their pollutant removal. The bioretention system should be sized between 5 and 10 percent of the impervious area draining to it. The practice should be designed with a soil bed that is a sand/soil matrix, with a mulch layer above the soil bed. The bioretention area should be designed to pond a small amount of water (6-9 inches) above the filter bed.

Conveyance

Conveyance of stormwater runoff into and through a stormwater practice is a critical component of any stormwater management plan. Stormwater should be conveyed to and from practices safely and to minimize erosion potential. Ideally, some stormwater treatment can be achieved during conveyance to and from the practice.

Bioretention practices often are designed with an underdrain system to collect filtered runoff at the bottom of the filter bed and direct it to the storm drain system. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of the filter bed. Designers should provide an overflow structure to convey flow from storms that are not treated by the bioretention facility to the storm drain.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of stormwater practices, some design features can be incorporated to reduce the required maintenance of a practice. Designers should ensure that the bioretention area is easily accessible for maintenance.

Landscaping

Landscaping is critical to the function and aesthetic value of bioretention areas. It is preferable to plant the area with native vegetation, or plants that provide habitat value, where possible. Another important design feature is to select species that can withstand the hydrologic regime they will experience. At the bottom of the bioretention facility, plants that tolerate both wet and dry conditions are preferable. At the edges, which will remain primarily dry, upland species will be the most resilient. Finally, it is best to select a combination of trees, shrubs, and herbaceous materials.

Design Variations

One design alternative to the traditional bioretention practice is the use of a "partial exfiltration" system, used to promote ground water recharge. Other design modifications may make this practice more effective in arid or cold climates.

Partial Exfiltration

In one design variation of the bioretention system, the underdrain is only installed on part of the bottom of the bioretention system. This design alternative allows for some infiltration, with the underdrain acting as more of an overflow. This system can be applied only when the soils and other characteristics are appropriate for infiltration (see Infiltration Trench and Infiltration Basin).

Arid Climates

In arid climates, bioretention areas should be landscaped with drought-tolerant species.

Cold Climates

In cold climates, bioretention areas can be used as snow storage areas. If used for this purpose, or if used to treat runoff from a parking lot where salt is used as a deicer, the bioretention area should be planted with salt-tolerant, nonwoody plant species.

Limitations

Bioretention areas have a few limitations. Bioretention areas cannot be used to treat a large drainage area, limiting their usefulness for some sites. In addition, although the practice does not consume a large amount of space, incorporating bioretention into a parking lot design may reduce the number of parking spaces available if islands were not previously included in the design.

Maintenance Considerations

Bioretention requires landscaping maintenance, including measures to ensure that the area is functioning properly, as well as maintenance of the landscaping on the practice. In many cases, bioretention areas initially require intense maintenance, but less maintenance is needed over time. In many cases, maintenance tasks can be completed by a landscaping contractor, who may already be hired at the site. Landscaping maintenance requirements can be less resource intensive than with traditional landscaping practices such as elevated landscaped islands in parking areas.

Table 1. Typical maintenance activities for bioretention areas (Source: ETA and Biohabitats, 1993)

Activity	**Schedule**
• Remulch void areas • Treat diseased trees and shrubs • Mow turf areas	As needed
• Water plants daily for 2 weeks	At project completion
• Inspect soil and repair eroded areas • Remove litter and debris	Monthly
• Remove and replace dead and diseased vegetation	Twice per year
• Add mulch • Replace tree stakes and wires	Once per year

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.

Flood Control

Bioretention areas are not designed to provide flood control. They can, however, divert initial flow which will aid in maintaining pre-development hydrology.

Channel Protection

Bioretention areas are generally not designed to provide substantial channel protection because at the scale at which they are typically installed they are not able to infiltrate large volumes. (They are typically designed to treat and infiltrate the first inch of runoff and are bypassed by larger flows that can erode channels.) Channel protection would be best reached by using bioretention cells in combination with other means, such as ponds or other volume control practices.

Ground Water Recharge

Bioretention areas do not usually recharge the ground water, except in the case of the partial exfiltration design (see Design Variations).

Pollutant Removal

Little pollutant removal data have been collected on the pollutant removal effectiveness of bioretention areas. A field and laboratory analysis of bioretention facilities conducted by Davis et al. (1997), showed very high removal rates (roughly 95 percent for copper, 98 percent for phosphorus, 20 percent for nitrate, and 50 percent for total Kjeldhal nitrogen (TKN). Table 2 shows data from two other studies of field bioretention sites in Maryland.

Table 2. Pollutant removal effectiveness of two bioretention areas in Maryland.

Pollutant	**Pollutant Removal**
Copper	43%-97%
Lead	70%-95%
Zinc	64%-95%
Phosphorus	65%-87%
Total Kjeldahl Nitrogen (TKN)	52-67%
Ammonium (NH_4^+)	92%
Nitrate (NO_3^-)	15%-16%
Total nitrogen (TN)	49%
Calcium	27%

Assuming that bioretention systems behave similarly to swales, their removal rates are relatively high.

There is considerable variability in the effectiveness of bioretention areas, and it is believed that properly designing and maintaining these areas 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 bioretention areas. A joint project of the American Society of Civil Engineers (ASCE) and the 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 might be made. More information on this database is accessible on the BMP database EXIT Disclaimer.

Cost Considerations

Bioretention areas can vary from being relatively inexpensive to expensive. 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 for bioretention areas, adjusting for inflation:

$C = 7.30\ V^{0.99}$

where:

C = Construction, design, and permitting cost ($); and

V = Volume of water treated by the facility (ft^3).

An important consideration when evaluating the costs of bioretention is that this practice replaces an area that most likely would have been landscaped. Furthermore, the use of bioretention areas may reduce the need for other BMPs that require large tracts of contiguous land. Thus, the true cost of the practice is less than the construction cost reported. Similarly, maintenance activities conducted on bioretention areas are not very different from maintenance of a landscaped area; however, bioretention areas may actually lower utility costs by requiring less watering than similarly landscaped areas. The land consumed by bioretention areas is relatively high compared with other practices (about 5 percent of the drainage area). Again, this area should not be considered lost, since the practice may be the same size or only slightly larger than a traditional landscaped area. Finally, bioretention areas can improve upon existing landscaping and are often an aesthetic benefit.

References

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection. Ellicott City, MD.

Davis, A., M. Shokouhian, H. Sharma, and C. Henderson. 1997. *Bioretention Monitoring-Preliminary Data Analysis*. Environmental Engineering Program of the University of Maryland, College Park, MD.

Engineering Technologies Associates and Biohabitats. 1993. *Design Manual for Use of Bioretention in Stormwater Management*. Prepared for Prince George's County Government, Watershed Protection Branch, Landover, MD.

Schueler, T. 1997. Comparative Pollutant Removal Capability of Urban BMPs: A Reanalysis. *Watershed Protection Techniques* 2(4): 515-520.

Information Resources

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 16, 2005.

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates.* Prepared for U.S. Environmental Protection Agency Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems*. Prepared for Chesapeake Research Consortium, Solomons, MD, and USEPA Region V, Chicago, IL.

Prince George's County Department of Environmental Resources. 1997. *Low Impact Development*. Prince George's County Department of Environmental Resources, Largo, MD.

Click here to comment on this fact sheet

URL:http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

Catch Basin Inserts

Click here to comment on this fact sheet

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

Subcategory: Filtration

Description

A worker inserts a catch basin insert for oil and grease, trash, debris, and sediment removal from stormwater as it enters the storm drainage system (Source: Ab Tech Industries, 2001)

Catch basins, also known as storm drain inlets and curb inlets, are inlets to the storm drain system. They typically include a grate or curb inlet and a sump to capture sediment, debris, and pollutants. Catch basins are used in combined sewer overflow (CSO) watersheds to capture floatables and settle some solids, and they act as pretreatment for other treatment practices by capturing large sediments. The effectiveness of catch basins, their ability to remove sediments and other pollutants, depends on its design (e.g., the size of the sump) and on maintenance procedures to regularly remove accumulated sediments from its sump.

Inserts designed to remove oil and grease, trash, debris, and sediment can improve the efficiency of catch basins. Some inserts are designed to drop directly into existing catch basins, while others may require retrofit construction.

Applicability

Though they are used in drainage systems throughout the United States, many catch basins are not ideally designed for sediment and pollutant capture. Catch basins are ideally used as pretreatment to another stormwater management practice. Retrofitting existing catch basins may substantially improve their performance. A simple retrofit option is to ensure that all catch basins have a hooded outlet to prevent floatable materials, such as trash and debris, from entering the storm drain system. Catch basin inserts for both new development and retrofits at existing sites may be preferred when available land is limited, as in urbanized areas.

Limitations

Catch basins have three major limitations:

- Even ideally designed catch basins cannot remove pollutants as well as structural stormwater management practices, such as wet ponds, sand filters, and stormwater wetlands.
- Unless frequently maintained, catch basins can become a source of pollutants through resuspension.
- Catch basins cannot effectively remove soluble pollutants or fine particles.

Siting and Design Considerations

The performance of catch basins is related to the volume in the sump (i.e., the storage in the catch basin below the outlet). Lager et al. (1997) described an "optimal" catch basin sizing criterion, which relates all catch basin dimensions to the diameter of the outlet pipe (D):

- The diameter of the catch basin should be equal to 4D.
- The sump depth should be at least 4D. This depth should be increased if cleaning is infrequent or if the area draining to the catch basin has high sediment loads.
- The top of the outlet pipe should be 1.5 D from the bottom of the inlet to the catch basin.

Catch basins can also be sized to accommodate the volume of sediment that enters the system. Pitt et al.(1997) proposed a sizing criterion based on the concentration of sediment in stormwater runoff. The catch basin is sized, with a factor of safety, to accommodate the annual sediment load in the catch basin sump. This method is preferable where high sediment loads are anticipated, and where the optimal design described above is suspected to provide little treatment.

The basic design should also incorporate a hooded outlet to prevent floatable materials and trash from entering the storm drain system. Adding a screen to the top of the catch basin would not likely improve the performance of catch basins for pollutant removal, but it would help capture trash entering the catch basin (Pitt et al., 1997).

Several varieties of catch basin inserts exist for filtering runoff. There are two basic catch basin insert varieties. One insert option consists of a series of trays, with the top tray serving as an initial sediment trap, and the underlying trays composed of media filters. Another option uses filter fabric to remove pollutants from stormwater runoff. Yet another option is a plastic box that fits directly into the catch basin. The box construction is the filtering medium. Hydrocarbons are removed as the stormwater passes through the box while trash, rubbish, and sediment remain in the box itself as stormwater exits. These devices have a very small volume, compared to the volume of the catch basin sump, and would typically require very frequent sediment removal. Bench test studies found that a variety of options showed little removal of total suspended solids, partially due to scouring from relatively small (6-month) storm events (ICBIC, 1995).

One design adaptation of the standard catch basin is to incorporate infiltration through the catch basin bottom. Two challenges are associated with this design. The first is potential ground water impacts, and the second is potential clogging, preventing infiltration. Infiltrating catch basins should not be used in commercial or industrial areas, because of possible ground water contamination. While it is difficult to prevent clogging at the bottom of the catch basin, it might be possible to incorporate some pretreatment into the design.

Maintenance Considerations

Typical maintenance of catch basins includes trash removal if a screen or other debris capturing device is used, and removal of sediment using a vactor truck.

Operators need to be properly trained in catch basin maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of GIS systems to track sediment collection and to optimize future catch basin cleaning efforts.

One study (Pitt, 1985) concluded that catch basins can capture sediments up to approximately 60 percent of the sump volume. When sediment fills greater than 60 percent of their volume, catch basins reach steady state. Storm flows can then resuspend sediments trapped in the catch basin, and will bypass treatment. Frequent clean-out can retain the volume in the catch basin sump available for treatment of stormwater flows.

At a minimum, catch basins should be cleaned once or twice per year (Aronson et al., 1993). Two studies suggest that increasing the frequency of maintenance can improve the performance of catch basins, particularly in industrial or commercial areas. One study of 60 catch basins in Alameda County, California, found that increasing the maintenance frequency from once per year to twice per year could increase the total sediment removed by catch basins on an annual basis (Mineart and Singh, 1994). Annual sediment removed per inlet was 54 pounds for annual cleaning, 70 pounds for semi-annual and quarterly cleaning, and 160 pounds for monthly cleaning. For catch basins draining industrial uses, monthly cleaning increased total annual sediment collected to six times the amount collected by annual cleaning (180 pounds versus 30 pounds). These results suggest that, at least for industrial uses, more frequent cleaning of catch basins may improve efficiency. However, the cost of increased operation and maintenance costs needs to be weighed against the improved pollutant removal.

In some regions, it may be difficult to find environmentally acceptable disposal methods for collected sediments. The sediments may not always be land-filled, land-applied, or introduced into the sanitary sewer system due to hazardous waste, pretreatment, or ground water regulations. This is particularly true when catch basins drain runoff from hot spot areas.

Effectiveness

What is known about the effectiveness of catch basins is limited to a few studies. Table 1 outlines the results of some of these studies.

Table 1. Pollutant removal of catch basins (percent).

Study	Notes	TSS[a]	COD[a]	BOD[a]	TN[a]	TP[a]	Metals
Pitt et al., 1997	-	32	-		-	-	-
Aronson et al., 1983	Only very small storms were monitored in this study.	60-97	10-56	54-88	-	-	-
Mineart and Singh, 1994	Annual load reduction estimated based on concentrations and mass of catch basin sediment.	-	-	-	-	-	For Copper: 3-4% (Annual cleaning) 15% (Monthly cleaning)

[a] TSS=total suspended solids; COD=chemical oxygen demand; BOD=biological oxygen demand; TN=total nitrogen; TP=total phosphorus

Cost Considerations

A typical pre-cast catch basin costs between $2,000 and $3,000. The true pollutant removal cost associated with catch basins, however, is the long-term maintenance cost. A vactor truck, the most common method of catch basin cleaning, 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. Typical vactor trucks can store between 10 and 15 cubic yards of material, which is enough storage for three to five catch basins with the "optimal" design and an 18-inch inflow pipe. Assuming semi-annual cleaning, and that the vactor truck could be filled and material disposed of twice in one day, one truck would be sufficient to clean between 750 and 1,000 catch basins. Another maintenance cost is the staff time needed to operate the truck. Depending on the regulations within a community, disposal costs of the sediment captured in catch basins may be significant.

Retrofit catch basin inserts range from as little as $400 for a "drop-in" type to as much as $10,000 or more for more elaborate designs.

References

AbTech Industries. 2001. Photo of Catch Basin Insert. AbTech Industries, Scottsdale, AZ.

Aronson, G., D. Watson, and W. Pisaro. *Evaluation of Catch Basin Performance for Urban Stormwater Pollution Control*. U.S. Environmental Protection Agency, Washington, DC.

Interagency Catch Basin Insert Committee (ICBIC). 1995. *Evaluation of Commercially-Available Catch Basin Inserts for the Treatment of Stormwater Runoff from Developed* Sites. Seattle, WA.

Lager, J., W. Smith, R. Finn, and E. Finnemore. 1977. *Urban Stormwater Management and Technology: Update and Users' Guide.* Prepared for U.S. Environmental Protection Agency. EPA-600/8-77-014. 313 pp.

Mineart, P., and S. Singh. 1994. *Storm Inlet Pilot Study*. Alameda County Urban Runoff Clean Water Program, Oakland, CA.

Pitt, R., and P. Bissonnette. 1984. *Bellevue Urban Runoff Program Summary Report*. U.S. Environmental Protection Agency, Water Planning Division, Washington, DC.

Pitt, R., M. Lilburn, S. Nix, S.R. Durrans, S. Burian, J. Voorhees, and J. Martinson. 2000. *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems)*. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Click here to comment on this fact sheet

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Dry Detention Ponds

Click here to comment on this fact sheet

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

Subcategory: Retention/Detention

Description

Photo of a dry detention pond designed to temporarily detain runoff during storm events.

Dry detention ponds (a.k.a. dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins whose outlets have been designed to detain stormwater runoff for some minimum time (e.g., 24 hours) to allow particles and associated pollutants to settle. Unlike wet ponds, these facilities do not have a large permanent pool of water. However, they are often designed with small pools at the inlet and outlet of the basin. They can also be used to provide flood control by including additional flood detention storage.

Applicability

Dry detention ponds have traditionally been one of the most widely used stormwater best management practices. In some instances, these ponds may be the most appropriate best management practice. However, they should not be used as a one size fits all solution. If pollutant removal efficiency is an important consideration then dry detention ponds may not be the most appropriate choice. Dry detention ponds require a large amount of space to build them. In many instances, smaller-sized best management practices are more appropriate alternatives (see Grassed Swales, Infiltration Basin, Infiltration Trench, Porous Pavement, and Bioretention (Rain Gardens), Alternative Pavers, or Green Roofs.

Regional Applicability

Dry detention ponds can be applied in all regions of the United States. Some minor design modifications might be needed, however, in cold or arid climates or in regions with karst (i.e. limestone) topography.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface is present. It is difficult to use dry detention ponds in the ultra-urban environment because of the land area each pond consumes.

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. Dry detention ponds can accept runoff from stormwater hot spots, but they need significant separation from ground water if they will be used for this purpose.

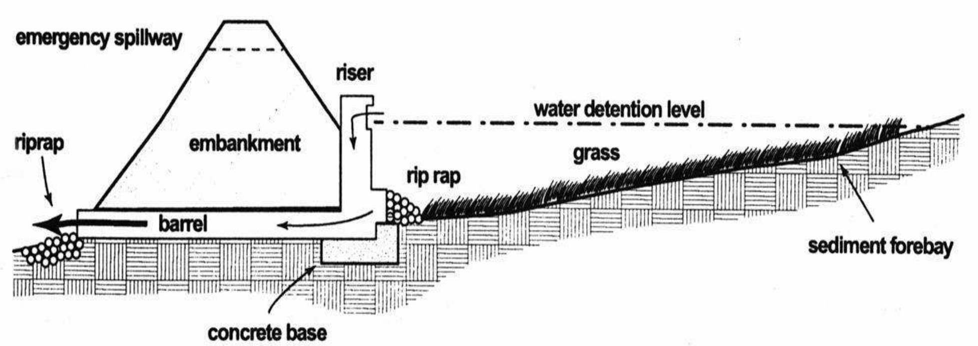
Stormwater Retrofit

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. Dry detention ponds are useful stormwater retrofits, and they have two primary applications as a retrofit design. In many communities in the past, detention basins have been designed for flood control. It is possible to modify these facilities to incorporate features that encourage water quality control and/or channel protection. It is also possible to construct new dry ponds in open areas of a watershed to capture existing drainage.

Cold Water (Trout) Streams

A study in Prince George's County, Maryland, found that stormwater management practices can increase stream temperatures (Galli, 1990). Overall, dry detention ponds increased temperature by about 5°F. In cold w ater streams, dry ponds should be designed to detain stormwater for a relatively short time (i.e., less than 12 hours) to minimize the amount of warming that occurs in the practice. If the temperature of the water is a factor, then alternative best management practices may be more appropriate.

Siting and Design Considerations



Example profile view of a dry pond design.

Siting Considerations

Designers need to ensure that the dry detention pond is feasible at the site in question. This section provides basic guidelines for siting dry detention ponds.

Drainage Area

In general, dry detention ponds should be used on sites with a minimum area of 10 acres. On smaller sites, it can be challenging to provide channel or water quality control because the orifice diameter at the outlet needed to control relatively small storms becomes very small and thus prone to clogging. Low impact development techniques and on-lot treatment controls are recommended for smaller sites.

Slope

Dry detention ponds can be used on sites with slopes up to about 15 percent. The local slope needs to be relatively flat, however, to maintain reasonably flat side slopes in the practice. There is no minimum slope requirement, but there does need to be enough elevation drop from the pond inlet to the pond outlet to ensure that flow can move through the system.

Soils / Topography

Dry detention ponds can be used with almost all soils and geology, with minor design adjustments for regions of karst topography or in rapidly percolating soils such as sand. In these areas, extended detention ponds should be designed with an impermeable liner to prevent ground water contamination or sinkhole formation.

Ground Water

Except for the case of hot spot runoff, the only consideration regarding ground water is that the base of the extended detention facility should not intersect the ground water table. A permanently wet bottom may become a mosquito breeding ground. Research in Southwest Florida (Santana et al., 1994) demonstrated that intermittently flooded systems, such as dry extended detention ponds, produced more mosquitoes than other pond systems, particularly when the facilities remained wet for more than 3 days following heavy rainfall.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. Some features, however, should be incorporated into most dry extended detention 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, which is a small pool (typically about 10 percent of the volume of water to be treated for pollutant removal).

Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. Designing dry ponds with a high length-to-width ratio (i.e., at least 1.5:1) and incorporating other design features to maximize the flow path effectively increases the detention time in the system by eliminating the potential of flow to short-circuit the pond. Designing ponds with relatively flat side slopes can also help to lengthen the effective flow path. Finally, the pond should be sized to detain the volume of runoff to be treated for between 12 and 48 hours.

Conveyance

Conveyance of stormwater runoff into and through the dry pond is a critical component. Stormwater should be conveyed to and from dry ponds safely in a manner that minimizes erosion potential. The outfall of pond systems should always be stabilized to prevent scour. To convey low flows through the system, designers should provide a pilot channel. A pilot channel is a surface channel that should be used to convey low flows through the pond. In addition, an emergency spillway should be provided to safely convey large flood events. To help mitigate the warming of water at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

Regular maintenance activities are needed to maintain the function of stormwater practices. In addition, some design features can be incorporated to ease the maintenance burden of each practice. In dry detention ponds, a "micropool" at the outlet can prevent resuspension of sediment and outlet clogging. A good design includes maintenance access to the forebay and micropool.

Another design feature that can reduce maintenance needs is a non-clogging outlet. Typical examples include 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 determines the water elevation of the micropool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris.

Landscaping

Designers should maintain a vegetated buffer around the pond and should select plants within the extended detention zone (i.e., the portion of the pond up to the elevation where stormwater is detained) that can withstand both wet and dry periods. The side slopes of dry ponds should be relatively flat to reduce safety risks.

Design Variations

Tank Storage

Another variation of the dry detention pond design is the use of tank storage. In these designs, stormwater runoff is conveyed to large storage tanks or vaults underground. This practice is most often used in the ultra-urban environment on small sites where no other opportunity is available to provide flood control. Tank storage is provided on small areas because underground storage for a large drainage area would generally be costly. Because the drainage area contributing to tank storage is typically small, the outlet diameter needed to reduce the flow from very small storms would very small. A very small outlet diameter, along with the underground location of the tanks, creates the potential for debris being caught in the outlet and resulting maintenance problems. Since it is necessary to control small runoff events (such as the runoff from a 1-inch storm) to improve water quality, it is generally infeasible to use tank storage for water quality and generally impractical to use it to protect stream channels.

Regional Variations

Arid or Semi-Arid Climates

In arid and semi-arid regions, some modifications might be needed to conserve scarce water resources. Any landscaping plans should prescribe drought-tolerant vegetation wherever possible. In addition, the wet forebay can be replaced with an alternative dry pretreatment, such as a detention cell. In regions with a distinct wet and dry season, as in many arid regions, regional detention ponds can possibly be used as a recreation area such as a ball field during the dry season.

Cold Climates

In cold climates, some additional design features can help to treat the spring snowmelt. One such modification is to increase the volume available for detention to help treat this relatively large runoff event. In some cases, dry facilities may be an option as a snow storage facility to promote some treatment of plowed snow. If a pond is used to treat road runoff or is used for snow storage, landscaping should incorporate salt-tolerant species. Finally, sediment might need to be removed from the forebay more frequently than in warmer climates (see Maintenance Considerations for guidelines) to account for sediment deposited as a result of road sanding.

Limitations

Although dry detention ponds are widely applicable, they have some limitations that might make other stormwater management options preferable:

- Dry detention ponds have only moderate pollutant removal when compared to other structural stormwater practices, and they are ineffective at removing soluble pollutants (See Effectiveness).
- Dry extended detention ponds may become a nuisance due to mosquito breeding if improperly maintained or if shallow pools of water form for more than 7 days.
- Although wet ponds can increase property values, dry ponds can actually detract from the value of a home (see Cost Considerations).

Dry detention ponds on their own only provide peak flow reduction and do little to control overall runoff volume, which could result in adverse downstream impacts.

Maintenance Considerations

In addition to incorporating features into the pond 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 dry ponds (Source: Modified from WMI, 1997)

Activity	Schedule
• Note erosion of pond banks or bottom	Semiannual inspection
• Inspect for damage to the embankment • 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 • Mow side slopes • Manage pesticide and nutrients • Remove litter and debris	Standard maintenance
• Seed or sod to restore dead or damaged ground cover	Annual maintenance (as needed)
• Remove sediment from the forebay	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pond volume has been reduced by 25 percent	25- to 50-year maintenance

Effectiveness

Structural management practices can be used to achieve four broad resource protection goals: flood control, channel protection, ground water recharge, and pollutant removal. Dry detention basins can provide flood control and channel protection, as well as some 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. Dry extended detention basins can easily be designed for flood control, and this is actually the primary purpose of most detention ponds.

Channel Protection

One result of urbanization is the geomorphic changes that occur in response to modified hydrology. Traditionally, dry detention basins have provided control of the 2-year storm (i.e., the storm that occurs, on average, once every 2 years) for channel protection. It appears that this control has been relatively ineffective, and research suggests that control of a smaller storm might be more appropriate (MacRae, 1996). Slightly modifying the design of dry detention basins to reduce the flow of smaller storm events might make them effective tools in reducing downstream erosion.

Pollutant Removal

Dry detention basins provide moderate pollutant removal, provided that the design features described in the Siting and Design Considerations section are incorporated. Although they can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. A few studies are available on the effectiveness of dry detention ponds. Typical removal rates, as reported by Schueler (1997), are as follows:

Total suspended solids: 61%

Total phosphorus: 19%

Total nitrogen: 31%

Nitrate nitrogen: 9%

Metals: 26%-54%

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 might help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of stormwater practices that 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. For more information on this database, access the BMP database EXIT Disclaimer.

Cost Considerations

The construction costs associated with dry detention ponds range considerably. One recent study evaluated the cost of all pond systems (Brown and Schueler, 1997). Adjusting for inflation, the cost of dry extended detention ponds can be estimated with the equation

$C = 12.4V^{0.760}$

where:

C = Construction, design, and permitting cost, and

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

Using this equation, typical construction costs are

$ 41,600 for a 1 acre-foot pond

$ 239,000 for a 10 acre-foot pond

$ 1,380,000 for a 100 acre-foot pond

Interestingly, these costs are generally slightly higher than the cost of wet ponds on a cost per total volume basis. Dry detention ponds are generally less expensive on a given site, because they are usually smaller than a wet pond design.

Ponds do not consume a large area compared to the total area treated (typically 2 to 3 percent of the contributing drainage area). It is important to note, however, that each pond is generally large. Other practices, such as filters or swales, may be "squeezed in" on 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. Finally, ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into pond systems can be spread over a relatively long time period.

Another economic concern associated with dry ponds is that they might detract slightly from the value of adjacent properties. One study found that dry ponds can actually detract from the perceived value of homes adjacent to a dry pond by between 3 and 10 percent (Emmerling-Dinovo, 1995).

References

Design References:

Denver Urban Drainage and Flood Control District. 1992. *Urban Storm Drainage Criteria Manual-Volume 3: Best Management Practices*. Denver, CO.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water. Washington, DC.

Other References:

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection. Ellicott City, MD.

Emmerling-Dinovo, C. 1995. Stormwater Detention Basins and Residential Locational Decisions. *Water Resources Bulletin* 31(3): 515-521

Galli, J. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices*. Metropolitan Washington Council of Governments. Prepared for Maryland Department of the Environment, Baltimore, MD.

MacRae, C. 1996. Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection? In *Effects of Watershed Development and Management on*

Aquatic Ecosystems. American Society of Civil Engineers. Edited by L. Roesner. Snowbird, UT. pp. 144-162.

Santana, F., J. Wood, R. Parsons, and S. Chamberlain. 1994. *Control of Mosquito Breeding in Permitted Stormwater Systems*. Prepared for Southwest Florida Water Management District, Brooksville, FL.

Schueler, T. 1997. Influence of Ground Water on Performance of Stormwater Ponds in Florida. *Watershed Protection Techniques* 2(4):525-528.

Information Resources

Center for Watershed Protection (CWP), Environmental Quality Resources, and Loiederman Associates. 1997. *Maryland Stormwater Design Manual*. Draft. Prepared for Maryland Department of the Environment, Baltimore, MD.

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds. Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Click here to comment on this fact sheet

Grassed Swales

Click here to comment on this fact sheet

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

Subcategory: Infiltration

Description


Grassed swales can be used along roadsides and parking lots to collect and treat stormwater runoff

In the context of BMPS to improve water quality, the term swale (a.k.a. grassed channel, dry swale, wet swale, biofilter, or bioswale) refers to a vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. As stormwater runoff flows along these channels, it is treated through vegetation slowing the water to allow sedimentation, filtering through a subsoil matrix, and/or infiltration into the underlying soils. Variations of the grassed swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch. These designs incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

Applicability

Grassed swales can be applied in most situations with some restrictions. Swales are well suited for treating highway or residential road runoff because they are linear practices. Swales are also useful as one of a series of stormwater BMPs or as part of a treatment train, for instance, conveying water to a detention pond and receiving water from filter strips. Furthermore, swales are highly recommended by the proponents of design approaches such as Low Impact Development and Better Site Design (Low Impact Development (LID) and Other Green Designs fact sheet).

Regional Applicability

Grassed swales can be applied in most regions of the United States. In arid and semi-arid climates, however, the value of these practices needs to be weighed against the water needed to irrigate them.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas with little pervious surface. Grass swales may not be well suited to ultra-urban areas because they require a relatively large area of pervious surfaces.

Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants exceeding those typically found in stormwater. A typical example is a gas station or convenience store. With the exception of the dry swale design (see Design Variations), hot spot runoff should not be directed toward grassed channels. These practices either infiltrate stormwater or intersect the ground water, making use of the practices for hot spot runoff a threat to ground water quality.

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 such as reducing loadings to comply with a TMDL waste load allocation. One retrofit opportunity using grassed swales modifies existing drainage ditches. Ditches have traditionally been designed only to convey stormwater. In some cases, it may be possible to incorporate features to enhance pollutant removal or infiltration such as check dams (i.e., small dams along the ditch that trap sediment, slow runoff, and reduce the effective longitudinal slope). Since grassed swales cannot treat a large area, using this practice to retrofit an entire watershed would be expensive because of the number of practices needed to manage runoff from a significant amount of the watershed's land area.

Cold Water (Trout) Streams

Grassed channels are a good treatment option within watersheds that drain to cold water streams. These practices do not pond water for a long period and often induce infiltration. As a result, standing water will not typically be subjected to solar warming.

Siting and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider site conditions. 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 considering the restrictions and adaptations of grassed swales to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, highly impermeable soils) might restrict the effectiveness of grassed channels.

<u>Drainage Area</u>

Grassed swales should generally treat runoff from small drainage areas (less than 5 acres). If used to treat larger areas, the flows through the swale become too large to produce designs to treat stormwater runoff in addition to conveyance.

Slope

Grassed swales should be used on sites with relatively flat slopes of less than 4 percent slope; 1 to 2 percent slope is recommended. When site conditions require installing the swales in areas with larger slopes, check dams can be used to reduce the influence of the slope. Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtering in the swale.

Soils / Topography

Grassed swales can be used on most soils, with some restrictions on the most impermeable soils. In the dry swale (see Design Variations) a fabricated soil bed replaces on-site soils in order to ensure that runoff is filtered as it travels through the soils of the swale.

Ground Water

The required depth to ground water depends on the type of swale used. In the dry swale and grassed channel options, the bottom of the swale should be constructed at least 2 ft above the ground water table to prevent a moist swale bottom or contamination of the ground water. In the wet swale option, treatment is provided by creating a standing or slow flowing wet pool, which is maintained by intersecting the ground water.

Design Considerations

Although there are different design variations of the grassed swale (see Design Variations), there are some design considerations common to all designs. An overriding similarity is the cross-sectional geometry. Swales often have a trapezoidal or parabolic cross section with relatively flat side slopes (flatter than 3:1), though rectangular and triangular channels can also be used. Designing the channel with flat side slopes increases the wetted perimeter. The wetted perimeter is the length along the edge of the swale cross section where runoff flowing through the swale contacts the vegetated sides and bottom. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage sorption, filtering, and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope.

Another similarity among designs is the type of pretreatment needed. In all design options, a small forebay should be used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river-run gravel, should be constructed along the length of the swale and used as pretreatment for runoff entering the sides of the swale. Other features designed to enhance the performance of grassed swales are a flat longitudinal slope (generally between 1 percent and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the flow velocity within the channel. The dense vegetation also helps reduce velocities, protects the channel from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel while the vegetation is becoming established, either with a temporary grass cover or with natural or synthetic erosion control products. In addition to treating runoff for water quality, grassed swales must convey runoff from larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

Design Variations

The following discussion identifies three different variations of open channel practices, including the grassed channel, the dry swale, and wet swale.

Grassed Channel

Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. Of all of the options, grassed channels are the least expensive but also provide the least reliable pollutant removal. An excellent application of a grassed channel is as pretreatment to other structural stormwater practices. A major difference between the grassed channel and many other structural practices is the method used to size the practice. Most stormwater management water quality practices are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel, is a flow-rate-based design. Based on the peak flow from the water quality storm (this varies regionally, but a typical value is the 1-inch/ 24-hr storm), the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in *Design of Stormwater Filtering Systems* (CWP, 1996).

Dry Swales

Dry swales are similar in design to bioretention areas (see Bioretention (Rain Gardens) fact sheet). These designs incorporate a fabricated soil bed into their design. The native soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is installed at the bottom of the soil bed. This underdrain is a gravel layer that encases a perforated pipe. Stormwater treated in the soil bed flows into the underdrain, which routes this treated stormwater to the storm drain system or receiving waters. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal.

Wet Swales

Wet swales intersect the ground water and behave similarly to a linear wetland cell (see Stormwater Wetland fact sheet). This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment. This design also has potentially high pollutant removal. Wet swales are not commonly used in residential or commercial settings because the shallow standing water may be a potential mosquito breeding area.

Regional Variations

In cold or snowy climates, swales may serve a dual purpose by acting as both a snow storage/treatment and a stormwater management practice. This dual purpose is particularly relevant when swales are used to treat road runoff. If used for this purpose, swales should incorporate salt-tolerant vegetation, such as creeping bentgrass.

Arid Climates

In arid or semi-arid climates, swales should be designed with drought-tolerant vegetation, such as buffalo grass. As pointed out in the Applicability section, the value of vegetated practices for water quality needs to be balanced against the cost of water needed to maintain them in arid and semi-arid regions.

Limitations

Grassed swales have some limitations, including the following:

- Grassed swales cannot treat a very large drainage area.
- Wet swales may become a nuisance due to mosquito breeding.
- If designed improperly (e.g., if proper slope is not achieved), grassed channels will have very little pollutant removal.

Maintenance Considerations

Maintenance of grassed swales mostly involves litter control and maintening the grass or wetland plant cover. Typical maintenance activities are included in Table 1.

Table 1. Typical maintenance activities for grassed swales (Source: Adapted from CWP, 1996)

Activity	Schedule
• Inspect pea gravel diaphragm for clogging and correct the problem. • Inspect grass along side slopes for erosion and formation of rills or gullies and correct. • Remove trash and debris accumulated in the inflow forebay. • Inspect and correct erosion problems in the sand/soil bed of dry swales. • Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established. • Replant wetland species (for wet swale) if not sufficiently established.	Annual (semi-annual the first year)
• Rototill or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours. • Remove sediment build-up within the bottom of the swale once it has accumulated to 25 percent of the original design volume.	As needed (infrequent)
• Mow grass to maintain a height of 3–4 inches	As needed (frequent seasonally)

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. Grassed swales can be used to meet ground water recharge and pollutant removal goals.

Ground Water Recharge

Grassed channels and dry swales can provide some ground water recharge as infiltration is achieved within the practice. Wet swales, however, generally make little, if any, contributions to ground water recharge. Infiltration is impeded by the accumulation of debris on the bottom of the swale.

Pollutant Removal

Few studies are available regarding the effectiveness of grassed channels (Table 2). The data suggest relatively high removal rates for some pollutants, negative removals for some bacteria, and fair performance for phosphorous. One study of available performance data (Schueler, 1997) estimates the removal rates for grassed channels as:

Total Suspended Solids:	81%
Total Phosphorous:	29%
Nitrate Nitrogen:	38%
Metals:	14% to 55%
Bacteria:	-50%

Table 2. Grassed swale pollutant removal efficiency data

Removal Efficiencies (% Removal)							
Study	**TSS**	**TP**	**TN**	**NO 3**	**Metals**	**Bacteria**	**Type**
Goldberg 1993	67.8	4.5	-	31.4	42–62	-100	grassed channel
Seattle Metro and Washington Department of Ecology 1992	60	45	-	-25	2–16	-25	grassed channel
Seattle Metro and Washington Department of Ecology, 1992	83	29	-	-25	46–73	-25	grassed channel
Wang et al., 1981	80	-	-	-	70–80	-	dry swale
Dorman et al., 1989	98	18	-	45	37–81	-	dry swale
Harper, 1988	87	83	84	80	88–90	-	dry swale
Kercher et al., 1983	99	99	99	99	99	-	dry swale
Harper, 1988.	81	17	40	52	37–69	-	wet swale
Koon, 1995	67	39	-	9	-35 to 6	-	wet swale
Occoquan Watershed Monitoring Lab, 1983	-100	-100	-100	-	-100	-	drainage channel
Yousef et al., 1985	-	8	13	11	14–29	-	drainage channel
Occoquan Watershed Monitoring Lab, 1983	-50	-9.1	-18.2	-	-100	-	drainage channel
Yousef et al., 1985	-	-19.5	8	2	41–90	-	drainage channel
Occoquan Watershed Monitoring Lab, 1983	31	-23	36.5	-	-100 to 33	-	drainage channel
Welborn and Veenhuis, 1987	0	-25	-25	-25	0	-	drainage channel
Yu et al., 1993	68	60	-	-	74	-	drainage channel
Dorman et al., 1989	65	41	-	11	14-55	-	drainage channel
Pitt and McLean, 1986	0	-	0	-	0	0	drainage channel
Oakland, 1983	33	-25	-	-	20–58	0	drainage channel
Dorman et al., 1989	-85	12	-	-100	14–88	-	drainage channel

While it is difficult to distinguish between different designs based on the small amount of available data, grassed channels generally have poorer removal rates than wet and dry swales, although wet swales may export soluble phosphorous (Harper, 1988; Koon, 1995). It is not clear why swales export bacteria. One explanation is that bacteria thrive in the warm swale soils. Another explanation is that studies have not accounted for some sources of bacteria, and like any open BMP, swales likely receive inputs from wildlife. Another possible explanation is that local residents might walk dogs within the grassed swale area. Signs identifying swales as a stormwater BMP leading to local receiving waters might encourage some pet owners to clean up after their pets.

Cost Considerations

Little data are available to estimate the difference in cost between various swale designs. One study (SWRPC, 1991) estimated the construction cost of grassed channels at approximately $0.25 per ft2. This price does not include design costs or contingencies. Brown and Schueler (1997) estimate these costs at approximately 32 percent of construction costs for most stormwater management practices. For swales, however, these costs would probably be significantly higher since the construction costs are so low compared with other practices. A more realistic estimate would be a total cost of approximately $0.50 per ft2, which compares favorably with other stormwater management practices.

Costs to construct swales should be taken in context. With most development designs, some conveyance structure must be constructed as part of the development. The construction of grass swales is less expensive than concrete ditches or sewers. Hence, the use of grass swales is often a less expensive alternative than traditional design approaches.

References

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems*. Prepared for the Chesapeake Research Consortium, Solomons, MD, and USEPA Region V, Chicago, IL, by the Center for Watershed Protection, Ellicott City, MD.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Dorman, M.E., J. Hartigan, R.F. Steg, and T. Quasebarth. 1989. *Retention, Detention and Overland Flow for Pollutant Removal From Highway Stormwater Runoff*. Vol. 1. FHWA/RD 89/202. Federal Highway Administration, Washington, DC.

Goldberg. 1993. *Dayton Avenue Swale Biofiltration Study*. Seattle Engineering Department, Seattle, WA.

Harper, H. 1988. *Effects of Stormwater Management Systems on Groundwater Quality*. Prepared for Florida Department of Environmental Regulation, Tallahassee, FL, by Environmental Research and Design, Inc., Orlando, FL.

Kercher, W.C., J.C. Landon, and R. Massarelli. 1983. *Grassy swales prove cost-effective for water pollution control*. Public Works, 16: 53-55.

Koon, J. 1995. *Evaluation of Water Quality Ponds and Swales in the Issaquah/East Lake Sammamish Basins*. King County Surface Water Management, Seattle, WA, and Washington Department of Ecology, Olympia, WA.

Oakland, P.H. 1983. *An evaluation of stormwater pollutant removal through grassed swale treatment. In Proceedings of the International Symposium of Urban Hydrology, Hydraulics and Sediment Control, Lexington, KY*. pp. 173-182.

Occoquan Watershed Monitoring Laboratory. 1983. *Final Report: Metropolitan Washington Urban Runoff Project*. Prepared for the Metropolitan Washington Council of Governments, Washington, DC, by the Occoquan Watershed Monitoring Laboratory, Manassas, VA.

Pitt, R., and J. McLean. 1986. *Toronto Area Watershed Management Strategy Study: Humber River Pilot Watershed Project*. Ontario Ministry of Environment, Toronto, ON.

Schueler, T. 1997. *Comparative Pollutant Removal Capability of Urban BMPs: A reanalysis*. Watershed Protection Techniques 2(2):379-383.

Seattle Metro and Washington Department of Ecology. 1992. *Biofiltration Swale Performance: Recommendations and Design Considerations*. Publication No. 657. Water Pollution Control Department, Seattle, WA.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Wang, T., D. Spyridakis, B. Mar, and R. Horner. 1981. *Transport, Deposition and Control of Heavy Metals in Highway Runoff*. FHWA-WA-RD-39-10. University of Washington, Department of Civil Engineering, Seattle, WA.

Welborn, C., and J. Veenhuis. 1987. *Effects of Runoff Controls on the Quantity and Quality of Urban Runoff in Two Locations in Austin, TX*. USGS Water Resources Investigations Report No. 87-4004. U.S. Geological Survey, Reston, VA.

Yousef, Y., M. Wanielista, H. Harper, D. Pearce, and R. Tolbert. 1985. *Best Management Practices: Removal of Highway Contaminants By Roadside Swales*. University of Central Florida and Florida Department of Transportation, Orlando, FL.

Yu, S., S. Barnes, and V. Gerde. 1993. *Testing of Best Management Practices for Controlling Highway Runoff*. FHWA/VA-93-R16. Virginia Transportation Research Council, Charlottesville, VA.

Information Resources

Maryland Department of the Environment (MDE). 2000. Maryland Stormwater Design Manual. [http://www.mde.state.md.us/environment/wma/stormwatermanua l EXIT Disclaimer]. Accessed May 22, 2001.

Reeves, E. 1994. *Performance and Condition of Biofilters in the Pacific Northwest*. Watershed Protection Techniques 1(3):117-119.

Seattle Metro and Washington Department of Ecology. 1992. *Biofiltration Swale Performance. Recommendations and Design Considerations*. Publication No. 657. Seattle Metro and Washington Department of Ecology, Olympia, WA.

USEPA 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water. Washington, DC.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water. Washington, DC, by the

Watershed Management Institute, Ingleside, MD.

Click here to comment on this fact sheet

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

Green Parking

Click here to comment on this fact sheet

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

Subcategory: Innovative BMPs for Site Plans

Description

A green parking lot at the Orange Bowl in Miami, Florida (Source: Invisible Structures, no date)

Green parking refers to several techniques that applied together reduce the contribution of parking lots to total impervious cover. From a stormwater perspective, green parking techniques applied in the right combination can dramatically reduce impervious cover and, consequently, reduce the amount of stormwater runoff. Green parking lot techniques include: setting maximums for the number of parking lots created; minimizing the dimensions of parking lot spaces; utilizing alternative pavers in overflow parking areas; using bioretention areas to treat stormwater; encouraging shared parking; and providing economic incentives for structured parking.

Applicability

All of the green parking techniques can be applied in new developments, and some can be applied in redevelopment projects, depending on the extent and parameters of the project. In urban areas, some techniques, like encouraging shared parking and providing economic incentives for structured parking, can be practical and necessary. Commercial areas can have excessively high parking ratios. By applying green parking techniques in various combinations, a site's impervious cover can be dramatically reduced.

Implementation

Parking lot designs frequently result in far more spaces than are required. This problem is exacerbated by a common practice of setting parking ratios to accommodate the highest hourly parking during the peak season. By determining average parking demand instead, a lower maximum number of parking spaces can accommodate most of the demand.

Table 1 provides examples of conventional parking requirements and compares them to average parking demand.

Table 1: Conventional minimum parking ratios (Source: ITE, 1987; Smith, 1984; Wells, 1994)

Land Use	Parking Requirement		Actual Average Parking Demand
	Parking Ratio	**Typical Range**	
Single family homes	2 spaces per dwelling unit	1.5-2.5	1.11 spaces per dwelling unit
Shopping center	5 spaces per 1000 ft^2 GFA	4.0-6.5	3.97 per 1000 ft^2 GFA
Convenience store	3.3 spaces per 1000 ft^2 GFA	2.0-10.0	--
Industrial	1 space per 1000 ft^2 GFA	0.5-2.0	1.48 per 1000 ft^2 GFA
Medical/ dental office	5.7 spaces per 1000 ft^2 GFA	4.5-10.0	4.11 per 1000 ft^2 GFA
GFA = Gross floor area of a building without storage or utility spaces.			

Minimizing the dimensions of parking spaces is another green parking lot technique. Besides reducing the length and width, parking stall dimensions can be reduced by providing compact- vehicle spaces. While large sport utility vehicles (SUVs) are often cited as barriers to stall minimization techniques, most local parking codes require stall widths wider than the widest SUVs (CWP, 1998).

Another effective green parking technique is the use of alternative pavers. Alternative pavers include gravel, cobbles, wood mulch, brick, grass pavers, turf blocks, natural stone, pervious concrete, and porous asphalt. In new developments and redevelopment projects, they can replace conventional asphalt and concrete. The effectiveness of alternative pavers in meeting stormwater quality goals can range from medium to relatively high. Alternative pavers require proper installation, and they generally need more maintenance that conventional asphalt or concrete. For more specific information on alternate pavers, refer to the Alternative Pavers fact sheet.

Bioretention areas can effectively treat stormwater leaving a parking lot. Stormwater is directed into a shallow, landscaped area, where it is temporarily detained. The runoff then filters down through the bed of the facility, where it is either infiltrated into the subsurface or collected into an under-drain pipe for discharge into a stream or another stormwater facility. Attractively designed bio-retention facilities can be integrated into landscaped areas and maintained by commercial landscaping firms. For detailed design specifications of bioretention areas, refer to the Bioretention (Rain Gardens) fact sheet.

In mixed use areas, shared and structured parking are green parking techniques that can reduce the conversion of land to impervious cover. A shared parking arrangement involves two parties that share one parking lot. For example, an office that experiences peak demand during weekdays can share their parking lot with a church that experiences peak demand during weekends and evenings. Costs may dictate the use of structured parking, but building above or below-ground structured parking garages can help minimize surface parking.

Limitations

Limitations to green parking techniques include applicability, cost, and maintenance. For example, shared parking is practical only in mixed use areas, and structured parking may be limited by the cost of land versus the cost of construction. Currently, alternative pavers are recommended only for overflow parking because of their expensive maintenance costs. Bioretention areas also increase construction costs.

The pressure to provide an excessive number of parking spaces can result from the fear of customer complaints, as well as the requirements of bank loans. These factors can pressure developers into constructing more parking than is necessary. Together, these barriers inhibit the construction of the greenest parking lots possible.

Effectiveness

Applied together, green parking techniques can effectively reduce the amount of impervious cover. They can help to protect local streams, reduce stormwater management costs, and enhance a site's ascetics. Proper design of bioretention areas can help meet stormwater management and landscaping requirements while keeping maintenance costs at a minimum.

Green parking lots can dramatically reduce the creation of new impervious cover. How much is reduced depends on the combination of techniques used to achieve the greenest parking lot. While the pollutant removal rates of bioretention areas have not been directly measured, their capability is considered comparable to a dry swale, which removes 91 percent of total suspended solids, 67 percent of total phosphorous, 92 percent of total nitrogen, and 80-90 percent of metals (Claytor and Schueler, 1996).

North Carolina's Fort Bragg vehicle maintenance facility parking lot is an excellent example of the benefits of rethinking parking lot design (NRDC, 1999). The redesign incorporated stormwater management features, such as detention basins located within grassed islands, and an onsite drainage system that exploited existing sandy soils. The redesign reduced impervious cover by 40 percent, increased parking by 20 percent, and saved 20 percent or $1.6 million on construction costs over the original, conventional design.

Cost Considerations

Setting maximums for parking spaces, minimizing stall dimensions, and encouraging shared parking can result in considerable construction cost savings. At the same time, implementing green parking techniques can also reduce stormwater management costs.

References

Center for Watershed Protection. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection, Ellicott City, MD.

Claytor, R.A., and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection, Inc., Ellicott City, MD.

Invisible Structures. No date. Grasspave2: Porous Paving System. [http://www.invisiblestructures.com/GP2/grasspave.htm EXIT Disclaimer]. Accessed November 17, 2005.

ITE. 1987. *Parking Generation*, 2nd edition. Institute of Transportation Engineers, Washington, DC.

Natural Resources Defense Council (NRDC). 1999. *Stormwater Strategies: Community Responses to Runoff Pollution*. Natural Resources Defense Council, Washington, DC.

Smith, T. 1984. *Flexible Parking Requirements*. Planning Advisory Service Report No. 377. American Planning Association, Chicago, IL.

Wells, C. 1994. *Impervious Surface Reduction Technical Study*. Draft Report. City of Olympia Public Works Department. Washington Department of Ecology, Olympia, WA.

Information Resources

Bergman, D. 1991. *Off-Street Parking Requirements*. American Planning Association, Chicago, IL.

Brown, W.E., D.S. Caraco, R.A. Claytor, P.M. Hinkle, H.Y. Kwon, and T.R. Schueler. 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection, Inc., Ellicott City, MD.

Brown, W.E., and T.R. Schueler. 1996. *The Economics of Stormwater BMPs in the Mid-Atlantic Region: Final Report*. Center for Watershed Protection, Ellicott City, MD.

Diniz, E. 1993. *Hydrologic and Water Quality Comparisons of Runoff from Porous and Conventional Pavements*. CRC Press, Lewis Publishers, Boca Raton, FL.

Morris, M. 1989. *Parking Standards¿Problems, Solutions, Examples*. PAS Memo, December 1989 issue. American Society of Planning Officials, Chicago, IL.

Smith, D.R. 1981. *Life Cycle and Energy Comparison of Grass Pavement and Asphalt Based on Data and Experience from the Green Parking Lot*. The Heritage Conservation and Recreation Service, Washington, DC.

Smith, D.R., and D.A. Sholtis. 1981. *An Experimental Installation of Grass Pavement*. The Heritage Conservation and Recreation Service, Washington, DC.

Click here to comment on this fact sheet

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Recent Additions | Contact Us | Print Version Search NPDES: GO

EPA Home > OW Home > OWM Home > NPDES Home > Stormwater > Menu of BMPs

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

Search BMPs All of the words Filter by Minimum Measure All GO Browse Fact Sheets Search Help

Green Roofs

Click here to comment on this fact sheet

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

Subcategory: Innovative BMPs for Site Plans

Description

Green roofs can be effectively used to reduce stormwater runoff from commercial, industrial, and residential buildings. In contrast to traditional asphalt or metal roofing, green roofs absorb, store, and later evapotranspire initial precipitation, thereby acting as a stormwater management system and reducing overall peak flow discharge to a storm sewer system. Furthermore, conventional roofing can act as a source for numerous toxic pollutants including lead, zinc, pyrene, and chrysene (Vane Metre and Mahler, 2003).

Figure 1. An intensive green roof at the Schwab Rehabilitation Hospital, Chicago, Illinois (picture courtesy of Green Roofs for Healthy Cities and American Hydrotech, Inc.).

Green roofs have the potential to reduce discharge of pollutants such as nitrogen and phosphorous due to soil microbial processes and plant uptake. However, initial studies conflict as to the removal efficiency of nutrients, particularly nitrogen, by green roofs. If implemented on a wide scale, green roofs will reduce the volume of stormwater entering local waterways resulting in less in-stream scouring, lower water temperatures and better water quality. In urban areas with combined sewer systems, stormwater and untreated human and industrial waste are collected in the same pipe. During periods of heavy rainfall and snow melt, these systems can become overwhelmed by the volume of water and overflow into nearby waterbodies resulting in combined sewer overflows (CSOs). Since green roofs can reduce the volume of stormwater discharged, CSOs can also be reduced, thus preventing the discharge of millions of gallons of sewage into local waterways.

Green roofs offer additional benefits including reduction of urban heat island effects, increased thermal insulation and energy efficiency, increased acoustic insulation, and increased durability and lifespan compared to conventional roofs. Europeans, led by the Germans, have been using green roofs for decades and have found them to be a cost effective method to mitigate some environmental impacts of development.

Green roofs are classified as extensive, semi-intensive, or intensive. Generally, extensive green roofs have six inches or less of growing medium, whereas intensive green roofs have greater than 6 inches of substrate. Semi-intensive green roofs can be defined as a hybrid between intensive and extensive green roofs, where at least 25 percent of the roof square footage is above or below the 6 inch threshold. Extensive green roofs provide many of the environmental benefits of intensive green roofs, but they are designed to be very low-maintenance and are not typically designed for public access. Semi-intensive and intensive green roofs are designed to be used by the public or building tenants as a park or relaxation area. However, they also require greater capital and maintenance investments than extensive green roofs. Intensive green roofs are particularly attractive for developers, property owners, and municipalities, in areas where land prices command a premium, but property owners want to provide some of the amenities associated with parks.

Due to increasing demand for green roofs, there is now commercial industry in many parts of the country. The industry organization Green Roofs for Healthy Cities EXIT Disclaimer website can provide additional information on green roofs and links to numerous companies that provide green roofing products and services.

Applicability

Green roofs can be applied to new construction or retrofitted to existing construction. They are applicable on residential, commercial, and industrial buildings and are easily constructed on roofs with up to a 20 percent slope. Many cities such as Chicago and Washington, DC are actively encouraging green roof construction as a means to reduce stormwater runoff and combined sewer overflows. Other municipalities are encouraging green roof development with tax credits, density credits, or allowing a small impervious credit to be applied to other structural BMP requirements.

Figure 2. An extensive green roof at the Deerborn Michigan, Ford Assembly Plant (picture courtesy of Green Roofs for Healthy Cities and William McDonough + Partners, ARCADIS).

Regional Applicability

Green roofs are applicable in all parts of the country. In climates with extreme temperatures, green roofs provide additional building insulation, which makes them more financially justifiable for many facility operators.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Green roofs are ideal for ultra-urban areas because they provide stormwater benefits and other valuable ecological services without consuming additional land. In a 2005 modeling study of Washington DC, Casey Trees and Limno-Tech found that green roofs on 20 percent of buildings over 10,000 square feet could add an additional 23 million gallons of storage and reduce outflow to the storm sewer or combined sewer systems by an average of just under 300 million gallons per year. According to the authors, this would reduce the annual number of CSO events in DC by 15 percent.

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. Green roofs are a useful tool for retrofitting existing impervious area associated with building footprints. The construction of most existing flat-roofed buildings is such that they can accommodate the weight of an extensive green roof without structural modifications. Although retrofitting existing structures with green roofs can be more complex and expensive than on new facilities, technological advances are bringing that cost down.

Siting and Design Considerations

Siting Considerations

Green roofs can be installed during initial construction or placed on buildings as part of a retrofit. The amount of stormwater that a green roof mitigates is directly proportional to the area it covers, the depth and type of the growing medium, slope, and the type of plants selected. The larger the green roof area, the more stormwater mitigated. Green roofs are appropriate for industrial and commercial facilities and large residential buildings such as condominiums or apartment complexes. Green roofs can also prove useful for small residential buildings under some circumstances. For instance, green roofs are commonly used on single family residential structures in Germany and other European countries. Single family residential structures, like all buildings with green roofs, must be able to support the loading from a saturated roof. Furthermore, the green roofs should be easily accessible and residents should understand the maintenance requirements necessary to keep the roof functional.

Design Considerations

A building must be able to support the loading of green roof materials under fully saturated conditions. These materials include a waterproofing layer, a soil or substrate layer, and a plant layer. Plants selected need to be suited for local climatic conditions and can range from sedums, grasses, and wildflowers on extensive roofs to shrubs and small trees on intensive roofs.

Design Variations

Green roofs can be designed to be either intensive, semi-intensive, or extensive green roofs. The type of design chosen will depend upon loading capacity, budget, design goals, and stormwater retention desired. There will also be variations in the type of green roof selected depending upon climate, types of plants chosen, soil layer depth desired and feasibility and other design considerations. Green roofs can be constructed layer by layer, or can be purchased as a system. Some vendors offer modular trays containing the green roof components.

Limitations

In most climates, green roofs will need to have drought tolerant plant species or an irrigation system to sustain vegetation. The slope of green roofs can range from 0 to 40 degrees. In new construction, buildings should be designed to manage a potentially increased load associated with the green roof. When designing green roofs for existing structures, engineers must take the load restrictions of the building into account.

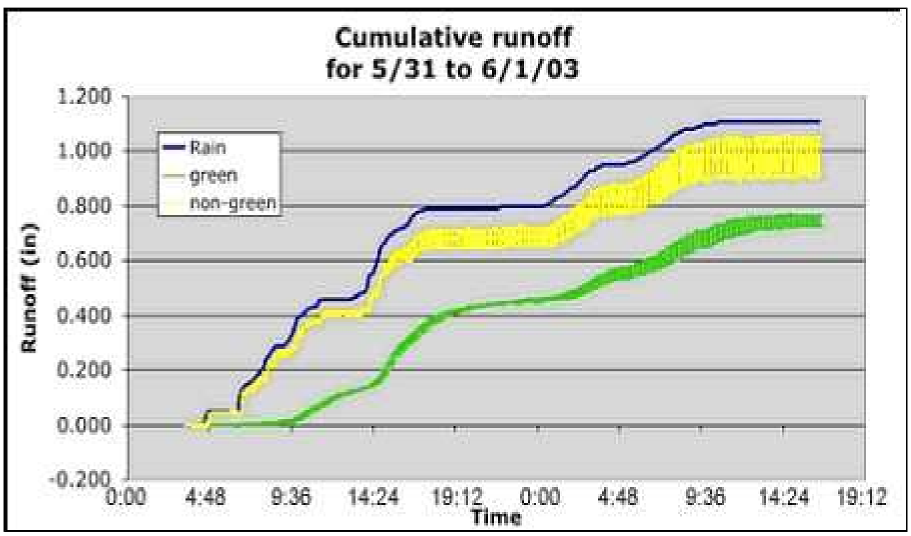
Maintenance Considerations

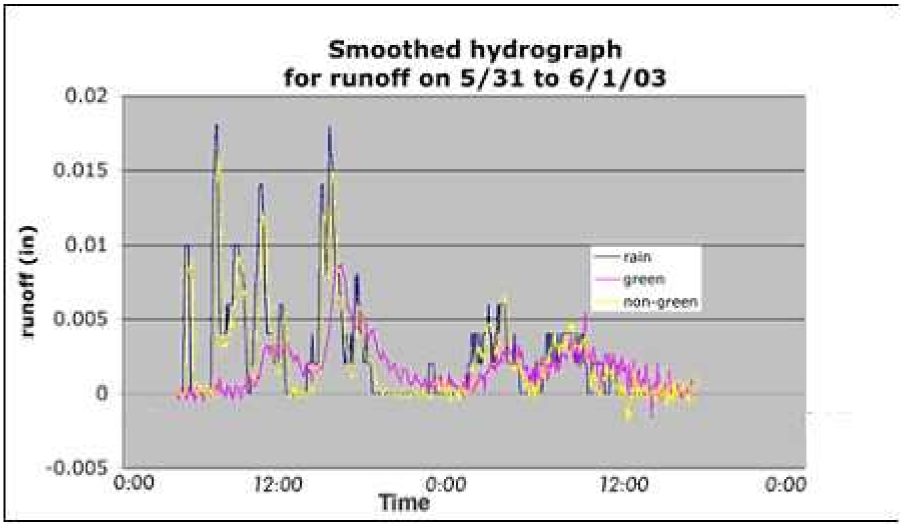
Immediately after construction, green roofs need to be monitored regularly to ensure the vegetation thrives. During the first season, green roofs may need to be watered periodically if there is not sufficient precipitation. After the first season, extensive green roofs may only need to be inspected and lightly fertilized approximately once per year. The roofs may need occasional weeding and may require some watering during exceptionally dry periods. If leaks should occur in the roof, they are relatively easy to detect and fix. Intensive green roofs need to be maintained as any other landscaped area. This can involve gardening and irrigation, in addition to other roof maintenance. Green roofs are less prone to leaking than conventional roofs. In most cases, detecting and fixing a leak under a green roof is no more difficult than doing the same for a conventional roof.

Effectiveness

Green roofs have been shown to be effective at removing some pollutants and reducing peak flows associated with storm events. As a general rule, developers can assume that extensive green roofs will absorb 50 percent of rainfall (Stephen Peck, 9/1/2005, personal communication). In a modeling study, Casey Trees and Limno-Tech (2005) assumed that extensive green roofs absorbed two inches of rainfall and intensive green roofs stored 4 inches of rainfall. Due to evapotranspiration and plant uptake, this storage is assumed to recharge once every 4 days. A study by Moran (2005) found that monthly stormwater retention rates varied between 40 percent and 100 percent on two green roofs in the Neuse River watershed, North Carolina. The study showed a decrease in peak flow runoff and total stormwater runoff, and a gradual and delayed release of the stormwater that was ultimately discharged. The reduction of peak flow discharge potentially mitigates stream channel scouring, resulting in improved aquatic habitat and lessening the risk of downstream property damage and flooding.

Penn State Green Roof Research Center has also noted a decrease in both total stormwater runoff and peak flow discharge. The graphs below show both the decrease in total discharge and peak flow run-off from roof area associated with three green roofs. In this 1+ inch storm event, the green roofs captured approximately 25 percent of total runoff compared to the conventional roofs. Over the period from May 23, 2003 to June 1, 2003, 2.21 inches of rain fell, of which the green roof detained 1.05 inches (~47 percent). The center noted that the spring of 2003 was wet and cool.





Graphs are courtesy of Penn State Green Roof Research Center, Rock Springs, PA. They are based on data from 3 buildings with green roofs and three with traditional roofing.

Cost Considerations

Extensive green roofs range in price from approximately 5 dollars per square foot to 20 dollars per square foot. However, there are significant cost savings associated with reducing energy consumption and longer roof lifespan. For instance, the green roof on the Gap building in San Bruno, California more than covered the additional cost associated with construction, through energy savings, within a few years. Annualized costs should be lowered considerably by the roof's increased lifespan. Furthermore, some municipalities offer incentives to help defray the higher up-front costs of green roof construction.

Intensive green roofs can be considerably more expensive than extensive green roofs. Estimates range from 20 dollars to 80 dollars per square foot. Other benefits should be taken into account, however, such as recreational space provided and costs relative to the price of land in an area.

References

Casey Trees Endowment Fund and Limno-Tech, Inc. 2005. Re-greening Washington DC: A Green Roof Vision Based on Quantifying Stormwater and Air Quality Benefits. Available at [http://www.caseytrees.org EXIT Disclaimer].

Green Roofs for Healthy Cities. Available at: [http://www.greenroofs.org EXIT Disclaimer]. Accessed on 07/06/05.

Jones, R. C. and C. C. Clark. 1987. Impact of Watershed Urbanization on Stream Insect Communities. Water Resources Bulletin **23**(6): 1047-1055.

Mentens, J., D. Raes, and M. Hermy. 2005. Landscape and Urban Planning (in press at time of this writing).

Scholz-Barth, K., 2001. Green Roofs, Stormwater Management from the Top Down. Environmental Design and Construction. Available at [http://www.edcmag.com EXIT Disclaimer]. Accessed on 6/27/05.

Van Metre, P.C. and B.J. Mahler. 2003. The contribution of particles washed from rooftops to contaminant loading to urban streams. Chemosphere **52**: 1727 - 1741.

Click here to comment on this fact sheet

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Recent Additions | Contact Us | Print Version Search NPDES: GO

EPA Home > OW Home > OWM Home > NPDES Home > Stormwater > Menu of BMPs

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

Search BMPs All of the words Filter by Minimum Measure All GO Browse Fact Sheets Search Help

Infiltration Basin

Click here to comment on this fact sheet

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

Subcategory: Infiltration

Description

An infiltration basin is a shallow impoundment which is designed to infiltrate stormwater into the soil. This practice is believed to have a high pollutant removal efficiency and can also help recharge the ground water, thus increasing baseflow to stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

Infiltration basins are designed to collect stormwater from impervious areas and provide pollutant removal benefits through detention and filtration

Applicability

Infiltration basins have select applications. Their use is often sharply restricted by concerns over ground water contamination, soils, and clogging at the site.

Regional Applicability

Infiltration basins 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. In these areas, few stormwater practices can be easily applied due to space limitations. Infiltration basins can rarely 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. In addition, while they consume only the space of the infiltration basin site itself, they need a continuous, relatively flat area. Thus, it is more difficult to fit them into small unusable areas on a site.

Stormwater Hot Spots

A stormwater hot spot is an area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. Infiltration basins should never receive runoff from stormwater hot spots, unless the stormwater has already been treated by another practice. This caution is due to potential ground water contamination.

Stormwater Retrofit

A stormwater retrofit is a stormwater practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Infiltration basins have limited applications as a stormwater retrofit. Their use is restricted by three factors. First, infiltration basins should be used to treat small sites (less than 5 acres). Practices that are applied to small sites, such as infiltration basins, are generally a high-cost retrofit option in terms of construction cost and the maintenance burden associated with the large number of practices needed to retrofit a watershed. Second, it is often difficult to find areas where soils are appropriate for infiltration in an already urban or suburban environment. Finally, infiltration basins are best applied to small sites, yet need a flat, relatively continuous area. It is often difficult to find sites with this type of area available.

Cold Water (Trout) Streams

Infiltration basins are an excellent option for cold water streams because they encourage infiltration of stormwater and maintain dry weather flow. Because stormwater travels underground to the stream, it has little opportunity to increase in temperature.

Siting and Design Considerations

When designing infiltration basins, designers need to carefully consider both the restrictions on the site and design features to improve the long-term performance of the practice.

Siting Considerations

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

Drainage Area

Infiltration basins have historically been used as regional facilities, serving for both quantity and quality control. In some regions of the country, this practice is feasible, particularly if the soils are particularly sandy. In most areas, however, infiltration basins experience high rates of failure when used in this manner. In general, the practice is best applied to relatively small drainage areas (i.e., less than 10 acres).

Slope

The bottom of infiltration basins needs to be completely flat to allow infiltration throughout the entire basin bottom.

Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging, and 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). Finally, infiltration basins 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 distance (2 to 5 feet) from the bottom of the infiltration basin and the seasonally high ground water table, to reduce the risk of contamination. Infiltration practices should also 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 basin 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 management practices, but it is particularly important for infiltration practices. In order to ensure that pretreatment mechanisms are effective, designers should incorporate "multiple pretreatment," using practices such as grassed swales, sediment basins, and vegetated filter strips in series.

Treatment

Treatment design features enhance the pollutant removal of a practice. For infiltration practices, designers need to stabilize upland soils to ensure that the basin does not become clogged with sediment. In addition, the facility needs to be sized so that the volume of water to be treated infiltrates through the bottom in a given amount of time. Because infiltration basins are designed in this manner, infiltration basins designed on less permeable soils should be significantly larger than those designed on more permeable soils.

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. In general, infiltration basins should be designed to treat only small storms (i.e., only for water quality). Thus, these practices should be designed "off-line," using a flow separator to divert only small flows to 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. In infiltration basins, designers need to provide access to the basin for regular maintenance activities. Where possible, a means to drain the basin, such as an underdrain, should be provided in case the bottom becomes clogged. This feature allows the basin to be drained and accessed for maintenance in the event that the water has ponded in the basin bottom or the soil is saturated.

Landscaping

Landscaping can enhance the aesthetic value of stormwater practices or improve their function. In infiltration basins, the most important purpose of vegetation is to reduce the tendency of the practice to clog. Upland drainage needs to be properly stabilized with a thick layer of vegetation, particularly immediately following construction. In addition, providing a thick turf at the basin bottom helps encourage infiltration and prevent the formation of rills in the basin bottom.

Design Variations

Some modifications may be needed to ensure the performance of infiltration basins in arid and cold climates.

Arid or Semi-Arid Climates

In arid regions, infiltration practices are often highly recommended because of the need to recharge the ground water. In arid regions, designers need to emphasize pretreatment even more strongly to ensure that the practice does not clog, because of the high sediment concentrations associated with stormwater runoff in areas such as the Southwest. In addition, the basin bottom may be planted with drought-tolerant species and/or covered with an alternative material such as sand or gravel.

Cold Climates

In extremely cold climates (i.e., regions that experience permafrost), infiltration basins may be an infeasible option. In most cold climates, infiltration basins can be a feasible practice, but there are some challenges to its use. First, the practice may become inoperable during some portions of the year when the surface of the basin becomes frozen. Other design features also may be incorporated to deal with the challenges of cold climates. One such challenge is the volume of runoff associated with the spring snowmelt event. The capacity of the infiltration basin might be increased to account for snowmelt volume.

Another option is the use of a seasonably operated facility (Oberts, 1994). A seasonally operated infiltration/detention basin combines several techniques to improve the performance of infiltration practices in cold climates. Two features, the underdrain system and level control valves, are useful in cold climates. These features are used as follows: At the beginning of the winter season, the level control valve is opened and the soil is drained. As the snow begins to melt in the spring, the underdrain and the level control valves are closed. The snowmelt is infiltrated until the capacity of the soil is reached. Then, the facility acts as a detention facility, providing storage for particles to settle.

Other design features can help to minimize problems associated with winter conditions, particularly concerns that chlorides from road salting may contaminate ground water. The basin may be disconnected during the winter to ensure that chlorides do not enter the ground water in areas where this is a problem, or if the basin is used to treat roadside runoff. Designers may also want to reconsider application of infiltration practices on parking lots or roads where deicing is used, unless it is confirmed that the practice will not cause elevated chloride levels in the ground water. If the basin is used for snow storage, or to treat roadside or parking lot runoff, the basin bottom should be planted with salt-tolerant vegetation.

Limitations

Although infiltration basins can be useful practices, they have several limitations. Infiltration basins are not generally aesthetic practices, particularly if they clog. If infiltration basins are designed and maintained so that standing water is left for no more than 3 days, mosquitoes should not be a problem. However, if an infiltration basin becomes clogged and takes 4 or more days to drain, the basin could become a source for mosquitoes. In addition, these practices are challenging to apply because of concerns over ground water contamination and sufficient soil infiltration. Finally, maintenance of infiltration practices can be burdensome, and they have a relatively high rate of failure.

Maintenance Considerations

Regular maintenance is critical to the successful operation of infiltration basins (see Table 1). Historically, infiltration basins have had a poor track record. In one study conducted in Prince George's County, Maryland (Galli, 1992), all of the infiltration basins investigated clogged within 2 years. This trend may not be the same in soils with high infiltration rates. A study of 23 infiltration basins in the Pacific Northwest showed better long-term performance in an area with highly permeable soils (Hilding, 1996). In this study, few of the infiltration basins had failed after 10 years.

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

Activity	Schedule
• Inspect facility for signs of wetness or damage to structures • Note eroded areas. • If dead or dying grass on the bottom is observed, check to ensure that water percolates 2-3 days following storms. • Note signs of petroleum hydrocarbon contamination and handle properly.	Semi-annual inspection
• Mow and remove litter and debris. • Stabilize of eroded banks. • Repair undercut and eroded areas at inflow and outflow structures.	Standard maintenance (as needed)
• Disc or otherwise aerate bottom. • Dethatch basin bottom.	Annual maintenance
• Scrape bottom and remove sediment. Restore original cross-section and infiltration rate. • Seed or sod to restore ground cover.	5-year maintenance

Effectiveness

Structural 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 basins can provide ground water recharge and pollutant removal.

Ground Water Recharge

Infiltration basins 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 basins. 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 basins based on data from land disposal of wastewater. The average pollutant removal, assuming the infiltration basin 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 basin 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 also provide additional information.

Cost Considerations

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about $2 per ft^3 (adjusted for inflation) of storage for a 0.25-acre basin (SWRPC, 1991). Infiltration basins typically consume about 2 to 3 percent of the site draining to them, which is relatively small. Maintenance costs are estimated at 5 to 10 percent of construction costs.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration basins have a high failure rate (see Maintenance Considerations). Thus, it may be necessary to replace the basin after a relatively short period of time.

References

Galli, J. 1992. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland*. Metropolitan Washington Council of Governments, Washington, DC.

Hilding, K. 1996. Longevity of infiltration basins assessed in Puget Sound. *Watershed Protection Techniques* 1(3):124-125.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed May 22, 2001.

Oberts, G. 1994. Performance of Stormwater Ponds and Wetlands in Winter.

Watershed Protection Techniques 1(2): 64-68.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency Office of Water, Washington, DC.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency Office of Wetlands, Oceans and Watersheds. Washington, DC.

Ferguson, B.K., 1994. *Stormwater Infiltration*. CRC Press, Ann Arbor, MI.

USEPA. 1993. *Guidance to Specify Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Click here to comment on this fact sheet

Infiltration Trench

Click here to comment on this fact sheet

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

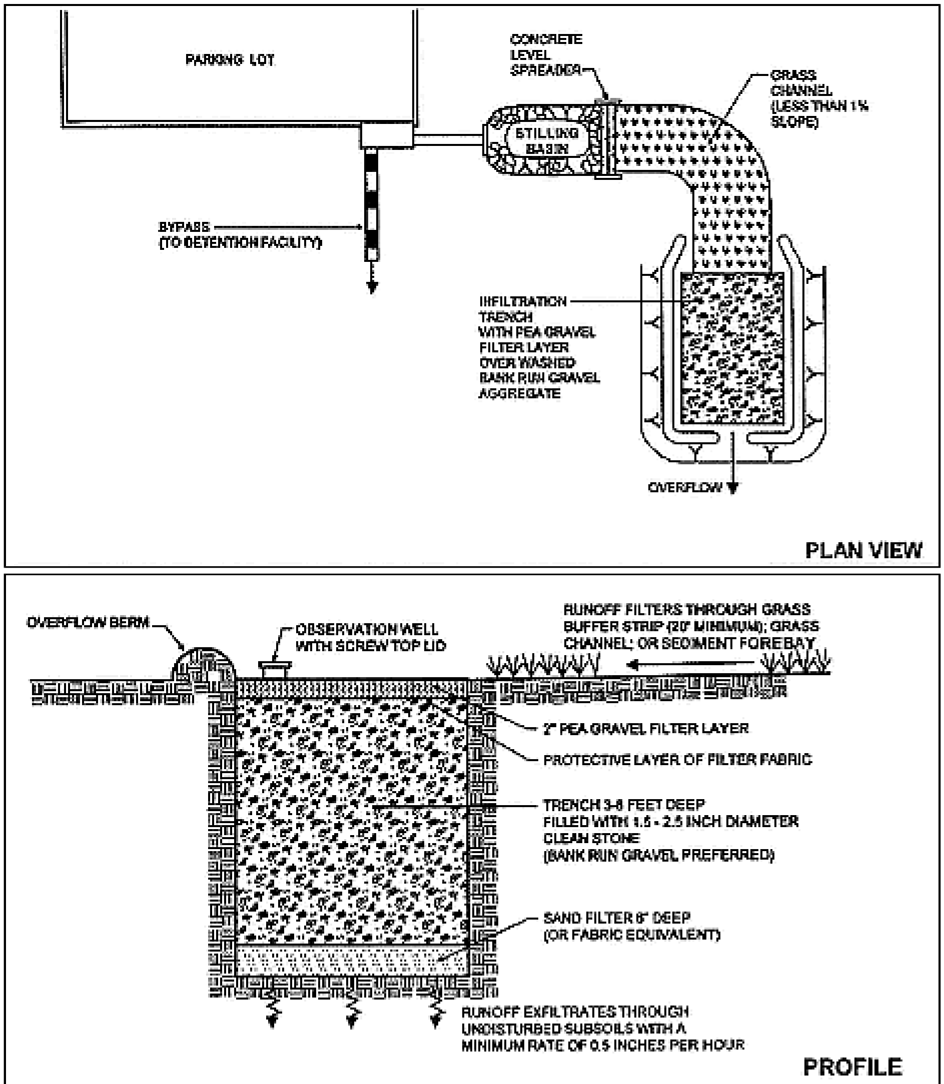
Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Infiltration trenches can sometimes be applied in the ultra-urban environment. Two features that can restrict their use are the potential of infiltrated water to interfere with existing infrastructure, and the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

References

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 10, 2005.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Galli, J. 1992. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland*. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991*. Costs of Urban Nonpoint Source Water Pollution Control Measures*. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Ferguson, B.K. 1994. *Stormwater Infiltration*. CRC Press, Ann Arbor, MI.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas: Best Management Practices*. Minnesota Pollution Control Agency, Minneapolis, MN.

USEPA. 1993. *Guidance to Specify Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Click here to comment on this fact sheet

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Manufactured Products for Stormwater Inlets

Click here to comment on this fact sheet

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

Subcategory: Other

Description

A variety of products called swirl separators or hydrodynamic structures have been widely applied to stormwater inlets in recent years. Swirl separators are modifications of traditional oil-grit separators. They contain an internal component that creates a swirling motion as stormwater flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as stormwater moves in this swirling path, and additional compartments or chambers are sometimes present to trap oil and other floatables. There are several different types of proprietary separators, each incorporating 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 Catch Basin Inserts fact sheet.

Applicability

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

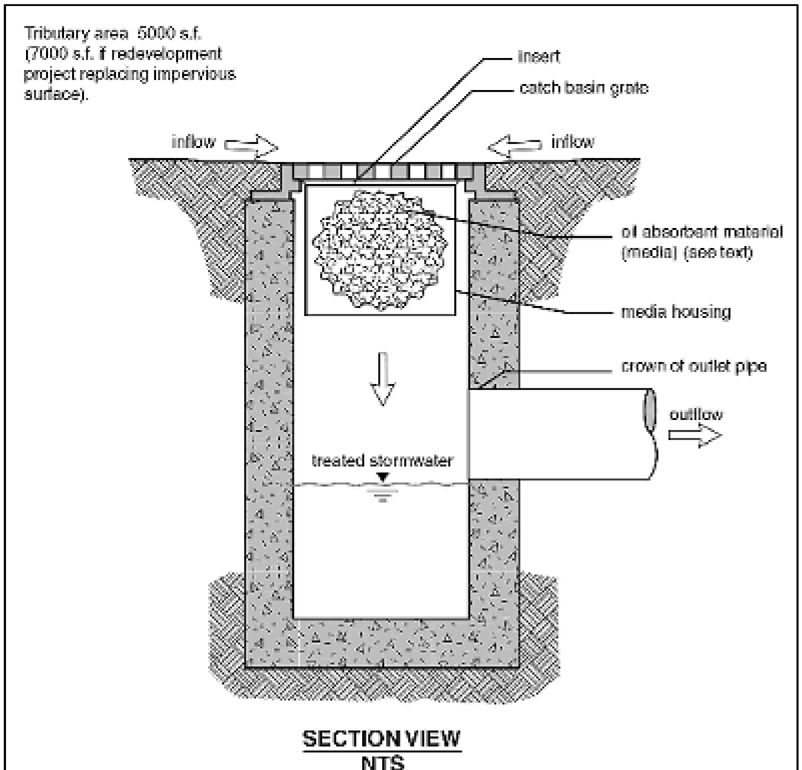
Limitations

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 design of swirl concentrators is specified in the manufacturer's product literature. For the most part, swirl concentrators are a rate-based designs. That is, their size is based on the peak flow of a specific storm event. This design contrasts with most other stormwater management practices, which are sized based on the capture, storage or treatment of a specific volume. Sizing based on flow rate allows the practice to provide treatment within a much smaller area than other stormwater management practices.



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)

Maintenance Considerations

Swirl concentrators require frequent, typically quarterly, maintenance. 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. Due to hazardous waste, pretreatment, or groundwater regulations, sediments may sometimes be barred from landfills, from land applications, and from introduction into sanitary sewer systems.

Effectiveness

While manufacturers' literature typically reports removal rates for swirl separators, there is little independent data to evaluate the effectiveness of these products. Two studies investigated one of these products. Both studies reported moderate pollutant removal, but 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 the two studies are presented below. Both studies are summarized in a Claytor (1999).

Table 1. Effectiveness of manufactured products for stormwater 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. The most common method of cleaning these practices is a vactor truck, which 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.

References

Claytor, R. 1999. Performance of a proprietary stormwater treatment device: The Stormceptor®. *Watershed Protection Techniques* 3(1):605-608.

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.

Labatiuk, C., V. Natal, and V. Bhardwaj. 1997. Field evaluation of a pollution abatement device for stormwater quality improvement. In *Proceedings of the 1997 CSCE-ASCE Environmental Engineering Conference, Edmonton, Alberta.* Canadian Society for Civil Engineering, Montréal, Québec, and American Society of Civil Engineers, Reston, VA.

Schueler, T. 1997. Performance of oil-grit separator at removing pollutants at small sites. *Watershed Protection Techniques* 2(4): 539-542.

King County, WA. 2000. *King County Surface Water Design Manual.* [splash.metrokc.gov/wlr/dss/manual.htm EXIT Disclaimer]. Accessed November 10, 2005.

Click here to comment on this fact sheet

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

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.

References

Brattebo, B.O., and Booth, D.B. 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. Water Research 37:4369-4376.

Cahill Associates. 1993. *Stormwater Management Systems: Porous Pavement with Underground Recharge Beds*. Cahill Associates, West Chester, PA.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Galli, J. 1992. *Preliminary Analysis of the Performance and Longevity of Urban BMPs Installed In Prince George's County, Maryland*. Department of Natural Resources, Annapolis, MD.

Gburek, W., and J. Urban, 1980. *Stormwater Detention and Groundwater Recharge Using Porous Asphalt Experimental Site*. In Proceedings: International Symposium on Urban Storm Runoff. University of Kentucky, Lexington, KY, p. 89-97.

Goforth, G., E. Diniz, and J. Rauhut. 1983. *Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems*. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Hossain, M., and L. Scofield, 1991. *Porous Pavement for Control of Highway Runoff*. Arizona Department of Transportation, Phoenix, AZ.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Metropolitan Washington Council of Governments, Washington, DC.

Stenmark, C. 1995. An Alternative Road Construction for Stormwater Management. *Water Science and Technology* 32(1):79-84.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection, Ellicott City, MD.

Click here to comment on this fact sheet

Sand and Organic Filters

Click here to comment on this fact sheet

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

Subcategory: Filtration

Description

Sand filters are usually designed as two-chambered stormwater practices; the first is a settling chamber, and the second is a filter bed filled with sand or another filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and Multi-Chamber Treatment Train. All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

Applicability

Sand filters can be applied in most regions of the country and on most types of sites. Some restrictions at the site level, however, might restrict the use of sand filters as a stormwater management practice (see Siting and Design Considerations).

Regional Applicability

Although sand filters can be used in both cold and arid climates, some design modifications might be necessary (See Siting and Design Considerations).

In cold climates, filters can be used, but surface or perimeter filters will not be effective during the winter months, and unintended consequences might result from a frozen filter bed. Using alternative conveyance measures such as a weir system between the sediment chamber and filter bed may avoid freezing associated with the traditional standpipe. Where possible, the filter bed should be below the frost line. Some filters, such as the peat/sand filter, should be shut down during the winter. These media will become completely impervious during freezing conditions. Using a larger under drain system to encourage rapid draining during the winter months may prevent freezing of the filter bed. Finally, the sediment chamber should be larger in cold climates to account for road sanding (up to 40 percent of the water quality volume). Filters have not been widely used in arid climates, however, it is probably also necessary to increase storage in the sediment chamber to up to 40 percent of the water quality volume to account for high sediment loads.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface is present. Sand filters in general are good options in these areas because they consume little space. Underground and perimeter sand filters in particular are well suited to the ultra-urban setting because they consume no surface 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. These areas include commercial nurseries, auto recycle facilities, commercial parking lots, fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/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/steam cleaning facilities. Sand filters are an excellent option to treat runoff from stormwater hot spots because stormwater treated by sand filters has no interaction with, and thus no potential to contaminate, the groundwater.

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. Sand filters are a good option to achieve water quality goals in retrofit studies where space is limited because they consume very little surface space and have few site restrictions. It is important to note, however, that sand filters cannot treat a very large drainage area. Using small-site BMPs in a retrofit may be the only option for a retrofit study in a highly urbanized area, but it is expensive to treat the drainage area of an entire watershed using many small-site practices, as opposed to one larger facility such as a pond.

Cold Water (Trout) Streams

Some species in cold water streams, notably trout, are extremely sensitive to changes in temperature. To protect these resources, designers should avoid treatment practices that increase the temperature of the stormwater runoff they treat. Sand filters can be a good treatment option for cold water streams. In some stormwater treatment practices, particularly wet ponds, runoff is warmed by the sun as it resides in the permanent pool. Surface sand filters are typically not designed with a permanent pool, although there is ponding in the sedimentation chamber and above the sand filter. Designers may consider shortening the detention time in cold water watersheds. Underground and perimeter sand filter designs have little potential for warming because these practices are not exposed to the sun.

Siting and Design Considerations

Drainage Area

Sand filters are best applied on relatively small sites (up to 10 acres for surface sand filters and closer to 2 acres for perimeter or underground filters [MDE, 2000]). Filters have been used on larger drainage areas, of up to 100 acres, but these systems can clog when they treat larger drainage areas unless adequate measures are provided to prevent clogging, such as a larger sedimentation chamber or more intensive regular maintenance.

Slope

Sand filters can be used on sites with slopes up to about 6 percent. It is challenging to use most sand filters in very flat terrain because they require a significant amount of elevation drop, or head (about 5 to 8 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

Soils/Topography

When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that stormwater never infiltrates into the soil or interacts with the ground water. Alternatively, sand filters can be designed as pretreatment for an infiltration practice, where soils do play a role.

Ground Water

Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high ground water table. This design feature prevents both structural damage to the filter and possibly, though unlikely, ground water contamination.

Pretreatment

Pretreatment is a critical component of any stormwater management practice. In sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. In this chamber, the coarsest particles settle out and thus do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential of these sediments to clog the filter. Designers should provide at least 25 percent of the water quality volume in a dry or wet sedimentation chamber as pretreatment to the filter system. 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 area of the sedimentation chamber may be determined based on the Camp-Hazen equation, as adapted by the Washington State Department of Ecology (2005). The Center for Watershed Protection (1996) used a settling of 0.0004 ft/s for drainage areas greater than 75% impervious and 0.0033 ft/s for drainage areas less than or equal to 75% impervious to account for the finer particles that erode from pervious surfaces.

Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. In filtering systems, designers should provide at least 75 percent of the water quality volume in the practice including both the sand chamber and the sediment chamber. The filter bed should be sized using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. In sand filters, designers should select a medium sand as the filtering medium.

Conveyance

Conveyance of stormwater runoff into and through the filter should be conducted safely and in a manner that minimizes erosion potential. Ideally, some stormwater treatment can be achieved during conveyance to and from the filter. Since filtering practices are usually designed as "off-line" systems, meaning that they have the smaller water quality volume diverted to them only during larger storms, using a flow splitter, which is a structure that bypasses larger flows to the storm drain system or to a stabilized channel. One exception is the perimeter filter; in this design, all flows enter the system, but larger flows overflow to an outlet chamber and are not treated by the practice. All filtering practices, with the exception of exfilter designs are designed with an under drain below the filtering bed. An under drain is a perforated pipe system in a gravel bed, installed on the bottom of filtering practices and used to collect and remove filtered runoff.

Maintenance

Typical annual maintenance requirements are:

- Check to see that the filter bed is clean of sediments, and the sediment chamber is no more than one-half full of sediment; remove sediment if necessary
- Make sure that there is no evidence of deterioration, sailing, or cracking of concrete
- Inspect grates (if used)
- Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion
- Repair or replace any damaged structural parts
- Stabilize any eroded areas
- Ensure that flow is not bypassing the facility

The sorbent pillows used in Multi-Chamber Treatment Trains should be replaced twice per year. Routine (monthly) maintenance typically includes:

- Ensure that contributing area, filtering practice, inlets, and outlets are clear of debris
- Ensure that the contributing area is stabilized and mowed, with clippings removed
- Check to ensure that the filter surface is not clogging (also after moderate and major storms)
- Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system
- If a permanent pool is present, ensure that the chamber does not leak and that normal pool level is retained
- Ensure that no noticeable odors are detected outside the facility

In addition to regular maintenance activities needed to ensure the proper function of most stormwater practices, some design features can be incorporated to ease the maintenance burden of each practice. Designers should provide maintenance access to filtering systems. In underground sand filters, confined space rules defined by the Occupational Safety and Health Administration (OSHA) need to be addressed.

Landscaping

Landscaping can add to both the aesthetic value and the treatment ability of stormwater practices. In sand filters, little landscaping is generally used on the practice, although surface sand filters and organic media filters may be designed with a grass cover on the surface of the filter. In all filters, designers need to ensure that the contributing drainage has dense vegetation to reduce sediment loads to the practice.

Limitations

Sand filters can be used in unique conditions where many other stormwater management practices are inappropriate, such as in karst (i.e., limestone) topography or in highly urbanized settings. There are several limitations to these practices, however. Sand filters cannot control floods and generally are not designed to protect stream channels from erosion or to recharge the ground water. In addition, sand filters require frequent maintenance, and underground and perimeter versions of these practices are easily forgotten because they are out of sight. Perhaps one of the greatest limitations to sand filters is that they cannot be used to treat large drainage areas. Surface sand filters are generally not aesthetically pleasing practices but underground and perimeter sand filters are not visible, and thus do not add or detract from the aesthetic value of a site.

Effectiveness

Filtering practices are for the most part adapted only to provide pollutant removal, although in exfilter designs, some ground water recharge can be provided. Sand filters are effective for pollutant removal with the exception of nitrates, which appear to be exported from filtering systems. The export of nitrates from filters may be caused by mineralization of organic nitrogen in the filter bed.

Typical percent removals rates or ranges are:

TSS	65 - 90+
TP	40 – 85
TN	44 – 47
Metals	25 – 90+
Bacteria	55

Cost Considerations

There are few consistent data on the cost of sand filters due to their not having been used widely and they have such varied designs that it is difficult to assign a cost to filters in general. A study by Brown and Schueler (1997) was unable to find a statistically valid relationship between the volume of water treated in a filter and the cost of the practice, but typical total cost of installation ranged between \$2.50 and \$7.50 per cubic foot of stormwater treated, with an average cost of about \$5 per cubic foot. The cost per impervious acre treated varies considerably depending on the region and design used. It is important to note that, although underground and perimeter sand filters can be more expensive than surface sand filters, they consume no surface space, making them a relatively cost-effective practice in ultra-urban areas where land is at a premium.

Table 4: Construction costs for various sand filters (Source: Schueler, 1994)

Region (Design)	Cost/Impervious Acre
Delaware (Perimeter)	\$10,000
Alexandria , VA (Perimeter)	\$23,500
Austin , TX (<2 acres) (Surface)	\$16,000
Austin , TX (>5 acres) (Surface)	\$3,400
Washington , DC (underground)	\$14,000
Denver , CO	\$30,000–\$50,000
Multi-Chamber Treatment Train	\$40,000–\$80,000

References

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems*. Prepared for the Chesapeake Research Consortium, Solomons, MD, and U.S. EPA Region 5, Chicago, IL, by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1997. *Multi-Chamber Treatment Train developed for stormwater hot spots*. Watershed Protection Techniques 2 (3):445¿449.

Maryland Department of the Environment (MDE). 2000. Maryland Stormwater Design Manual. Available at: [http://www.mde.state.md.us/programs/waterprograms/sedimentandstormwater/stormwater_design/index.asp EXIT Disclaimer].

Schueler, T. 1994. *Developments in sand filter technology to improve stormwater runoff quality*. Watershed Protection Techniques 1(2):47¿54.

Click here to comment on this fact sheet

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℉. 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.

References

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for Chesapeake Research Consortium, Edgewater, MD by Center for Watershed Protection, Ellicott City, MD.

Emmerling-Dinovo, C. 1995. Stormwater Detention Basins and Residential Locational Decisions. *Water Resources Bulletin*, 31(3):515-521.

Galli, F. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Prepared for Maryland Department of the Environment, Baltimore, MD, by Metropolitan Council of Governments, Washington, DC.

MacRae, C. 1996. Experience from morphological research on canadian streams: Is control of the two-year frequency runoff event the best basis for stream channel protection? In *Effects of Watershed Development and Management on Aquatic Ecosystems*. American Society of Civil Engineers, Snowbird, UT.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 10, 2005.

Click here to comment on this fact sheet

Vegetated Filter Strip

Click here to comment on this fact sheet

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.

References

Design Reference

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems.* Prepared for Chesapeake Research Consortium, Solomons, MD, and EPA Region V, Chicago, IL.

Other References

Desbonette, A., P. Pogue, V. Lee, and N. Wolff. 1994. *Vegetated Buffers in the Coastal Zone: A Summary Review and Bibliography*. Coastal Resources Center. University of Rhode Island, Kingston, RI.

Magette, W., R. Brinsfield, R. Palmer and J. Wood. 1989. Nutrient and Sediment Removal by Vegetated Filter Strips. *Transactions of the American Society of Agricultural Engineers* 32(2): 663-667.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures.* Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Yu, S., S. Barnes and V. Gerde. 1993. *Testing of Best Management Practices for Controlling Highway Runoff*. FHWA/VA 93-R16. Virginia Transportation Research Council, Charlottesville, VA.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency Office of Wetlands, Oceans and Watersheds. Washington, DC.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 10, 2005.

Click here to comment on this fact sheet

EPA Home | Privacy and Security Notice | Contact Us

Last updated on May 24, 2006

URL:http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

U.S. ENVIRONMENTAL PROTECTION AGENCY

National Pollutant Discharge Elimination System (NPDES)

Recent Additions | Contact Us | Print Version Search NPDES: GO

EPA Home > OW Home > OWM Home > NPDES Home > Stormwater > Menu of BMPs

Search BMPs | All of the words | Filter by Minimum Measure | All | GO | Browse Fact Sheets | Search Help

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

Wet Ponds

Click here to comment on this fact sheet

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

Subcategory: Retention/Detention

Description

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

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.

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.

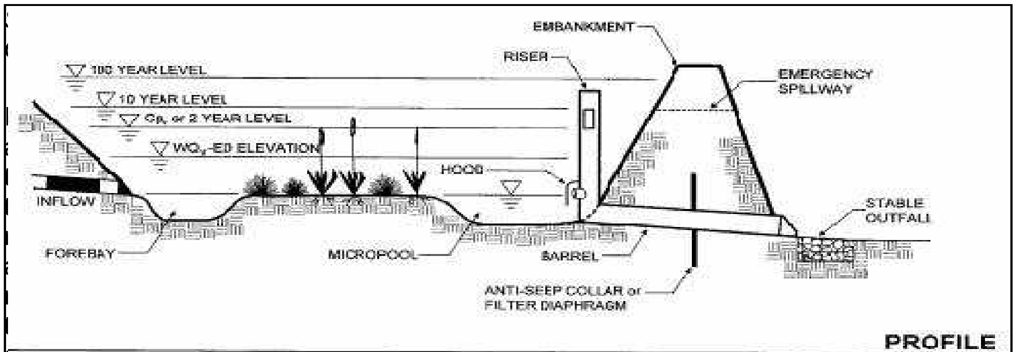
Stormwater Retrofit

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, 1 990).

Siting and Design Considerations



Example profile view of a wet pond design.

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.

<u>Drainage Area</u>

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.

<u>Slope</u>

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).

References

Bannerman, R., and R. Dodds. 1992. Unpublished data. Bureau of Water Resources Management, Wisconsin Department of Natural Resources, Madison, WI.

Borden, R. C., J.L. Dorn, J.B. Stillman, and S.K. Liehr. 1996. *Evaluation of Ponds and Wetlands For Protection of Public Water Supplies.* Draft Report. Water Resources Research Institute of the University of North Carolina, Department of Civil Engineering, North Carolina State University, Raleigh, NC.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

City of Austin, TX. 1991. *Design Guidelines for Water Quality Control Basins*. Public Works Department, Austin, TX.

City of Austin, TX. 1996. Evaluation of Non-Point Source Controls: A 319 Grant Project. Draft Water Quality Report Series, Public Works Department, Austin, TX.

Cullum, M. 1985. Stormwater Runoff Analysis at a Single Family Residential Site. Publication 85-1. University of Central Florida, Orlando, FL. pp. 247.256.

Dorman, M.E., J. Hartigan, R.F. Steg, and T. Quasebarth. 1989. *Retention, Detention and Overland Flow for Pollutant Removal From Highway Stormwater Runoff.* Vol. 1 Research Report. FHWA/RD 89/202. Federal Highway Administration, Washington, DC.

Driscoll, E.D. 1983. *Performance of Detention Basins for Control of Urban Runoff Quality.* Presented at the 1983 International Symposium on Urban Hydrology, Hydraulics and Sedimentation Control, University of Kentucky, Lexington, KY.

Emmerling-Dinovo, C. 1995. Stormwater detention basins and residential locational decisions. *Water Resources Bulletin*, 31(3):515.52.

Gain, W.S. 1996. *The Effects of Flow Path Modification on Water Quality Constituent Retention in an Urban Stormwater Detention Pond and Wetland System.* Water Resources Investigations Report 95-4297. U.S. Geological Survey, Tallahassee, FL.

Galli, F. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Prepared for the Maryland Department of the Environment, Baltimore, MD, by the Metropolitan Council of Governments, Washington, DC.

Holler, J.D. 1989. Water quality efficiency of an urban commercial wet detention stormwater management system at Boynton Beach Mall in South Palm Beach County, FL. *Florida Scientist* 52(1):48.57.

Holler, J.D. 1990. Nonpoint source phosphorous control by a combination wet detention/filtration facility in Kissimmee, FL. *Florida Scientist* 53(1):28.37.

Horner, R.R., J. Guedry, and M.H. Kortenhoff. 1990. *Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control.* Final

Report. Washington State Transportation Commission, Olympia, WA.

Kantrowitz, I., and W. Woodham. 1995. *Efficiency of a Stormwater Detention Pond in Reducing Loads of Chemical and Physical Constituents in Urban Streamflow, Pinellas County, Florida.* Water Resources Investigations Report 94-4217. U.S. Geological Survey, Tallahassee, FL.

Martin, E. 1988. Effectiveness of an urban runoff detention pond/wetland system. *Journal of Environmental Engineering* 114(4):810.827.

Oberts, G.L. 1994. Performance of stormwater ponds and wetlands in winter. *Watershed Protection Techniques* 1(2):64.68.

Oberts, G.L., P.J. Wotzka, and J.A. Hartsoe. 1989. *The Water Quality Performance of Select Urban Runoff Treatment Systems.* Publication No. 590-89-062a. Prepared for the Legislative Commission on Minnesota Resources, Metropolitan Council, St. Paul, MN.

Oberts, G.L., and L. Wotzka. 1988. The water quality performance of a detention basin wetland treatment system in an urban area. In *Nonpoint Source Pollution: Economy, Policy, Management and Appropriate Technology*. American Water Resources Association, Middleburg, VA.

Occoquan Watershed Monitoring Laboratory. 1983. Metropolitan Washington Urban Runoff Project. Final Report. Prepared for the Metropolitan Washington Council of Governments, Washington, DC, by the Occoquan Watershed Monitoring Laboratory, Manassas, VA.

Ontario Ministry of the Environment. 1991. *Stormwater Quality Best Management Practices.* Marshall Macklin Monaghan Limited, Toronto, Ontario.

Saunders, G. and M. Gilroy. 1997. *Treatment of Nonpoint Source Pollution With Wetland/Aquatic Ecosystem Best Management Practices.* Texas Water Development Board, Lower Colorado River Authority, Austin, TX.

Schueler, T. 1997a. Comparative pollutant removal capability of urban BMPs: A reanalysis. *Watershed Protection Techniques* 2(4):515.520.

Schueler, T. 1997b. Influence of groundwater on performance of stormwater ponds in Florida. *Watershed Protection Techniques* 2(4):525.528.

Urbonas, B., J. Carlson, and B. Vang. 1994. Joint Pond-Wetland System in Colorado. Denver Urban Drainage and Flood Control District, Denver, CO.

U.S. Environmental Protection Agency (USEPA). 1995. *Economic Benefits of Runoff Controls*. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC, by the Watershed Management Institute, Ingleside, MD.

Wu, J. 1989. Evaluation of Detention Basin Performance in the Piedmont Region of North Carolina. Report No. 89-248. North Carolina Water Resources Research Institute, Raleigh, NC.

Yousef, Y., M. Wanielista, and H. Harper. 1986. Design and Effectiveness of Urban Retention Basins. In *Urban Runoff Quality.Impact and Quality Enhancement*

Technology. B. Urbonas and L.A. Roesner (Eds.). American Society of Civil Engineering, New York, New York. pp. 338.350.

Information Resources

Center for Watershed Protection (CWP). 1995. *Stormwater Management Pond Design Example for Extended Detention Wet Pond*. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Denver Urban Drainage and Flood Control District. 1992. *Urban Storm Drainage Criteria Manual.Volume 3: Best Management Practices*. Denver Urban Drainage and Flood Control District, Denver, CO.

Galli, J. 1992. *Preliminary Analysis of the Performance and Longevity of Urban BMPs Installed in Prince George's County, Maryland*. Prince George's County, Maryland, Department of Natural Resources, Largo, MD.

MacRae, C. 1996. Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection? In *Effects of Watershed Development and Management on Aquatic Ecosystems*. American Society of Civil Engineers. Snowbird, UT. pp. 144.162.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed May 22, 2001.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas: Best Management Practices*. Minnesota Pollution Control Agency, Minneapolis, MN.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Click here to comment on this fact sheet

Appendix C: FHWA Fact Sheets

(Provided in alphabetical order by BMP)

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

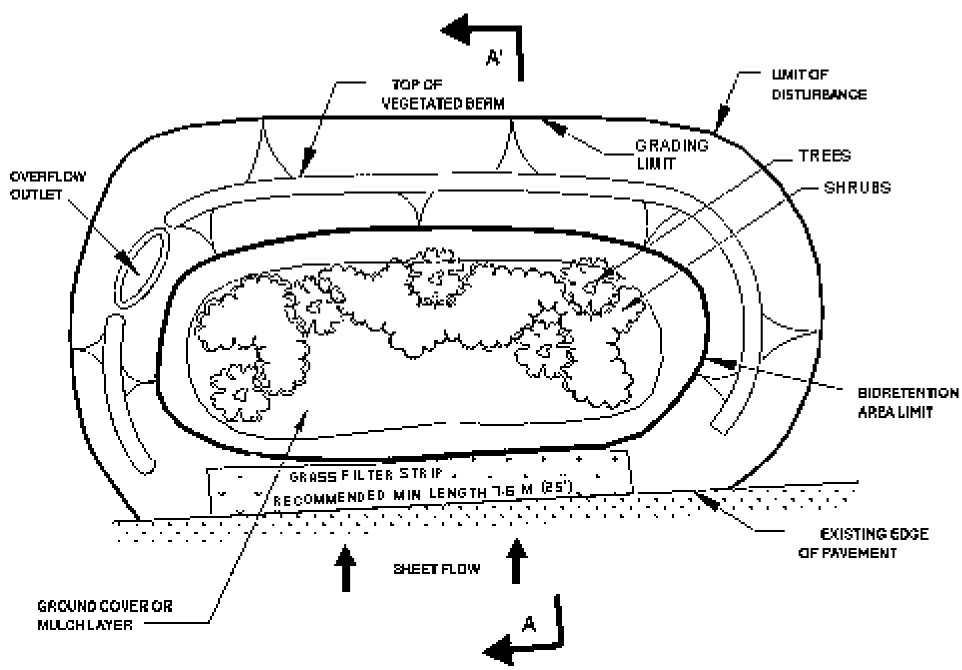
Fact Sheet - Bioretention

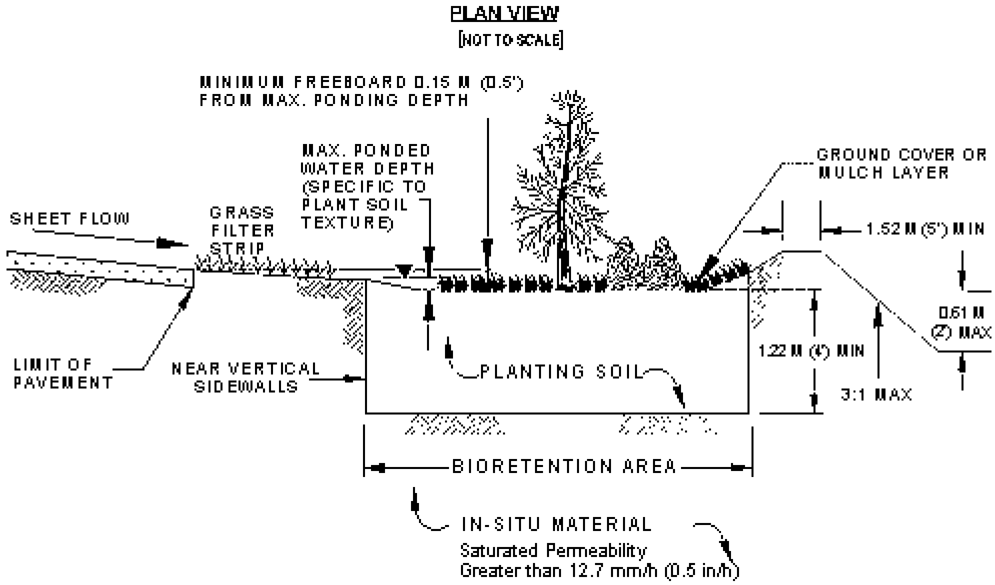
Bioretention was developed as an innovative approach in the ultra-urban environment. Bioretention areas (BAs) are easy to construct and require less infrastructure maintenance than many other BMPs. In addition to their well-accepted aesthetic value, BAs can be tailored in design and location to fit into the ultra-urban landscape.

Water quality improvements result from sedimentation, filtration, soil adsorption, microbial decay processes, and the uptake of pollutants by plants. The use of vegetation in BAs is modeled from the properties of a terrestrial forest community-an ecosystem dominated by mature trees, subcanopy of understory trees, shrubs, and herbaceous plants. Plants are selected based on their tolerance to varying hydrologic conditions, soil and pH requirements, and general characteristics like aesthetics. An additional important feature of bioretention is the soil in the system, which contains a mixture of detritus, humus, and mineral and biological complexes. The soil layer and the microbes living in the soil enhance infiltration, groundwater recharge, and nitrogen and metals removal; provide valuable water and nutrients for plant growth; and provide oxygen for plant root metabolism and growth.

BAs consist of a flow-regulating structure that processes inflow passing through a shallow depressed planted area containing ground cover (low-lying plant growth or an organic mulch), a planting soil supporting a range of facultative plant types, and a bottom support soil layer. Each of these features has a specific role in stormwater pollutant removal (Figure 6).

Figure 6. Parking edge and perimeter without curb (Prince George's County, Maryland, 1993)





Applicability

BAs have unique features that make them attractive for use in the ultra-urban environment. They have the ability to fit in existing or proposed medians or grassy areas along streets and parking lots. In addition, by disposing of a significant volume of annual rainfall on-site, BAs may reduce the infrastructure costs required to collect and convey the runoff off-site. BAs can also provide benefits other than stormwater management, including creating green areas and natural habitat. For facilities placed in new developments, the land area requirement and cost can be minimized if the local jurisdiction considers BAs part of the required vegetated open space set-aside or if installed trees count against local landscaping and tree coverage requirements.

Effectiveness

Limited monitoring of the effectiveness of BAs has been completed to date although there are ongoing monitoring efforts. Due to the similarity between bioretention technology and dry swales, however, the pollutant removal capability should be comparable (Claytor and Schueler, 1996). For planning purposes it is acceptable to anticipate BAs will remove 50 percent of total phosphorus (TP), 50 percent of total nitrogen (TN), between 75 and 80 percent of metals, and 75 percent of total suspended solids (TSS). Based on the nature of the planting soil and the facultative plants normally installed, BAs should be capable of managing some petroleum hydrocarbon concentrations commonly encountered in urban settings. Pretreatment is not considered crucial to the removal performance of BAs except where there is an atypically high level of pollutant loading, which can harm the planted growth (i.e., heavy commercial or industrial settings).

In variable climates, seasonal differences in removal performance should be anticipated for BAs, due to the growing and dormant periods of plants. Fall and winter temperatures force vegetation into dormancy, thereby reducing uptake of some runoff pollutants. However, carefully selected planting soil should provide significant storage capacity for many common urban pollutants during no/slow growth periods as long as soil infiltration can occur. Freezing temperatures greatly reduce infiltration in BAs and inactivate the most important pollutant removal mechanism.

BAs are intended to be water quality control practices, but they can be employed as either an on-line or off-line design. If BAs are employed as on-line facilities, design features must be incorporated to ensure nonerosive flow velocities exist within the BA. During these larger rainfall events, BAs should provide marginal treatment of the high flow volume (principally large-diameter suspended solids) even though the residence time in most facilities will be short.

Siting and Design Considerations

Bioretention is a relatively new technology being refined to achieve maximum water quality benefits. The basic design elements and major components of BAs are discussed below. For design examples and additional information, several good sources are available, including Design Manual for Use of Bioretention in Stormwater

Management (Prince George's County, 1993), Design of Stormwater Filtering Systems (Claytor and Schueler, 1996), and Highway Runoff Manual (WSDOT, 1995).

The basic design elements to be addressed are proper soils, vegetation, and drainage. For most ultra-urban applications designers should look for relatively flat areas where deep soils (1.68 m [6 ft] to bedrock) are present and where seasonal high groundwater elevations are at least 1.68 m (6 ft) below grade. Ideally, BAs will discharge collected stormwater into underlying in situ soils and then into the surficial groundwater aquifer. As an option, designers can employ an underdrain system to collect exfiltration from the BA wherever existing deep soil layers will prevent exfiltration. Underdrains are typically placed approximately 1.52 m (5 ft) below grade and must drain by gravity to either an outlet or a storm drain. Underdrain systems can also be used in BAs where they will be placed in close proximity of building foundations. A minimum 9.2 m (30 ft) offset is recommended for BAs without underdrains.

Bioretention facilities combine a number of physical, biological, and hydrologic components to provide complementary functions to improve water quality, control hydrology, and provide wildlife and aesthetic improvements. The major components of the BA are:

- Pretreatment area (optional).
- Ponding area.
- Ground cover layer.
- Planting soil.
- In-situ soil.
- Plant material.
- Inlet and outlet controls.

Pretreatment Area

Some BA designs incorporate an upstream pretreatment area. Pretreatment is necessary where a significant volume of debris or suspended material will be conveyed by stormwater into the BA; for example, parking lots or commercial areas that are regularly sanded. In Figure 6, a grass buffer strip is used to reduce the runoff velocity and to filter large-diameter particulates from the runoff. Other pretreatment devices that can be employed are oil/grit separators, forebays, and stilling basins.

Ponding Area

In BAs the ponding area is located over the planting soil and provides surface storage for stormwater runoff while it infiltrates and/or evaporates after the rainfall period. Major design parameters for the ponding area are the maximum ponding depth and the duration of ponding. In Prince George's County, Maryland, these parameters were established based on the type of planting soil used and the type of adjacent land use. The higher the infiltration rate of the planting soil, the greater the maximum ponding depth (up to 0.3 m [12 in]). Applications in residential areas are permitted ponding for less than 24 hours; all other applications are permitted 36 hours of ponding (Prince George's County, Maryland, 1993).

Ground Cover Layer

The surface of the BA is covered with an organic ground cover layer. The organic layer provides a medium for biological growth and provides the carbon source needed for biological activities at the air/soil interface. It also helps to maintain a sufficient organic percentage in the surface soil horizon, in a sense simulating the leaf litter in forest communities. It is recommended that designers of BAs either use a mature mulch (maximum depth of 76.2 mm [3 in]) or establish permanent growth (e.g., grasses) within one growing season (Prince George's County, Maryland, 1993).

Planting Soil

BAs contain a thick layer of planting soil, located below the ground cover layer and supported by the underlying in situ soils. This thickness also provides for deep root plant growth. Planting soil must have a high infiltration rate, support healthy plant growth, adsorb nutrients and pollutants, and provide additional storage capacity for stormwater. These objectives can be met by using a planting soil containing a clay content of 2.5 to 10 percent and an organic content between 1.5 and 3 percent.

Prince George's County permits BAs with higher infiltration soils to have a greater ponding depth, which resulted in a smaller surface area of the BA. Based on this approach, designers might have to choose between using less expensive existing onsite soils or replacing existing soils with imported highly permeable soils to permit a smaller

BA. To provide the infiltration necessary to remove ponded stormwater it is recommended that the soil texture be sand, loamy sand, sandy loam, loam, or silt loam. In addition it is recommended that the planting soil thickness be 1.22 m (4 ft) to ensure significant contact time between infiltrating stormwater and the soil. This soil depth will also help deeply rooted plant growth become well established (Prince George's County, Maryland, 1993).

In Situ Soil

As shown in Figure 6, the in situ soil layer provides a foundation for planting soils and drains the infiltrated stormwater from BAs. Experimental BAs have shown that in situ soils are crucial to the success of the facility; if a location drains in a poor manner, the BA will fail unless another means of drainage is established. Prince George's County, Maryland, recommended percolation tests be performed to demonstrate that in situ soils possess at least 12.7 mm/h (0.5 in/h) infiltration capacity. Where poorly drained in situ soils are encountered, it is still feasible to install bioretention but only with the aid of an underdrain system. Additional information on investigating in situ soils and designing underdrain systems is provided in the Prince George's County Design Manual for Use of Bioretention in Stormwater Management (Prince George's County, Maryland, 1993).

Plant Material

The role of plant species is to use nutrients and other pollutants and remove water from the planting soil through evapotranspiration. Plants must be a low-maintenance, aesthetically pleasing variety that is tolerant of urban stormwater pollutants. They must have the ability to adapt to conditions of drought and inundation. Key design parameters for optimum plant material function include species diversity, density, and morphology, and the use of native plants. Ideally, the community structure will be similar to that of a forest community, providing diversity to reduce susceptibility to insect and disease infestation. The intention is to create a microclimate that is resistant to urban stresses. The plants selected must be able to prosper even when flooded to a depth of 0.15 m (0.5 ft) or more at frequent intervals.

Inlet and Outlet Controls

The specifics of inlets and outlets of BAs are highly dependent on whether the BA is an on-line or off-line design. An on-line facility is one that does not have a bypass that diverts excess stormwater around the BA once it becomes full.

Because all stormwater will pass through an on-line bioretention facility, both inlets and outlets must be designed to ensure that the runoff rate does not damage the BA. Prince George's County states that designers must ensure nonerosive flow velocities exist within the BA for the 10-year postdevelopment event (Prince George's County, Maryland, 1993). On-line facility designs usually include protection such as riprapped inlets and outlets, which are designed through an in-depth hydraulic evaluation. Possible outlets for on-line areas include drop inlets or overflow weirs that feed downstream swales or pipe systems.

Off-line BAs generally require smaller inlets than on-line facilities because inlets are usually designed to convey the runoff from the first 12.7 mm (0.5 in) of runoff from the site. All other runoff must be diverted around the BA and downstream to subsequent swales or pipe systems without passing through the BA. This diversion can be established by creating a ponding area in the BA, which causes backwater conditions and a resulting shift in discharge direction.

Designers must be careful not to undersize entrances into BAs and to keep entrance velocities in excess of 0.15 m/s (0.5 ft/s) to help prevent clogging of the inlet area. Debris (e.g., sand) on the parking area can be washed toward the bioretention inlet and form a small dike, blocking the inlet.

Maintenance Considerations

BAs require routine, low-cost maintenance, similar to conventional landscaping maintenance, to ensure the system functions well as a stormwater BMP and remains aesthetically pleasing. Routine inspections of the bioretention facility, semiannually for the first year and annually thereafter, along with spot inspections after major storms the first year to verify the BA has not been significantly disturbed, aid in ensuring the performance of the BA. Other maintenance considerations include:

- Planting soil bed - check the pH of the soils, correct erosion, cultivate unvegetated areas to reduce clogging from fine sediments over time.
- Ground cover layer - mulch or replant bare spots annually.

- Planting materials - replace dead or severely distressed vegetation, perform periodic pruning, etc.
- Inflow/outflow - inspect for clogging, remove sediment build-up, repair eroded pretreatment areas, remove accumulated trash and debris.

Cost Considerations

Initial estimates from engineers designing BAs suggest project costs will be approximately $24,700 per impervious hectare ($10,000 per impervious acre), exclusive of real estate costs (Bell, 1996).

References

Bell, W. 1996. BMP Technologies for Ultra-Urban Settings. In Proceedings of Effective Land Management for Reduced Environmental Impact, Tidewater's Land Management Conference on Water Quality, August 22, 1996.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Prince George's County. 1993. Design Manual for Use of Bioretention in Stormwater Management. Department of Environmental Resources, Prince George's County, Landover, MD.

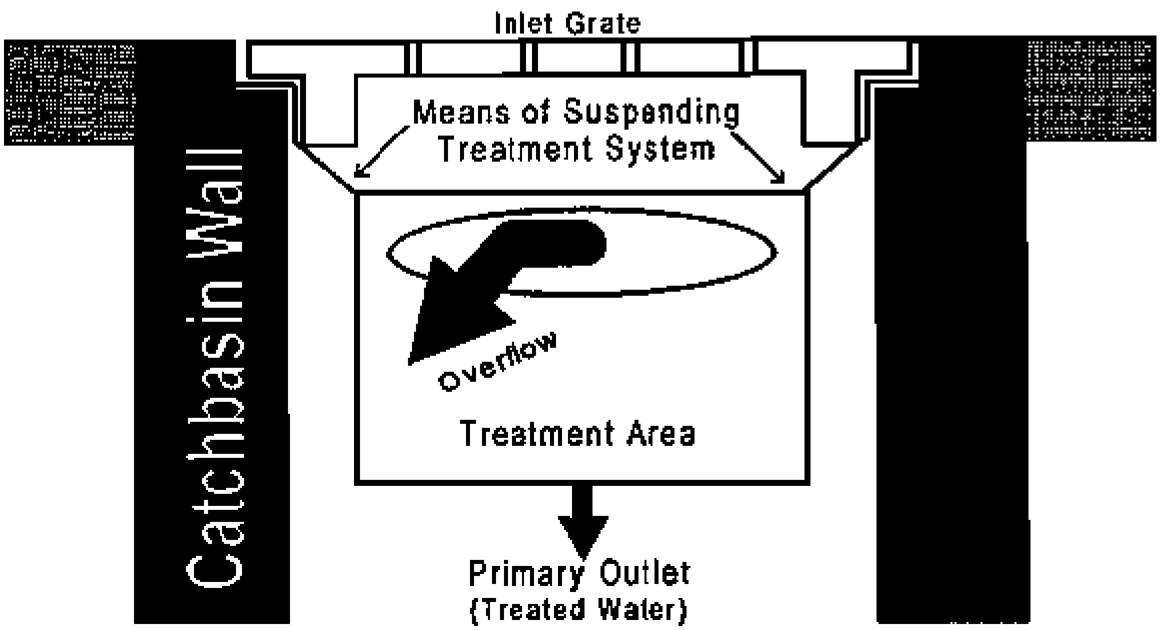
Washington State Department of Transportation (WSDOT). 1995. Highway Runoff Manual. Washington State Department of Transportation.

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Catch Basin Inserts

Catch basin inserts (CBIs) are designed either to hang from a drain-inlet frame or to be inserted well below the drain inlet in the sump area, taking advantage of additional space in the lower part of the catch basin. The information provided here refers to drain-inlet inserts that are mounted directly beneath the frame. Figure 22 shows a typical frame-mounted CBI. CBIs work by gravitational filtering to remove debris and large (gravel-sized) sediment particles entering the catch basin. Some of the insert models also are designed with an inner component that contains an oil-absorbent material to facilitate in the removal process.

Figure 22. Typical features of a catch basin insert (King County, Washington, 1995)



CBI devices are designed to be suspended from the storm drain inlet structure. Hydraulically, they are designed with a high-flow bypass to prevent resuspension and washout. Only the designed flow rate should pass through treatment surfaces. The insert can contain one or more treatment mechanisms, which include filtration, sedimentation, or gravitational absorption of oils. Two outlets also are designed into the devices. The first outlet is for treated stormwater, and the second is for stormwater that exceeds the capacity of the device. In some manufactured CBIs, the overflow outlet is not a true bypass because excess water still contacts the treatment area prior to overflow. For such CBIs, due to the very short contact time and potential for flushing previously trapped materials, treatment may be compromised at higher flow rates (King County, 1996).

Applicability

CBIs are not suitable for removal of fine particulate stormwater pollutants such as metals, nutrients, silts, or clays; however, inserts can be used in unpaved areas where the sediment concentration in the stormwater is expected to contain coarse material. In addition, CBIs are suited for sites where a substantial amount of debris is found in stormwater runoff. Areas where CBIs would be appropriate include unpaved roads or parking areas, construction sites, or unpaved industrial sites and lumber yards. Because oil/grit separators are not recommended for unpaved areas, CBIs could be used in lieu of them.

Effectiveness

In a recent study by King County, Washington, and others (King County et al., 1995), six different CBIs were evaluated. The inserts tested did not remove significant amounts of pollutants associated with silt- or clay-sized particles; however, the inserts were capable of trapping and removing the coarser materials and debris that are typically found in unpaved areas. New inserts that were designed to remove petroleum hydrocarbons were found to reduce oil and grease concentrations by 30 to 90 percent; after some use, the sustained removal rates were reduced to 30 percent or less. While the inserts varied in their ability to remove oil and grease, most units exhibited some level of treatment if maintained on a regular basis. Inserts did not exhibit any ability to remove metals such as total copper, lead, or zinc. Tests on new and used insert units showed that the CBIs were not effective at removing total phosphorus associated with very fine sediment.

Siting and Design Considerations

Because of their limited ability to remove stormwater runoff pollutants, CBIs should not be used as a stand-alone BMP, but rather installed in conjunction with other BMPs. CBIs are best suited for installation as pretreatment for other BMPs to remove large sediment or debris from unpaved or pervious areas. It should be noted that there are different types of CBI designs and media and one type might not cover all possible pollutants. It is important, therefore, to specify which pollutant is of primary importance because systems optimized for large sediment or debris might not provide acceptable long-term removal of oils and grease, and vice versa. Because catch basin inserts are commercially available, design and installation information can be obtained from their manufacturers or distributors. Catch basin inserts developed by three vendors were evaluated by the Interagency Catch Basin Insert Committee in the Seattle, Washington, area (King County et al., 1995). General design criteria and siting recommendations can be found in the King County, Washington, Surface Water Design Manual (King County, 1996).

CBIs should be designed to perform acceptably for a reasonable design storm (e.g., 2-yr rainfall event) based on hydrologic characteristics and the percent of imperviousness of the site. At the same time, they should not interfere with the drainage for larger rainfall events (e.g., the 10-year rainfall event).

Maintenance Considerations

One of the major concerns with CBIs is the need to regularly clean the filter system or medium. Units designed for coarse sediment or debris removal tend to have more holding capacity and, depending on their location, will operate correctly if cleaned after every two or three major storms. Maintenance for CBIs configured for oil and grease removal is also a function of specific site conditions but in general is more intensive. In the majority of the cases, this maintenance focuses on removing accumulated fine-grain sediment from the filter surface or screens. The filter or medium has to be replaced less frequently because of saturation by oil and grease. Streetsweeping could potentially reduce the maintenance frequency for inserts that have this problem.

There is currently an effort to improve the design of CBIs to manage oil and grease and sediment. CBIs currently under development would separate sediment holding areas from the filter media. Captured sediment collected from several storm events would be stored in a dead-storage area at the base of the catch basin, thereby, preventing clogging of the filter media.

Most of the inserts are made of lightweight material and can be removed by one person; however, filter inserts allowed to fill up with sediment or debris may require two-person crews to lift.

Cost Considerations

Depending on the complexity of the unit, the CBI grate-mounted units can range in cost from as little as $100 up to $1,500. Variables affecting cost include the size of the insert, the type of filter medium, the filtering system, and the material used to construct the insert. Another consideration is the clean-out and maintenance requirements of a sump with an insert versus a sump without the insert. Costs for maintaining CBIs range from $10 to $100 per unit per month, assuming monthly replacement of filter media (King County, 1996). In a study conducted by the Port of Seattle, it took one person 90 minutes to clean 18 inserts. In contrast, it took two vacuum truck operators about three hours to clean 18 sumps (King County et al., 1995).

References

King County Surface Water Management Division, King County Department of Metropolitan Services, Snohomish County Surface Water Management Division, Seattle Drainage and Wastewater Utility, and Port of Seattle. 1995. Evaluation of Commercially-Available Catch Basin Inserts for the Treatment of Stormwater Runoff from Developed Sites. Interagency Catch Basin Insert Committee.

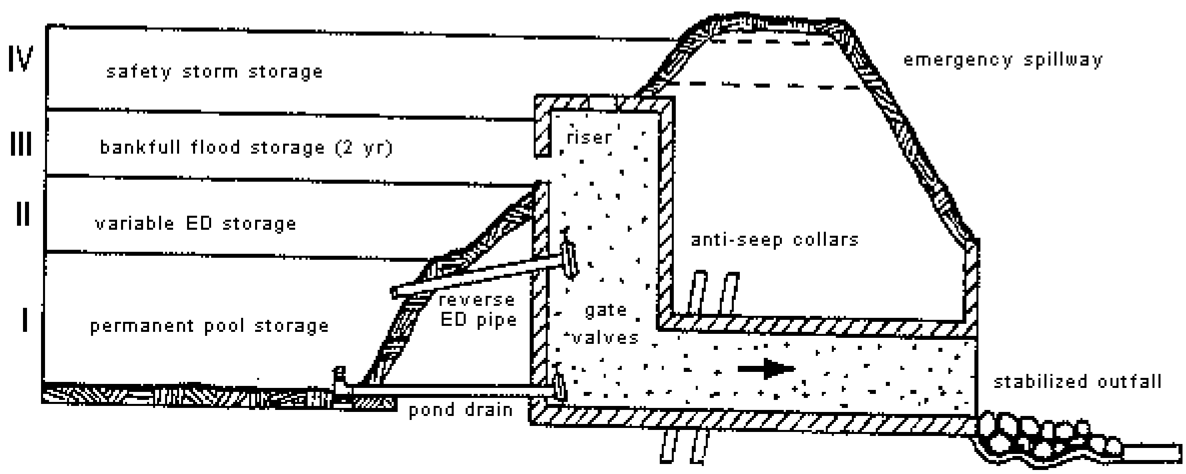
King County. 1996. Surface Water Design Manual. Draft. King County Surface Water Management Division, King County, WA.

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Detention Ponds

Extended detention ponds have been used for a number of years in urban applications, and are designed to mitigate highway runoff stormwater quality and/or quantity impacts. These systems function by storing the increased runoff volume that results from development, then slowly releasing it at predevelopment runoff rates. The controlled release rate is designed to maintain the existing hydraulic conditions in the downstream watercourse (ASCE, 1992). The most commonly built facilities are dry extended detention (ED) ponds and wet ponds with extended detention. Figure 8 illustrates a cross-sectional view of a standard ED pond system design.

Figure 8. Cross-section view of a standard extended detention pond system (Schueler, 1992)



Water quality benefits are achieved by treating the "first flush" of runoff from impervious areas. The "first flush" of runoff often contains the most pollutants. When extended detention is the method used for water quality treatment, the required volume is released over a long period of time, allowing sufficient time for particulates to settle out. Nutrients, heavy metals, and other pollutants associated with these particulates can also be removed.

Applicability

In an ultra-urban application, detention ponds are generally applicable as an end-of-pipe treatment facility. The pond design will be site-specific and extremely dependent on the site soils, existing utility conflicts, property ownership, and drainage area to be routed through the pond. Additional space constraints may reduce the applicability of some pond enhancement features such as a forebay, micropool, and safety bench. For example, the additional area needed to provide a safety bench (0.3 m [1 ft] wide strip around facility) may not exist in an ultra-urban setting. A safety alternative such as a chain-link fence, although not as aesthetically pleasing, may be required.

Another problem that may occur in siting detention ponds in ultra-urban environments is finding an adequate 100-year storm overflow path. Unfortunately, in the ultra-urban environment, space is usually limited at the end of storm drain systems. Additional opportunities for siting extended detention facilities are in medians, interchanges, adjacent to ramps, and along rights-of-way adjacent to roads.

Effectiveness

Properly designed detention ponds can greatly reduce the stormwater runoff impacts of highway development.

When coordinated with other BMPs in the watershed, they can effectively reduce stormwater peak flows. Dry detention ponds can also remove up to 90 percent of particulates (Kehoe, 1993). Dry detention ponds, however, are not as effective at removing soluble pollutants. Other design approaches such as wet ponds and wetlands may be used in conjunction with extended detention for more efficient water quality control. Additional data on pollutant removal effectiveness of detention ponds is shown in Table 10.

Table 10. Pollutant removal effectiveness of detention ponds (%)

Study	TSS	TP	TKN	NO_3	Metals	Comments
City of Austin (1990) [1]	46	37	14	36	40 - 60	On-line wet pond
City of Austin (1995) [1]	94	81	44	64	-	Wet retention pond
Yu & Benelmouffok (1988)[2]	76	70	65	75	50 - 57	Extended detention wet pond
Martin & Smoot (1986)[2]	78	20	-	-	63	In-line wet detention pond as pretreatment to wetland system. Efficiencies are for pond only
Gain (1996)[1]	54	30	16	24	24 - 73	Evaluates modification by flow barrier in wet pond; pond is pretreatment to wetland
Harper & Herr (1993)[1]	85	54	26	92	37 - 75	Based on water column sampling from various sites in the wet detention pond
Yu et al. (1993)[2]	67 - 93	75 - 94	-	-	-	Dry detention pond
Yu et al. (1994)[2]	96	81	44	64	-	Dry detention pond, study evaluated modifications to outlet

[1] Removal efficiencies based on concentrations.
[2] Removal efficiencies based on mass loading.

Siting and Design Considerations

The success of a stormwater management pond design is very dependent on site-specific conditions. The major components common to each system are the water storage area for quantity and/or quality control and some type of outlet structure. The outlet structure can be a concrete or corrugated metal pipe (CMP) riser with openings to release the stormwater at the predevelopment runoff rates for specific storm events. The calculations and routings may be accomplished with very simple techniques, such as the Rational and Storage-Indication methods, or more complex models, such as HEC-22 or the Storm Water Management Model (SWMM), may be used.

A number of physical conditions are critical to siting and designing a pond. The side slopes of the pond and embankment may be steep. To protect both pedestrians and passengers, sufficient barriers, such as fences, guardrails, and safety zones, must be incorporated into the design. The saturated soils found below a wet pond can affect the structural stability of adjacent road embankments. The rate and timing of the peak discharge of the pond may be critical to preventing or increasing downstream flooding.

Although ponds are classified into the major categories of detention and retention facilities, there are also hybrid facilities that contain features found in both systems. The most common of such facilities, which are described below, are extended detention dry ponds and wet ponds with extended detention. Additional design examples and information can be found in Urban Drainage Design Manual Hydraulic Engineering Circular 22 (Brown et al., 1996), Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996), and Design and Construction of Urban Stormwater Management Systems (ASCE, 1992).

Extended Detention Dry Ponds

Extended detention dry ponds can be designed as two-stage, or water surface elevation, 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 12.7 mm (0.5 in) or a design storm frequency, such as the 1-year 24-hour storm event. The water is drawn down over a period of time, normally between 24 and 48 hours, through an orifice in the riser of the principal spillway. This residence time may allow for as much as 90 percent removal of particulates through settling (Young et al., 1996). Residence times that are too long may allow the water to become heated, resulting in a potential thermal impact to receiving waters. Removal of soluble compounds is limited in dry ponds. 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.

Extended Detention Wet Ponds

Wet ponds use a permanent pool of water to aid in achieving water quality control. The pool may cover the entire pond bottom or may be located in only a portion of the pond. Sufficient drainage area, fairly impermeable soils, and an adequate base flow to the pond are important to maintain a permanent pool. Sizing of the wet pool should consider the "first flush" runoff volume.

Consideration must also be given to water depth and pond length for settling. The pond depth must be deep enough, usually 0.9 m (3 ft) or more, so that wind-generated disturbance of bottom sediments does not cause the resuspension of sediments. Also, the pond depth should be shallow enough, usually 2.4 m (8 ft) or less, so that mixing occurs and the pond does not become anoxic. Pond depths in excess of 2.4 m (8 ft) should be avoided to prevent thermal stratification (Schueler, 1987). Alternating areas of shallow and deep pools in wet ponds can also be used to increase the sediment trapping efficiency and habitat diversity. Forebays are usually included to reduce sediment deposition throughout the system and facilitate maintenance. Incorporation of wetland plants along the fringe of the pond helps reduce erosion on the banks, provides some habitat, and may provide opportunities for nutrient removal.

The extended detention volume for a wet pond occurs above the water quality volume and below the crest of the pond. The water is released through openings in the outlet structure. An emergency spillway should be required to allow water to discharge safely in the event of a large-scale storm event.

Maintenance Considerations

Many detention facilities are embankment ponds. Regular inspections are required to check for seepage through the embankment, burrowing animals, deep-rooted vegetation, and erosion along the embankment and sides of the pond. Other routine maintenance includes reseeding of the pond banks and bottom and removal of debris from the spillway. Over time, sediment accumulation may significantly reduce the capacity of the pond. Studies have shown that every year up to 1 percent of the storage of the 2-year 24-hour storm event can be lost to sediment deposition (siltation) (Yousef et al., 1986). Sediment can reduce the quantity storage in a pond up to 20 percent over a 10-year period. Dredging of the material may be required every 5 to 10 years to restore the capacity of the pond. The sediment should be tested to determine if it is a hazardous material. Other considerations critical to the efficiency of the pond include maintenance of outlet structures, flow splitters, and clean-out gates (Koon, 1995).

Cost Considerations

Cost factors for stormwater management ponds are extremely sensitive to site conditions. Availability of in situ materials for embankment construction, outlet protection, cost of excavation, liner materials, and land costs are significant factors. Maintenance and inspection costs for mowing and periodic dredging are postdevelopment factors. Other technologies such as infiltration trenches may be more cost-effective in smaller drainage areas due to construction and long-term maintenance costs (Young et al., 1996). Studies have suggested that preliminary costs can be estimated by the following equation (adapted from Wiegand et al., 1986):

$$C = 168.39 \times V0.69$$

where:

C = construction cost estimate (1995 dollars) and
V = volume of storage of the pond (cubic meters) up to the crest of the emergency spillway.
This cost should be increased by 25 percent for construction contingencies.

References

ASCE. 1992. Design and Construction of Urban Stormwater Management Systems. The Urban Water Resources Research Council of the American Society of Civil Engineers (ASCE) and the Water Environment Federation. American Society of Civil Engineers, New York, NY.

Brown, S.A., S.M. Stein, and J.C. Warner. 1996. Urban Drainage Design Manual Hydraulic Engineering Circular 22. FHWA-SA-96-078. Federal Highway Administration, Office of Technology Application.

City of Austin. 1990. Removal Efficiencies of Stormwater Control Structures. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, TX.

City of Austin. 1995 (draft). Characterization of Stormwater Pollution for the Austin, Texas Area. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, TX.

Gain, S.W. 1996. The Effects of Flow-Path Modifications on Urban Water-Quality Constituent Retention in Urban Stormwater Detention Pond and Wetland System, Orlando, Florida. Florida Department of Transportation, Orlando, FL.

Harper, H.H., and J.L. Herr. 1993. Treatment Efficiencies of Detention with Filtration Systems. Environmental Research and Design, Inc, Orlando, FL.

Kehoe, M.J. 1993. Water Quality Survey of Twenty-Four Stormwater Wet-Detention Ponds. Southwest Florida Water Management District, Brooksville, FL.

Koon, J. 1995. Evaluation of Water Quality Ponds and Swales in the Issaquah/East Lake Sammamish Basins. King County Surface Water Management Division, Seattle, WA.

Martin, E.H., and J.L. Smoot. 1986. Constituent-Load Changes in Urban Stormwater Runoff Routed Through a Detention Pond-Wetlands System in Central Florida. U.S. Geological Survey Water Resources Investigations Report 85-4310. Tallahassee, FL.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, DC.

Wiegand, C., T. Schueler, W. Chittenden, and D. Jellick. 1986. Cost of Urban Runoff Quality Controls. In Urban Runoff Quality - Impact and Quality Enhancement Technology, ed. B. Urbonas and L.A. Roesner, p.366-382. American Society of Civil Engineers, New York, NY.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Yousef, Y.A., M.P. Wanielista, and H.H. Harper. 1986. Best Management Practices - Effectiveness of Retention/Detention Ponds for Control of Contaminants in Highway Runoff. Florida Department of Transportation, Gainesville, FL.

Yu, S.L., M. Barnes, R.J. Kaighn, and S.L. Liao. 1994. Field Test of Stormwater Best Management Practices in Watershed Wastewater Treatment. In Proceedings of the 1994 National Conference on Environmental Engineering. American Society of Civil Engineers, New York, NY.

Yu, S.L., S.L. Barnes, and V.W. Gerde. 1993. Testing of Best Management Practices for Controlling Highway Runoff. Virginia Transportation Research Council, Charlottesville, VA.

Yu, S.L., and D.E. Benelmouffok. 1988. Field Testing of Selected Urban BMPs in Critical Water Issues and Computer Applications. In Proceedings of the 15th Annual Water Resources Conference. American Society of Civil Engineers, New York, NY.

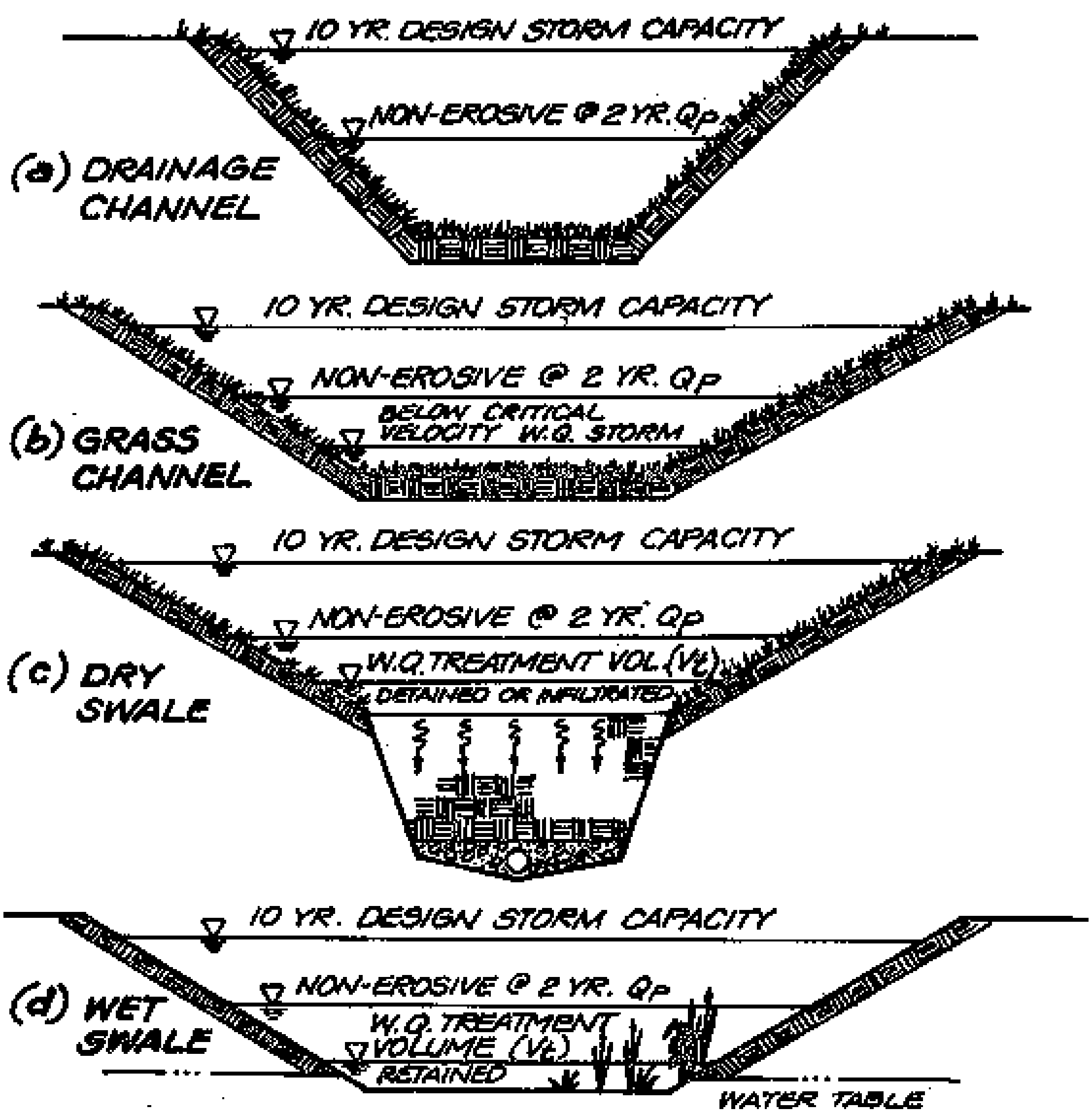
Previous Table of Contents Next

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Dry and Wet Vegetated Swales

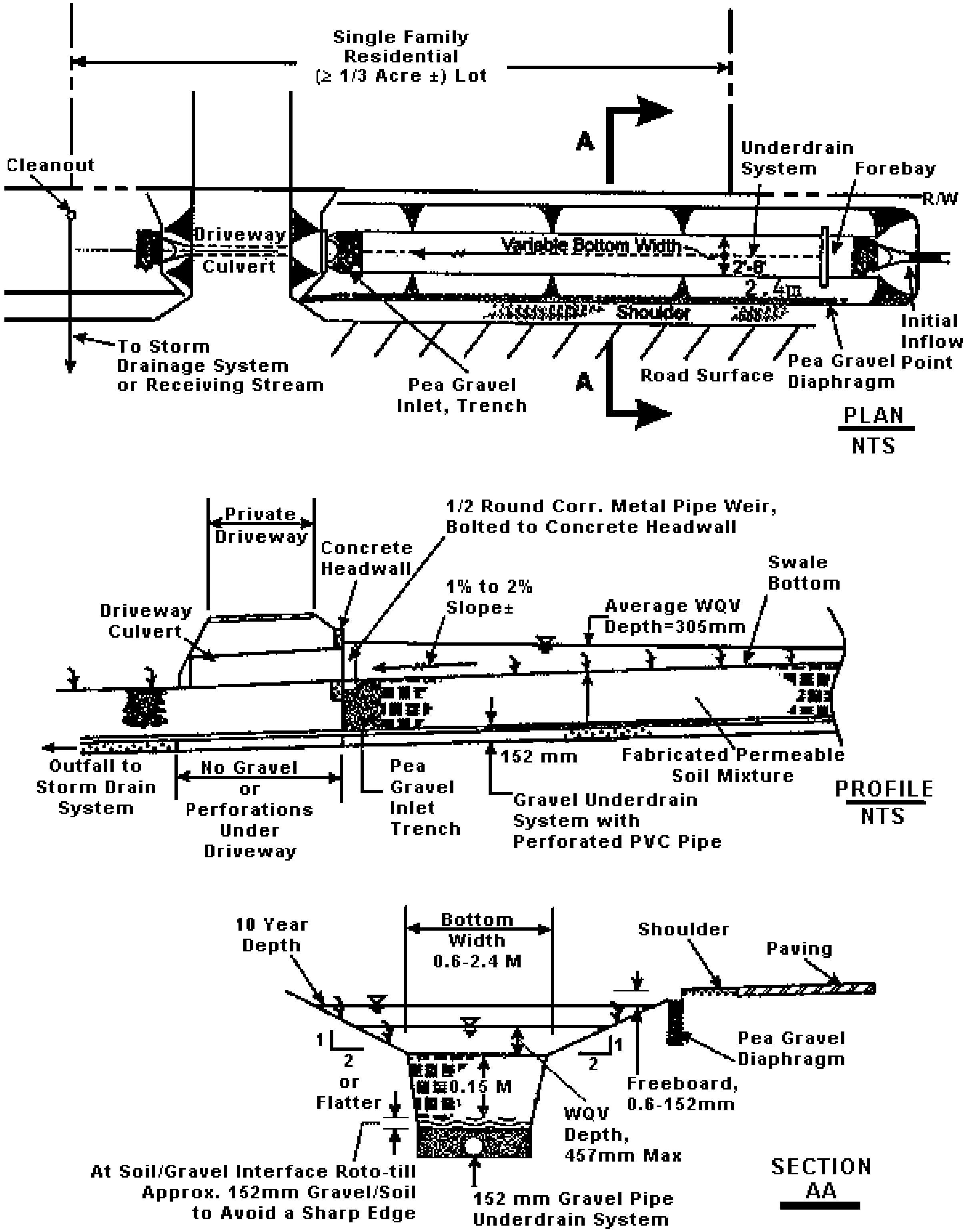
Traditionally, swale designs were simple drainage and grassed channels (Figure 17) that primarily served to transport stormwater runoff away from roadways and rights-of-way and provided inconsistent water quality treatment (Claytor and Schueler, 1996). Today, designers emphasizing water quality management are shifting from the drainage/grassed channel design concepts to carefully engineered dry/wet vegetated swale designs (Figure 17). Two general types of grassed swales are discussed in detail here-a dry swale, which provides water quality benefits by facilitating stormwater infiltration, and a wet swale, which uses residence time and natural growth to treat stormwater prior to discharge to a downstream surface water body.

Figure 17. Channels and swales (Claytor & Schueler, 1996)



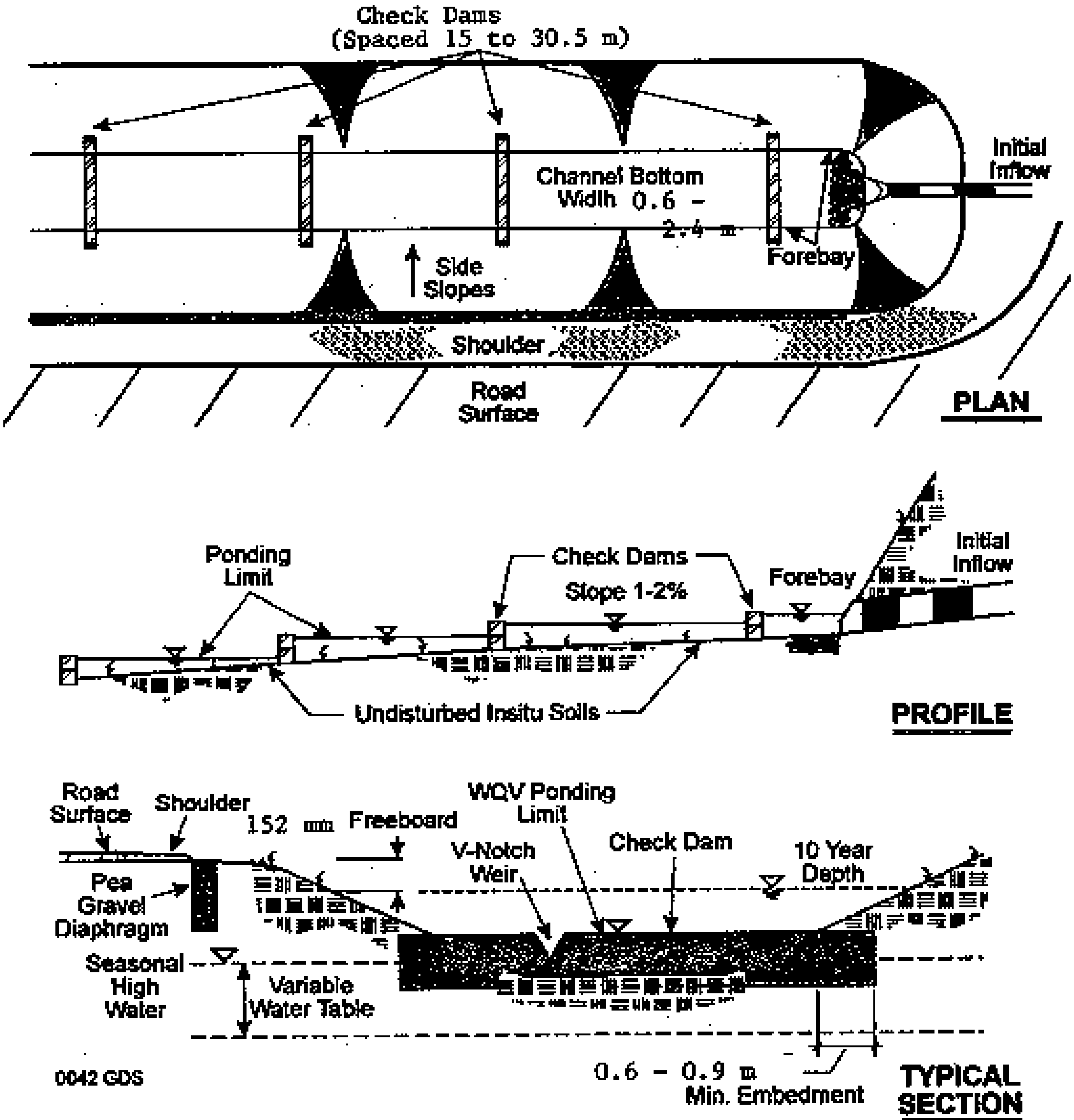
Dry swales are distinguished from a simple drainage/grassed channel by the addition of carefully selected, highly permeable soil (usually sandy loam), check dams, and an underdrain system (Figure 18). These design features ensure that infiltration of stormwater will not depend only on the infiltration rate of the existing natural soils. Only in special circumstances where natural soil and groundwater conditions consistently provide high infiltration will a traditional drainage/grassed channel design provide the same water quality benefits as a dry swale design.

Figure 18. Dry swale (adapted from Claytor & Schueler, 1996)



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 (Figure 19). 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.

Figure 19. Wet swale (adapted from Claytor & Schueler, 1996)



Applicability

Dry and wet swales are appropriate for use in narrow areas along roads and medians where sufficient space exists to accommodate the additional storage depth and width. These swales are relatively inexpensive BMPs, and the total cost is principally related to earth moving construction costs. Because drainage/grassed channels are commonly installed in roadway right-of-way areas to provide essential drainage, implementing a more complex dry or wet swale design usually results in a relatively small additional cost and provides significantly better water quality management. Where sufficient space is available in ultra-urban areas, either dry or wet swales may be appropriate BMPs.

The design requirements of swales are relatively flexible; the gradient, size, and shape are typically based on local regulations that ensure adequate conveyance of the stormwater. In most applications, swales are placed parallel to roadways and care must be taken to ensure they do not impose an unacceptable safety hazard to any vehicles that might leave the roadway. Swales are practically vandal-proof and add an aesthetic value to roadside areas as long as they are maintained and litter and debris are regularly removed. However, wet swales can create ideal breeding habitat areas for nuisance insects such as mosquitoes.

Effectiveness

Both dry and wet swales demonstrate good pollutant removal, with dry swales providing significantly better performance for metals and nitrate. Dry swales typically remove 65 percent of total phosphorus (TP), 50 percent of total nitrogen (TN), and between 80 and 90 percent of metals. Wet swale removal rates are closer to 20 percent of TP, 40 percent of TN, and between 40 and 70 percent of metals. The total suspended solids (TSS) removal for both swale types is typically between 80 and 90 percent. In addition, both swale designs should effectively remove petroleum hydrocarbons based on the performance reported for grass channels. See Table 15 for additional removal effectiveness rates for swales. Seasonal differences in dry/wet swale performance have been reported; pollutant removal efficiencies for many constituents can be markedly different during the growing and dormant periods (Driscoll and Mangarella, 1990). In seasonal climates, fall and winter temperatures force vegetation into dormancy, thereby reducing uptake of runoff pollutants and removing an important mechanism for flow rate reduction. Furthermore, decomposition of accumulated organic matter can lead to production of nutrients in a soluble form, making them free to be transported downstream. Freezing temperatures greatly reduce infiltration in dry swales, removing an important pollutant removal mechanism.

Table 15. Pollutant removal effectiveness for swales (%)

Study	TSS	TP	TN	NO_3	Metals	Comments
City of Austin (1995)[1]	68	43	23	-2		Grassed channel
Yu et al. (1993)[2]	21-95	32-85	-	-	-	Vegetated swale
Yu et al. (1994)[2]	49	33	-	-	13	Length of swale evaluated reduced to 100 ft
Yu and Kaighn (1995)1	30	negligible	-	-	11	Grassed swale
Yousef et al. (1985)1	-	(-48)-48	(-14)-25	-	(-25)-92	Grassed swale
Kahn et al. (1992)2	83	29	-	-	30 - 72	200 foot swale

[1]Removal efficiencies based on concentrations.
[2]Removal efficiencies based on mass loading.

There are limited data currently available on wet swale treatment processes and it can only be assumed that the treatment processes are similar to those of a wetland. In the absence of infiltration, biological activity and limited sedimentation are probably important treatment mechanisms. The data available at this time suggest wet swales provide less pollutant removal than dry swales, which might be due to the absence of infiltration.

Siting and Design Considerations

Designers of grassed swales must have site-specific data on topography, depth to seasonal high groundwater, and soil type prior to designing dry or wet swales. Existing topography will establish the general bottom slope of the swale (recommended between one and two percent) and dictate whether check dams will be required. The depth to groundwater is needed to determine if the swale will be of a dry or a wet design. In dry swales the surficial groundwater table should be more than 0.92 m (3 ft) below the proposed invert; wet swales require that the surficial groundwater table is close to the proposed invert. If the depth to the surficial groundwater table and fluctuations in this depth are not considered, it may result in an unacceptable design. Evaluating in situ soil characteristics such as color and structure is helpful in identifying whether excavated soil can be used for the highly permeable soil medium placed below the invert of a dry swale (e.g., a well-drained silty sand).

Dry or wet swales can be designed to treat the first flush of stormwater runoff (frequently taken as the first 12.7 mm [0.5 in] of runoff from the impervious area). In sizing dry or wet swales it is important to define what depth of runoff is associated with the first flush or water quality volume (WQV), as this runoff depth varies from state to state. Swales are configured as on-line facilities; while providing treatment of the WQV for small, frequent storms, swales must still retain the ability to convey high runoff rates from the roadway when high-intensity storms occur. During these larger rainfall events, swales provide marginal treatment of the high flow rates; however, because the flow velocity in the swale is nonerosive, resuspension or transport of accumulated pollutants is minimized.

Pretreatment is not considered crucial to the removal performance of dry/wet swales unless there is sufficient loading of pollutants (e.g., oil and grease) to harm the grassed surface. However, pretreatment (e.g., streetsweeping or forebays) can provide a benefit by reducing and simplifying operation and maintenance of dry/wet swales.

Dry swales provide the majority of treatment by the process of soil infiltration, which filters suspended pollutants and facilitates adsorption of dissolved pollutants. It has been found that the mass removal of pollutants in dry swales is roughly proportional to the mass runoff that infiltrates through the bottom of the channel (Yousef et al., 1985). Even though the residence time in swales can be relatively long (on the order of a day), a review of water monitoring results suggests sedimentation plays a very small role in treatment in dry swales (Claytor and Schueler, 1996).

A dry swale is designed to capture and filter runoff from a water quality rainfall event. In designing a dry swale it is important to first determine the volume of water to be stored. This establishes the basic swale dimensions of width, length, and side slopes. Of equal importance in the design is to select a soil that permits infiltration of the stored stormwater within a reasonable period of time (typically on the order of one day). Infiltration rates for soils are quite variable, even within a single textural class. For example, soils classified as "Loam" may have infiltration rates ranging from 1.5 mm/h to 86 mm/h (0.06 in/h to 3.4 in/h). Computer programs, such as Soil Conservation Service Technical Release 20 Project Formulation Hydrology, can be used to evaluate how effective the storage capacity and infiltration rates of the swales are at attenuating peak stormwater runoff. Additional design procedures and information can be found in Urban Drainage Design Manual Hydraulic Engineering Circular 22 (Brown et al., 1996), Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996), Design of Stormwater Filtering Systems (Claytor and Schueler, 1996), and Highway Runoff Manual (WSDOT, 1995).

In establishing the grassed swale, it is important to check that the swale has sufficient conveyance to drain large rainfall event. Depending on the applicable state or local ordinance this might be as large as the 25-year event. This requirement will establish the minimum size of any culverts and maximum size of any low-flow weirs placed in the swale.

Maintenance Considerations

Maintenance efforts and costs for swales are minimal (Schueler, 1992). Periodic maintenance for dry/wet swales should primarily focus on removing accumulated materials (e.g., sediment and trash or debris). Sediment build-up within the bottom of the swale should be removed when it has accumulated to the point where it occupies approximately 25 percent of the original design volume (Claytor and Schueler, 1996) or when the depth of sediment exceeds 101.6 mm (4 in) (Young et al., 1996). For publicly maintained swales, planners should anticipate removing sediment from 3 to 10 percent of the total swale length for each year of operation (Urbonas et al., 1992).

Maintenance of dry swales includes steps to ensure a vigorous and healthy grass growth. This includes periodic mowing to keep grasses at acceptable levels and minimize the growth of successional vegetation. The frequency of mowing varies with location, but it is recommended that the maximum height of the grass be between 7.62 and 10.2 cm (3 and 4 in) (Claytor and Schueler, 1996). Growth established above the sustained waterline in wet swales must also be maintained; wetland growth will colonize those areas below the waterline. Unfortunately, there is no firm rule for establishing when and where vegetation must be managed so it does not interfere with the basic function of the wet swale. For both dry and wet swales, it is important to avoid the use of herbicides and fertilizers. Particularly in urban areas, the low-lying nature of swales makes them a likely collector of unsightly litter, which must be removed by hand. It is recommended that twice-a-year inspection be performed for litter (Urbonas et al., 1992). One source gives the annual cost of maintaining a grassed swale (in Wisconsin) at between $1.90 and $4.10 (1995 dollars) per linear meter ($0.58 and $1.25 per linear ft) (SWRPC, 1991).

Cost Considerations

Dry and wet swales are considered moderate and low-cost BMPs, respectively. The principal cost difference between the two swale designs arises from the cost of installing highly permeable soils and underdrain systems in a dry swale. The construction cost per hectare served is typically around $3,700 ($1,500 per acre served) based on a nearly flat dry swale with a 3.05 m (10 ft) bottom width, 3:1 side slopes, and a ponding depth of 0.31 m (1 ft). This cost estimate excludes real estate, design, and contingency costs. This unit cost value should be used for conceptual cost estimating only. The cost of a dry/wet swale can also be inferred from the cost of a traditional grass swale, which typically ranges between $16 and $49 per linear meter ($5 and $15 per linear foot) depending on local conditions, swale dimensions, and the degree of internal storage (i.e., check dams) provided (Schueler, 1992).

References

Brown, S.A., S.M. Stein, and J.C. Warner. 1996. Urban Drainage Design Manual Hydraulic Engineering Circular 22. FHWA-SA-96-078. Federal Highway Administration, Office of Technology Applications.

City of Austin. 1995 (draft). Characterization of Stormwater Pollution for the Austin, Texas Area. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, Texas.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Driscoll, E., and P. Mangarella. 1990. Urban Targeting and BMP Selection. Prepared by Woodward-Clyde Consultants, Oakland, CA, for U.S. Environmental Protection Agency, Washington, DC.

Khan, Z., C. Thrush, P. Cohen, L. Kulzer, R. Franklin, D. Field, J. Koon, and R. Horner. 1992. Biofiltration Swale Performance, Recommendations, and Design Considerations. Municipality of Metropolitan Seattle, Water Pollution Control Department, Seattle, WA.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, DC.

SWRPC. 1991. Costs of Urban Nonpoint Source Water Pollution Control Measures. Technical Report No. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Urbonas, B.R., J.T. Doerfer, J. Sorenson, J.T. Wulliman, and T. Fairley. 1992. Urban Storm Drainage Criteria Manual. Vol. 3. Best Management Practices, Stormwater Quality. Urban Drainage and Flood Control District, Denver, CO.

Washington State Department of Transportation (WSDOT). 1995. Highway Runoff Manual. Washington State Department of Transportation.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Yousef, Y.A., M.P. Wanielista, H.H. Harper. 1985. Removal of Highway Contaminants by Roadside Swales. Transportation Research Record 1017:62-68.

Yu, S.L., S.L. Barnes, and V.W. Gerde. 1993. Testing of Best Management Practices for Controlling Highway Runoff. Virginia Department of Transportation, Report No. FHWA/VA-93-R16, Richmond, VA.

Yu, S.L., R.J. Kaighn, and S.L. Liao. 1994. Testing of Best Management Practices for Controlling Highway Runoff, Phase II. Virginia Department of Transportation, Report No. FHWA/VA-94-R21, Richmond, VA.

Yu, S.L., and R.J. Kaighn. 1995. The Control of Pollution in Highway Runoff Through Biofiltration. Volume II: Testing of Roadside Vegetation. Virginia Department of Transportation, Report No. FHWA/VA-95-R29, Richmond, VA.

Previous Table of Contents Next

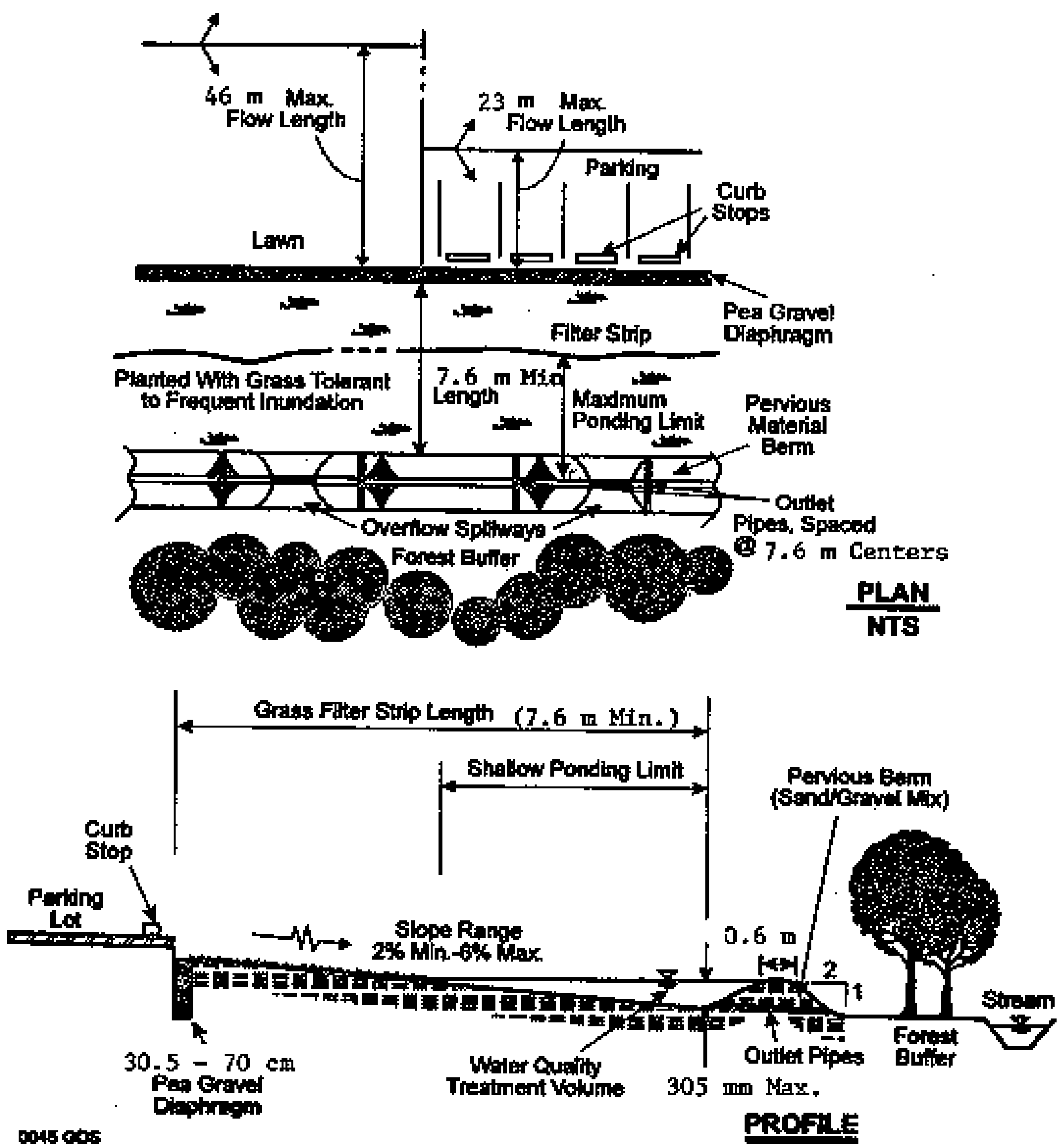
FHWA Home | HEP Home | Feedback

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Filter Strips

Filter strips, also known as vegetated buffer strips, use biological and chemical processes to filter stormwater runoff. Water flows in a sheet across the vegetated area, and is treated by infiltration into the soil and uptake by plants (Figure 20). Small berms may be installed at the downslope edge of the filter strip so that the water can be detained and infiltrated into the underlying soils.

Figure 20. Typical filter strip (adapted from Claytor & Schueler, 1996)



Filter strips are not designed to attenuate peak stormwater flows, but can be an effective water quality measure. A dense vegetative cover, long flow length, and low gradient provide the most efficient removal rates.

Applicability

Filter strips are appropriate only where ample room exists for installation. There must be sufficient flow length and gradient to adequately treat the stormwater. In the ultra-urban environment, they have limited application due to the required flow length. 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 (WSDOT, 1995).

A filter strip is commonly operated as a pre-treatment BMP located upstream of other BMPs capable of greater pollutant removal rates. As a stand-alone BMP, filter strips can only treat the lowest intensity rainfall events. While providing water quality treatment for small frequent storms, filter strips operating as on-line facilities must still retain the ability to convey high runoff rates from the roadway when high-intensity storms occur. Filter strips cannot treat high-velocity flows and do not provide enough storage or infiltration to effectively reduce peak discharges to predevelopment levels (Schueler, 1992).

By design, filter strips are relatively flexible BMPs; the gradient, width, and length can be set based on local constraints. In most applications, filter strips are placed perpendicular to roadways and, therefore, may make highways safer by providing stopping distance for any vehicles that may leave the roadway. Filter strips are practically vandal-proof and add an aesthetic value to roadside areas as long as they are maintained and litter and debris are regularly removed. In most cases, however, site constraints will restrict their use in ultra-urban areas.

Effectiveness

There is relatively little data on the effectiveness of filter strips on urban stormwater runoff. In one study, moderate to high removal rates were found for a 45.7-m-long (150-ft-long) grass filter strip treating urban runoff, but only mediocre pollutant removal occurred with a 22.9-m-long (75-ft-long) grass filter strip (Yu et al., 1993). Slope length and slope are also related to sediment removal efficiency (Wong and McCuen, 1982). These results are different from applications in agriculture, where much shorter grass strips have been found to work acceptably for agricultural runoff. Additional data on pollutant removal effectiveness is shown in Table 16.

Table 16. Pollutant removal effectiveness for filter strips (%)

Study	TSS	TP	NO_3	Lead	Zinc	Comments
Yu and Kaighn (1992)	27	22	6	2	17	18-foot flow length[1]
	67	22	8	18	46	50-foot flow length
	68	33	9	20	50	150-foot flow length

[1] Flow length is distance traveled uphill to downhill on surface of the filter strip.

Pretreatment is not considered crucial to the removal performance of filter strips unless there is sufficient loading of pollutants (e.g., sand, oil and grease) to harm the vegetated surface. Designers should note that field surveys indicate many filter strips lack good vegetative cover, are subject to excessive sediment deposition, or are short-circuited by channels formed by concentrated flow (i.e., rill development). This is particularly true for filter strips employed in urban areas, where runoff concentrates very quickly (Claytor and Schueler, 1996). Furthermore, it is expected that there will be seasonal differences in filter strip performance in seasonal climates, where plant growth will be dormant and thinned. Cold winter temperatures will freeze the soil surface and prevent runoff infiltration into soils. Filter strips are not recommended for arid areas where sustaining growth is difficult.

Filter strips provide relatively low rates of pollutant removal and are most effective for total suspended solids (TSS), with approximately 70 percent removal. It has been estimated that filter strips can remove approximately 10 percent of total phosphorus (TP), 30 percent of total nitrogen (TN), and between 40 and 50 percent of suspended metals. During large rainfall events, filter strips provide marginal treatment and may in fact become sources of erosion.

Siting and Design Considerations

The most important features of the filter strip that dictate effectiveness are the slope of the vegetated surface, the length of the vegetated surface, the uniformity of the surface, and the density of plant growth.

First, slope constraints exist for filter strips; most sources recommend that the surface slope be between two and six percent (Claytor and Schueler, 1996). Designers should note that with steeper slopes it becomes difficult to meet other design recommendations such as having a peak flow velocity of 0.27 m/s (0.9 ft/s) and a desired hydraulic residence time of nine minutes (Young et al., 1996). In addition, there are suggested flow length limits for filter strips, such as a minimum flow length (uphill to downhill) of 7.6 m (25 ft) (Claytor and Schueler, 1996). Field monitoring found that limited pollutant removal occurred in an urban application when the flow length was 23 m (75 ft); moderate to high removal of pollutants was found to occur for a filter strip with twice the flow length (45.7 m [150 ft]).

There are also recommended limits on the size of the service area served by the filter strip. The maximum recommended overland flow distance starting at the uphill edge of the filter strip and going uphill in the service area should not be more than 23 m (75 ft) for an impervious service area or 45.7 m (150 ft) for a pervious service area. However, various states have developed local limits or design requirements for filter strips. The Washington State Department of Transportation suggests that filter strips be used to treat runoff from roadways with a maximum of two lanes, and for a roadway with average daily traffic of less than 30,000 vehicles (WSDOT, 1995). The Colorado Department of Transportation sets the maximum flow depth on the filter strip at 0.64 cm (0.25 in) (CDOT, 1992).

To be effective, filter strips require sheet flow across the entire strip. Once flow concentrates to form a channel, it effectively short-circuits the filter strip. Unfortunately, this usually occurs within a short distance for filter strips in urban areas. It is difficult to maintain sheet flow over a distance of 45.7 m (150 ft) for pervious areas and 23 m (75 ft) for impervious areas. This may be due in part to the inability to obtain evenly compacted and level soil surfaces using common construction methodology. For some applications, a level spreader can be used to help ensure even distribution of stormwater onto the filter strip. To help maintain a uniform soil surface, some designs divert runoff from storms greater than the 2-year rainfall around the filter strip to avoid erosion and rill development.

During the construction phase, the topsoil should be of good quality and the subsoil should be tilled to reduce erosion and promote establishment of vegetation. Soil amendments such as lime, fertilizer, and organic material may be required.

Designers considering the application of filter strips can roughly estimate they need a filter strip 177 m (580 ft) wide by 23 m (75 ft) long (uphill to downhill) to manage a 0.4 ha (1 ac) service area (100 percent imperviousness). For those seeking design examples and additional information, several good sources are available, including Design of Stormwater Filtering Systems (Claytor and Schueler, 1996), Urban Drainage Design Manual Hydraulic Engineering Circular 22 (Brown et al., 1996), Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996), and Highway Runoff Manual (WSDOT, 1995).

Maintenance Considerations

In general, maintenance efforts and costs for filter strips are small. Periodic maintenance for filter strips is primarily focused on ensuring a vigorous and healthy plant growth, preventing the formation of rills and gullies, and removing debris and litter. Of these items the most significant, costwise, is periodic mowing to keep grasses at acceptable levels and to minimize the growth of successional vegetation. It is recommended that mowing be performed perpendicular to the slope to help minimize the development of rills. For filter strips, it is important to avoid the use of herbicides and fertilizers on grassed portions of the strip, since these applications can directly contribute undesirable pollutants to waterways.

Filter strips can last for 10 to 20 years with proper conditions and regular maintenance. Proper maintenance is defined as those operations needed to ensure that uniform sheet flow and dense vegetation are maintained. For example, in locations where sanding of roadways or parking lot areas occur, it may be necessary to scrape away sediment build-up at the edge of the pavement to maintain even inflow to the filter strip. It is also recommended that maintenance of the filter strip be performed twice a year to patch any bare spots and fill and replant any rills that are forming.

Cost Considerations

Filter strips are low-cost BMPs. The principal cost to install is related to earth moving construction costs and planting costs. The cost for vegetative establishment, in 1995 dollars, is approximately $5,000 per ha ($2,000 per ac) for establishing an area by hydroseeding (Schueler, 1987). This does not include real estate, design, and contingency costs. Costs for sodding and planting of woody vegetation are significantly higher. (Note, that this unit cost value should be used for conceptual cost estimating only.)

References

Brown, S.A., S.M. Stein, and J.C. Warner. 1996. Urban Drainage Design Manual Hydraulic Engineering Circular 22. FHWA-SA-96-078. Federal Highway Administration, Office of Technology Applications.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Colorado Department of Transportation (CDOT). 1992. Erosion Control and Stormwater Quality Guide. Colorado Department of Transportation.

Driscoll, E., and P. Mangarella. 1990. Urban Targeting and BMP Selection. Prepared by Woodward-Clyde Consultants, Oakland, CA, for U.S. Environmental Protection Agency, Washington, DC.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, DC.

Urbonas, B.R., J.T. Doerfer, J. Sorenson, J.T. Wulliman, and T. Fairley. 1992. Urban Storm Drainage Criteria Manual. Vol. 3. Best Management Practices, Stormwater Quality. Urban Drainage and Flood Control District, Denver, CO.

Washington State Department of Transportation (WSDOT). 1995. Highway Runoff Manual. Washington State Department of Transportation.

Wong, S.L., and R.H. McCuen. 1982. The Design of Vegetative Buffer Strips for Runoff and Sediment Control. Appendix J in Stormwater Management for Coastal Areas. American Society of Civil Engineers, New York, New York.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Yu, S.L., S.L. Barnes, and V.W. Gerde. 1993. Testing of Best Management Practices for Controlling Highway Runoff. Virginia Transportation Research Council, Charlottesville, VA.

Yu, S.L., and R.J. Kaighn. 1992. VDOT Manual of Practice for Planning Stormwater Management. Federal Highway Administration, FHWA/VA-92-R13, Virginia Department of Transportation, Virginia Transportation Research Council, Charlottesville, VA.

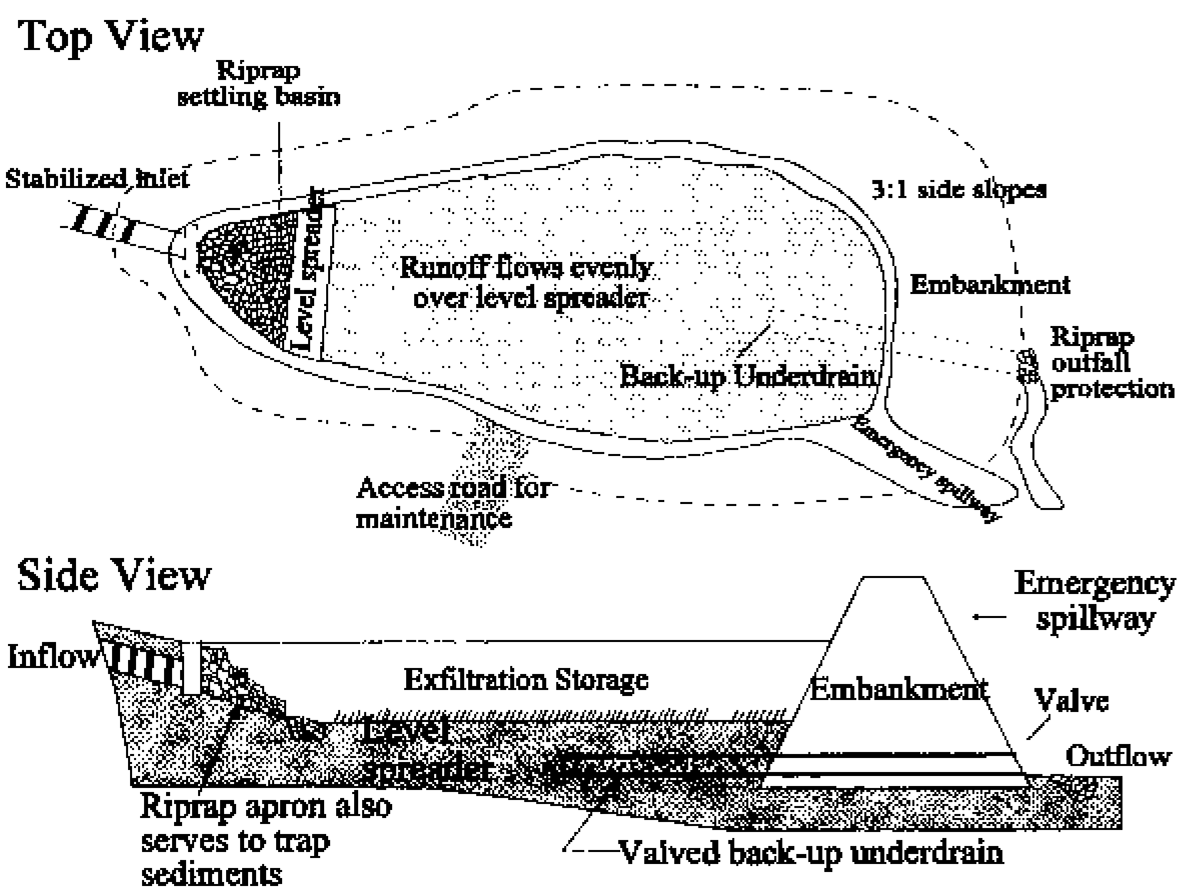
Previous Table of Contents Next

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Infiltration Basin

An infiltration basin is a shallow depression created by excavation or berming that captures stormwater and stores it until it can infiltrate into the soil (Figure 5). Infiltration basins typically serve drainage areas from 2 to 20 ha (5 to 50 ac). In an ultra-urban setting it is strongly recommended that they be used in an off-line configuration because sediment accumulation and particulates from stormwater runoff can clog the system. The principal advantages of infiltration basins are that they help preserve the natural water balance of a site, they can serve large or small developments, and they can be integrated into a site's landscaping or open space. If the area served is less than 2 ha (5 ac), an infiltration trench is usually the preferred BMP.

Figure 5. Schematic of an infiltration basin design (Young et al., 1996)



Infiltration basins provide the majority of treatment by processes related to soil infiltration, which include absorption, precipitation, trapping, straining, and bacterial degradation. That the soils below infiltration basins are effective filters is best indicated by the tendency for these soils to clog if heavily loaded with oil, grease, and sediment. The extent of sorption and filtration is a function of the soil type; for example, highly permeable soils (i.e., sandy soils) usually have low cation exchange capacities (CECs, or the affinity for capturing positively charged pollutants). The majority of infiltration basins are placed in highly permeable soils. However, as the basin is used, fine material suspended in stormwater is captured within the natural soil, creating a more effective straining matrix and potentially increasing pollutant removal. There is limited information available on chemical/biological changes in the soils surrounding infiltration basins and the extent to which the soils operate aerobically and anaerobically.

Applicability

Infiltration basins are appropriate only where there is ample room for installation. The basin can occupy an area between two and four percent of the upstream impervious area, but can be placed in confined spaces if necessary. These facilities are ideal for siting in interchanges and areas adjacent to roadways. The primary highway application for an infiltration basin is along roadways where runoff conveyed in a grassed swale can be diverted into the basin in areas where groundwater is not used for drinking purposes.

Infiltration basins are a relatively inflexible BMP primarily because a successful design requires soils with a reasonably high infiltration rate. If a high-infiltration-rate soil is not present, then the surface of the basin will become prohibitively large. If the proper soils are present, the designer is free to establish the basin width and length based on local constraints. Infiltration basins can be any shape; in fact, many review agencies are advocating nonrectangular shapes, which create aesthetically pleasing earth forms. Infiltration basins add an aesthetic value to roadside areas as long as they are maintained and litter and debris are regularly removed.

Effectiveness

Effectiveness is a function of the fraction of stormwater infiltrated. The amount of stormwater that bypasses the system due to overflow during large storm events or that cannot be absorbed by the system determines infiltration effectiveness. To date, only limited data are available on the intensity and amount of pollutants discharged to surficial groundwater aquifers from infiltration basins. Removal rates (in percent) reported for three different design sizes are shown in Table 8.

In variable climates, harsh winter temperatures can freeze the infiltration basins and when frozen, infiltration basins will not provide pollutant removal. Local meteorologic records should be obtained to verify the mean monthly average low temperature remains above freezing.

Table 8. Estimated pollutant removal effectiveness for infiltration basins (%)

TSS	TP	TN	Metals	BOD	Bacteria	Comments
75	50 - 55	45 - 55	75 - 80	70	75	Capture of 12.7 mm (0.5 in) of runoff (first flush)
99	65 - 75	60 - 70	95 - 99	80	90	Capture of 25.4 mm (1 in) of runoff
90	60 - 70	55 - 60	85 - 90	80	90	Capture of 50.8 mm (2 in) of runoff
Source: Schueler (1987).						

Siting and Design Considerations

Infiltration basins can be installed where there is sufficient surface area and soil infiltration capacity. Given the general lack of open surface area in the ultra-urban setting, infiltration trenches are generally more applicable than infiltration basins. However, infiltration basins can be employed wherever large redevelopment efforts are planned or along roadways where there is sufficient right-of-way available.

Groundwater is one key issue in siting infiltration basins. For ultra-urban applications, the surface aquifer under many municipalities is not used as a drinking water source, however, in some areas it is the surface aquifer directly connected to a drinking water aquifer. Nevertheless, most states or municipalities have developed rules regarding the placement of any facilities that discharge to the groundwater, which must be researched by the designer. As a general rule a minimum buffer between the basin invert and the seasonal high groundwater level of 0.6 to 1.2 m (2 to 4 ft) is typically used in the eastern United States in areas where water table depths are relatively shallow, while 3 m (10 ft) is the buffer distance used in some western states (Dorman et al., 1996). Infiltration basins can be designed in a number of ways. Often, infiltration basins are designed as stand-alone facilities to provide water quality management-a design that infiltrates the 2-year runoff event. As an alternative, infiltration basins are sometimes combined with detention ponds to provide both stormwater quality and quantity management. This arrangement yields multiple benefits: the detention pond provides pretreatment for the basin and provides flood protection, and the infiltration basin can be located off-line, where it is protected from high flows (Young et al., 1996).

Pretreatment is considered crucial to sustaining the performance of infiltration basins; infiltration basins are often preceded by detention ponds, grassed swales, and filter strips. Additional design examples and information can be found in Urban Drainage Design Manual Hydraulic Engineering Circular 22 (Brown et al., 1996), Evaluation and

Management of Highway Runoff Water Quality (Young et al., 1996), and Design and Construction of Urban Stormwater Management Systems (ASCE, 1992).

The performance of infiltration basins can be improved by keeping the infiltration area large, ensuring the bottom is flat, and vegetating with a dense turf of water-tolerant grass (Livingston, 1995). The actual size of the basin footprint is dependent on long-term meteorologic trends, the site's demonstrated minimum infiltration rate, and the dewatering time.

Construction activities will greatly affect the performance of infiltration basins and the potential for failure. It is critical to install the basin only after the construction site has been stabilized to minimize introduction of fine sediment into the basin. In one study, approximately 40 percent of the investigated basins had partially or totally clogged within their first few years of operation. Many of these systems failed almost immediately after construction (MDE, 1986). During excavation, compaction of the bottom and sides of the infiltration basin must be minimized by using vehicles equipped with oversized tires. The infiltration basin should be marked off or bermed prior to any construction activity to ensure vehicle entrance to the footprint area is not possible.

Maintenance Considerations

Routine and nonroutine maintenance is required to keep infiltration basins operating effectively. Infiltration basins should be inspected following major storms, especially in the first few months after construction. If stormwater remains in the system beyond the design drawdown time (typically 72 to 96 hours), either the infiltration capacity was overestimated or maintenance is needed.

Routine, periodic maintenance typically involves moderate costs. Periodic maintenance includes removing debris (litter, leaves, brush), mowing the sides and bottom once growth exceeds 0.3 m (12 in) in height, and revegetating eroded or barren areas. However, mowing is not necessary to maintain performance. If mowed, grass clippings should be removed to prevent clogging of the surface. It is recommended that the side wall slope be 3 (horizontal) to 1 (vertical) or flatter to help sustain vegetation, permit access for maintenance, and ensure public safety and ease of mowing. However, side slopes of 2:1 have been used successfully.

Occasionally, nonroutine maintenance or basin rehabilitation may be required, which can be costly, if clogging occurs. As a part of nonroutine maintenance, deep tilling every 5 to 10 years to break up the clogged surface layers followed by regrading and revegetating is recommended. This may include removing any accumulated sediment; sediment removal should be performed only when the soil surface is in a very dry condition to avoid compaction of the basin bottom (Livingston, 1995). For infiltration basins it is important to avoid the use of herbicides and fertilizers on grassed portions of the strip since these applications can directly contribute undesirable pollutants to waterways.

Cost Considerations

Infiltration basins are moderate-cost BMPs. The principal cost to install relates to earth moving and construction costs and installation of inlet systems. The construction cost can be estimated from the following equation, where V is the volume of stormwater managed in cubic meters (Schueler, 1987):

$$C = 13.9 \, (V / 0.02832)^{0.69}$$

Note that the cost estimate obtained should be used for conceptual cost estimating only and is in terms of 1995 dollars.

References

ASCE. 1992. Design and Construction of Urban Stormwater Management Systems. The Urban Water Resources Research Council of the American Society of Civil Engineers (ASCE) and the Water Environment Federation. American Society of Civil Engineers, New York, NY.

Brown, S.A., S.M. Stein, and J.C. Warner. 1996. Urban Drainage Design Manual Hydraulic Engineering Circular 22. FHWA-SA-96-078. Federal Highway Administration, Office of Technology Applications.

Dorman, M.E., T.S. George, J.P. Hartigan, and T.F. Quasebarth. 1996. Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Volume II: Design Guidelines. FHWA-RD-96-096, Federal

Highway Administration, Office of Research, Development, and Technology.

Livingston, E.H. 1995. "Infiltration Practices: The Good, the Bad, and the Ugly." In Proceedings of a National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels. March 30-April 2, 1993, Chicago, Illinois. U.S. Environmental Protection Agency, Center for Environmental Research Information. EPA/625/R-95/003.

Maryland Department of the Environment (MDE). 1986. Maintenance of Stormwater Management Structures: A Departmental Summary. Maryland Department of the Environment, Sediment and Stormwater Division, Annapolis, MD, and Maryland Department of Natural Resources, Water Resources Administration, Annapolis, MD.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Previous Table of Contents Next

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Infiltration Trench

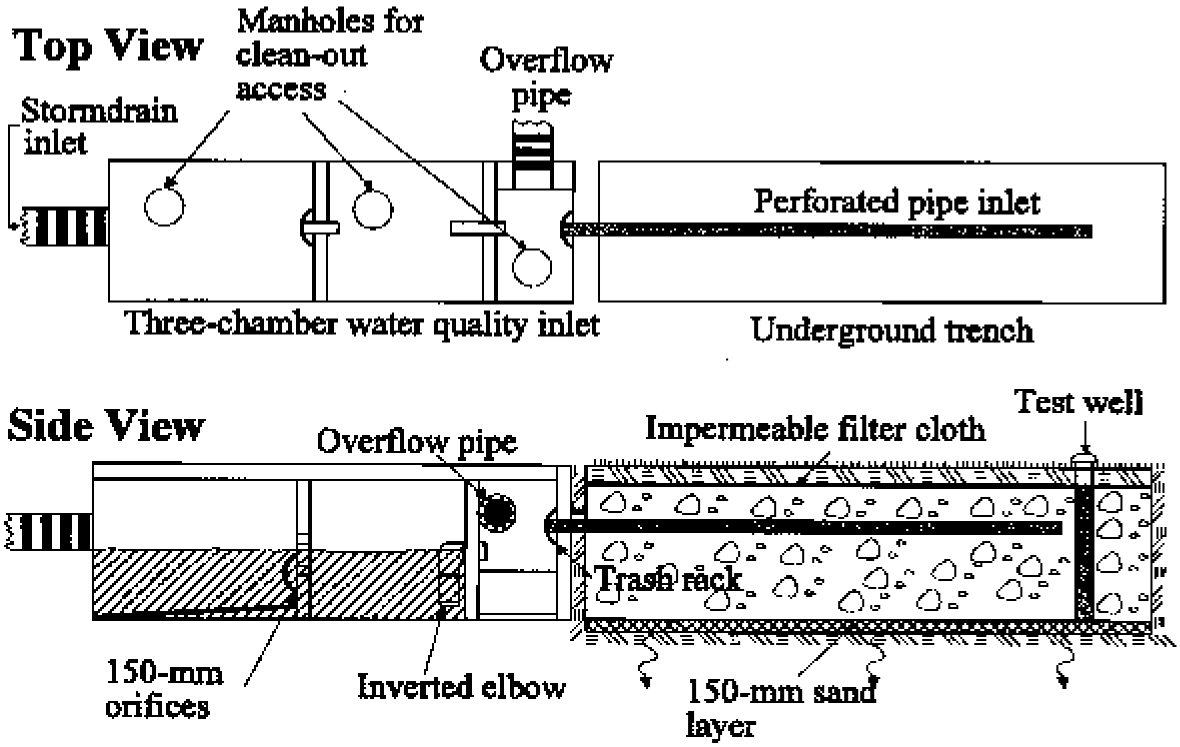
An infiltration trench is an excavated trench that has been lined and backfilled with stone to form a subsurface basin. Stormwater runoff is diverted into the trench and is stored until it can infiltrate into the soil, usually over a period of several days. Infiltration trenches are very adaptable BMPs, and the availability of many practical configurations make it ideal for small (less than 4 ha [10 ac]) 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 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. That the soils surrounding infiltration trenches are effective filters is best indicated by the tendency for these soils to clog if heavily loaded with oil, grease, and sediment. The extent of sorption and filtration is a function of the soil type; for example, highly permeable soils (i.e., sandy soils) usually have low cation exchange capacities (CECs, or the affinity for capturing positively charged pollutants). However, as an infiltration trench is used, fine material suspended in stormwater is captured within the natural soil, creating a more effective filtering matrix and increasing the pollutant removal. Based on the limited information available on chemical/biological changes in the soils surrounding infiltration trenches, the soil/stormwater interaction is complicated and site specific. It is difficult to generalize regarding the extent to which the soils operate aerobically or anaerobically.

Applicability

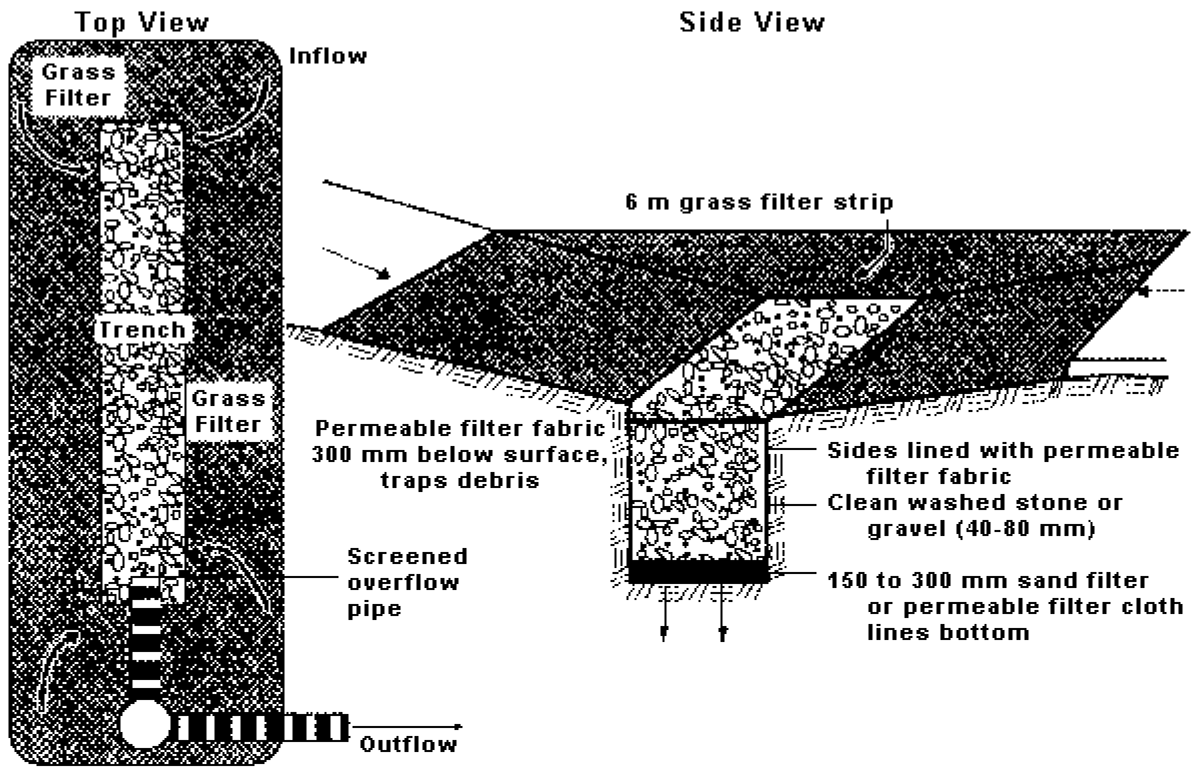
Infiltration trenches are appropriate for ultra-urban applications, particularly subsurface designs that are covered with grating or pavement (Figure 3). Essentially all of the surface above a subsurface infiltration trench can be used as parking or public areas. Unfortunately, subsurface infiltration trenches are relatively expensive BMPs; the expense is due to construction of an underground vault, which must be placed among other subsurface utilities. Surface trench designs can be moderately expensive BMPs and can be easier to construct and operate, but they require greater space commitments because they are usually combined with area-intensive pretreatment such as grass filter strips (Figure 4). Surface infiltration trench designs are better suited to roadside application where space is at less of a premium.

Figure 3. Underground trench with oil/grit chamber (adapted from Schueler, 1987)



Figures 3 and 4 indicate only two of many possible configurations. Both of these configurations illustrate the essential design features, which include pretreatment of runoff to minimize sediment loading, stormwater storage in a subsurface trench filled with stone, and discharge of all captured stormwater into underlying ground layers.

Figure 4. Median strip trench design (adapted from Schueler, 1987)



Both configurations shown in Figures 3 and 4 are complete trench designs or designs that discharge all treated stormwater into a highly permeable underlying soil trench. Where a complete trench design is undesirable or not feasible, a partial trench design can be employed to infiltrate only a portion of the stormwater runoff. Partial trench designs may incorporate an underdrain system placed several feet below the invert to intercept exfiltrating stormwater. This approach enables trench placement where there are relatively impermeable soils or there is a confining soil layer. As an alternative, a partial trench design can integrate a discharge pipe that limits the storage depth in the trench and routes all surplus stormwater to an outlet. The principal advantage of this design is it permits diversion of high flows and if the soils become clogged stormwater can still be discharged. Partial trenches can also be used as off-line facilities and can easily be retrofitted onto existing subsurface storm drains.

Effectiveness

For infiltration trenches, effectiveness is solely a function of the amount of stormwater infiltrated; that is, the only pollutants not treated are those associated with the stormwater that bypasses the trench and are not infiltrated. The pollutants discharged to surficial groundwater aquifers are not generally accounted for in reported removal rates. Projected removal rates reported for two different designs are shown in Table 7.

In variable climates, harsh winter temperatures can freeze the water in infiltration trenches and eliminate the ability of the trench to store and infiltrate water. It is recommended that information on the soil freeze depth be obtained and the trench invert be located below this depth.

Table 7. Estimated pollutant removal effectiveness for water quality trenches (%)

TSS	TP	TN	Metals	BOD	Bacteria	Comments
75	50 - 55	45 - 55	75 - 80	70	75	Capture of 12.7 mm (0.5 in) of runoff (first flush)
90	60 - 70	55 - 60	85 - 90	80	90	Capture of 50.8 mm (2 in) of runoff
Source: Schueler (1987).						

Siting and Design Considerations

For most ultra-urban applications designers should look for soils with high percolation rates below the proposed trench invert, surficial groundwater aquifers that are not used for drinking purposes, and ample clearance over bedrock. A range of recommendations have been made regarding the minimum permeability of the soil surrounding the infiltration trench; some suggest a minimum infiltration rate of 12.7 mm/h (0.5 in/h) (Yu and Kaighn, 1992; Schueler et al., 1992), but some states accept minimum values of 6.9 mm/h (0.27 in/h) (MDE, 1986). Minimum infiltration rates between 6.9 and 12.7 mm/h (0.27 and 0.50 in/h) are usually associated with loamy sand, sandy loam, loam, and silt loam texture soils; however, site-specific infiltration rates are a function of more than the soil texture. It is recommended that site-specific infiltration be measured in soils located below the proposed invert of the infiltration trench. In addition, soils should be examined to a depth at least 1.52 m (5 ft) below the proposed invert to identify if there are any underlying impermeable soil layers (clay lenses, fragipans, or hardpans). It should be noted that ultra-urban developments are frequently placed on disturbed cut/fill soils. This greatly increases the importance of site-specific infiltration testing.

Designs can be sized to manage a range of runoff volumes to meet specific water quality and quantity objectives. Small-scale units can be designed just to manage the first flush runoff volume; these designs are sometimes referred to as water quality exfiltration systems. Conversely, the size of the trench can be increased to significantly decrease the postdevelopment runoff rates and limit flooding.

While placing infiltration trenches in low permeability soils is questionable, trench designs can be made to work in lower infiltrating soils, but the surface area or size of the trench may become prohibitively large. Designers should note that the invert of the infiltration trench should be at least 1.22 m (4 ft) above underlying bedrock and at least 1.22 to 2.44 m (4 to 8 ft) over the seasonal high groundwater elevation (Yu and Kaighn, 1992). The trench bottom should be rototilled after excavation. The addition of a sand filter layer at the trench bottom should be considered to facilitate movement of water between the stone storage area and the subgrade. Designers considering application of infiltration trenches can roughly estimate 121 m^2 (1300 ft^2) of trench bottom area (a 1.22 m [4 ft] deep trench) is needed to store 12.7 mm (0.5 in) of runoff from a 0.4 ha (1 ac) impervious service area. In addition, the minimum recommended drain time is 24 hours and the maximum recommended drainage time is 72 hours. Finally, it is recommended that trenches should be located a minimum of 3.05 m (10 ft) downgradient and 30.5 m (100 ft) upgradient of any buildings and the ground slope should be less than 20 percent. There are several good sources available for detailed design and construction procedures and information, including Urban Drainage Design Manual Hydraulic Engineering Circular 22 (Brown et al., 1996), Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996), and Maintenance of Stormwater Management Structures (MDE, 1986).

Maintenance Considerations

If appropriate sediment removal pretreatment is not provided, the life expectancy of an infiltration trench may be only five years (Schueler et al., 1992) due to the pore space and trench bottom becoming clogged. With proper regular maintenance, however, a trench may last as long as 10 or 15 years before major rehabilitation of the trench is required (Schueler, 1987). Following installation, frequent inspections are recommended at first, but these can be decreased to twice per year. These inspections should look into water levels in the infiltration trench, clogging of inlets or outlets, and accumulation of sediment in upstream pretreatment units. Immediate failure of the trench might occur if sediment is not directed away from the trench area during construction. Consequently, it is recommended that all upstream areas be stabilized before the trench is constructed.

Failure of an infiltration trench is determined by the continued presence of pooled water three days after rainfall has ended. A failure of this type leads to removal or replacement of part or all of the rock backfill. Surface infiltration trench rehabilitation can be estimated to cost approximately 20 percent of the initial construction costs, whereas rehabilitation of an underground trench can exceed the initial construction cost (Young et al., 1996). Clearly, proper, regular maintenance is essential to avoid costly trench rehabilitation.

Numerous design features can simplify maintenance. An example includes placing a filter fabric on top of the rock media, which can easily be stripped off when it is full of debris.

Cost Considerations

Infiltration trenches are most cost-effective for small drainage areas where space is at a premium and the water quality storage volume is less than 280 m^3 (10,000 ft^3 or approximately 12.7 mm [0.5 in] of runoff from 2 ha [5 ac]). Trench construction costs (1995 dollars) can be estimated using the following equation where V is the storage volume in cubic meters (Young et al., 1996):

$$C=1317.1\ V^{0.63}$$

This cost estimation is valid only for trenches that have storage volume on the order of 280 m^3 (10,000 ft^3). This formula does not include the cost of special inlets or grass filters for pretreatment of runoff but does include costs for excavation, backfill, filter cloth, inlet and outlet pipes, and fixtures.

References

Brown, S.A., S.M. Stein, and J.C. Warner. 1996. Urban Drainage Design Manual Hydraulic Engineering Circular 22. FHWA-SA-96-078. Federal Highway Administration, Office of Technology Applications.

Maryland Department of the Environment (MDE). 1986. Maintenance of Stormwater Management Structures: A Departmental Summary. Maryland Department of the Environment, Sediment and Stormwater Division, Annapolis, MD, and Maryland Department of Natural Resources, Water Resources Administration, Annapolis, MD.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices-Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, DC.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Yu, S.L., and R.J. Kaighn. 1992. VDOT Manual of Practice for Planning Stormwater Management. Federal Highway Administration, FHWA/VA-92-R13, Virginia Department of Transportation, Virginia Transportation Research Council, Charlottesville, VA.

FHWA

United States Department of Transportation - **Federal Highway Administration**

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Manufactured Systems

Cylindrical access hole and box structure stormwater treatment devices have become increasingly popular for the removal of particulate matter normally found in stormwater runoff. The two main treatment mechanisms are vortex motion particle and particulate settling and oil-water separation. The devices operate by intercepting a portion of the flow traveling through the storm drain system and using a vortex motion and/or conventional settling chamber to separate out large sediments and oils. Two common types of access hole treatment devices include the Stormceptor® and the Downstream Defender™. An example of a box-type treatment unit is the Vortechs™ Stormwater Treatment System. Figures 23, 24, and 25 show the Stormceptor®, Downstream Defender™, and Vortechs™ treatment devices, respectively.

Figure 23. Storm*ceptor*® operation during average flow conditions (Storm*ceptor*®, 1995)

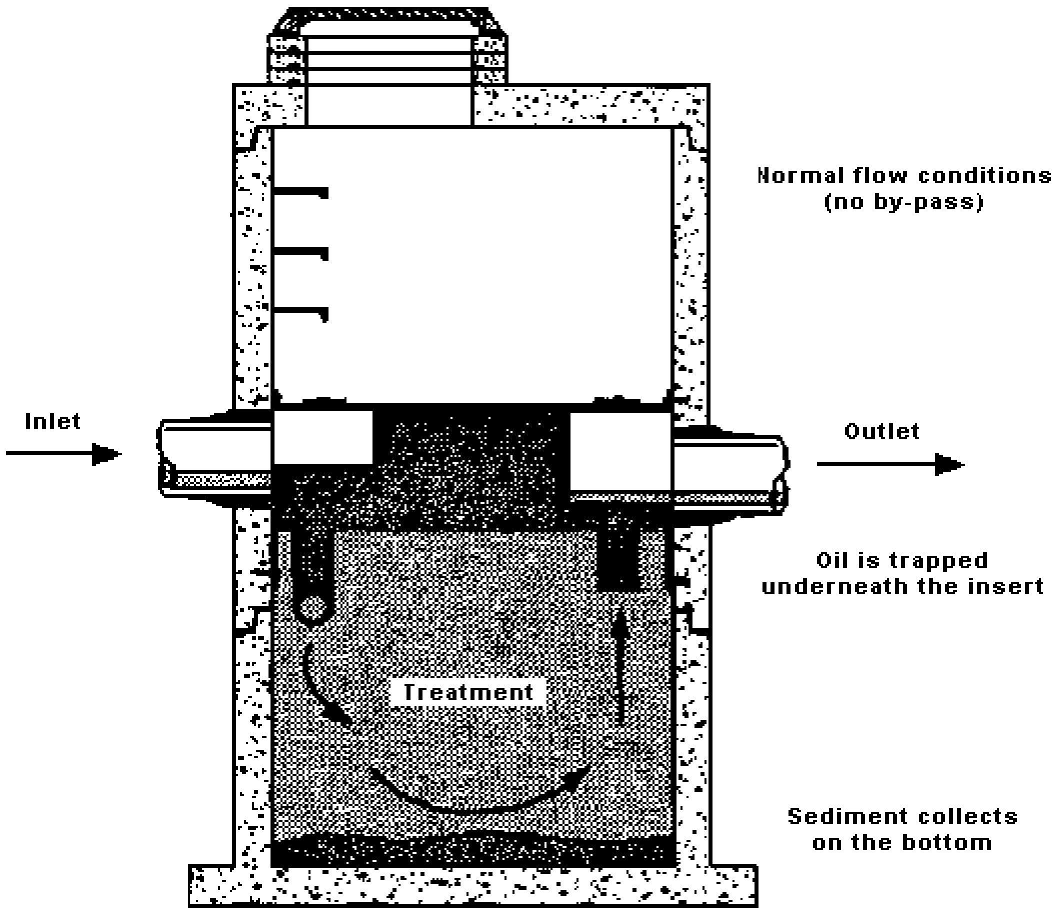


Figure 24. Downstream Defender™ (H.I.L. Technology, 1996)

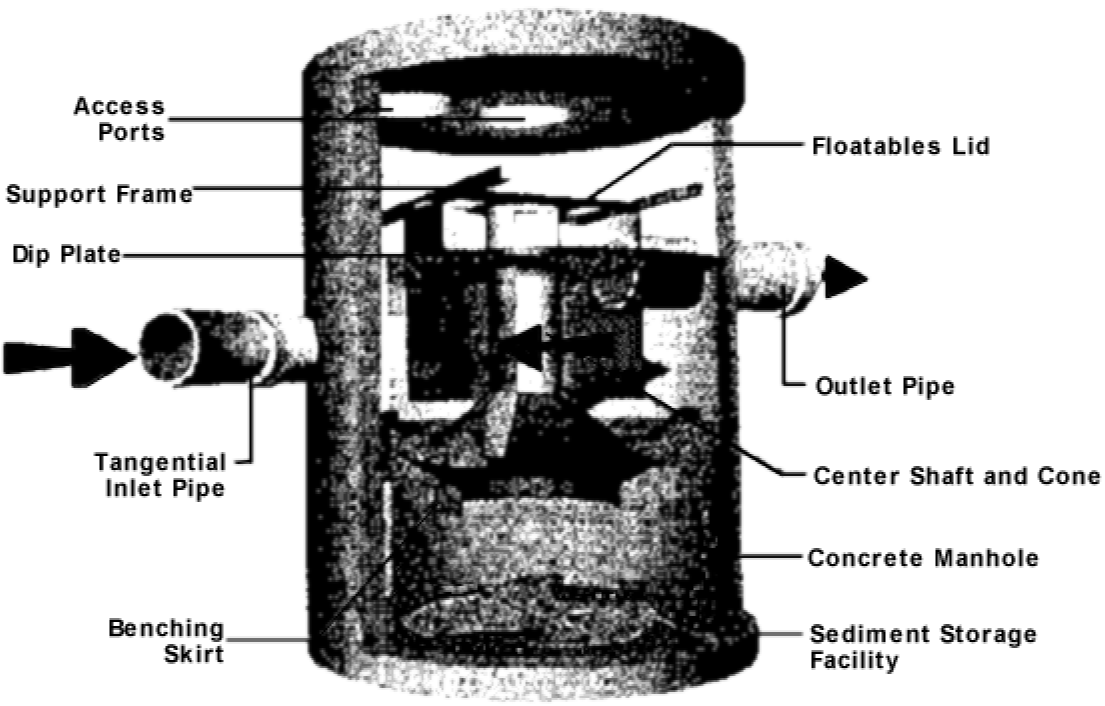
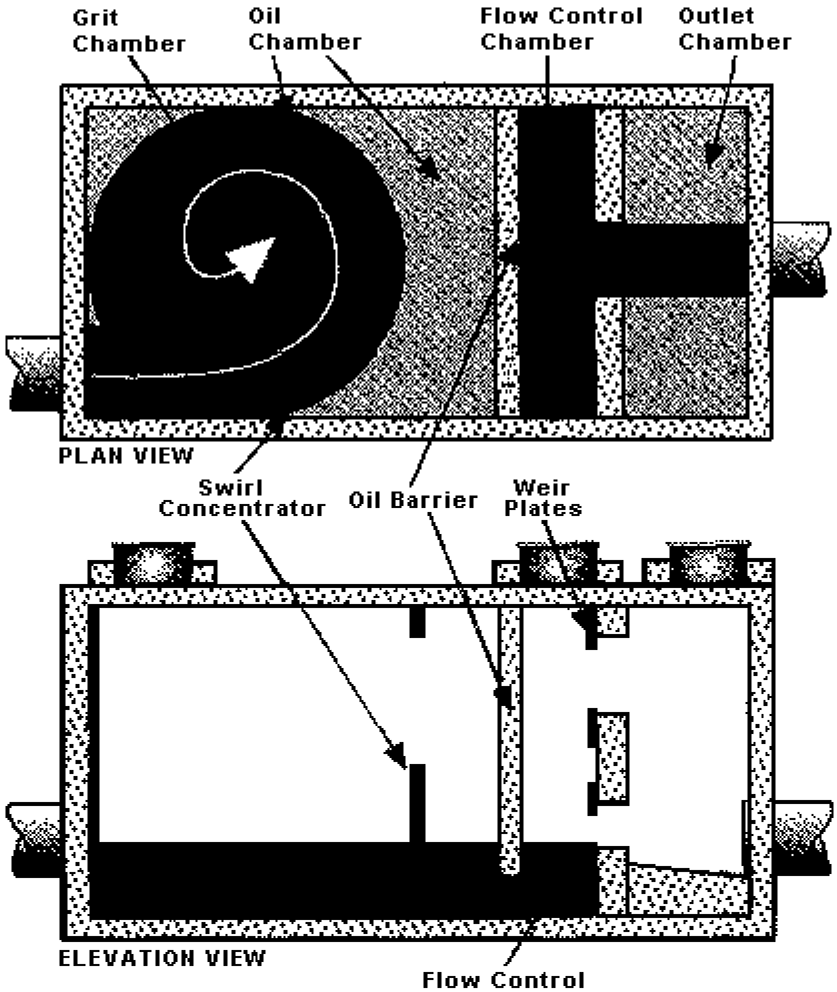


Figure 25. Vortechs^{TM} Stormwater Treatment System (Vortechnics, 1996)



The Stormceptor® and Downstream Defender™ can be designed to retrofit an existing stormwater access hole structure or be designed as a new storm drain system. Each of the devices is designed to treat low to moderate storm flows. The incoming stormwater and pollutants enter a diversion chamber and are diverted into the lower chamber for treatment. While oils and floatable particulate matter rise to the surface, sediments settle out to the bottom. During peak or high flows, the excess stormwater bypasses the lower treatment chamber and flows directly to the downstream storm drain system.

The Stormceptor® is divided into two water quality chambers designed for removal of the oil and sediment normally found in urban stormwater runoff. Stormwater flows into the upper chamber and is diverted by a V-shaped weir down a drop pipe and into the lower chamber. The flow is then redirected horizontally around the circular walls of the lower chamber and through an outlet pipe. The inlet drop pipe and outlet riser pipe are set at the same elevation to provide storage for oil and sediment within the lower chamber.

The Downstream Defender™ operates by introducing stormwater into its cylindrical base, where the runoff spirals down the perimeter, allowing the larger sediments to settle out. The internal components of the Downstream Defender™ allow oils, grease, and floatables to be trapped. Unlike the conventional oil/grit separator unit, the Stormceptor® and Downstream Defender™ are designed to prevent the resuspension of sediment, thereby providing actual removal during every storm event.

The Vortechs™ system consists of four chambers. The first chamber is termed the grit or swirl chamber. Settleable particles are swept to the center of this chamber, where they are induced to settle out. The higher the flow rate through the system, the greater the strength of the vortex settling motion. Particles eventually migrate toward the center of the cylindrical chamber, where velocities are low and conditions are tranquil. The particles remain trapped until the system is cleaned. The first chamber is designed to prevent wash-outs that occur in conventional water quality inlet devices. The second chamber is the oil chamber. The oil barrier traps floatables, oils, and grease. Unlike conventional oil traps that lack flow controls and extra tank capacity, the Vortechs™ system is designed to handle most flow surges. The third chamber is the flow control chamber, which is designed to reduce forces that encourage resuspension and wash-out. During conditions of intense storm surge through the unit, the low-flow control within the Vortechs™ system causes the inlet pipe to become submerged. This process floats oily constituents up above the inlet pipe and out of the influent stream; thus, oils and grease are kept within the trap. The fourth chamber is the outlet chamber.

Applicability

The Stormceptor® and Downstream Defender™ treatment systems are used primarily for treatment of stormwater runoff from impervious surfaces. The devices are ideal for use in ultra-urban settings since each is composed of a precast structure that is installed beneath the ground and can either be retrofitted to an existing storm drain system or replace a proposed access hole in a storm drain system. The structures are designed to capture and treat a portion of the flow that enters into the storm drain system; however, the volume of runoff treated is limited to the available volume in the lower chamber structure. Because of this, Stormceptor® and Downstream Defender™ might treat less than a typical water quality treatment volume and should be placed at the beginning of the storm drain line for maximum treatment efficiency. The Stormceptor® and Downstream Defender™ treatment devices do not significantly reduce either biological or nutrient pollutants that are not sorbed to particles (Weatherbe, et al., 1995; Bryant, et al., 1995; H.I.L. Technology, 1996).

The Vortechs™ system is designed to counter the resuspension problem associated with conventional oil/grit separator water quality inlets. Data for a Vortechs™ system obtained through in-field monitoring of an actual installation in Freeport, Maine, showed that particulate matter within the unit increased over a 20-month period (Vortechnics, 1996).

Effectiveness

There are only a few independently verified studies of the effectiveness of manufactured systems. Field testing at over 21 installed and operating Stormceptor® units in the Toronto, Canada, area has shown that 86 percent of the trapped sediments were in the clay and silt particle size range (Weatherbe, et al., 1995). The average annual accumulation rate was determined to be about 0.70 m^3/ha (0.37 yd3/ac) of land. Unlike conventional oil/grit separators, the study showed that the accumulation was increasing over time. This was important because it showed captured sediments (both fine and coarse) were not being resuspended by subsequent storms. On average, monitoring studies have reported a 96 percent removal of oil, 83 percent removal of sand, and 72 percent removal of peat. Depending on the size of the unit, treatment rates range between 7,079 and 4,201 L/min (285 and 1,110 gal/min); all flow greater than the treatment rate is bypassed.

Preliminary results for the Downstream Defender™ show overall removal efficiencies in excess of 90 percent of particles greater than 150 microns (sand-sized particles). The device intercepts the first flush and retains floatables, oils, and grease. Head loss across the Downstream Defender™ is typically less than 30.5 cm (12 in); thus backwater effects are generally not a problem.

Bench-scale testing performed on the Vortechs™ system showed that for silt-sized sediments, the average removal efficiency was in excess of 80 percent. The removal efficiency is greater for larger-sized particles. For example, for a single 2-month storm event in Portland, Maine, the same bench-scale test showed that the Vortechs™ unit exhibited a removal efficiency of approximately 89 percent for sand-sized particles (Vortechnics, 1996).

Siting and Design Considerations

Vendors of manufactured systems are often willing to provide services to build, install, and maintain manufactured systems. These services frequently include technical support to design a system for a customer in the process of making a sale. If not carefully evaluated by the customer, however, these systems may become a problem, especially with respect to maintenance considerations (see below). The Stormceptor®, Downstream Defender™, and Vortechs™ units are structural precast BMP water quality devices that can be installed on-line in new storm drain systems. The structures come in various sizes and are best suited for land uses with drainage areas of 4 ha (10 ac) or less. The Stormceptor®, Downstream Defender™, and Vortechs™ systems are stand-alone BMPs and do not require any pretreatment; however, they can be used to pretreat stormwater runoff to other BMPs such as ponds, sand filters, or infiltration/exfiltration trenches. On the other hand, some BMPs, such as water quality inlets (see Section 3.6), should be used only for pretreatment and never as a stand-alone BMP.

The Stormceptor® comes in eight different precast sizes and can treat 0.018 to 0.07 m^3/s (0.64 to 2.5 ft^3/s, respectively) of stormwater runoff prior to bypass. The individual size of the Stormceptor® would depend on the amount of stormwater runoff expected to drain to the device. The Downstream Defender^{TM} comes in four different precast sizes and can treat 0.021 to 0.37 m^3/s (0.75 to 13 ft^3/s) of stormwater runoff prior to bypass. Vortechs^{TM} systems are sized based on required design flow rate. The precast units come in nine different sizes that handle flow rates between 0.04 and 0.7 m^3/s (1.6 and 25 ft^3/s).

Design specifications for these manufactured systems can be obtained from their manufacturers or distributors. Current information is readily available on the web sites for each manufacturer. Web site addresses are:

- Stormceptor®: http://www.stormceptor.com.
- Downstream Defender^{TM}: http://www.hil-tech.com.
- Vortechs^{TM}: http://www.vortechnics.com.

Maintenance Considerations

The Stormceptor® and Downstream Defender^{TM} systems are access hole structures that are engineered to be installed within roadways in residential, commercial, industrial, or institutional areas. The access hole includes a built-in internal device that diverts stormwater runoff to the lower treatment chamber. Normal installations take only a few hours once the excavation is complete. The general maintenance procedure for the Stormceptor® is to clean out the unit once a year, or when 15 percent of the operating storage volume is filled with solids, or when oil levels reach 25 mm (1.0 in) or greater (Stormceptor®, 1996). The sediment holding capacity of the Stormceptor® units range from 2.12 to 20.56 m^3 (2.77 to 26.87 yd3). The manufacturer of the Downstream Defender^{TM} recommends cleaning out the units at least twice a year using a conventional vacuum truck (H.I.L. Technology, 1996).

The Vortechs^{TM} system sediment storage capacity ranges from 0.57 to 5.4 m^3 (0.75 to 7 yd3), depending on the size of the unit. Routine inspections are necessary to schedule cleaning. The Vortechs^{TM} system can be cleaned by a conventional vacuum truck (Vortechnics, 1996).

If not properly maintained, manufactured systems can become exporters of oil and grease and other constituents. Generally, however, manufactured systems are designed to counter the resuspension problem associated with conventional oil/grit separators.

Cost Considerations

Stormceptor® and Downstream Defender^{TM} units are precast manhole structures that contain a built-in diversion device. The structures are delivered to the site partially assembled. Contractors need only set the grade and alignment to properly install the units. The Stormceptor® comes in eight standard sizes, with the cost of the units ranging from $7,600 to $33,560. Based on the maximum impervious drainage area in hectares treated for the 60 percent TSS removal rate, the cost per impervious hectare ranges from $9,900 to $26,800. On average, the cost of maintaining the system is about $300 to $500 per cleaning (pumping, dewatering, and disposing of solids). The expected life of the Stormceptor® is 50 to 100 years (Stormceptor®, 1996).

Downstream Defender^{TM} devices are available in four standard sizes. An average cost at capacity is $44,100 per m^3/s ($1,250 per ft^3/s) (H.I.L. Technology, 1996).

The Vortechs^{TM} unit comes in nine different sizes depending on the quantity of stormwater for treatment. The average cost is $52,900 to $123,500 per m^3/s of capacity ($1,500 to $3,500 per ft^3/s) (Vortechnics, 1997). Installation costs for all of the structures are site-dependent but generally run about 25 to 35 percent of the unit cost of the structures.

References

Bryant, G., F. Misa, D.G. Weatherbe, and W. Snodgrass. 1995. Field Monitoring of Stormceptor Performance, Case Study of Stormceptors in the Greater Toronto Area.

H.I.L. Technology, Inc. 1996. Downstream Defender, Portland, ME. Product Literature.

H.I.L. Technology. 1996. Personal communication from A. Knight. H.I.L. Technology, Inc., Portland, ME.

Stormceptor® Corporation. 1996. Product Literature.

Vortechnics. 1996. Vortechs Stormwater Treatment System, Portland, ME. Product Literature.

Vortechnics. 1997. Personal communication from G. Novick. Vortechnics, Inc., Portland, ME.

Weatherbe, D.G., G. Bryant, and W. Snodgrass. 1995. Performance of the Stormceptor Water Quality Inlet. Proceedings of the Water Environment Federation Specialty Conference, Toronto, Canada.

Previous Table of Contents Next

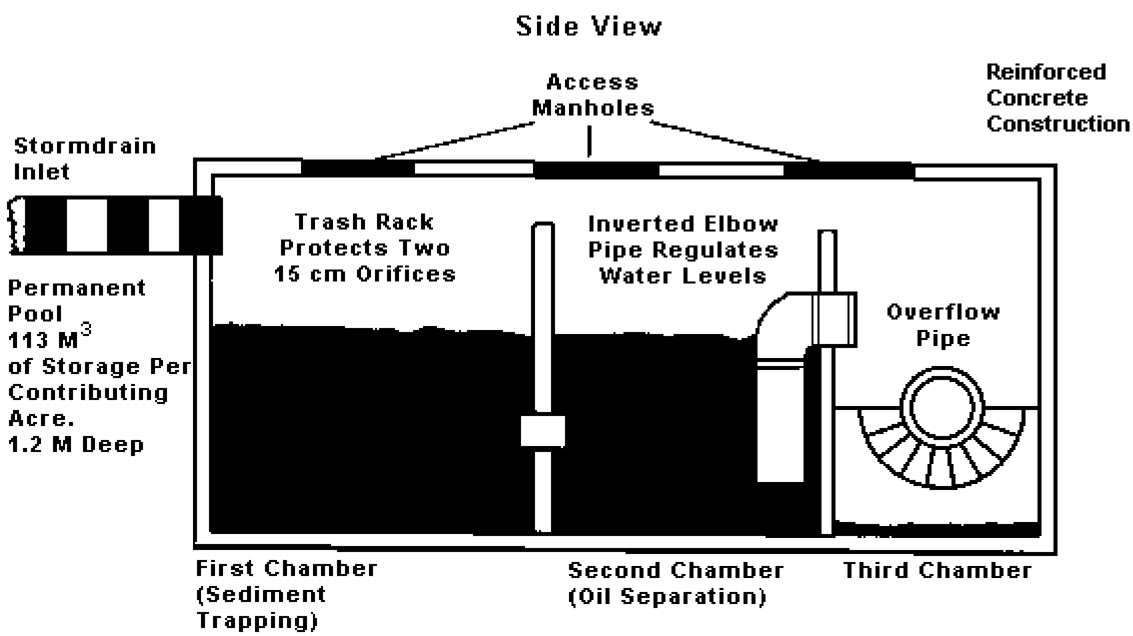
FHWA Home | HEP Home | Feedback

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Oil/Grit Separator Units

The typical oil/grit separator (OGS) unit operates by settling sediment and particulate matter, screening debris, and separating free surface oils from stormwater runoff. The unit typically consists of three or four chambers. Figure 21 is a schematic of a typical water quality oil/grit separator unit. In the case of a conventional OGS unit, the first chamber, termed the grit chamber, is designed to settle sediment and large particulate matter; the access from the first chamber to the second chamber is covered with a trash rack, which operates as a screen to prevent debris from passing through to the second chamber. The second chamber, termed the oil chamber, is designed to trap and separate free surface oils and grease from the stormwater runoff. The third chamber houses the stormwater outlet pipe that discharges the overflow to the storm drain system.

Figure 21. Schematic of an oil/grit separator (OGS) (adapted from Schueler, 1987)



Most OGS units are designed to be placed in highly impervious parking areas that drain about 0.4 ha (1 ac). Results from one OGS study conducted in the State of Maryland showed that the treatment capacity of most conventional OGS units inventoried was less than 5.1 mm (0.2 in) of runoff for the service area (Schueler and Shepp, 1993). Because of the limited retention capacity, conventional OGSs are not capable of removing large quantities of stormwater constituents. Instead, they are designed and implemented to control hydrocarbons, debris, large organic matter, and coarse sediments that are commonly associated with heavily traveled parking areas.

Applicability

The OGS unit is designed to trap and settle large sediments and particulate matter, debris, and hydrocarbons from highly impervious areas such as parking lots, gas stations, loading docks, and roadside rest areas. The OGS unit is constructed beneath the surface of the impervious area, and as such does not require additional space. Because of this, it can be easily retrofitted into existing impervious land use conditions, which makes it suitable for ultra-urban environments. Results from an OGS study in the State of Maryland have shown that detention times for conventional OGS units are generally less than 30 minutes during storm events (Schueler and Shepp, 1993). Trapped sediments and particles tend to resuspend during subsequent storms and exit the chambers. Because settling and trapping are temporary, actual pollutant removal occurs only when the units are cleaned out. Therefore, these devices are best suited for an off-line configuration where only a portion of the first flush is treated by the unit and clean out occurs after every major storm event. A study produced by the Metropolitan Washington Council of Governments showed that particulate matter within conventional OGS units remained the same or decreased over a 20-month period (Shepp et al., 1992).

Effectiveness

Conventional OGS units have demonstrated poor pollutant removal capabilities. The primary removal mechanism of the OGS is settling; with short detention times, and resuspension occurring after every storm event, removal effectiveness is limited to what is physically cleaned out after every storm. If the unit is not cleaned after each storm, resuspended trace metals, nutrients, organic matter, and sediments will eventually pass through each chamber and into the storm drain system.

A study performed on OGS units in the State of Maryland showed that negative sediment deposition from storm to storm indicated that re-suspension and washout were a common problem (Schueler and Shepp, 1993). The only constituent that was trapped with some efficiency in the second chamber was total hydrocarbons. This was probably due to the inverted siphon, which is designed to retain free surface oils and grease (Schueler et al., 1992; Schueler and Shepp, 1993).

Siting and Design Considerations

The OGS unit is a structural BMP that is easily installed in areas of high imperviousness such as parking lots, gas stations, commercial and industrial sites, and shopping centers, and even along roadways. The OGS unit would be well suited for ultra-urban environments where available land area is a major constraint. OGS units typically are sized for highly impervious drainage areas of less than 0.4 ha (1 ac), though up to 0.61 ha (1.5 ac) is feasible. Locating the units off-line would alleviate some of the problems associated with the retention and resuspension of pollutants.

The OGS units are designed using a three- or four-chamber configuration. Settling of larger sediments, trash, and debris takes place in the first chamber. The primary function of the second chamber is to separate oils and grease from the stormwater runoff; some absorption of oils and grease to smaller sediments, and settling will also occur in the first chamber. The third chamber houses the overflow pipe. The OGS unit typically is sized based on the drainage area, which often includes rooftops, and the percent imperviousness of the basin. One common practice is to size the unit based on a design storm to provide some amount of storage. In general, OGS units are rectangular in shape, with the largest chamber being the initial settling chamber. Approximate dimensions for an OGS unit located in a parking area that drains 0.4 ha (1 ac) would be 1.82 m deep by 1.22 m wide by 4.23 long (6 ft deep by 4 ft wide by 14 ft long) (inside dimensions). The length of the first chamber would be 1.82 m (6 ft) with 1.22 m (4 ft) for each of the other two chambers.

Specific dimensions for each OGS design are dependent on site characteristics and local design storm requirements. Improvement in OGS performance can be achieved by extending the interior chamber walls to the top of the chamber, thereby eliminating recirculation and overflow from one chamber to another. In addition, placing the OGS off-line from the main stormwater system helps to reduce resuspension of oil and grit.

Additional design examples and information can be found in Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs (Schueler, 1987), and Northern Virginia BMP Handbook: A Guide to Planning and Designing Best Management Practices in Northern Virginia (NVPDC, 1992). Because studies have shown that water quality inlets are a marginal method for removing particulate matter (Schueler and Shepp, 1993), other design references (Claytor and Schueler, 1996) do not recommend them for sand filter pretreatment.

Maintenance Considerations

Very few structural or clogging problems have been reported during the first five years of OGS operation (Schueler and Shepp, 1993). The OGS unit should be inspected after each major storm event. Clean-out would require the removal of sediments, trash, and debris. In reality, OGSs are rarely cleaned out after every storm because such intensive maintenance is beyond most budgets.

The removal of oily debris, sediments, and trash might require disposal as a hazardous waste. However, some local landfills may accept the sediment and trash if it is properly dewatered.

Cost Considerations

OGS units can be either cast-in-place or precast. Precast concrete chambers are usually delivered to the site partially assembled and tend to cost slightly less than the cast-in-place option. The cost associated with a cast-in-place concrete OGS unit is a function of several parameters. Excavation, gravel bedding, amount and size of rebar, amount of concrete and form work, and grate and clean-out access holes all contribute to the total cost of the OGS unit. In 1992, OGS units were reported to cost between $5,000 and $15,000 fully installed. On average, costs per inlet ranged from $7,000 to $8,000 (Schueler et al., 1992).

References

Botts, J., L. Allard, and J. Wheeler. 1996. Structural Best Management Practices for Storm Water Pollution Control at Industrial Facilities. Watershed '96, pp. 216-219.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

NVPDC. 1992. Northern Virginia BMP Handbook: A Guide to Planning and Designing Best Management Practices in Northern Virginia. Prepared by Northern Virginia Planning District Commission (NVPDC) and Engineers and Surveyors Institute.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, DC.

Schueler, T.R., and D. Shepp. 1993. The Quality of Trapped Sediments and Pool Water Within Oil-Grit Separators in Suburban Maryland. Chapter 6. Interim Report for the Maryland Department of the Environment Hydrocarbon Study, 81-115.

Shepp, D., D. Cole, and F.J. Galli. 1992. A Field Survey of the Performance of Oil/Grit Separators. Prepared for the Maryland Department of the Environment by the Metropolitan Washington Council of Governments, Department of Environmental Programs, Washington, DC.

Previous Table of Contents Next

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Organic Media Filters

There are two types of organic filter media typically used for stormwater management - peat/sand and compost. The use of organic media in surface or subsurface filter designs is intended to provide a higher level of stormwater treatment than a sand-only filter. Both of these organic media are typically installed in filters to depths between 460 to 600 mm (18 to 24 in), and are drained by piped underdrain systems. (Figures 15 and 16 illustrate typical filter cross sections.)

Figure 15. Typical peat-sand filter cross section (Young et al., 1996)

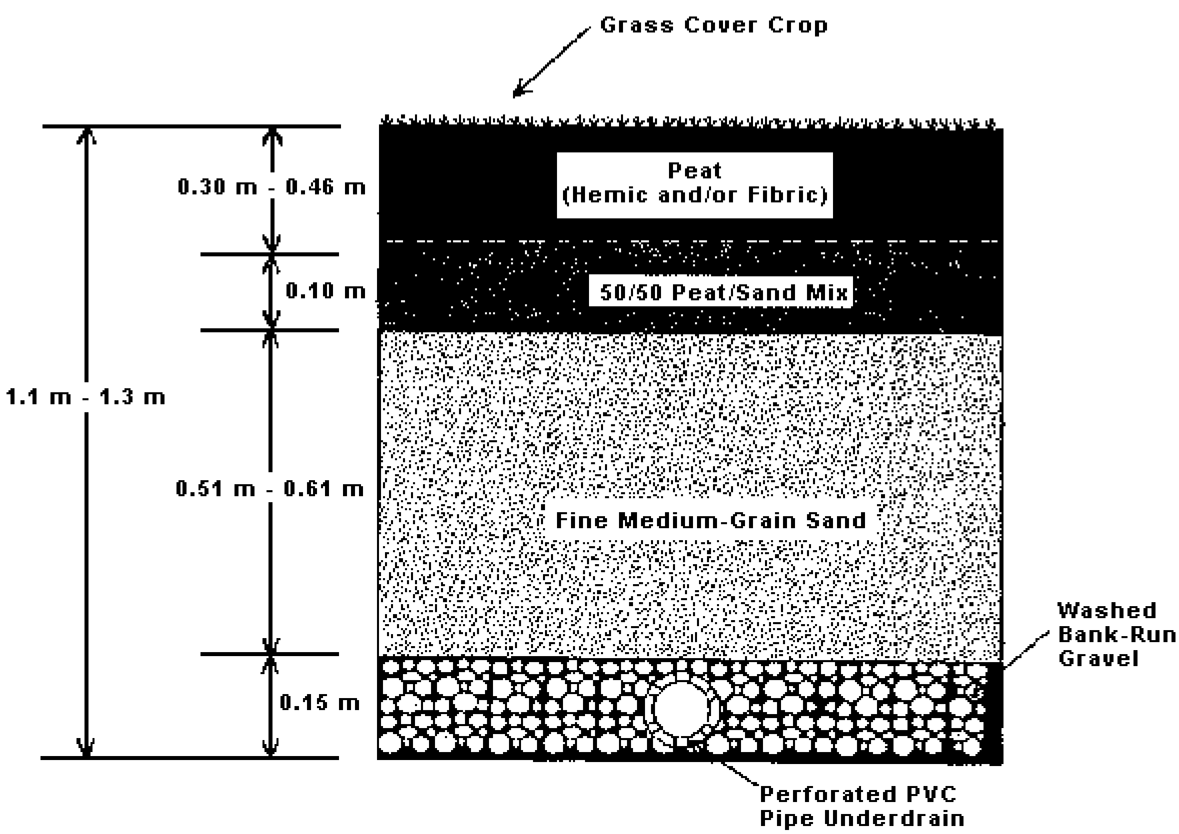
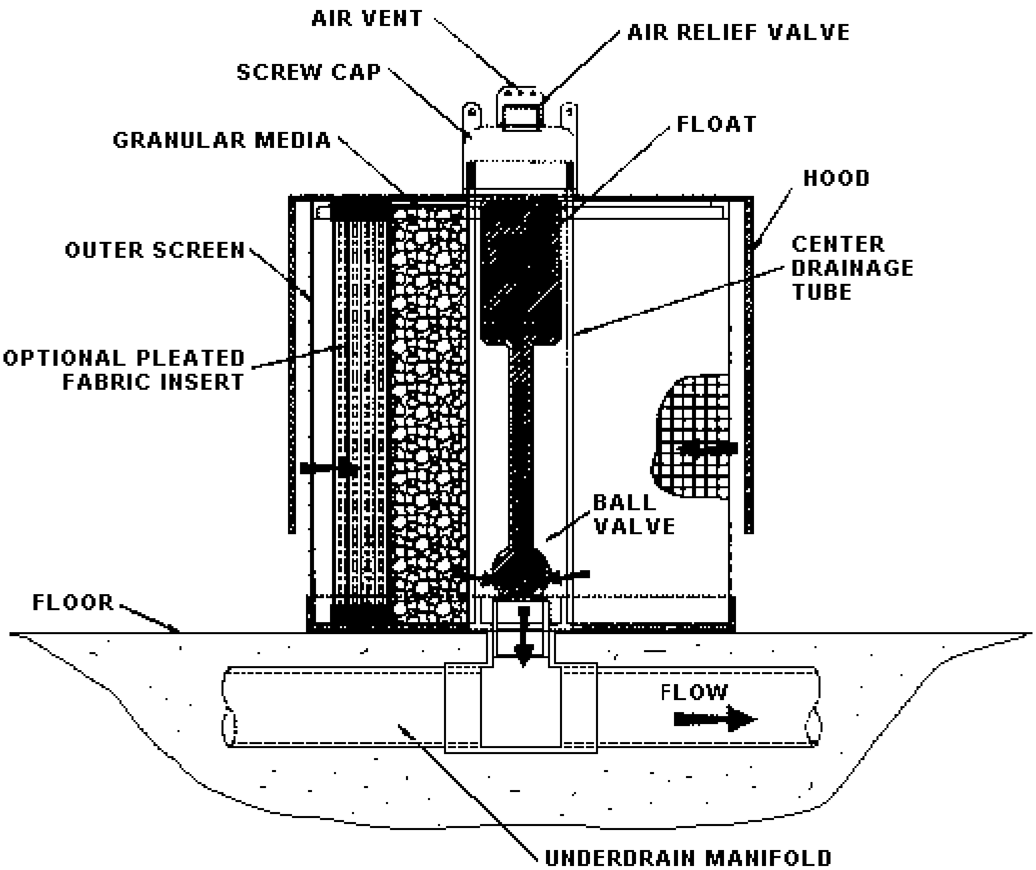


Figure 16. Cross-section of a StormFilter siphon-actuated cartridge (Stormwater Management, 1998)



The organic media filters improve water quality through a combination of sedimentation, filtration, and adsorption processes. The sedimentation section located just upstream of the filter section serves as pretreatment, removing larger diameter suspended solids and capturing floating hydrocarbons. Partially treated stormwater then flows slowly into the filter section where fine-grain material is strained from stormwater as it passes through the filter media.

The subsurface or underground filter design is well adapted for applications with limited land area and provides turnkey performance that is independent of local soil conditions, groundwater levels, and other factors. The underground filter design typically consists of a multi-chamber vault that is completely below grade and is covered with a grating or structural concrete. It is most useful for multipurpose land uses, that is, where committed land area will also be used for automobile parking or for public parks. The surface filter design, sometimes called the Austin filter, also consists of a multichambered facility. While most of the filter is located at or slightly below grade the filter is not covered and so requires a commitment of land area (refer to the Fact Sheets on Underground Sand Filters and Surface Sand Filters for additional information).

As with other stormwater filters, the purpose of organic media filters is to manage the first flush, which typically contains the highest concentration of pollutants. If designed as an off-line facility, however, such filters can provide true capture and treatment of any water quality volume.

A number of design variations or proprietary systems featuring organic media are currently available (e.g., CSF® Stormwater Treatment System, now StormFilter™). While these systems basically use the same treatment mechanisms, there are differences in the size of settling areas or chambers, loading rates, and media configuration.

Applicability

Organic media filters can be used in underground and surface filter designs. Of these, the underground sand filter is considered to be more applicable to the ultra-urban setting. It requires a small commitment of land area, provides dependable service, and is relatively effective in removing urban pollutants. Furthermore, its design is inherently flexible, and the size and shape of the unit can be set based on local requirements.

Surface filter designs can also utilize organic media and are typically less expensive to construct and maintain than underground filter designs. Unfortunately, surface designs typically prevent multipurpose land uses and therefore are limited in their application to ultra-urban settings. In roadside settings where there is sufficient space (typically two to three percent of the drainage area served), a surface filter design may be preferred.

If they are placed below the frost line, the performance of organic media filters is relatively independent of season. In addition, the level of treatment is generally independent of placement and in situ soil conditions do not affect performance. For most designs pretreatment is integrated into the filter facility in the form of a settling chamber. Additional pretreatment may be provided by streetsweeping to remove accumulated sand and trash, which can diminish the useful life of the filter.

Effectiveness

Organic media filters are highly efficient in removing fine-grain material (small particles in stormwater runoff between 6 and 41 microns). As an additional benefit, organic media are capable of removing a portion of dissolved material found in stormwater. For example, the peat medium has a cation exchange capacity (CEC) 500 times that of sand. This greatly increases its ability to adsorb or capture positively charged dissolved metals and hydrocarbons, increasing the removal performance.

Organic media filters have demonstrated good total suspended solids (TSS) removals, typically providing 90 to 95 percent removal (Claytor and Schueler, 1996; Stewart, 1992). Performance for nutrients is less significant; in fact, the organic media may be a source of soluble phosphorus and nitrate (NO_3). Total phosphorus (TP) removals range up to 49 percent, while variable removal of metals is typically between 48 and 90 percent (Figure 14). Removal of oil and gasoline averages about 90 percent (Claytor and Schueler, 1996).

Table 14. Pollutant removal effectiveness of organic filters (%)

Study	TSS	TP	TKN	NO_3	Metals	Comments
Stewart, 1992	95	41	56	-34	50 - 90	CSF® Type I system
Stormwater Management, 1994	92	49	57	-145	48 - 81	3-year results for CSF® Type I system

Siting and Design Considerations

Two broad categories of organic media designs exist: (1) variations on existing sand medium filter designs and (2) proprietary designs that are optimized for organic media. For the first design category, organic media are simply substituted for sand, affecting the size of the filter portion of the facility. Information on existing sand filter designs is provided in the Surface Sand Filters and Underground Sand Filters Fact Sheets. These sand medium designs should be varied to reflect the permeability of the substituted organic media. It has been recommended in a recent evaluation that combination peat/sand filters be designed based on a permeability of 0.8 m/day (2.75 ft/day), or a value approximately 79 percent of that recommended for sand-only filters (City of Austin, 1991). On the other hand, compost medium filters have a wide range of permeability values depending on their age and degree of clogging. Designers should be aware that initial permeability can be very high (in the range of 122 m/day [400 ft/day], a value much higher than that used to specify the filter area); Claytor and Schueler (1996) recommend a design permeability value of 2.7 m/day (8.7 ft/day). Several good sources are available for detailed design procedures and information on underground and surface filter designs, including Design of Stormwater Filtering Systems (Claytor and Schueler, 1996) and Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996).

One proprietary underground design that features organic media is the CSF® Type II system, which uses cylindrical filter cartridges filled with a granular organic medium consisting of composted leaves. (Figure 16 illustrates a recent advancement in StormFilter™ technology, formerly the CSF® system.) The filter works by percolating stormwater through the cylindrical cartridges containing certified CSF® compost media. Because of the highly porous nature of the granular media, the flow through a newly installed cartridge is restricted by a valve to 57 L/min (15 gal/min). This allows more time for sediment to settle and ensures adequate contact time for pollutant removal. The CSF® system is equipped with scum baffles that trap floating debris and surface films; even during overflow conditions. A typical unit requires 0.67 m (2.2 ft) of drop from the inlet invert to the outlet invert. A portion of the sediment settles out in the area around the cylinders; more sediment, including particulate forms of nutrients and heavy metals, are trapped by the porous structure of the compost. Sizes range from 1.83 m X 2.44 m (6 ft X 8 ft) (treating about 284 L/min [75 gal/min] peak flow) to 2.44 m X 5.49 m (8 ft X 18 ft) vaults (which treat about 1360 L/min [360 gal/min], or 0.023 m^3/s [0.8 ft^3/s]). Housed in standard size precast or cast in place concrete vaults, the filter systems are installed in-line with storm drains.

Maintenance Considerations

Annual maintenance costs for organic filters vary as a function of the design used. Surface filter designs using a peat/sand medium require periodic mowing and removal of the grass cuttings to avoid unwanted plant growth. In addition, at least an annual inspection is required for this design and reseeding of the grass cover crop may be required.

Filter designs that feature horizontal compost bed filters will likely be replaced every three to four years to prevent heavy metal concentrations from reaching levels that exceed the "clean sludge" definition under 40 CFR Part 503 (USEPA, 1994). These designs also require removal of accumulated material and rototilling of the compost to reestablish the required permeability.

Maintenance for underground designs that use organic media can be inferred from information given for sand-only medium filters given in the Fact Sheets for Underground Sand Filters and Surface Sand Filters. A D.C. underground sand filter serving a 0.4 ha (1 ac) area was serviced by removal and replacement of a gravel ballast and filter cloth, for $1300 in 1994 (Bell, 1996). It is reasonable to assume organic media filters would require comparable service. It should be noted that repair of subsurface filters requires confined space entry, which dictates larger management crews and a higher cost to repair than surface filters.

The maintenance of proprietary organic media filters varies with the manufacturer; it is likely that maintenance will include removing accumulated material that has settled in the facility and periodic replacement of organic media cartridges on an annual or biennial basis. For example, manufacturers of the CSF® system indicate annual maintenance costs will range from $500 to $1200 (for 280 and 1360 L/min [75 and 360 gal/min] systems, respectively).

Cost Considerations

The cost of surface facilities using organic media filters is comparable to the cost of filtration facilities that use sand medium (with the exception of proprietary systems). For conceptual costing a price of $8,400 to $39,500 per impervious hectare served (or $3,400 to $16,000 per impervious acre served) can be used to estimate the construction cost of a proposed facility, excluding real estate, design, and contingency costs (Schueler, 1994).

Underground filters are generally considered to be a high-cost BMP option for water quality management. The construction cost per hectare served is typically around $34,600 and the cost per acre served is typically around $14,000, excluding real estate, design, and contingency costs (Schueler, 1994).

Drop-in CSF® vertical organic media units are typically precast vaults delivered to the site either partially or fully assembled. Typical cost variables include the need for ballast, type of lids and doors, customized casting of sections or holes, and depth of the vault. Systems treating peak flows of 280 and 1360 L/min (75 and 360 gal/min) have an estimated installed cost of $10,000 and $25,000, respectively (Stormwater Management, 1996).

References

Bell, W. 1996. BMP Technologies for Ultra-Urban Settings. In Proceedings of Effective Land Management for Reduced Environmental Impact, Tidewater's Land Management Conference on Water Quality, August 22, 1996.

City of Austin. 1991. Austin Environmental Design Criteria Manual. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, TX.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Schueler, T.R. 1994. Developments in Sand Filter Technology to Improve Stormwater Runoff Quality. Watershed Protection Techniques 1(2):47-54.

Stewart, W.S. 1992. Compost Storm Water Treatment System. W&H Pacific Consultants, Portland, OR. Final Report.

Stormwater Management. 1994. Three Year Performance Summary of Stormwater Pollutant and Treatment - 185th

Avenue, Hillsboro, Oregon. Technical Memorandum. Stormwater Management, Portland, OR.

Stormwater Management. 1996. Product literature.

USEPA. 1994. Land Application of Sewage Sludge. EPA 831-B-93-002b. U.S. Environmental Protection Agency (USEPA), Office of Enforcement and Compliance Assurance.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

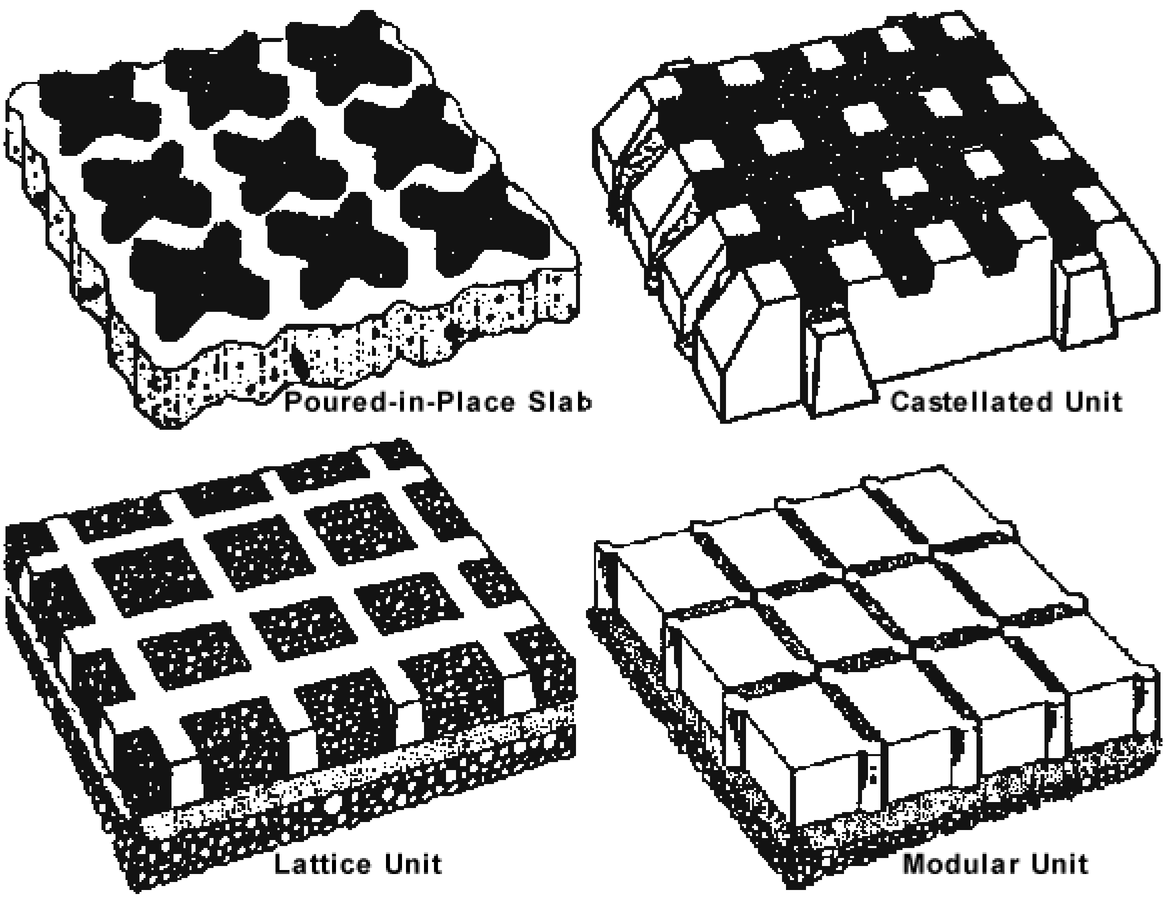
Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Porous Pavements

Porous pavements have the potential to be an effective ultra-urban BMP. While conventional pavement results in increased rates and volumes of surface runoff, porous pavements allow some of the stormwater to percolate through the pavement and enter the soil below.

The types of porous pavements used include porous asphalt and concrete surfaces, as well as several types of lattice pavers, which are hollow concrete blocks or stones (Figure 26). Porous pavements work by allowing streets, parking lots, sidewalks, and other impervious covers to retain their natural infiltration capacity while maintaining the structural and functional features of the materials they replace.

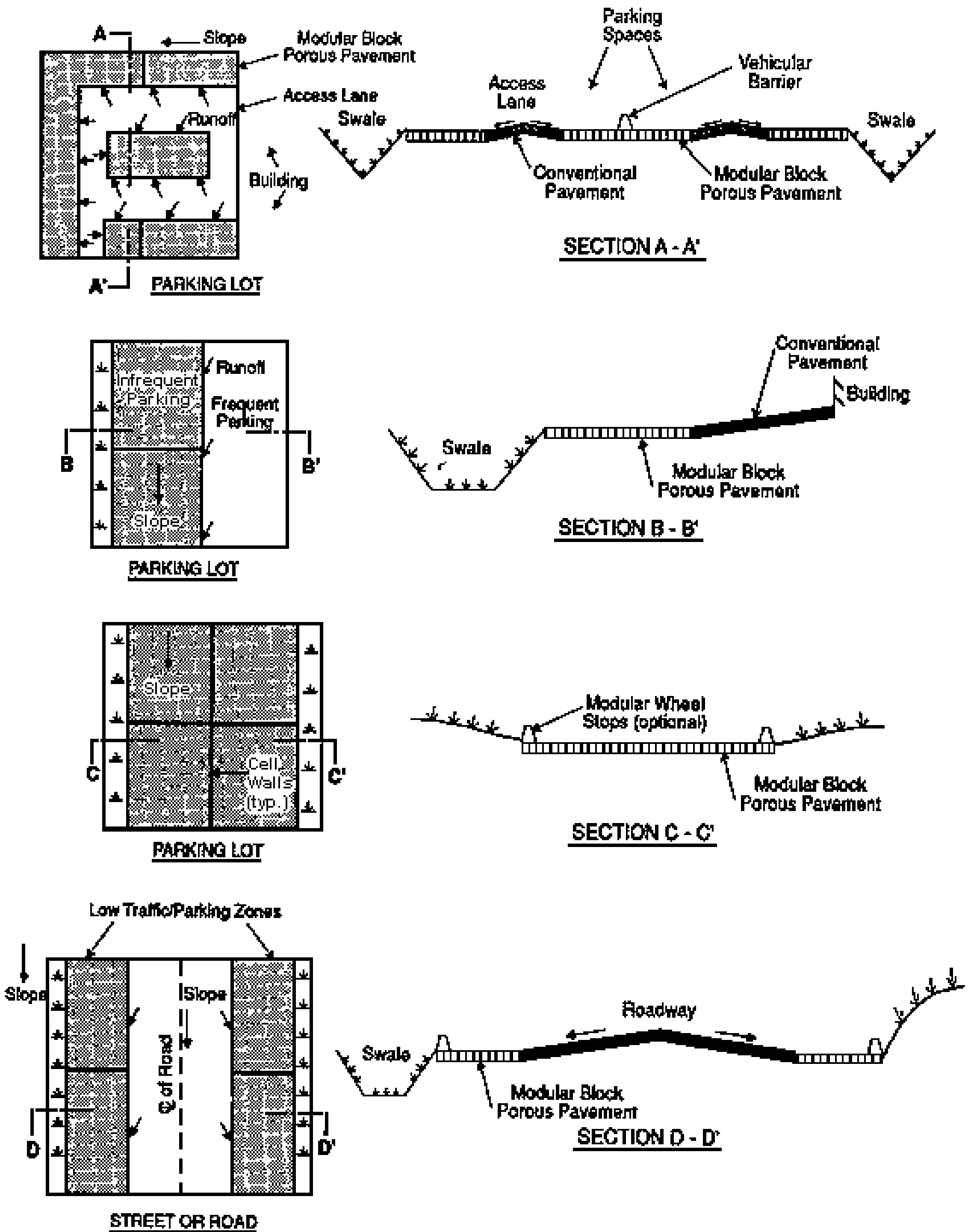
Figure 26. Types of grid and modular pavements (Virginia Soil and Water Commission, 1990)



Applicability

In many instances porous pavements can be used in place of conventional asphalt or concrete in an ultra-urban environment. They are generally not suited for areas with high traffic volumes or loads. Composite designs that use conventional asphalt or concrete in high-traffic areas adjacent to porous pavements along shoulders or in parking areas have, however, been designed (Figure 27). Generally, porous pavements are most often used in the construction of parking areas for office buildings, recreational facilities, and shopping centers. Other uses include emergency stopping areas, traffic islands, sidewalks, road shoulders, vehicle cross-overs on divided highways, and low-traffic roads. Some porous pavements such as porous asphalt have also been tested for use in highway projects (Hossain and Scofield, 1991). Their use at gas stations, truck stops, and industrial sites is not recommended due to the high risk of groundwater contamination from trace organic compounds (Cahill, undated). As a BMP retrofit option, porous pavement might have limited application because prior disturbance or modification of in situ soil often significantly reduces its infiltration capacity (Schueler et al., 1992).

Figure 27. Typical applications of modular block porous pavement (not to scale) (Urban Drainage and Flood Control District, 1992)



Porous pavements such as porous asphalt are also effective at reducing hydroplaning, as well as improving wet weather visibility (Stotz and Krauth, 1994). The use of interlocking concrete paving stones on walks and crosswalks can also make them more visible and safer for both drivers and pedestrians, thereby reducing the need for repainting.

Effectiveness

When operating properly, porous pavements are as effective at removing pollutants from stormwater as other infiltration devices. Also like other infiltration BMPs, porous pavements are not designed to sustain a high removal rate for suspended sediment. While initial removal rates for suspended sediment are very high, the removal process causes clogging of the pavement and subsequently reduces its infiltration capacity. As the infiltration capacity decreases, so does the capture and treatment of runoff pollutants. Careful attention to maintenance is necessary to reduce the potential for clogging. In addition, all adjacent areas should be stabilized to prevent sediment from washing onto the pavement surface to prevent premature clogging. Hossain and Scofield (1991) found that a test section of porous pavement performed satisfactorily over five years. Although a slight decrease in the infiltration rate occurred, both the infiltration rate and storage capacity were above design values. Typical removal rates based on load reductions observed are summarized in Table 17.

Table 17. Pollutant removal effectiveness for porous pavement (%)

Study	TSS[2]	TP	TN	NO_3	Metals	Comments
MWCOG (1983)	95	60	88	-	99	Rainfall
Hogland et al. (1987)	95	71	-305[1]	-1607[1]	33-96	Snowmelt

[1] Prior agricultural land use in the area.
[2] High loadings of TSS significantly reduce the life expectancy of porous pavement BMPs.

Siting and Design Considerations

Suitable sites for porous pavements are generally limited to low-traffic areas with a minimum soil infiltration capacity of 7 mm/h (0.27 in/h) (greater than 13 mm/h (0.5 in/h) is preferred). Geotechnical testing of potential installation locations is needed to quantify the infiltration capacity. In siting porous pavement, groundwater contamination can be minimized by ensuring that the depth to the seasonally high water tables is at least 1.2 m (4 ft) below the reservoir layer and that installations are no closer to drinking water wells than 30 m (100 ft). Sites that are probable sources of high contaminant loads, such as gas stations, should be avoided.

Porous pavement installations should also be 30 m (100 ft) upgradient and 3 m (10 ft) downgradient of building foundations. More detailed guidelines for the siting of porous pavements and related design specifications can be found in Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996), and A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone (Schueler et al., 1992). Additional information on existing designs and their effectiveness is available in Stormwater Infiltration (Furgerson, 1994).

The design considerations for porous pavement should be consistent with the concepts of flexible pavement design. These requirements, summarized by Rollings and Rollings (1993), include:

- The use of sufficient pavement thickness to protect the subgrade from being overstressed.
- The use of quality base and subbase materials that can support the applied loads.
- A stable surface that serves as the wearing course for traffic.
- The compaction of all materials to provide strength and to resist densification under traffic.

Standard cross section designs typical of those for porous asphalt and modular paving stones are shown in Figures 28 and 29, respectively.

Figure 28. Schematic of typical porous pavement section (Young et al., 1996)

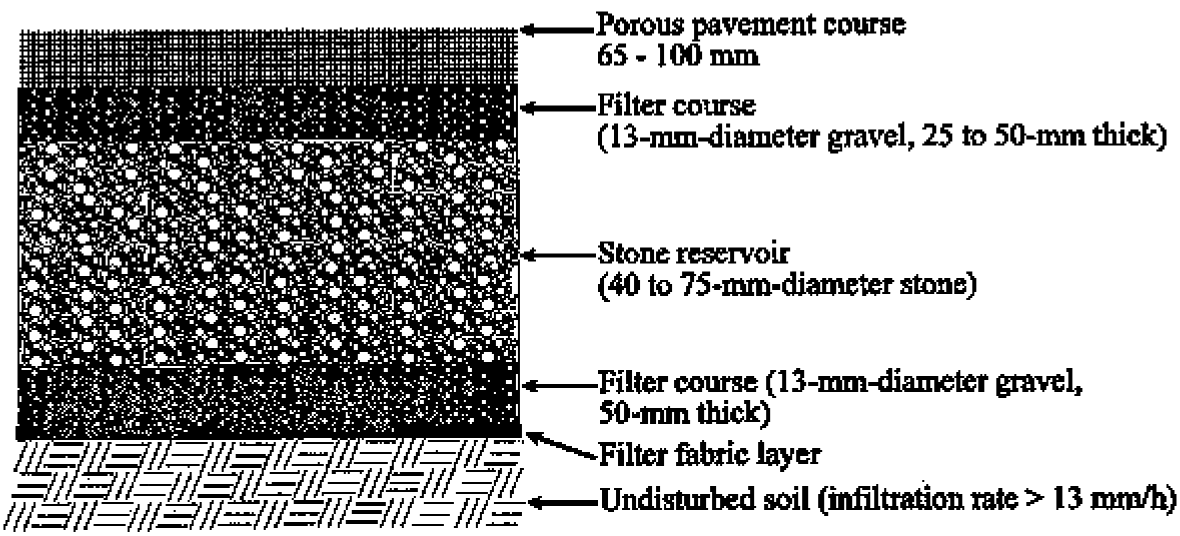
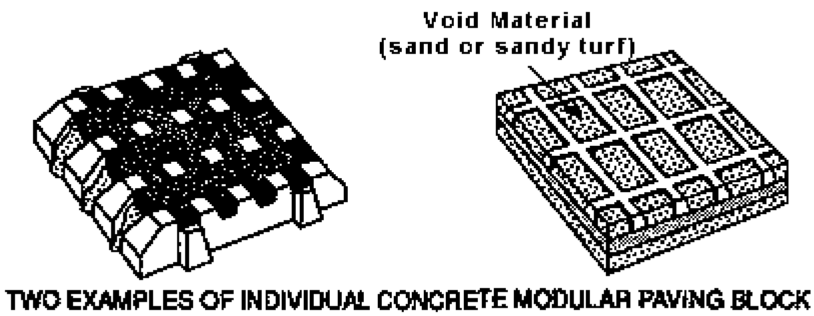
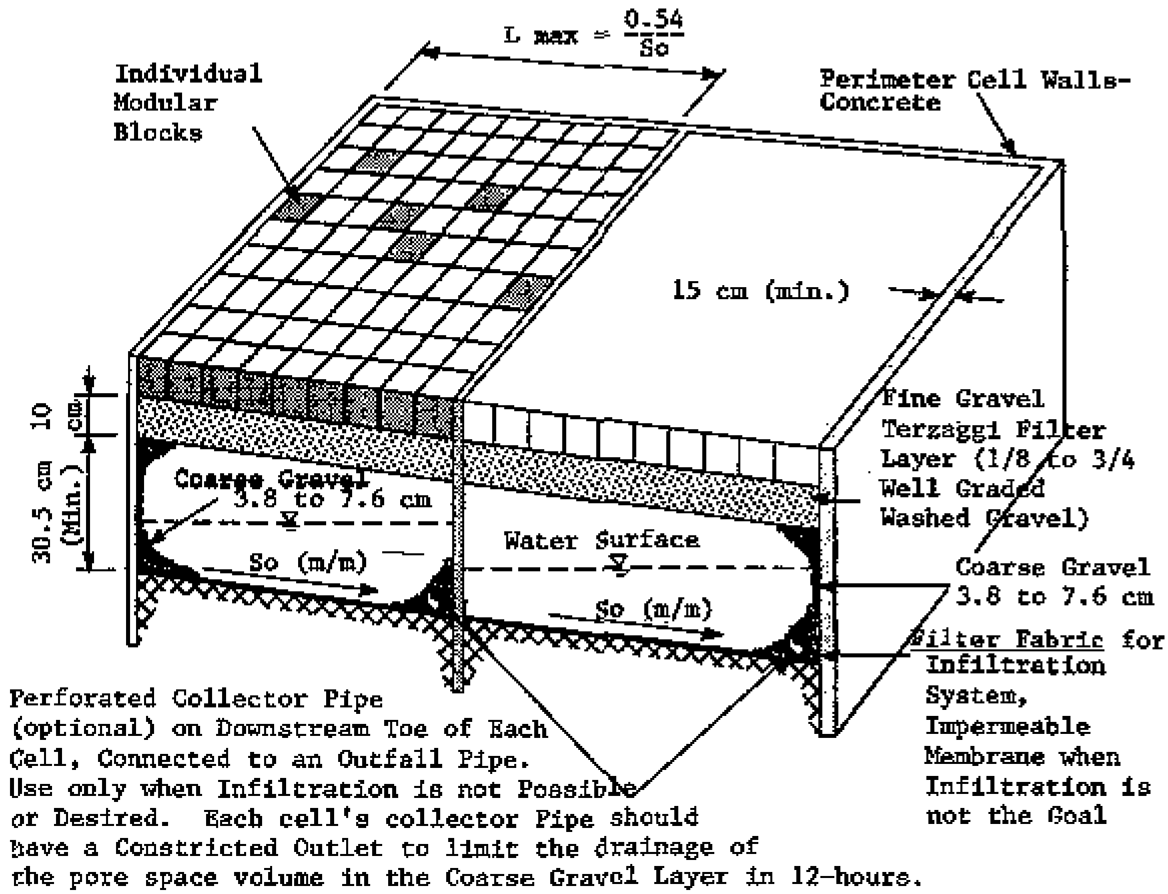


Figure 29. Modular block porous pavement
(adapted from Urban drainage and Flood Control District, 1992)





PERSPECTIVE OF SIDE-BY-SIDE MODULAR BLOCK CELLS

Porous pavements using lattice-type pavers or hollow concrete blocks and paving stones have similar construction details. Paving stones, however, can generally be designed to have a much higher load-bearing capacity and therefore have more widespread applicability. Detailed construction information and specifications are generally available from the manufacturers of these products (Florida Concrete and Products Association, 1989; Rollings and Rollings, 1993).

Based on construction experience, Cahill (undated) recommends the inclusion of a perimeter stone filter inlet around the edges of porous pavement installations as a reliable means of ensuring that runoff enters the stone filter reservoir if surface clogging of the pavement occurs. In addition, when specifying the pavement or paver stones it is important to ensure the surface infiltration rate is greater than the peak design rainfall intensity. One source gives this peak design rainfall intensity as the 1-h, 2-year rainfall (Young et al., 1996).

Maintenance Considerations

To maintain the infiltrative capacity of porous pavements such as asphalt, quarterly vacuum sweeping in conjunction with jet hosing or jet hosing alone is recommended (Schueler et al., 1992). Therefore, the installation of porous pavement BMPs in regions that lack the equipment or resources for routine maintenance is not recommended; a high failure rate for porous asphalt installations in Maryland is attributed in part to a lack of routine maintenance (Lindsey et al., 1991). Failures at sites in the Middle Atlantic states have also been attributed to poor site conditions and installation practices (Cahill, undated). In contrast, unmaintained parking areas constructed in 1985 with concrete block pavers had retained an infiltration capacity in excess of 100 mm/h (4 in/h) when inspected in 1994 (Pratt et al., 1995). Pratt et al. (1995) estimated the useful life of these types of permeable surfaces to be between 15 and 20 years. Since paving stones can be lifted and reused, the repair or reconstruction of these surfaces is also expected to be less than that associated with porous asphalt or concrete.

When modular pavements incorporate turf into their void area, normal turf maintenance practices, including watering, fertilization, and mowing might be required (WDOE, 1992). Mowing is not usually necessary in high-traffic areas. In regions were rainfall is infrequent, provisions for watering are required.

Cost Considerations

Costs for porous asphalt are approximately 10 to 15 percent higher than those for regular asphalt; porous concrete is about 25 percent more expensive than regular concrete. Requirements for site preparation or the use of specialized equipment may also increase these costs. The use of modular paving stones can be up to four times as expensive as either regular asphalt or concrete. The higher costs of installation of porous pavements can be offset to some extent by the elimination of curbs, gutters, and storm drains. In some cases this may lower the overall cost for a project (Field et al., 1982). The final economics associated with a particular site are also affected by site-specific conditions, such in situ permeability, and the cost and proximity of gravel supplies.

References

Cahill, T.H. Undated. A Second Look at Porous Pavement/Underground Recharge. Technical Note 21. Technical Notes - Urban Best Management Practices. Cahill Associates, West Chester, PA.

Field, R., H. Masters, and M. Singer. 1982. Porous Pavement: Research; Development; and Demonstration. Transportation Engineering Journal of ASCE, Vol. 108, No. TE3.

Florida Concrete and Products Association. 1989. Pervious Pavement Manual.

Furgerson, B.K. 1994. Stormwater Infiltration. Lewis Publishers, Ann Arbor, MI.

Hossain, M., and L.A. Scofield. 1991. Porous Pavement for Control of Highway Run-off. Final Report. FHWA-AZ91-352. Prepared by Arizona Transportation Research Center, Phoenix, AZ.

Hogland, W., J. Niemczynowice, and T. Wahlan. 1987. The Unit Superstructure during the Construction Period. The Science of the Total Environment (59):411-424.

Lindsey, G., L. Roberts, and W. Page. 1991. Stormwater Management Infiltration Practices in Maryland: A Second Survey. Maryland Department of the Environment, Baltimore, MD.

Metropolitan Washington Council of Governments (MWCOG). 1983. Urban Runoff in the Washington Metropolitan Area: Final Report, Urban Runoff Project, EPA Nationwide Urban Runoff Program. Metropolitan Washington Council of Governments, Washington, DC.

Pratt, C.J., J.D.G. Mantle, and P. A. Schofield. 1995. UK Research into the Performance of Permeable Pavement, Reservoir Structures in Controlling Stormwater Discharge Quantity and Quality. Wat. Sci. Tech., 33(1):63-69.

Rollings, R.S., and M.P. Rollings. 1993. Design Considerations for the Uni Eco-Stone® Concrete Paver. Uni-Group, Palm Beach Gardens, FL.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. 1992. A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, D.C.

Stotz, G., and K. Krauth. 1994. The Pollution of Effluents from Pervious Pavements of an Experimental Highway Section: First Results. The Science of the Total Environment (146/147):465-470.

WDOE. 1992. Stormwater Management Manual for the Puget Sound Basin (The Technical Manual). Washington State Department of Ecology, Seattle, WA.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Street Sweepers

Streetsweeping is an effective ultra-urban best management practice for reducing total suspended solids and associated pollutant washoff from urban streets. Recent studies have found that streetsweeping programs using equipment based on new technologies can significantly reduce pollutant washoff from urban streets, with potential reductions of up to 80 percent in annual total suspended solids and associated pollutants (Sutherland and Jelen, 1996).

Applicability

Streetsweeping is well suited to ultra-urban environments where little land is available for installation of structural controls. It should be considered in commercial business districts, industrial sites, and intensely developed areas in close proximity to receiving waters. For highway applications, streetsweeping may be considered for road shoulders, where safety permits, rest stop parking areas, or maintenance yards. The benefits of streetsweeping will be best realized by using the most sophisticated sweepers at a weekly to bimonthly frequency depending on local conditions, with a careful assessment of whether certain rules such as restricted street parking prior to and during sweeping can be enforced. Streetsweeping is not effective in removing oil and grease, and older conventional mechanical sweepers are limited in their ability to remove fine sediment.

Types of Street Sweepers

Mechanical sweepers employ a rotating gutter broom to remove particles from the street gutter area, with a water spray used to control dust. The particles removed are placed in the path of a cylindrical broom that rotates to carry the material onto a conveyor belt and into a storage hopper. This is the most widely used equipment for street cleaning in the United States.

Vacuum-assisted sweepers also use gutter brooms to remove particles from the street. However, the refuse is then placed in the path of a vacuum intake that transports the dirt to the hopper. The transported dirt is usually saturated with water. The overall efficiency of vacuum-assisted cleaners is generally higher than that of mechanical cleaners, especially for particles larger than the dust and dirt range (larger than about 3 mm).

Tandem sweeping operations involve two successive cleaning passes, first by a mechanical (broom and conveyor belt) sweeper, followed immediately by a vacuum-assisted sweeper.

Regenerative air sweepers blow air onto the pavement and immediately vacuum it back to entrain and capture accumulated sediments. Air is regenerated for blowing through a dust separation system. If the accumulated loading is not too great, regenerative air sweepers are generally considered effective for removing fine sediment (Sutherland and Jelen, 1996).

Vacuum-assisted dry sweepers combine the important elements of tandem sweeping into a single unit. These sweepers apply technology originally developed to remove spilled coal and coal dust from railroad tracks. The technology has also been applied to industrial sites where complete removal without leakage of particulate matter is important. The mechanical sweeping component in these sweepers is completely dry. A specialized rotating brush is used to scratch and loosen dirt and dust from impervious surfaces, allowing the vacuum system to recover practically all particulate matter. A continuous filtration system prevents very fine particulate matter from leaving the hopper, which prevents the formation of the dust trails typically seen with conventional mechanical sweepers.

Effectiveness

The effectiveness of streetsweeping programs depends on several factors, including:

Type and operation of equipment used: Vacuum-assisted and regenerative air sweepers are generally more efficient than mechanical sweepers at removing finer sediments, which often bind a higher proportion of heavy metals (Table 18). The performance of sweepers can be enhanced by operating them at optimal speeds (6 to 8 mi/h), ensuring that brushes are properly adjusted, and ensuring that appropriate rotation rates and sweeping patterns are used. Tests conducted on the newer vacuum-assisted dry sweepers have shown they have significantly enhanced capabilities to remove sediment compared to conventional sweepers, with projected reductions of up to 79 percent in total suspended solids loadings from urban streets. In addition, these sweepers are extremely effective at removing respirable (PM-10) particulate matter (particles with an aerodynamic diameter less than or equal to 10 microns) compared to conventional sweepers (Table 19) and are designed to help meet National Ambient Air Quality standards.

Table 18. Efficiencies of mechanical (broom) and vacuum-assisted sweepers

Constituent	Mechanical sweeper efficiency (%)	Vacuum-assisted sweeper efficiency (%)
Total Solids	55	93
Total Phosphorus	40	74
Total Nitrogen	42	77
COD	31	63
BOD	43	77
Lead	35	76
Zinc	47	85
Source: NVPDC (1992), as cited in Young et al. (1996).		

Table 19. PM-10 Particulate removal efficiencies for various sweepers

Sweeper type	Removal Efficiency (%)
Mechanical - Model 1	-6.7
Mechanical - Model 2	8.6
Regenerative Air	31.4
Vacuum-assisted wet - Model 1	40.0
Vacuum-assisted wet - Model 2	82.0
Vacuum-assisted dry	99.6

Sweeping frequency and number of passes: To achieve a 30 percent removal of street dirt, the sweeping interval should be less than two times the average interval between storms. To achieve 50 percent removal, sweeping must occur at least at least once between storms. Generally two passes per run should be conducted, which will result in the removal of up to 75 percent of total solids present before sweeping. Certain conditions may warrant increased sweeping frequencies. These include streets with high traffic volumes in industrial areas and streets with high litter or erosion zones. In addition, the sweeping frequency should be increased just before the wet season to remove sediments accumulated during the summer.

Climate: Sweeping appears most effective in areas with distinct wet and dry seasons (CDM et al., 1993).

Factors that limit the overall effectiveness of streetsweeping programs include:

- Presence of parked cars and traffic congestion during sweeping.
- Poor road surface and curb conditions.
- Presence of construction projects nearby.

Considerations for Equipment Selection

The selection of the type of sweeper will depend on specific conditions prevailing at sites targeted for sweeping. In general, mechanical sweepers are more effective at picking up large debris and cleaning wet streets and have lower capital and operating costs. However, mechanical sweepers can create large amounts of airborne dust. Vacuum-assisted and regenerative air sweepers are more effective at removing fine particles and associated heavy metals but tend to be ineffective at cleaning wet streets. They may also be noisier than mechanical sweepers, which can restrict the hours of operation in some areas. It may also be necessary to deploy a mechanical sweeper ahead of vacuum-assisted sweepers to remove large debris.

The somewhat larger capital costs associated with the newer vacuum-assisted dry sweepers may be warranted for areas where worker and public safety from respirable particulate matter is of concern. Vacuum-assisted sweepers are capable of providing close to 100 percent removal of PM-10 particulates and also provide better overall removal of sediment.

Maintenance and Operational Requirements

The overall maintenance requirements for mechanical sweepers are greater than those for vacuum-assisted and regenerative air sweepers since mechanical sweepers contain more moving parts that require periodic replacement. Vacuum-assisted dry sweepers have significantly less down time than water-based sweepers (less than 10 percent of total operating time compared to about 50 percent for water-based sweepers) because they require no water loading. In addition, clean-up and dumping times are shorter.

For an effective streetsweeping program, consideration should be given to the following operational requirements:

- Ensure there are adequately trained sweeper operators and maintenance personnel.
- Provide traffic control officers to enforce parking restrictions.
- Choose sweeping frequencies and cleaning routes to optimize overall sweeping efficiencies.
- Make appropriate arrangements for disposal of collected waste.
- Reduce source loadings through various measures such as public awareness of proper disposal procedures for used oil and yard waste, and enforcement of erosion control and stormwater pollution prevention practices at urban construction sites.

Cost Considerations

Conventional sweeper costs range from $69,000 to $127,000 (1995 dollars), with the higher end of this range associated with vacuum-assisted and regenerative air sweepers (CDM, 1993). The useful life span of these sweepers is generally four to seven years, and the operating cost associated with these sweepers about $70 per hour (1996 dollars; Finley, 1996). The capital cost of vacuum-assisted dry sweepers is on the order of $170,000 (1996 dollars; Enviro Whirl Technologies, personal communication, 1996) with a projected useful life span of about eight years and operating costs of approximately $35 per hour (Satterfield, 1996 dollars).

References

Camp Dresser & McKee (CDM), Larry Walker Associates, Uribe and Associates, and Resources Planning Associates. 1993. California Stormwater Best Management Practice Municipal Handbook. BMP: Street Cleaning, pp. 4-64 to 4-66.

Enviro Whirl Technologies, Inc. 1996. Product literature. Enviro Whirl Technologies, Inc., Centralia, IL.

Finley, S. 1996. Sweeping Works. Pavement Maintenance and Reconstruction. October/November, pp. 16-17.

NVPDC. 1992. Northern Virginia BMP Handbook: A Guide to Planning and Designing Best Management Practices in Northern Virginia. Prepared by Northern Virginia Planning District Commission (NVPDC) and Engineers and Surveyors Institute.

Satterfield, C. 1996. Enviro Whirl I PM-10 Efficiency Study Removing Reentrained Road Dust. Prepared for Enviro Whirl Technologies Inc. by Satterfield & Associates, June Lake, CA.

Sutherland, R.C., and S.L. Jelen. 1996. Studies Show Sweeping has Beneficial Impact on Stormwater Quality. APWA Reporter (November):8-23.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

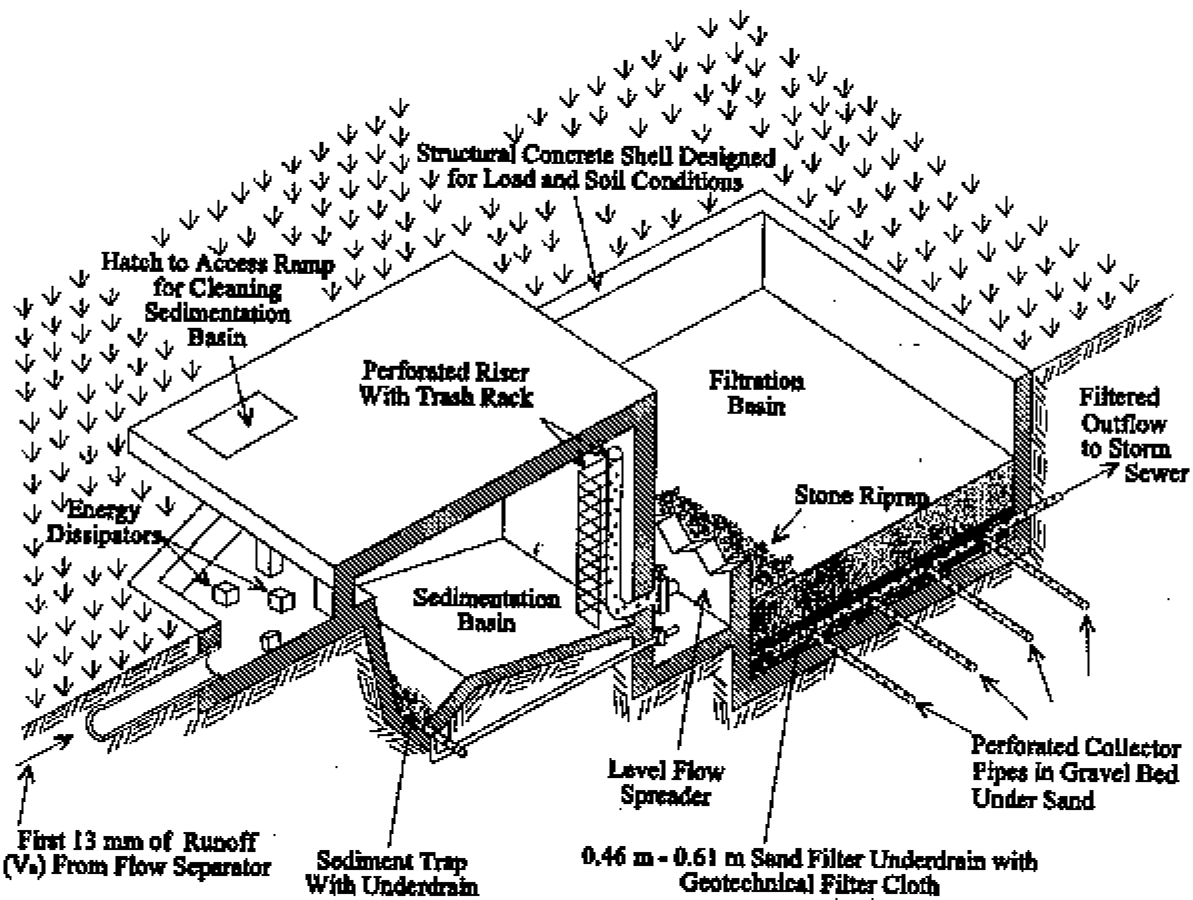
Previous Table of Contents Next

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Surface Sand Filters

The surface sand filter has been employed since the early 1980s to provide stormwater quality management. One of the forerunners in developing the surface sand filter design has been the City of Austin, Texas. As shown in Figure 14, the Austin design consists of a bypass chamber, a sedimentation chamber that provides pretreatment, a flow distribution cell, and a sand filter bed. The design illustrated shows many of the features common to surface sand filters. Typically, the filter bed has a 450 to 600 mm (18 to 24 in) deep sand layer that traps or strains pollutants before runoff is collected in an underdrain system (gravel and perforated pipe) and conveyed to a discharge point.

Figure 14. Austin sand filter with full sedimentation protection (Young et al., 1996)



A bypass chamber is used to protect the BMP from high inflows, diverting any flow in excess of the capacity of the structure. This works with the sedimentation cell(s) to prevent high loads of coarse sediment from entering the filter bed. While the design illustrated in Figure 14 consists of concrete structures/walls, earthen walls backed with geomembranes and riprap sections can be substituted in the basic design. In terms of drainage area, the Austin design has been successfully employed for drainage areas ranging from 0.4 to 40.5 ha (1 to 100 ac).

Surface sand filters are very well suited to managing the first flush volume, which typically contains the highest concentration of pollutants. However, the design is poorly suited to providing stormwater quantity management to prevent flooding because high flows can easily damage the filter bed. As a result, it is strongly recommended that the design be installed in an off-line configuration.

The Austin filter works by a combination of sedimentation, filtration, and adsorption. The sedimentation section located just upstream of the filter section serves as pretreatment, removing larger-diameter suspended solids. Partially treated stormwater then flows slowly into the filter section, where fine-grain material is strained from the stormwater as it passes through the filter medium. The sand medium filter traps up to 90 percent of the small particles in stormwater runoff (6 to 41 microns) if a 460 mm (18 in) layer of sand is used. However, the extent of adsorption by sand of some dissolved pollutants is relatively small when compared to other filter media. For example, sand medium adsorbs much less positively charged dissolved metals and hydrocarbons than either soil or peat medium primarily due to its relatively low cation exchange capacity (CEC); sand has a CEC that is 13 percent that of the soil medium and 0.002 percent of the peat medium.

Applicability

Although it has been applied within an urban setting, the Austin sand filter may require a significant commitment of land area (generally between two and seven percent of the drainage area). Consequently, many of the installations within the City of Austin are in newer, less densely developed portions of the municipality. Within an ultra-urban setting this design might be restrictive requiring a completely subsurface BMP (see underground sand filter design in the Underground Sand Filters Fact Sheet).

The applicability of surface sand filters to roadway projects has been demonstrated. For example, the Texas Department of Transportation has designed and/or installed Austin sand filters to provide stormwater management for several large highway projects. Overall, the design provides dependable performance and can be designed so it does not pose an additional safety hazard for automotive traffic.

Effectiveness

The Austin sand filter design has demonstrated good total suspended solids (TSS) removals, typically providing 85 percent treatment. Performance for nutrients is less significant, and in fact the sand filter may be a source of nitrate (NO_3) since ammonia in stormwater will undergo nitrification in the aerobic filter. However, sand filters are reported to decrease the total nitrogen (TN) load by approximately 35 percent. Total phosphorus (TP) removals range up to 55 percent, and there is a wide variation in metal removal rates (ranging between 35 and 90 percent). Removal of oil and grease by sand filters has been reported to average between 55 and 84 percent (Horner and Horner, 1995). Reduction in fecal coliform bacteria ranges between 40 and 80 percent.

The bulk of Austin sand filter designs have been in a warmer climate (central Texas) and reported removal rates probably reflect this influence (see Table 13). The filter performance would probably decrease if exposed to prolonged cold periods, which freeze the filter media. However, in a recent application of a sand filter in Alexandria, Virginia, it was reported that the filter operated effectively immediately after an arctic freeze even with several inches of frozen runoff in the settling area (Bell et al., 1995).

With the integration of a sedimentation chamber, the design provides pretreatment for the filter. However, where high loadings of oil or grease are encountered, additional pretreatment measures, such as grassed swales or vegetated filter strips are advisable.

Table 13. Pollutant removal effectiveness for surface sand filters (%)

Study	TSS	TP	TN	NO_3	Metals	Comments
City of Austin (1990)	75	59	44	-13	34-82	Lead and zinc removal high; copper removal low
City of Austin (1990)	92	80	71	23	84-91	
City of Austin (1990)	87	61	32	-79	60-81	
Welborn & Veenhuis (1987)	78	27	27	-111	33-60	

Siting and Design Considerations

Various design approaches can be taken in designing surface sand filters, including those developed in Austin. Design differences tend to be found in the size of the sedimentation area, the duration of sedimentation, and the loading rate of the filter media. For practicality, most designs limit the maximum water depth in the facility to less than 2.4 m (8 ft) and drain the system by gravity.

There are two basic designs for the Austin surface sand filter that manage the first 12.7 mm (0.5 in) of runoff, a partial sedimentation design and a full sedimentation design. The designs differ in terms of the volume of the sedimentation chamber and the size of the filter area. A partial sedimentation design creates a smaller footprint than a full sedimentation design but typically requires more maintenance. The partial sedimentation design is intended for areas that are relatively flat sloped and requires sufficient sedimentation area to store 20 percent of the water quality volume. The partial sedimentation design requires 16.7 m^2 (180 ft^2) of filter area per impervious acre. The full sedimentation design provides sufficient sedimentation area to store the entire water quality volume (100 percent), a volume that is subsequently released to the filter bed over a 24-hour period. The full sedimentation design requires 9.3 m^2 (100 ft^2) of area per impervious acre (assuming a permeability of the sand medium of 1 m/day [3.5 ft/day]). More extensive information regarding the design process used for the Austin sand filter should be acquired directly from the City of Austin's Environmental Criteria Manual (City of Austin, 1991).

There are also other approaches to surface sand filter designs that can be considered. One general rule of thumb is the required sedimentation area in square meters should be equal to 0.020 times the water quality volume in cubic meters (0.066 for area in square feet and volume in cubic feet) for drainage areas with an imperviousness of less than 75 percent (Claytor and Schueler, 1996). For areas with imperviousness greater than 75 percent, the sedimentation area commitment is 0.0024 times the water quality volume (0.0081 for area in square feet and volume in cubic feet). These recommendations recognize that ultra-urban runoff typically contains a high percentage of large-diameter sediment particles and therefore the settling area can be decreased (Shaver, 1994). When using this design approach, the recommended length-to-width ratio of the settling chamber is 2:1 or greater to limit short-circuiting, and the minimum recommended water depth in the settling chamber is 0.92 m (3 ft). This design approach also calls for the total storage volume in the sedimentation chamber and filter chamber to be equal to 75 percent of the water quality volume. At least half of the total storage volume should be located in the sedimentation chamber. The facility storage volume calculation should include void storage in the sand medium (typical porosity between 30 and 40 percent). In sizing the filter area it is recommended that a drawdown time of 40 hours be used and that the total depth of sand medium not exceed 0.61 m (2 ft). More information regarding this design approach can be found in Design of Stormwater Filtering Systems (Claytor and Schueler, 1996).

It should be noted that for any of the surface filter designs it is possible to substitute filter media other than sand. Refer to the Organic Media Filters Fact Sheet for additional information on organic media filters (peat/sand and compost media) and their advantages and disadvantages. Although over 500 Austin sand filters are currently operating, it is not known how long the basic design will last. Given the relatively low level technology typically employed, it seems reasonable to assume an effective life between 25 and 50 years with regular maintenance.

Maintenance Considerations

In general, the recommended frequency for performance monitoring is at least once per year. Each inspection should log information on the depth and location of any ponding, the depth of discoloration in the filter bed, and the depth of accumulated material over the sand media.

Most filters exhibit diminished capacity after a few years due to surface clogging by organic matter, fine silts, and hydrocarbons. Restoration of the original filtration capacity includes manual removal of any accumulated material and the first several inches of discolored sand. New sand is placed to reestablish the design grade of the filter medium. From a review of numerous references, it appears the material (sand/silt) accumulates in most sand filters at a rate between 13 to 25 mm/yr (0.5 to 1 in/yr). Maintenance can be reduced by employing surface sand filters only in drainage areas with 100 percent imperviousness. This significantly reduces the fine-grain material reaching the filter (silt and clay) which can clog the filter bed (Schueler, 1995). In areas with high trash loading, a wide-mesh geotextile screen can be placed over portions of the filter surface to simplify removal of the debris.

Regarding specific maintenance issues for the Austin sand filter design, the partial sedimentation design requires more frequent maintenance of the filter bed because there is less settling of solids in the sedimentation chamber. This tends to lead to greater sediment loads entering the filter bed than is experienced for full sedimentation designs (Young et al., 1996). Greater sediment loads translate into higher maintenance costs because more frequent replacement of the sand media will be required.

Cost Considerations

The surface sand filter design is a moderately expensive BMP to employ (Claytor and Schueler, 1996). However, the cost of installation is strongly correlated with the nature of the construction employed. If the filter is installed within an ultra-urban setting, it is likely that relatively expensive concrete walls will be used to create the various chambers. This type of installation will be significantly more expensive than an earthen-walled design, where relatively inexpensive excavation and compaction construction techniques lower the installation cost. However, earthen-wall designs require a greater land area commitment, which can offset the reduction in construction costs.

The construction cost of surface sand filters is also related to economies of scale-the cost per impervious hectare or acre served decreases with an increase in the service area. In 1994, the construction costs for Austin sand filters were $39,500 per impervious hectare (or $16,000 per impervious acre) for facilities serving less than two acres and $8,400 per impervious hectare (or $3,400 per impervious acre) for facilities serving greater than five acres (Schueler, 1994). These construction cost estimates exclude real estate, design, and contingency costs. (Note that these unit cost values should be used for conceptual cost estimating purposes only.)

References

Bell, W., L. Stokes, L.J. Gavan, and T.N. Nguyen. 1995. Assessment of the Pollutant Removal Efficiencies of Delaware Sand Filter BMPs. City of Alexandria, Department of Transportation and Environmental Services, Alexandria, VA.

City of Austin. 1991. Water Quality Management: Environmental Criteria Manual. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, TX.

City of Austin. 1990. Removal Efficiencies of Stormwater Control Structures. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, TX.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Horner, R.R., and C.R. Horner. 1995. Design, Construction, and Evaluation of a Sand Filter Stormwater Treatment System. Part II. Performance Monitoring. Report to Alaska Marine Lines, Seattle, WA.

Schueler, T.R. 1994. Developments in Sand Filter Technology to Improve Stormwater Runoff Quality. Watershed Protection Techniques 1(2):47-54.

Schueler, T.R. 1995. Performance of Delaware Sand Filter Assessed. Watershed Protection Techniques 2(1)291-293.

Shaver, E. 1994. Sand Filter Design for Water Quality Treatment. Proceedings of the Urban Runoff and Receiving Systems Conference, ed. E. Herricks. ASCE, New York, NY.

Welborn, C., and J. Veenhuis. 1987. Effects of Runoff Control on the Quality and Quantity of Urban Runoff in Two Locations in Austin, TX. USGS Water Resources Investigations Report. 87-4004.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

Previous Table of Contents Next

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Underground Sand Filters

The underground sand filter typically consists of a multi-chamber underground vault accessible by access holes or grate openings. Multiple configurations have been developed for underground sand filters including the D.C. filter design (Figure 12) and the Delaware filter design (Figure 13). The D.C. design is intended to treat flow conveyed by a storm drain, and can be retrofitted within existing systems. The Delaware filter design is intended to collect flow directly from an impervious area and is well suited to placement along parking areas. While their deployments may differ, both of these designs operate in basically the same manner.

Figure 12. Original D.C. underground sand filter system (Young et al., 1996)

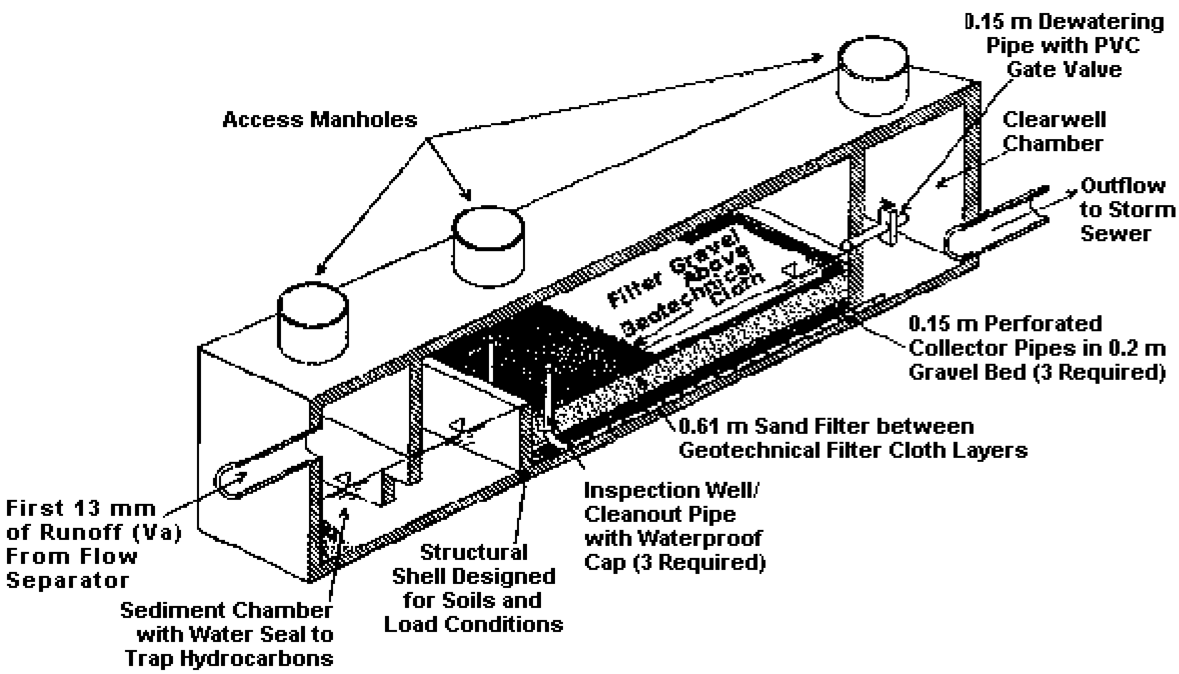
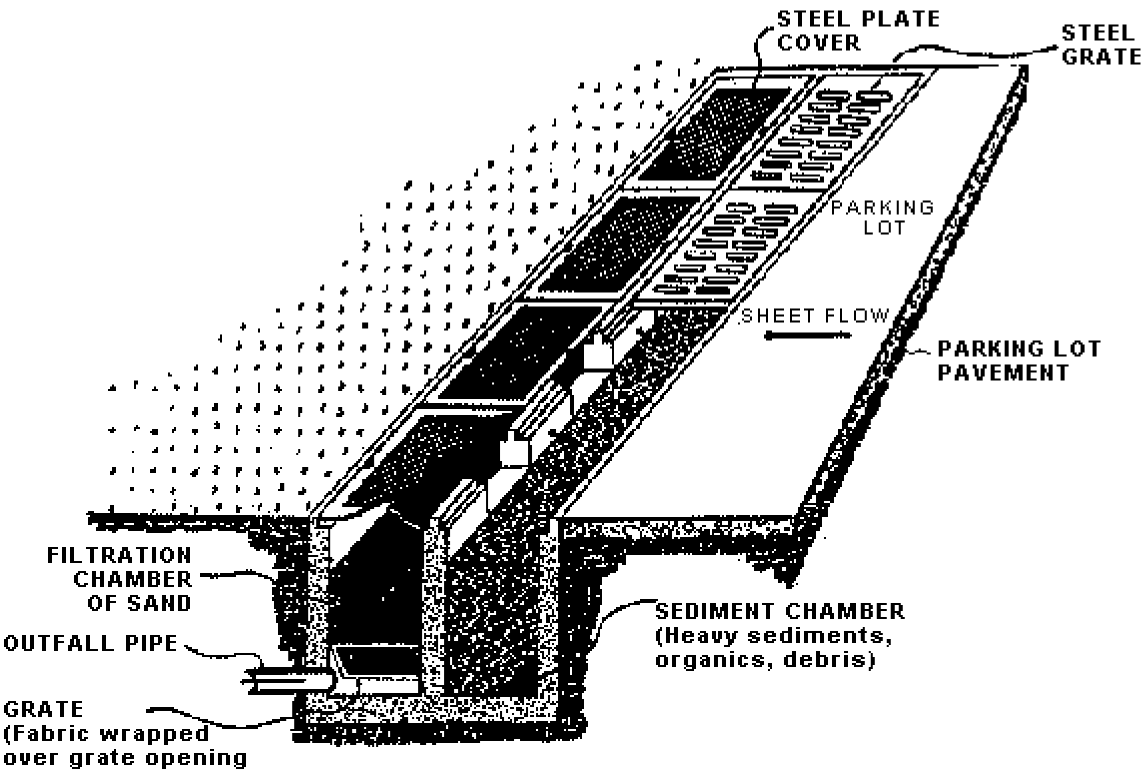


Figure 13. Delaware sand filter with grated inlets (Bell et al., 1995)



During a storm, the water quality volume is temporarily stored in an underground chamber(s) that provides for pretreatment by settling. Over time the stored volume flows by gravity into a filter chamber where it moves through the sand filter. Filtered runoff is collected in underdrains and is then discharged into an adjacent storm drain or natural channel. During large rainfall events any flow in excess of the filter's capacity is diverted around the sand filter by means of an overflow weir.

The underground sand filter works by a combination of sedimentation and filtration. The sedimentation section serves as a pretreatment measure by removing larger diameter suspended solids and capturing floating hydrocarbons. If the filter consists of a 45.7 cm (18 in) layer of sand the filter will trap up to 90 percent of the small particles in stormwater runoff (diameters between 6 to 41 microns). A lower level of removal will occur for any dissolved pollutants because the sand medium adsorbs relatively small amounts of positively charged dissolved materials. For example, sand has a cation exchange capacity that is 13 percent that of soil and 0.002 percent that of peat. This means it is less effective in filtering and removing dissolved metals and hydrocarbons.

Often the intended use of sand filter BMPs is to manage the first flush, which typically contains the highest concentration of pollutants. If designed as an off-line facility, however, it can provide true capture and treatment of any water quality volume. However, designers should note that it is relatively expensive to install large structures (e.g., concrete vaults) below grade and between any existing subsurface utilities.

In summary, the underground sand filter is well adapted for applications with limited land area and provides turnkey performance that is independent of local soil conditions, groundwater levels, and other factors. It is most useful where multiple uses of land area are required (i.e., where committed land area is to be used for automobile parking or for public parks).

Applicability

The underground sand filter is considered to be highly applicable to the ultra-urban setting. It requires a small commitment of land area, provides dependable service, and is relatively effective at urban pollutant removal. Its design is inherently flexible; the size and shape of the unit can be set based on local constraints. Because the unit is below grade, it is safe for application in public areas and is relatively vandal-proof. For roadside applications, it can be placed adjacent to roadways without imposing a safety hazard and can function satisfactorily in the area below elevated roadways or ramps. The effective life of a typical, maintained underground sand filter is 5 to 20 years.

If there is a disadvantage associated with underground sand filters, it is the relative expense of construction compared to surface BMPs like detention ponds. However, recognizing the premium for space in the ultra-urban environment, the underground filter is actually cost-effective and sometimes may be the only feasible alternative.

Effectiveness

Underground sand filters can be designed to effectively treat a range of target water quality volumes (e.g., the first 12.7 mm [0.5 in] runoff of a storm). The design water quality volume may be established by available space constraints, hydraulic conditions, or by local stormwater ordinances. Performance of this BMP is not greatly affected by climate since its subsurface placement will be below the frost line in most locations, limiting freezing of the filter. In addition, the level of treatment is generally independent of placement and on-site soil conditions do not affect performance. For larger-than-design events, underground sand filters (on-line and off-line) will only provide partial treatment. Pretreatment options such as streetsweeping or catch basins remove trash and accumulated sand from roadway sanding, both of which diminish a filter's operational performance and increase maintenance requirements.

The underground sand filter has demonstrated good total suspended solids (TSS) removals, typically providing 85 percent treatment. Effectiveness for nutrient removal is low, and in fact the sand filter may be a source of nitrate (NO_3) since ammonia in stormwater will undergo nitrification in an aerobic filter environment. Trace metal removal rates range from between 65 and 95 percent. Removal of oil and grease averages about 80 percent with influent concentrations of 20 ppm and below. Reductions in fecal coliform bacteria range from between 40 and 80 percent. See Table 12 for additional information on the effectiveness of underground sand filters.

The sand filter is most effective in managing suspended solids but has questionable benefit where downstream conditions are sensitive to loadings of nitrogen or where high loadings of hydrocarbon pollutants are expected. Anions such as chloride from salted roadways are not removed during sand filtration.

Table 12. Pollutant removal effectiveness for underground sand filters (%)

Study	TSS	TP	TKN	NO_3	Metals	Bacteria	Comments
Bell et al., 1995	79	65	NA	(-53)	25-91	NA	Delaware sand filter
Horner and Horner, 1995	< 81	43-60	NA	NA	22-66	NA	Delaware sand filter; oil and grease removal at >80%

Siting and Design Considerations

The flexible design of an underground sand filter permits a variety of applications. A first test of the feasibility of an application can be based on the space requirements for 12.7 mm (0.5 in) of runoff from an impervious area of 0.4 ha (1 ac). Using an assumed storage depth of 0.9 m (3 ft), the surface area requirement for a sand filter is approximately 14 m^2 (150 ft^2) for the sediment chamber and 18.6 m^2 (200 ft^2) for the sand filter area. More detailed design information can be found in Design of Stormwater Filtering Systems (Claytor and Schueler, 1996) and Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996).

In the final design the key components are the sedimentation chamber that is usually a 0.92 m (3 ft) permanent pool depth and the filter bed that is typically 45.7 to 61 cm (18 to 24 in) deep. A maximum residence time of 40 hours is generally applied to ensure the sand filter drains prior to subsequent rainfall events. The total hydraulic drop from inlet to outlet should be between 1.5 and 2.4 m (5 and 8 ft) to reduce the potential for backwater flow into the sand filter from the downstream outlet. If the filter discharges to an existing storm drain, it is recommended that the underdrain outlet pipe drain into the top half of the downstream storm drain. The main collector pipe should be constructed with a minimum slope of 0.5 percent, and observation/inspection ports and cleanouts must be incorporated for all pipes. Access must be provided to all chambers in the design, and the design must conform to standards established by OSHA for worker safety.

Underground sand filters consist of precast or cast-in-place concrete vaults and can be installed as on-line or off-line facilities. Off-line applications are generally simpler to design because a high-flow bypass is not required and there is less potential for backwater flow entering the facility. During construction no runoff should enter the sand filter bed until the upstream drainage area is completely stabilized and site construction is completed. If practical, a sedimentation basin may serve as a temporary sediment control basin during site construction with the provision that overflows will bypass the filter bed. It is recommended that underground sand filters located in areas with sensitive groundwater aquifers be tested for water tightness prior to placement of the filter layers.

Maintenance Considerations

The recommended frequency for performance monitoring is four times per year. Each inspection should log information on the depth of ponding and oil and grease in the first chamber, the depth of water over the sand medium, and the accumulation of material over the sand medium. Any standing water over the sand medium 40 hours after the cessation of rainfall is indicative of clogging. Silt accumulation of more than 12.7 mm (0.5 in) indicates the need for replacement of the top layer or all of the sand medium. Typical sand media replacement intervals are from one to three years (Claytor and Schueler, 1996).

The sand filter design can be modified to minimize the effort associated with maintenance. For example, incorporating a plastic filter cloth covered with a gravel layer (ballast) on top of the sand medium creates a sacrificial layer that can be easily replaced when clogging occurs.

Currently, there are limited data on the expected maintenance costs associated with subsurface sand filters. A Washington, D.C., underground sand filter serving a 0.4 ha (1 ac) area was serviced by removal and replacement of a gravel ballast and filter cloth, for $1300 in 1994 (Bell, 1996). Note that repair of subsurface sand filters requires confined space entry, which requires larger management crews, leading to higher repair costs.

Preparations must be made for disposing of fluids and sediment removed from underground sand filters. Captured fluids may have a high hydrocarbon fraction and require special handling, and if the sand filter medium is not regularly replaced pollutants such as metals may accumulate in the sediment to the point where their level is considered hazardous.

Cost Considerations

Underground sand filters are generally considered to be a high-cost BMP option for water quality management. In 1994, the construction cost per impervious hectare served was $24,700 to $34,600 (or $10,000 to $14,000 per impervious acre served), excluding real estate, design, and contingency costs (Schueler, 1994). (Note that this unit cost value should be used for conceptual cost estimating purposes only.) In ultra-urban areas where land costs are high, however, underground sand filters can represent significant cost savings in reduced land consumption. For small ultra-urban areas with no land available, they may be the only practical option for stormwater quality treatment as they can be placed under roads or parking lots.

At this time manufacturers are beginning to make available prefabricated units that include precast vaults and inlets delivered to the site either partially or fully assembled. These units will eventually result in a decrease in construction costs. Typical significant cost variables include the location of subsurface utilities; type of lids and doors; customizing casting of weirs, sections, or holes; and depth of the vault.

References

Bell, W. 1996. BMP Technologies for Ultra-Urban Settings. In Proceedings of Effective Land Management for Reduced Environmental Impact, Tidewater's Land Management Conference on Water Quality, August 22, 1996.

Bell, W., L. Stokes, L.J. Gavan, and T. Nguyen. 1995. Assessment of the Pollutant Removal Efficiencies of Delaware Sand Filter BMPs. City of Alexandria, Department of Transportation and Environmental Services, Alexandria, VA.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Horner, R.R., and C.R. Horner. 1995. Design, Construction, and Evaluation of a Sand Filter Stormwater Treatment System. Part II: Performance Monitoring. Report to Alaska Marine Lines, Seattle, WA.

Schueler, T.R. 1994. Developments in Sand Filter Technology to Improve Stormwater Runoff Quality. Watershed Protection Techniques 1(2):47-54.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

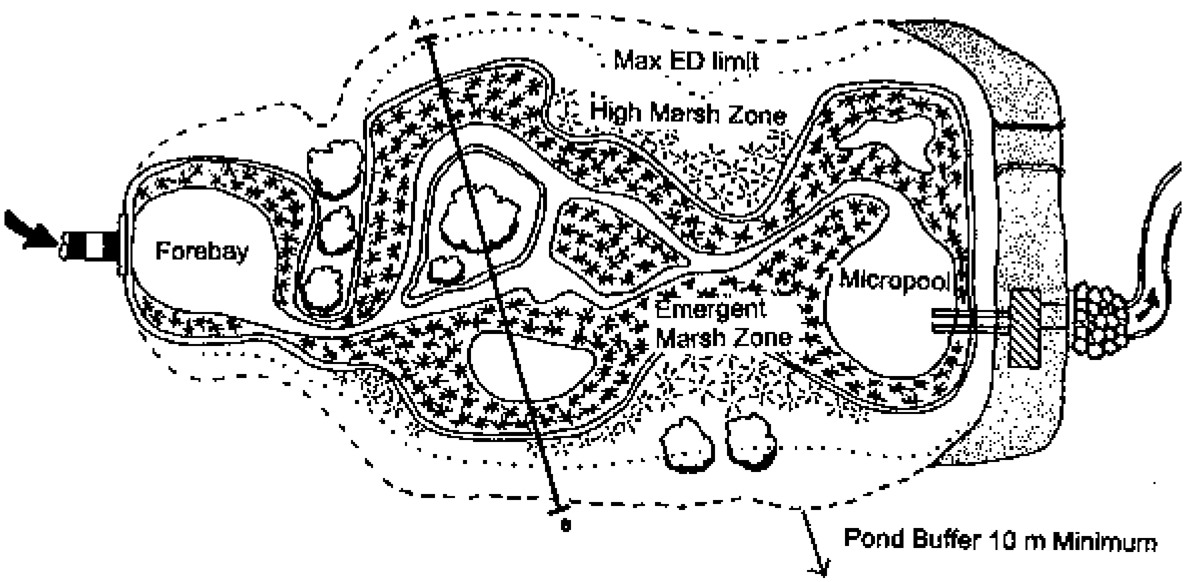
Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring

Fact Sheet - Wetlands and Shallow Marsh Systems

Wetlands and shallow marsh systems use the biological and naturally occurring chemical processes in water and plants to remove pollutants (ASCE, 1992). Oils, particulates, suspended sediment, and soluble nutrients are removed or settled out due to their residence time in the wetland system and before they enter the downstream receiving waters. Wetland and marsh systems can have additional stormwater features that help to attenuate peak storm flows. Figure 9 is an example of a shallow marsh system.

These systems can often have great habitat value. The fringe wetlands and deep water habitats provide shelter and breeding places for many species. Properly sited wetland systems can also be scenic assets along a highway corridor.

Figure 9. Schematic design of a shallow ED marsh system (adapted from Schueler, 1992)

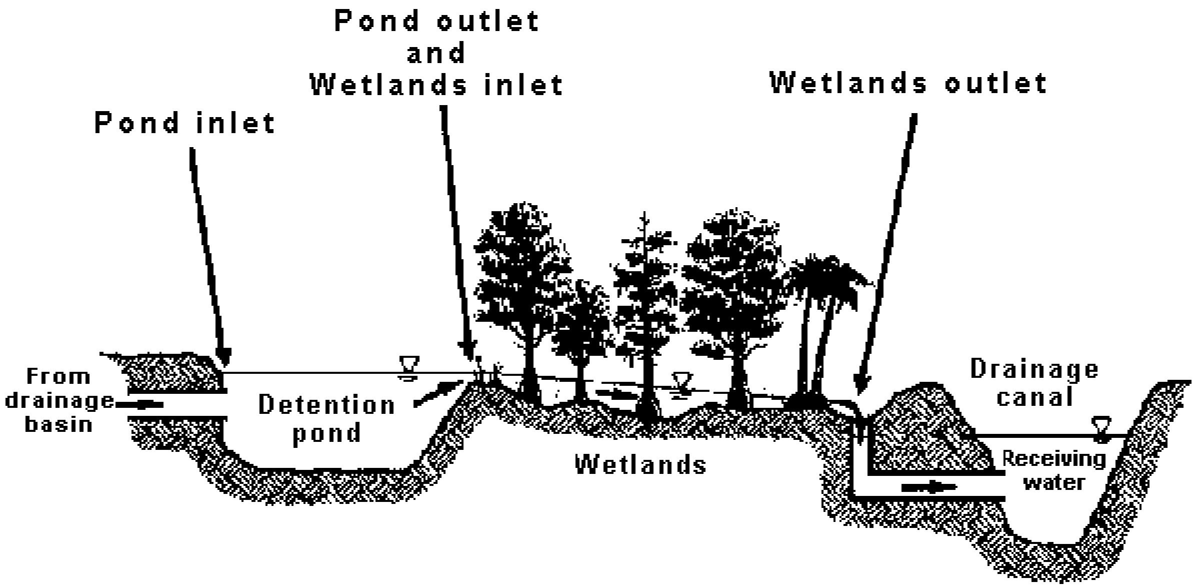


Applicability

Wetland and shallow marsh systems must be carefully sited to ensure that the desired functions for the system are established and maintained. In the ultra-urban environment the feasibility of wetland establishment may be limited due to factors such as drainage area or the absence of high groundwater tables. Due to these considerations, potential sites are most likely at low-lying interchanges or medians where runoff can be directed to them, or existing open areas such as parks, which provide additional aesthetic and educational benefits.Wetland and shallow marsh systems have habitat value and can be efficient at removing pollutants. Since these systems are frequently inundated, adequate safety measures such as safety benches, fences, guardrails, and safety zones must be provided.

Effectiveness

Figure 10. Movement of water through a detention pond-wetlands system (Martin and Smoot, 1986)



Properly designed wetland systems are extremely effective at removing soluble pollutants and particulates from ultra-urban stormwater runoff. Biological oxygen demand (BOD), chemical oxygen demand (COD), and metals are also significantly reduced. As the system ages and more algae and detritus are generated in the pond, the efficiency increases. When combined with extended detention, wetland BMPs may be one of the most effective systems to mitigate stormwater runoff impacts. Figure 10 illustrates the use of an extended detention pond as a pretreatment for a wetland system. Table 11 provides data from a study that monitored the pond and wetland system at the inlet and outlet to the wetland. Many of the suspended solids and some of the solubles were removed by the pretreatment in the detention facility (OWML, 1990). Average removal rates that can be expected from a stormwater wetland are 65 percent for total suspended solids (TSS), 25 percent for total phosphorus (TP), 20 percent for total nitrogen (TN), and 35 to 65 percent for metals (USEPA, 1993).

Table 11. Pollutant removal effectiveness for wetlands (%)

Study	TSS	TP	TN	NO_3	Lead	Zinc	Comments
Martin & Smoot (1986)	95	53	42	47	90	92	Pretreatment by in-line detention pond. Results are maximum removals for shallow wetland system only.
OWML, 1990	96	69	73	53	94	90	Results are maximum removals for pond and wetland system.

Siting and Design Considerations

Hydrology is likely to be the most important limiting factor in the feasibility of a wetland or marsh system for an ultra-urban area. Such facilities may be on-line or off-line. On-line facilities allow all stormwater flows to pass through the system. Off-line facilities divert higher flows, which may have erosive velocities or which would inundate the system. There must be a sufficient drainage area to maintain base flow in the system. Water budgets should be performed to determine the ability of the pond to maintain vegetation in dry months. Adequate water will help prevent the die-off of planted vegetation, which can prevent invasive species from taking hold. The groundwater elevation is also important since it helps maintain the hydrology. A ratio of watershed area to wetlands area of at least two percent is recommended to have efficient removal capabilities (Schueler, 1992). However, smaller systems could be used in ultra-urban settings.

The wetland system should be designed to have pockets of deeper water to help trap sediments and to provide a diverse habitat. The length of the wetland system and ratio of surface area to width are important pollutant removal factors. The flow length must be long enough to provide adequate residence time to remove soluble pollutants and sufficient settling time for particulates. A length-to-width ratio of 2:1 is recommended to achieve an adequate residence time.

Proper soil conditions are necessary for wetland success. The wetland site must have existing natural soil conditions that facilitate ponding, or these conditions must be created using clay, PVC, or other types of liners. In addition, wetland pollutant removal functions are mediated in part by the supply of organic material in the site.

Organic matter also affects the success of wetland plant establishment. Consequently, organic material must be incorporated into project soils if construction requirements necessitate removal of topsoil from the site.

Native plant species that are present in the area should be retained whenever possible. When planting a site is necessary, a diverse plant community of species native to the project area should be established to maximize wildlife and water quality benefits. Planting a variety of species increases the probability of establishing a vigorous plant community and reduces the chance of exotic species invasion into the site. A vegetative buffer strip included around the marsh or pond will reduce sediment inflow and provide additional pollutant filtration. Irregular shorelines, incorporation of nesting boxes, use of plants with habitat characteristics of cover or food, islands for nesting of waterfowl, and sufficient mudflat and deepwater areas will also greatly enhance wildlife habitat. For a thorough discussion of design considerations, refer to Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996). Designers are generally cautioned to avoid species known to be aggressive colonizers, noxious weeds, or ones not recognized by state regulatory agencies.

Maintenance Considerations

Frequent maintenance and inspection, which usually involves moderate costs, are critical during the establishment of vegetation in the marsh or wetland. Invasive and undesirable plants must be culled from the planting area. The outfall structure might also have to be adjusted to maintain the proper hydrology for introduced plant species. Though sediment rates may initially be high from construction activity, it is important that sediment be removed so that the plants can become established and the pond capacity is maintained. Once established, the wetland vegetation should be periodically harvested so that the stand can regenerate and the pond is not choked off by vegetation. Systems that do not have consistent and steady base flow may become eutrophic. The outlet structure should incorporate features that protect it from blockage by debris and that allow adjustments to be made to the water surface.

Cost Considerations

Costs for ponds typically include costs for embankment, riser and spillway structures, outfall protection, vegetative stabilization, excavation, and grading. Additional costs for site preparation can include soil amendments, precision grading, plant materials and creation of occluding layers in coarse-textured soil types if wetlands systems must be created on upland sites due to project constraints. Project costs can be lowered if existing pre-construction site conditions are carefully considered and isolated areas with hydric soils contained within the footprint of the project are utilized as stormwater management facilities.

Additional maintenance costs will be incurred until the establishment of the wetland ecosystem. Invasive plants must be culled and dead plants replaced. The outlet structure may have to be adjusted, based on seasonal observations, to achieve the proper water surface in the pond.

References

ASCE. 1992. Design and Construction of Urban Stormwater Management Systems. The Urban Water Resources Research Council of the American Society of Civil Engineers (ASCE) and the Water Environment Federation. American Society of Civil Engineers, New York, NY. Martin, E.H., and J.L. Smoot. 1986. Constituent-Load Changes in Urban Stormwater Runoff Routed Through A Detention Pond-Wetlands System in Central Florida. U.S. Geological Survey Water Resources Investigations Report 85-4310, Tallahassee, FL.

Occoquan Watershed Monitoring Laboratory (OWML). 1990. The Evaluation of a Created Wetlands as an Urban Best Management Practice. Occoquan Watershed Monitoring Laboratory. Occoquan, VA.

Schueler, T.R. 1992. Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Region. Metropolitan Washington Council of Governments, Washington, D.C.

USEPA. 1993. Guidance Specifying Management Measures For Sources of Nonpoint Pollution in Coastal Waters. EPA-840-B-92-002. U.S. Environmental Protection Agency (USEPA), Office of Water, Washington, D.C.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032. Federal Highway Administration, Office of Environment and Planning.

POST-CONSTRUCTION STORM WATER BEST MANAGEMENT PRACTICES RESEARCH REPORT

Tennessee Department of Transportation

Prepared for:

Prepared by:

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

TriAD Project No. 04-SAI16-03

OCTOBER 15, 2007

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

Appendices

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

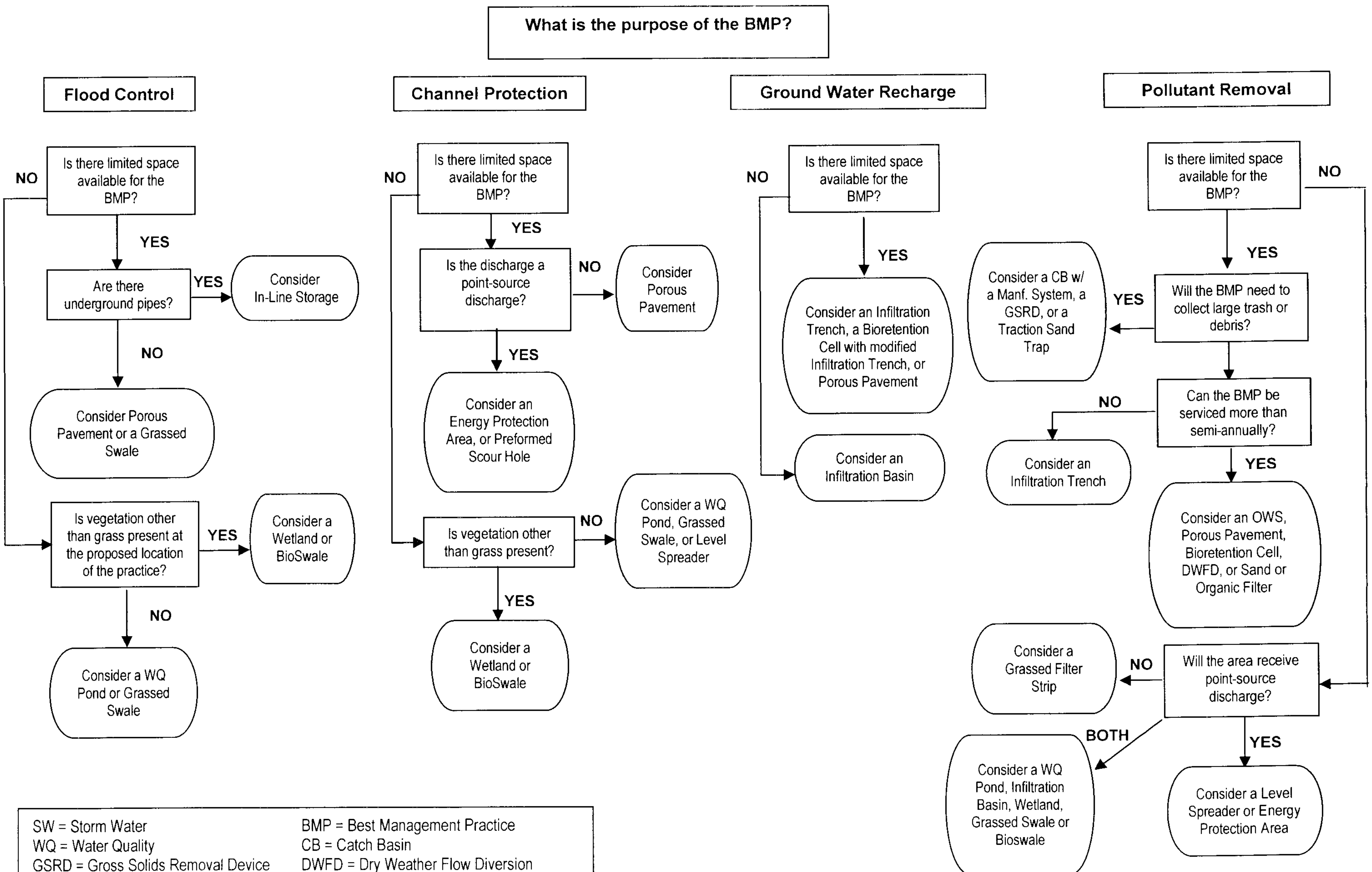
Virginia DOT has several post-construction BMPs that are approved for use. The selection of BMPs is based on the percent of impervious cover upstream of the practice. The Location and Design Division of the Virginia DOT issued an instruction and information memorandum on the management of SW. A copy 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	BMP = Best Management Practice
WQ = Water Quality	CB = Catch Basin
GSRD = Gross Solids Removal Device	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

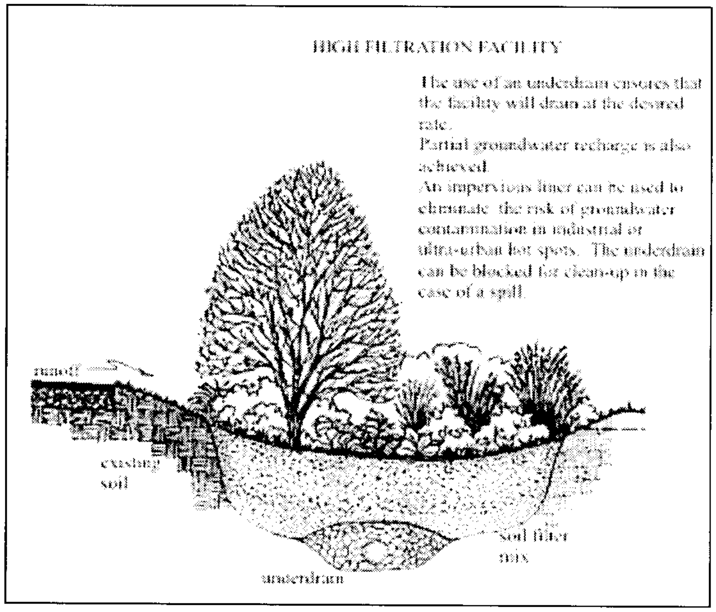
SELECTED POST-CONSTRUCTION STORM WATER BEST MANAGEMENT PRACTICES

BIORETENTION / BIORETENTION CELL / VEGETATED BUFFER

Low Impact Development Center, Inc.

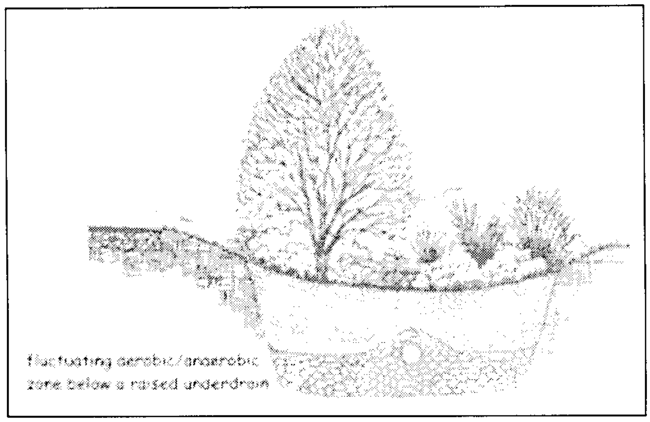
Watershed Benefits of Bioretention Techniques

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]

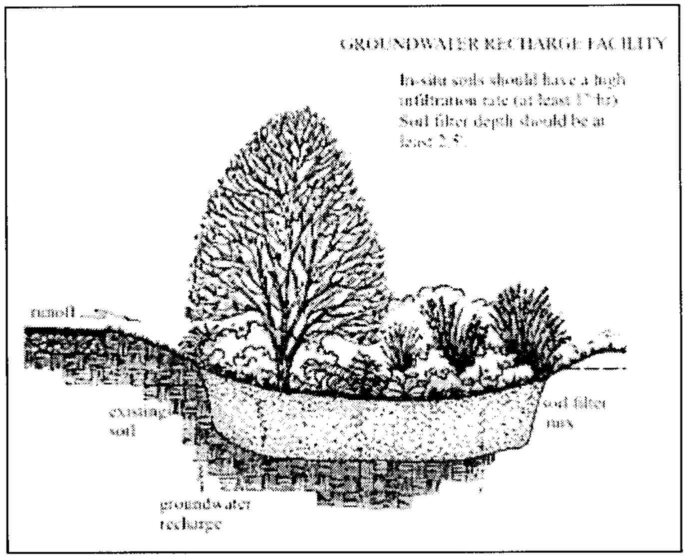


These studies indicate that in urban areas where heavy metals are the focal pollutants, shallow bioretention facilities with a significant mulch layer may be recommended. In residential areas, however, where the primary pollutants of concern are nitrogen and phosphorus, the depth dependence will require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

Back to top

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.

[2] Kim, H., E.A. Seagren and A.P. Davis, 2000: Engineered bioretention for removal of nitrate from stormwater runoff. WEFTEC 2000 Conference Proceedings on CDROM Research Symposium, Nitrogen Removal,

October, Anaheim, California.

[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.

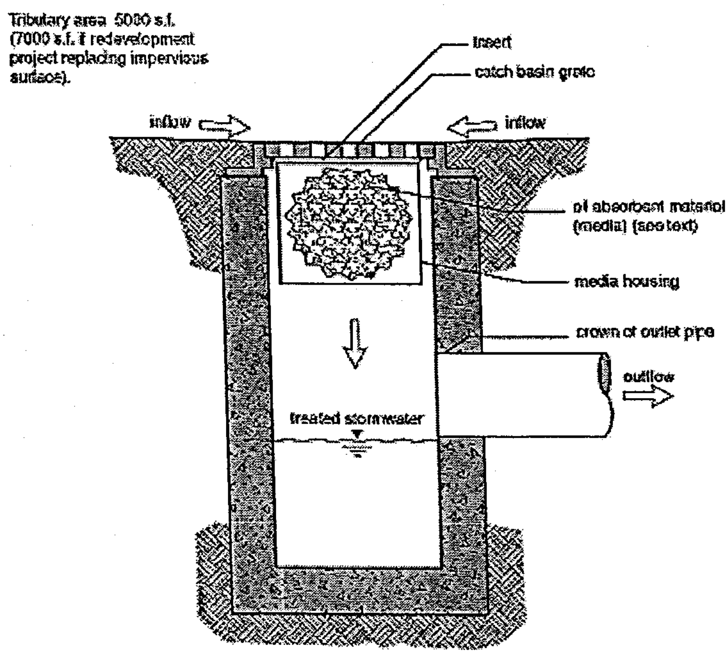
[8] Winogradoff, D.A. and L.S. Coffman, 1999: Bioretention water quality performance data and design modifications. Proceedings of the 26th Annual Water Resources Planning and Management Conference ASCE, June 6-9, Tempe, Arizona.

Back to top

CATCH BASIN WITH MANUFACTURED SYSTEM

Manufactured Products for Storm Water Inlets

Postconstruction Storm Water Management in New Development and Redevelopment



SECTION VIEW
NTS

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 Catch Basin 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.

References

Claytor, R. 1999. Performance of a proprietary stormwater treatment device: The Stormceptor®. *Watershed Protection Techniques* 3(1):605–608.

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.

Labatiuk, C., V. Natal, and V. Bhardwaj. 1997. Field evaluation of a pollution abatement device for stormwater quality improvement. In *Proceedings of the 1997 CSCE-ASCE Environmental Engineering Conference, Edmonton, Alberta.* Canadian Society for Civil Engineering, Montréal, Québec, and American Society of Civil Engineers, Reston, VA.

Schueler, T. 1997. Performance of oil-grit separator at removing pollutants at small sites. *Watershed Protection Techniques* 2(4): 539–542.

King County, WA. 2000. *King County Surface Water Design Manual.* [splash.metrokc.gov/wlr/dss/manual.htm]. Last updated March 6, 2000. Accessed January 5, 2001.

DRY WEATHER FLOW DIVERSION

PPDG Page B-23

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

PPDG Page B-24

Dry Weather Diversion - Siting Criteria

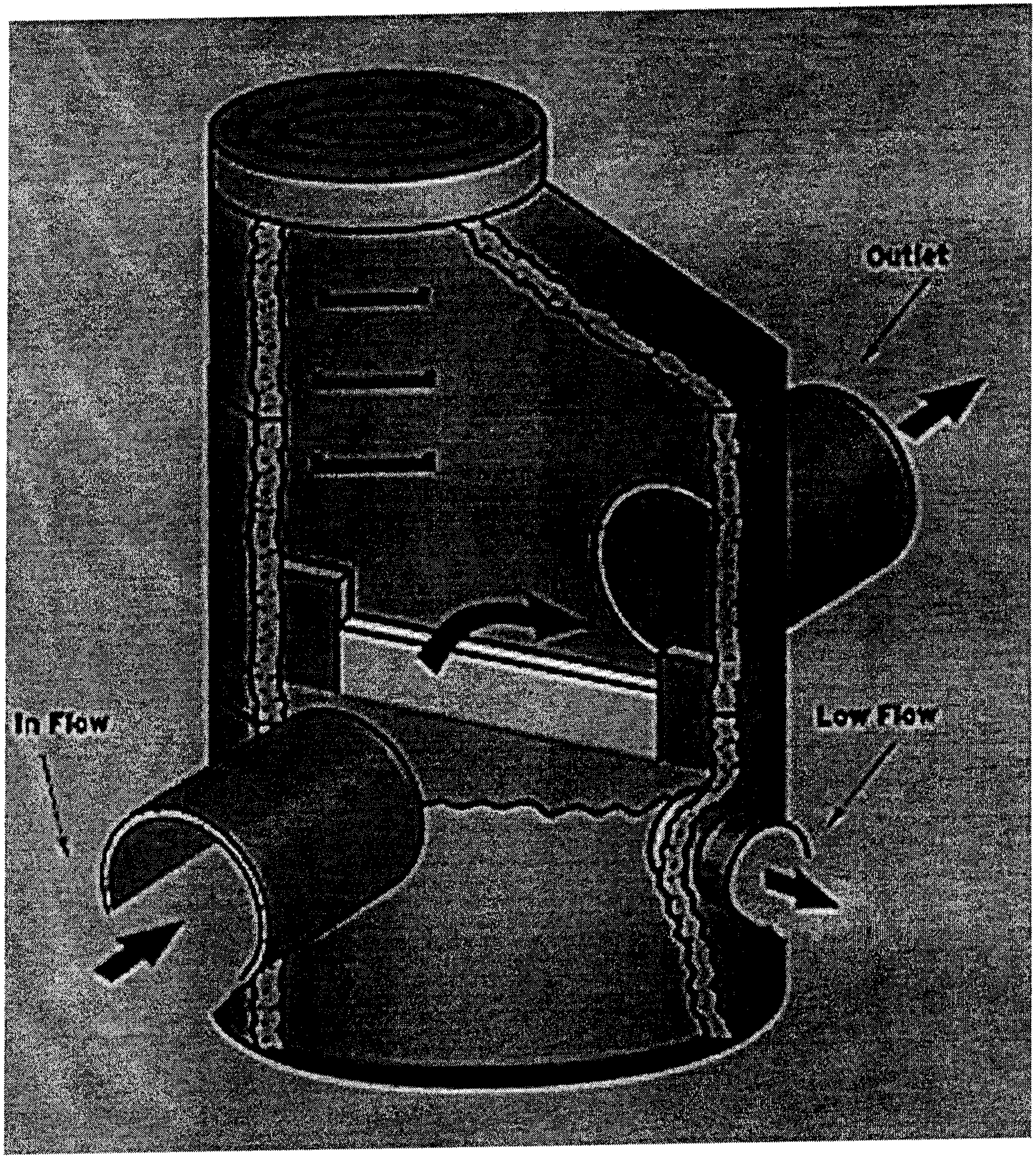
- Dry Weather flow is persistent over significant parts of the year
- A relatively easy connection to the sanitary sewer is available
- The POTW is willing to accept additional flow during the dry season
- Diversion is recommended by the local health officials to benefit receiving waters

Target Pollutants

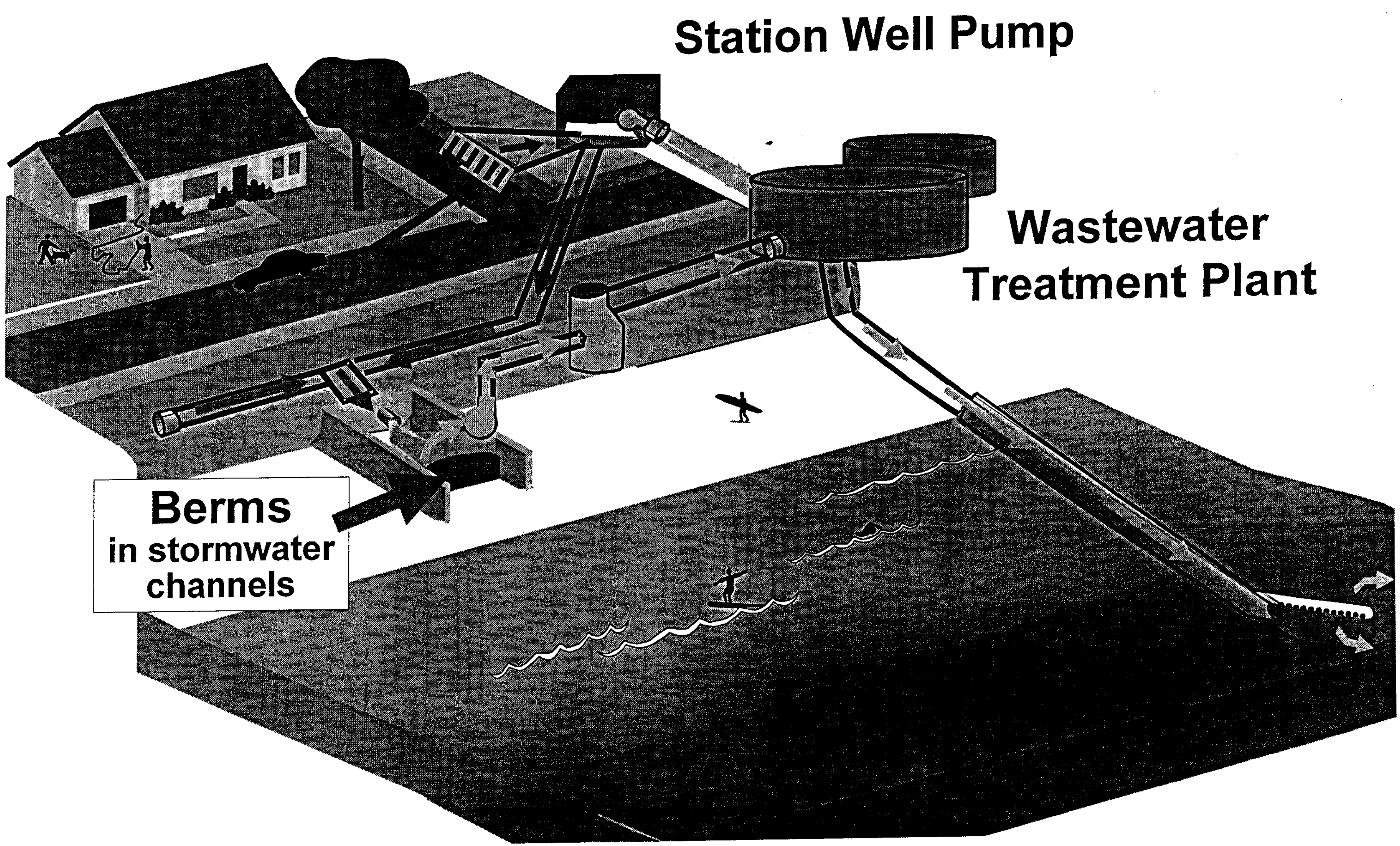
	Biofil Sys	Dry Weather Flow Diversions[1]	Gross Solids Removal Devices	Traction Sand Traps
Total Suspended Solids		✓		✓
Nutrients		✓		
Pesticides		✓		
Particulate Metals		✓		
Dissolved Metals		✓		
Pathogens		✓		
Litter		✓	✓	
Biochemical Oxygen Demand		✓		
Total Dissolved Solids		✓		

PPDG Table 2-2, Page 2-7

Dry Weather Diversion



Dry Weather Diversion



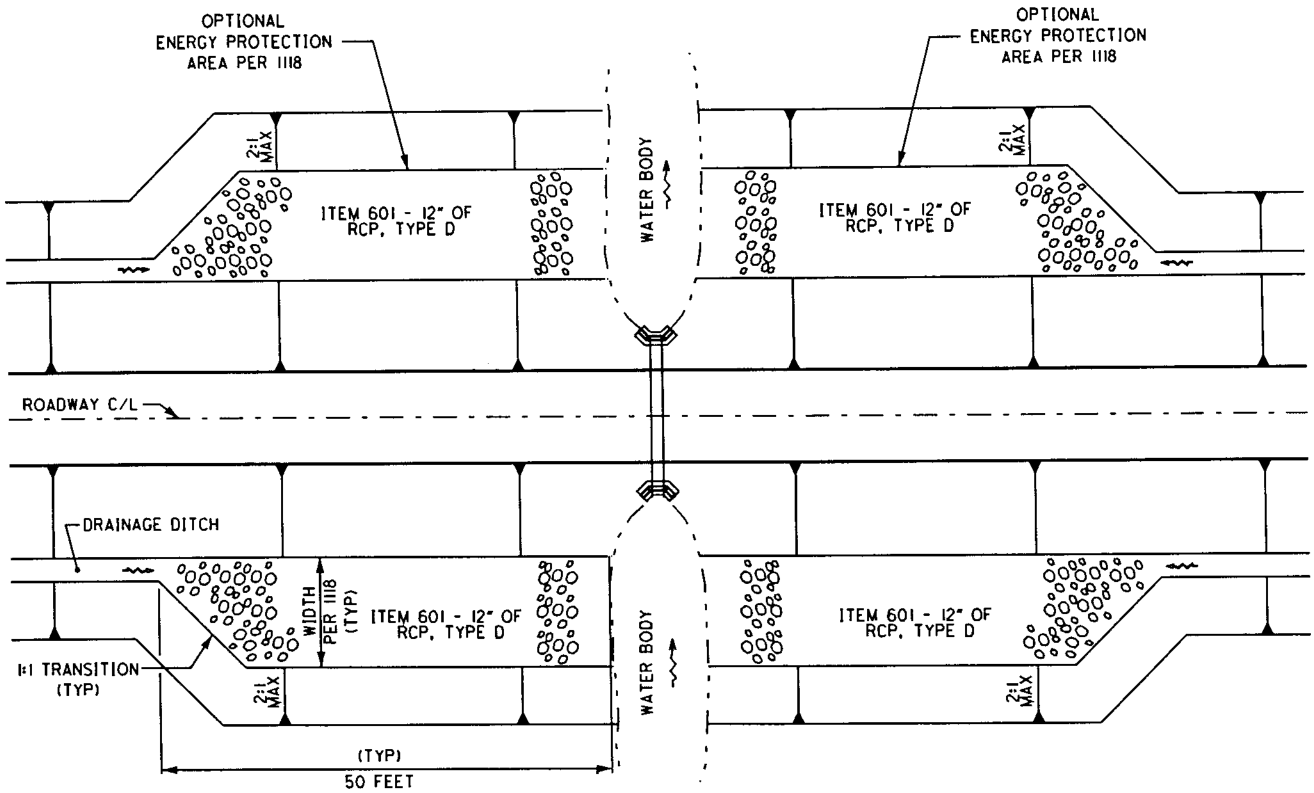
Dry Weather Diversion

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

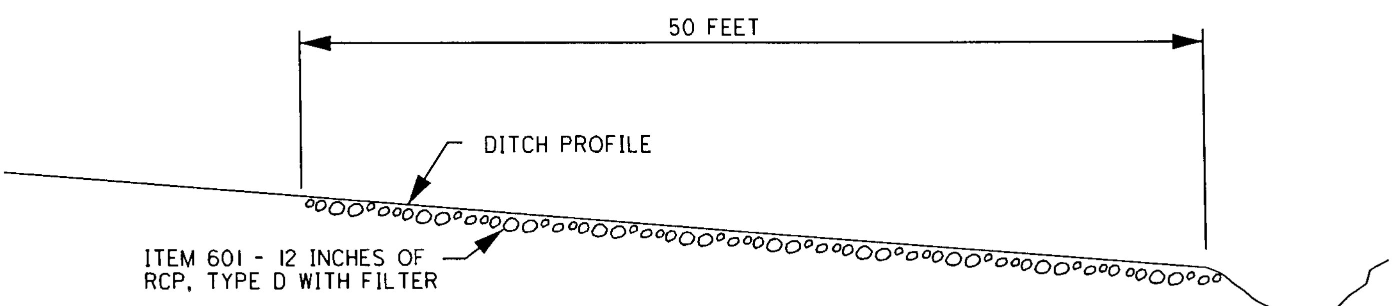
ENERGY PROTECTION AREA

January 2006

ENERGY PROTECTION AREA DETAIL	1118-5
	REFERENCE SECTION 1118



PLAN VIEW
NOT TO SCALE



PROFILE
NOT TO SCALE

GRASSED / VEGETATED FILTER STRIP

Vegetated Filter Strip

Click here to comment on this fact sheet

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.

References

Design Reference

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems.* Prepared for Chesapeake Research Consortium, Solomons, MD, and EPA Region V, Chicago, IL.

Other References

Desbonette, A., P. Pogue, V. Lee, and N. Wolff. 1994. *Vegetated Buffers in the Coastal Zone: A Summary Review and Bibliography.* Coastal Resources Center. University of Rhode Island, Kingston, RI.

Magette, W., R. Brinsfield, R. Palmer and J. Wood. 1989. Nutrient and Sediment Removal by

Vegetated Filter Strips. *Transactions of the American Society of Agricultural Engineers* 32(2): 663-667.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures.* Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Yu, S., S. Barnes and V. Gerde. 1993. *Testing of Best Management Practices for Controlling Highway Runoff.* FHWA/VA 93-R16. Virginia Transportation Research Council, Charlottesville, VA.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates.* Prepared for U.S. Environmental Protection Agency Office of Wetlands, Oceans and Watersheds. Washington, DC.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 10, 2005.

Click here to comment on this fact sheet

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:

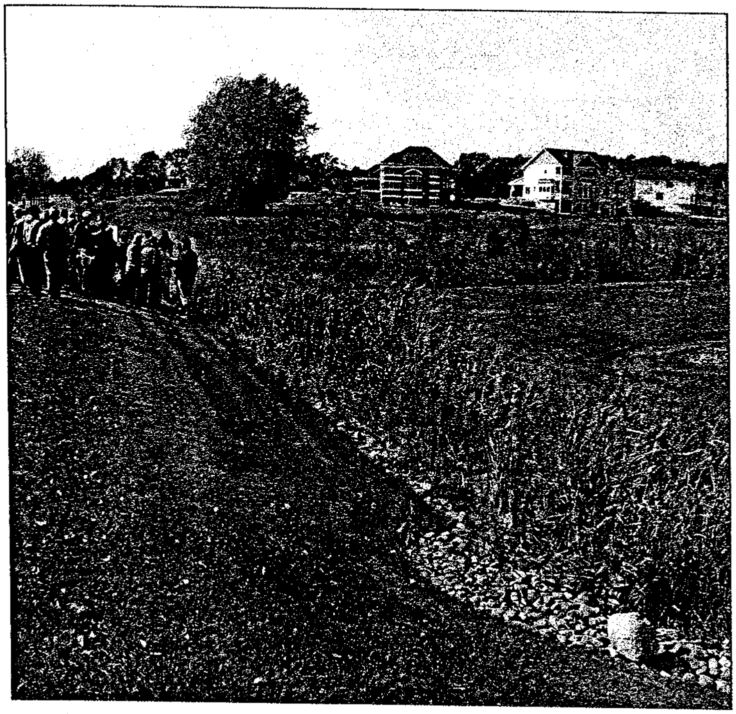
- Costs vary greatly depending on size, plant material, and site considerations. Bioswales are generally less expensive when used in place of underground piping.
- Deep-rooted native plants are preferred for infiltration and reduced maintenance.
- Soil infiltration rates should be greater than one-half 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

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.

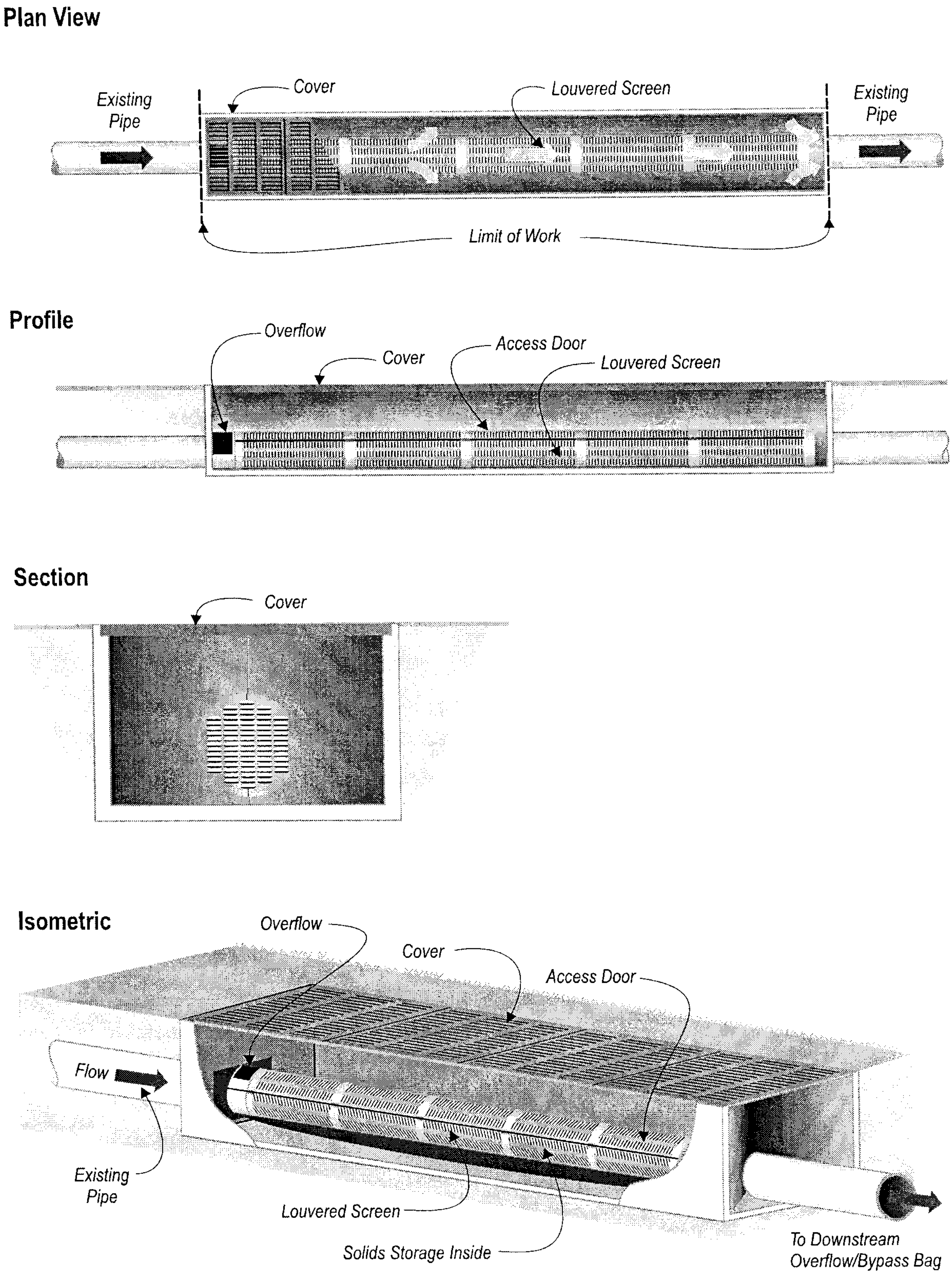


Figure 2-1
Concept Linear Radial Configuration #1

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.

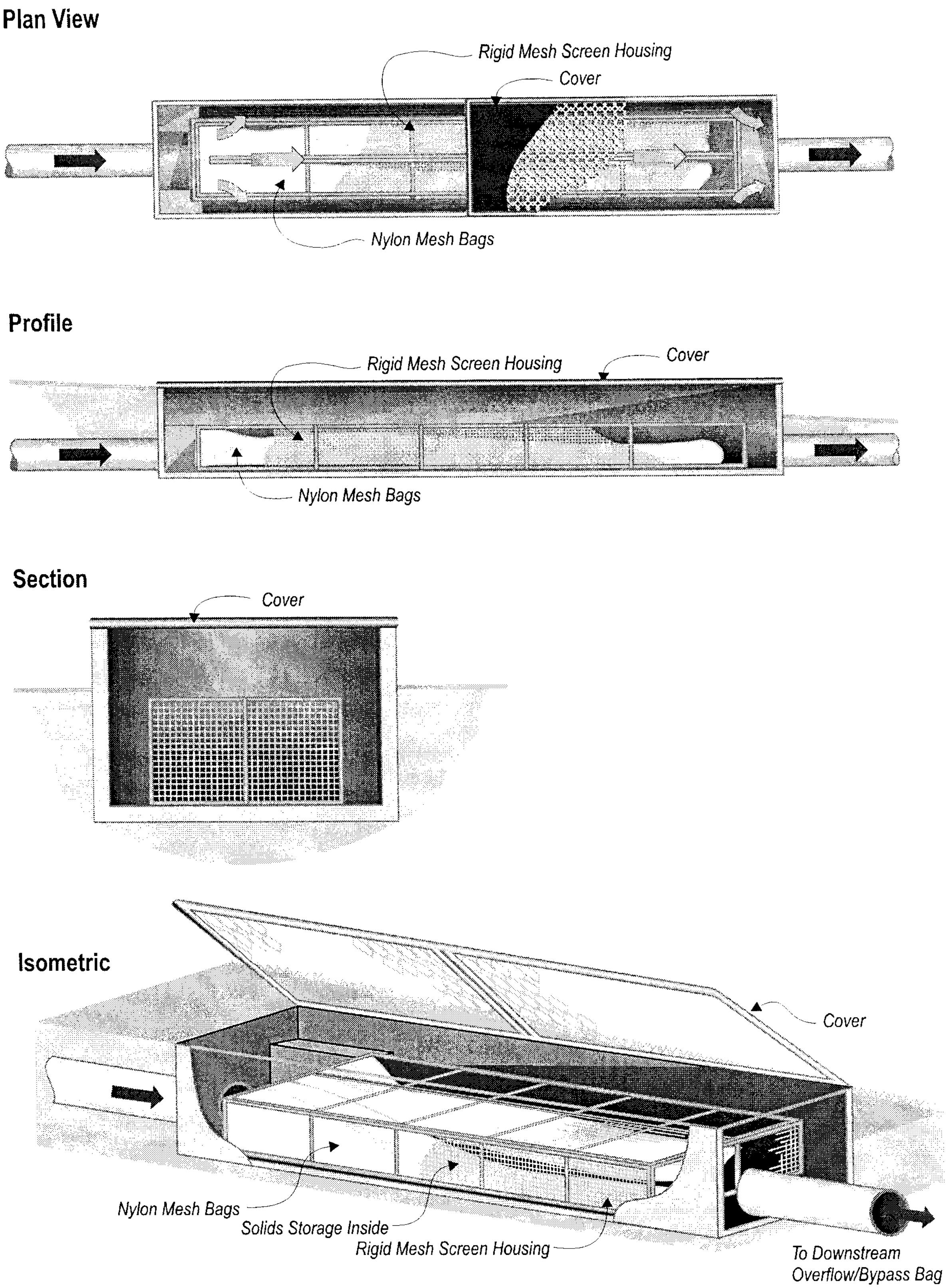


Figure 2-2
Concept Linear Radial
Configuration #2

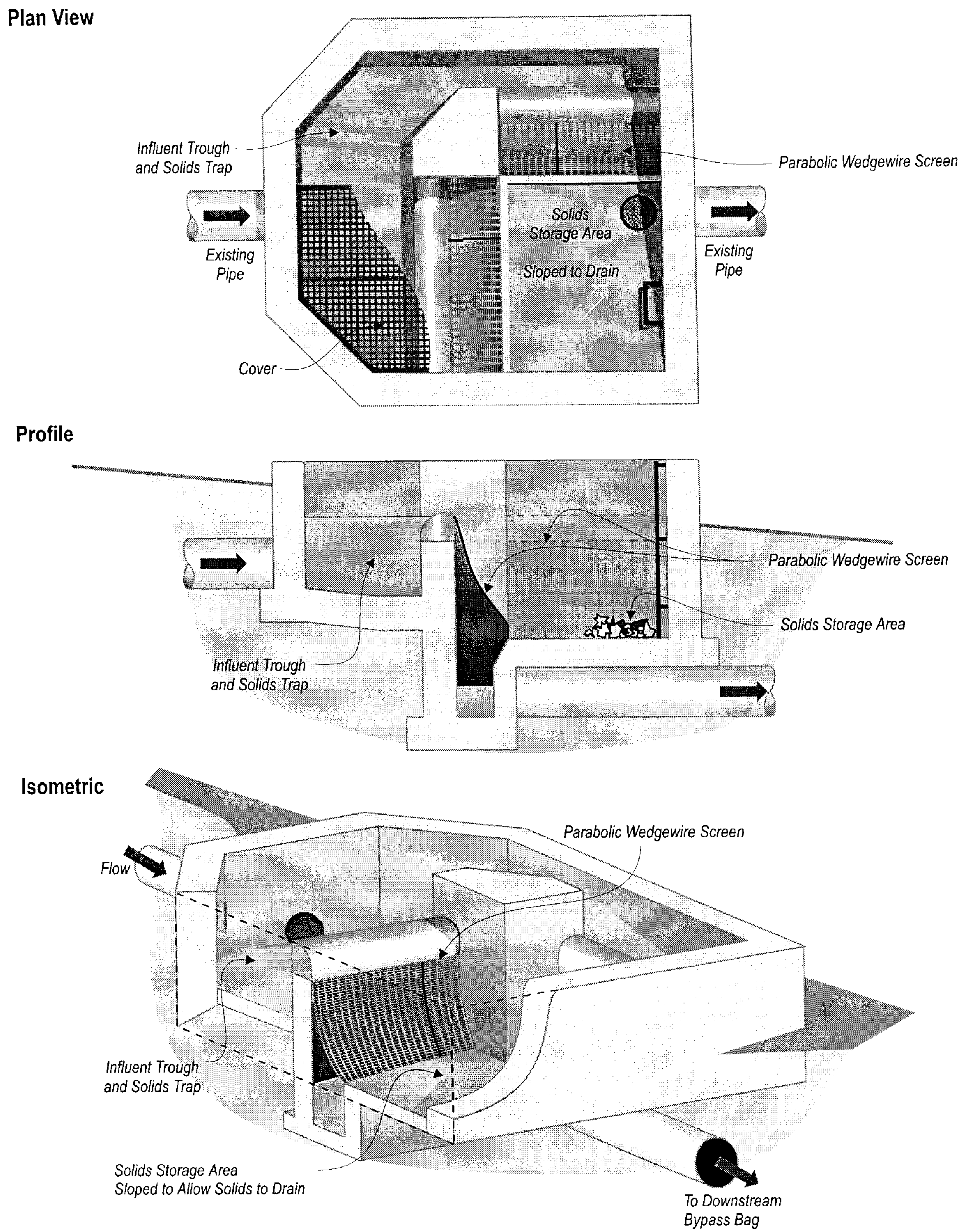


Figure 2-3
Concept Inclined Screen
Configuration #1

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.

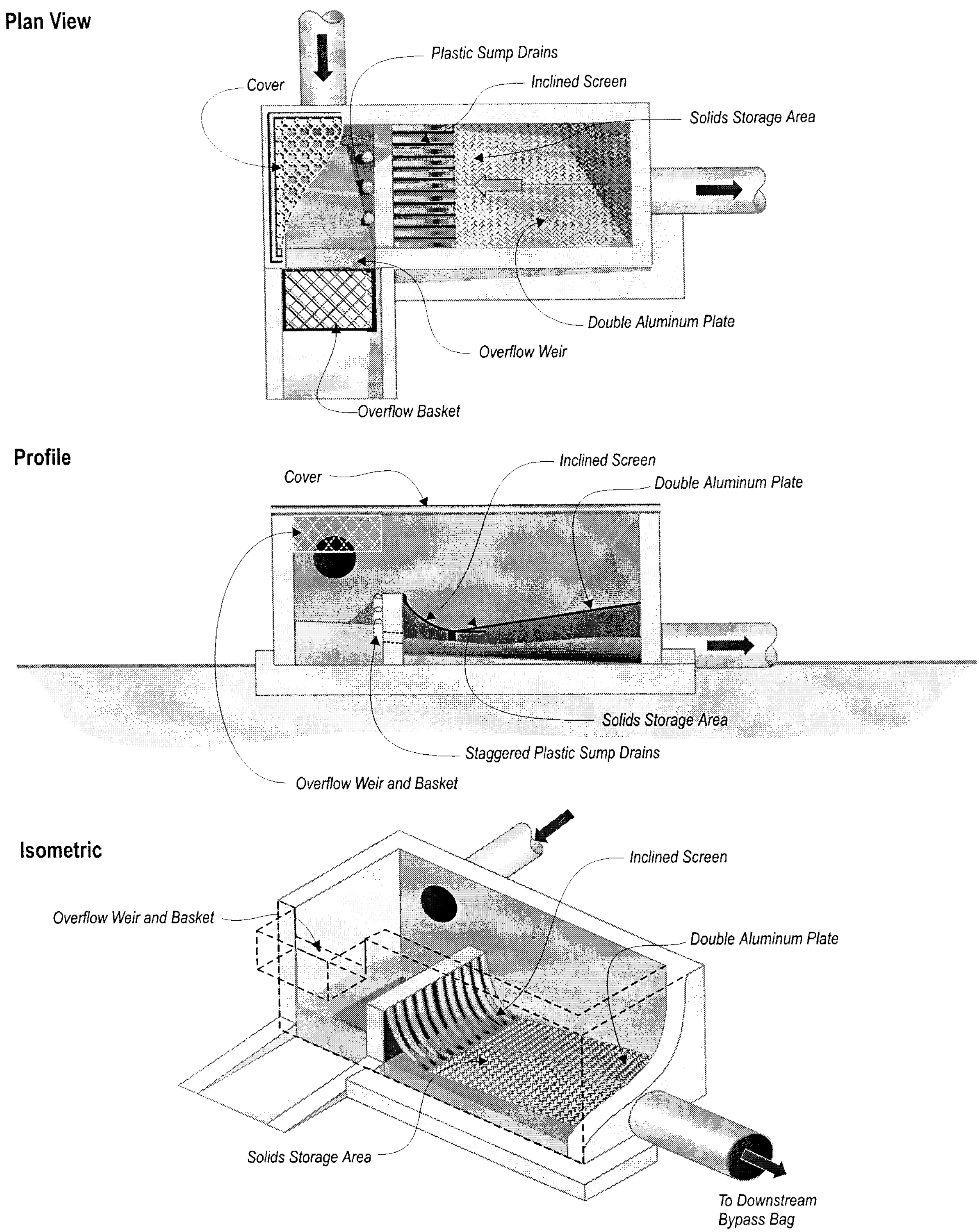


Figure 2-4
Concept Inclined Screen
Configuration #2

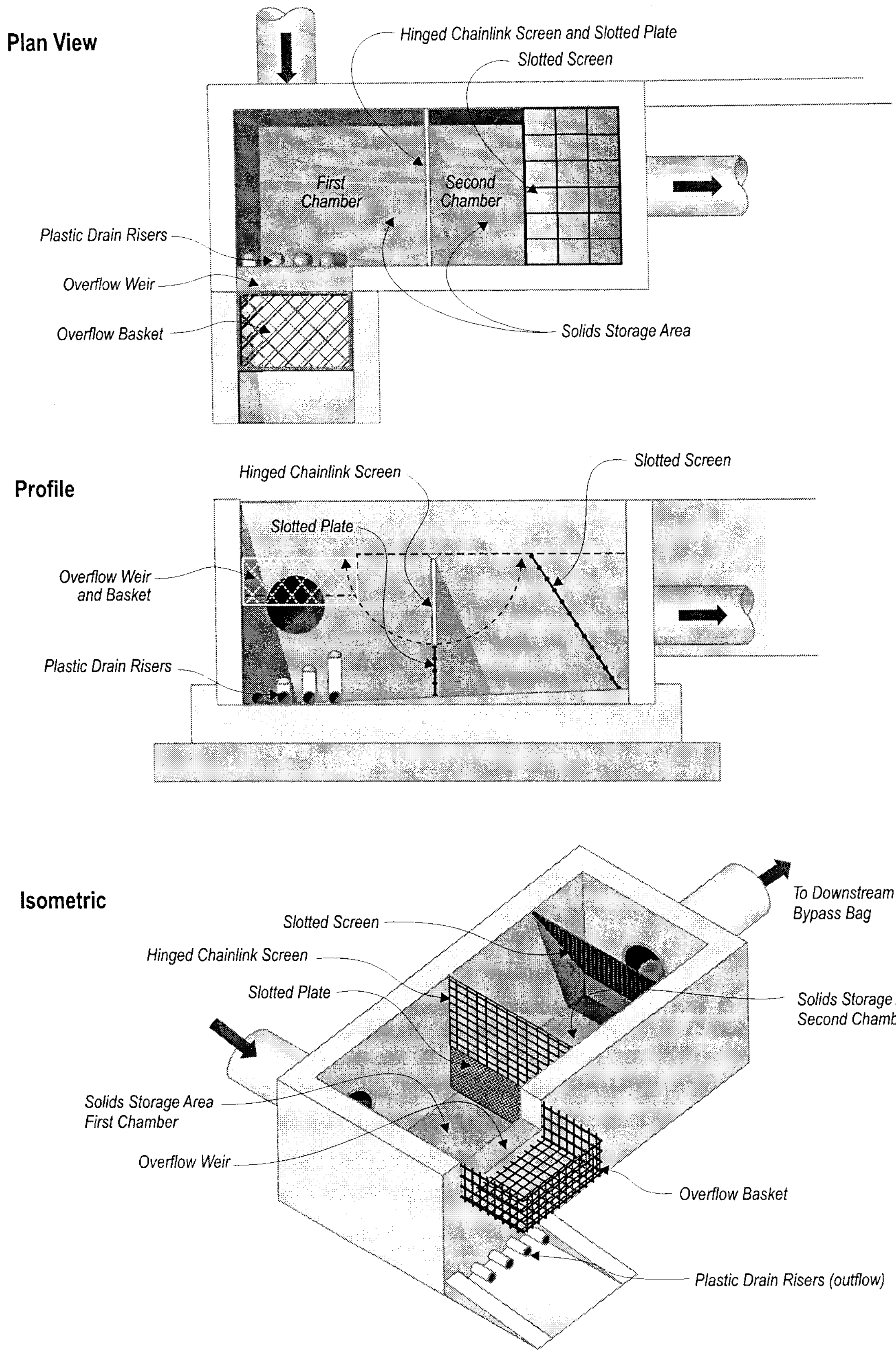


Figure 2-5
Concept Baffle Box

INFILTRATION TRENCH

U.S. Environmental Protection Agency

National Pollutant Discharge Elimination System (NPDES)

Infiltration Trench

Click here to comment on this fact sheet

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

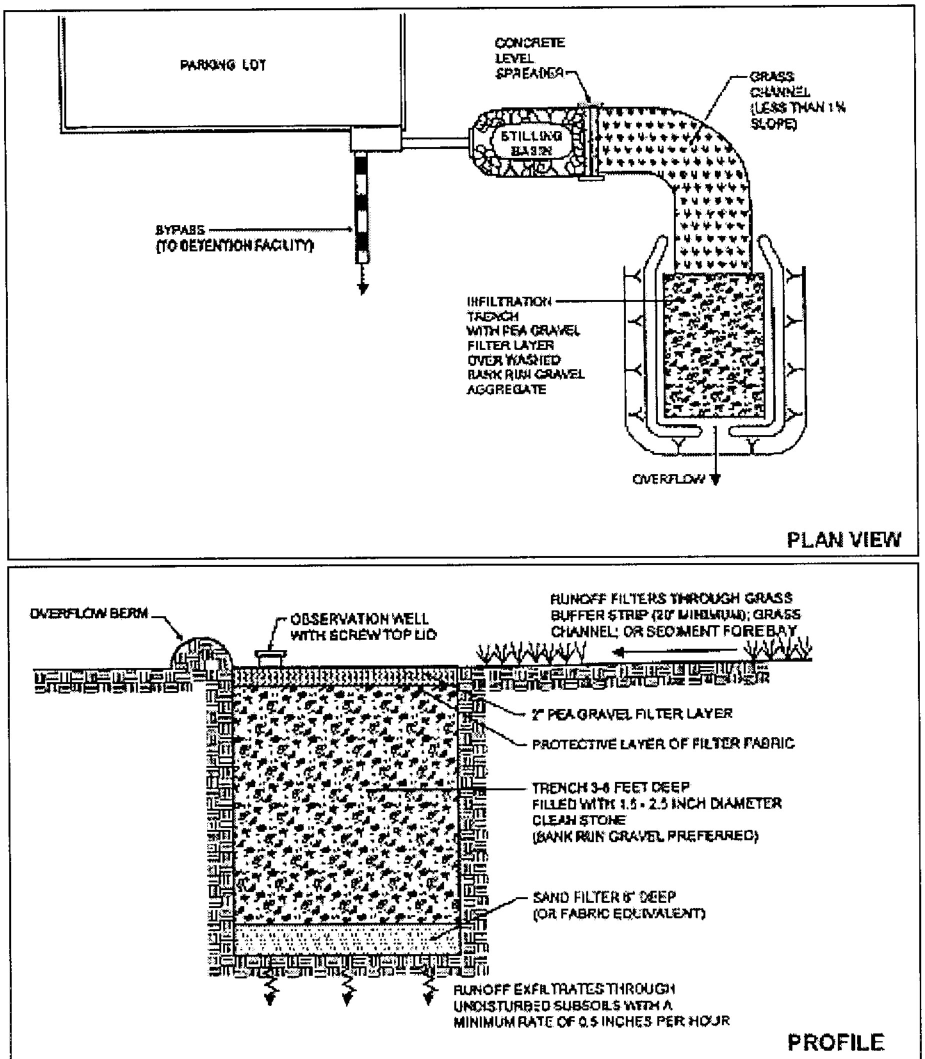
Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Infiltration trenches can sometimes be applied in the ultra-urban environment. Two features that can restrict their use are the potential of infiltrated water to interfere with existing infrastructure, and the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

References

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 10, 2005.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Galli, J. 1992. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland*. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Ferguson, B.K. 1994. *Stormwater Infiltration*. CRC Press, Ann Arbor, MI.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas: Best Management Practices*. Minnesota Pollution Control Agency, Minneapolis, MN.

USEPA. 1993. *Guidance to Specify Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Click here to comment on this fact sheet

IN-LINE STORAGE

In-Line Storage

Click here to comment on this fact sheet

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).

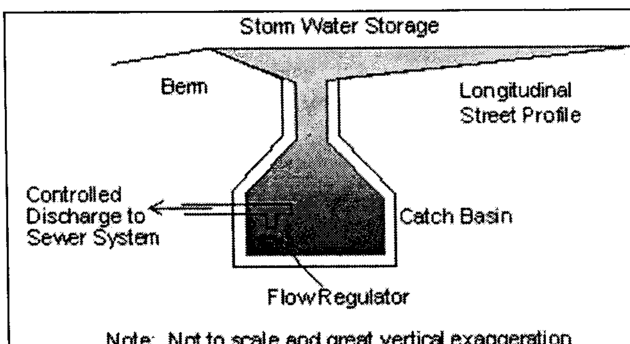
Applicability

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.

References

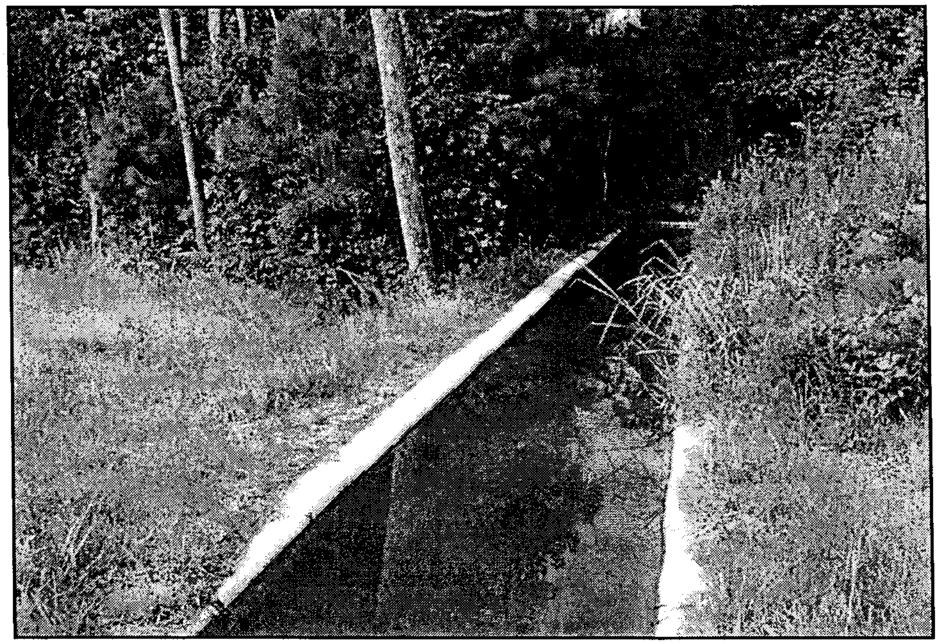
Urbonas, B., and T. Stahre. 1990. *Stormwater Best Management Practices and Detention for Water Quality, Drainage and CSO Management*. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Virginia Department of Conservation and Recreation (VDCR). 1999. *Watershed and Lake BMPs--Best Management Practices for Established Urban Communities*. Virginia Department of Conservation and Recreation, Richmond, VA.

Click here to comment on this fact sheet

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.

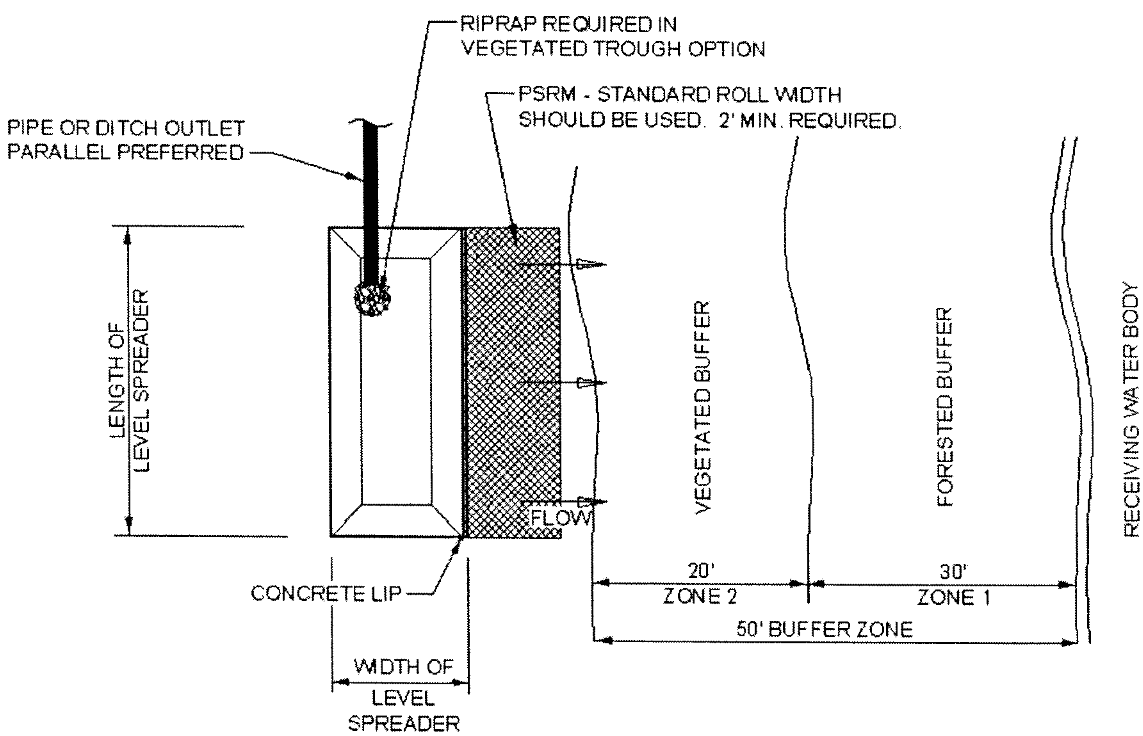


Figure 3-1. Typical level spreader layout and components

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.

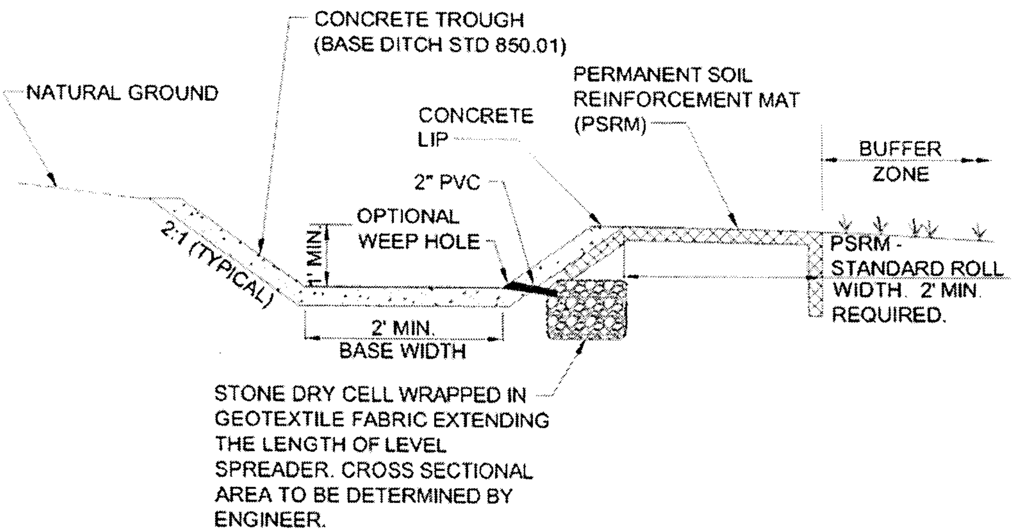


Figure 3-2. Level spreader with concrete trough

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.

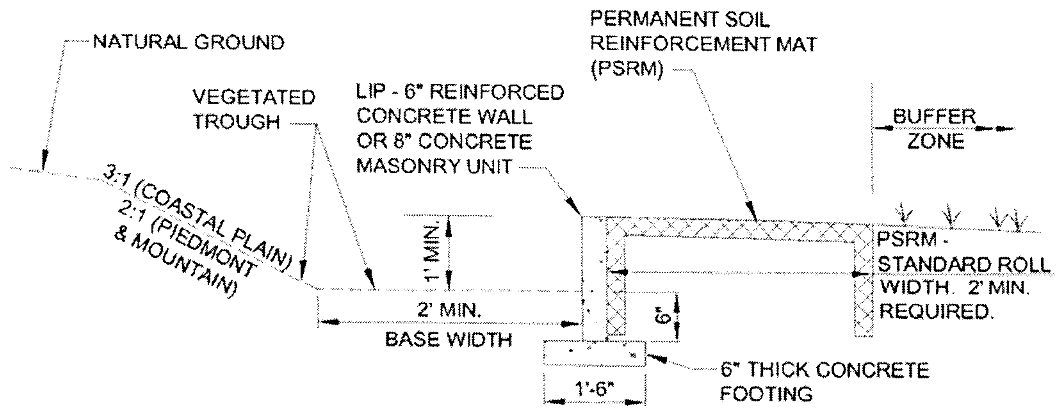


Figure 3-3. Level spreader with vegetated trough

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.

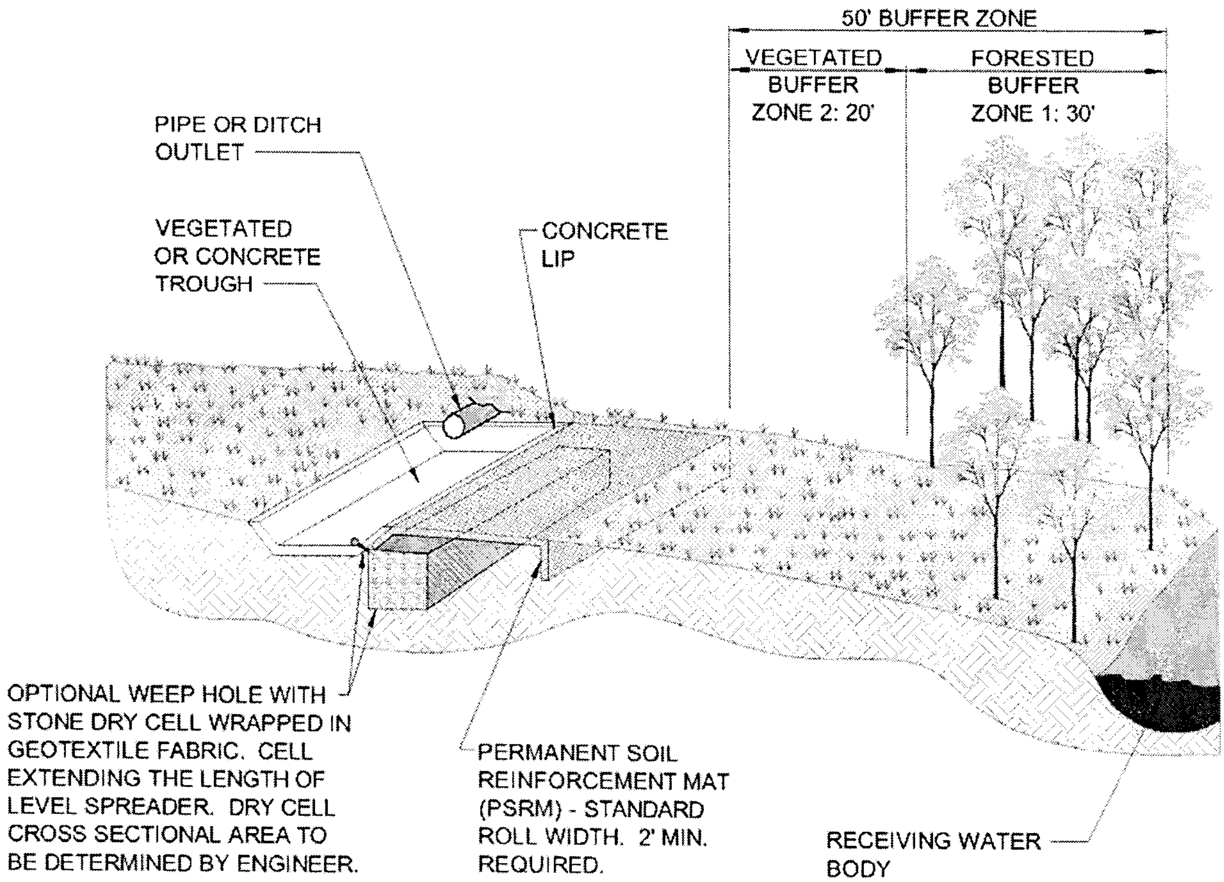


Figure 3-4. Typical level spreader with buffer

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.

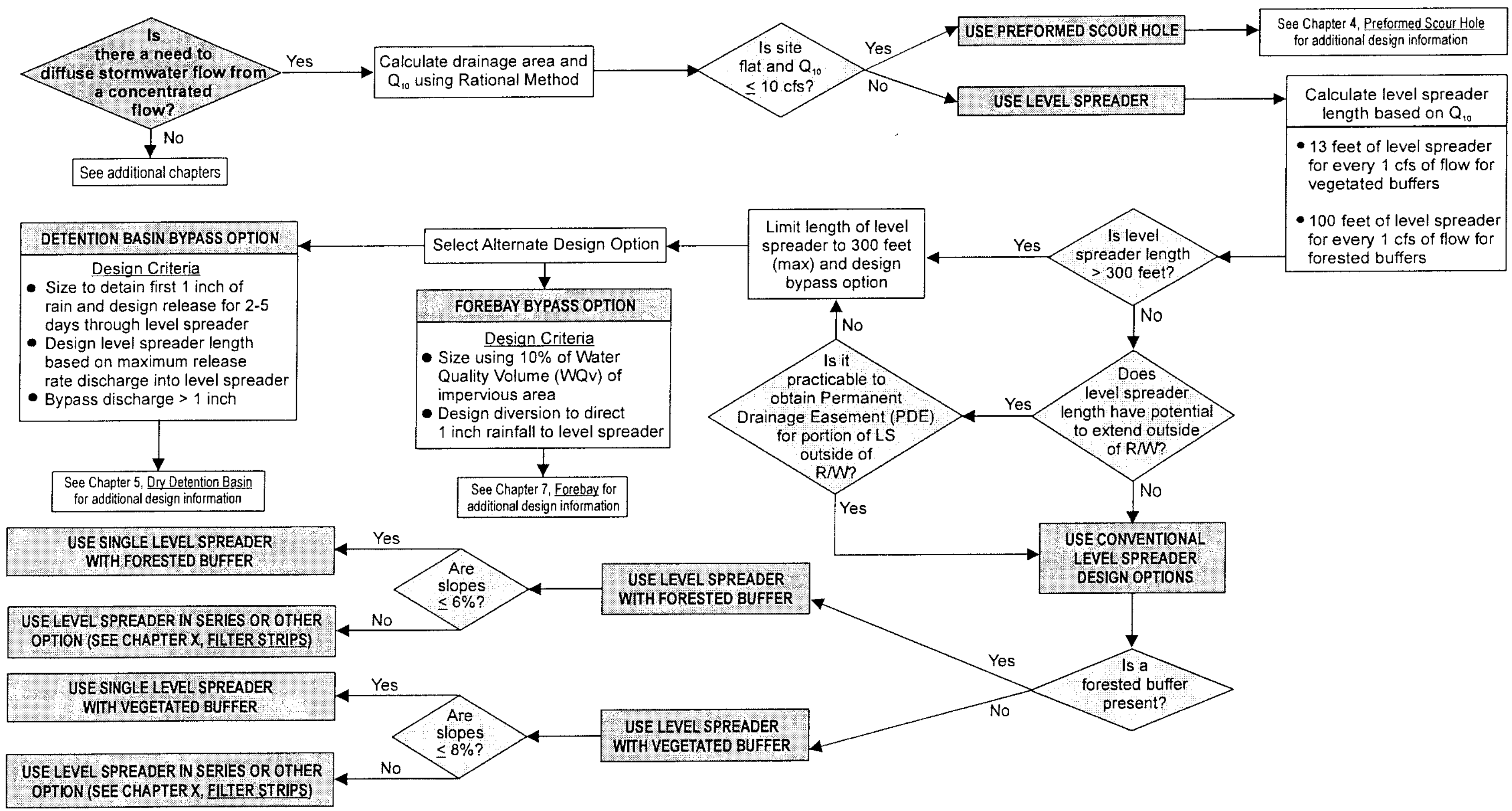


Figure 3-5. Level spreader design flowchart

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.

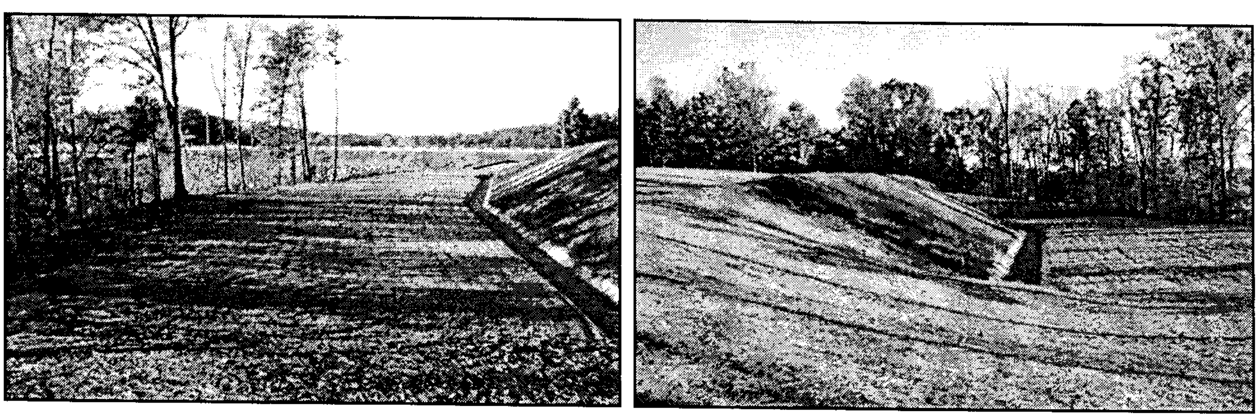


Figure 3-6. Level spreader with mixed vegetated and forested buffers

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

U.S. Environmental Protection Agency

National Pollutant Discharge Elimination System (NPDES)

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.

References

Brattebo, B.O., and Booth, D.B. 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. Water Research 37:4369-4376.

Cahill Associates. 1993. *Stormwater Management Systems: Porous Pavement with Underground Recharge Beds.* Cahill Associates, West Chester, PA.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems.* Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Galli, J. 1992. *Preliminary Analysis of the Performance and Longevity of Urban BMPs Installed In Prince George's County, Maryland.* Department of Natural Resources, Annapolis, MD.

Gburek, W., and J. Urban, 1980. *Stormwater Detention and Groundwater Recharge Using Porous Asphalt Experimental Site.* In Proceedings: International Symposium on Urban Storm Runoff. University of Kentucky, Lexington, KY, p. 89-97.

Goforth, G., E. Diniz, and J. Rauhut. 1983. *Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems.* U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Hossain, M., and L. Scofield, 1991. *Porous Pavement for Control of Highway Runoff.* Arizona Department of Transportation, Phoenix, AZ.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Metropolitan Washington Council of Governments, Washington, DC.

Stenmark, C. 1995. An Alternative Road Construction for Stormwater Management. *Water Science and Technology* 32(1):79-84.

Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates.* Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community.* Center for Watershed Protection, Ellicott City, MD.

Click here to comment on this fact sheet

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

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.

References

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for Chesapeake Research Consortium, Edgewater, MD by Center for Watershed Protection, Ellicott City, MD.

Emmerling-Dinovo, C. 1995. Stormwater Detention Basins and Residential Locational Decisions. *Water Resources Bulletin*, 31(3):515-521.

Galli, F. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Prepared for Maryland Department of the Environment, Baltimore, MD, by Metropolitan Council of Governments, Washington, DC.

MacRae, C. 1996. Experience from morphological research on canadian streams: Is control of the two-year frequency runoff event the best basis for stream channel protection? In *Effects of Watershed Development and Management on Aquatic Ecosystems*. American Society of Civil Engineers, Snowbird, UT.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed November 10, 2005.

Click here to comment on this fact sheet

WATER QUALITY POND

Menu of BMPs Home

BMP Background

Public Education & Outreach on Stormwater Impacts

Public Involvement/ Participation

Illicit Discharge Detection & Elimination

Construction Site Stormwater Runoff Control

Post-Construction Stormwater Management in New Development & Redevelopment

Pollution Prevention/Good Housekeeping for Municipal Operations

Measurable Goals

Stormwater Home

Wet Ponds

Click here to comment on this fact sheet

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

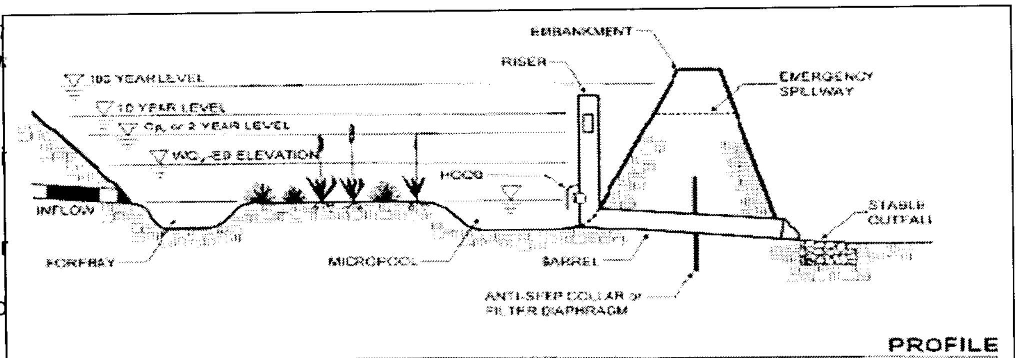
A stormwater retrofit is a stormwater management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Wet ponds are very useful stormwater retrofits and have two primary 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

Sitin Con



Example profile view of a wet pond design.

In add to the rest and mod to ada 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).

References

Bannerman, R., and R. Dodds. 1992. Unpublished data. Bureau of Water Resources Management, Wisconsin Department of Natural Resources, Madison, WI.

Borden, R. C., J.L. Dorn, J.B. Stillman, and S.K. Liehr. 1996. *Evaluation of Ponds and Wetlands For Protection of Public Water Supplies.* Draft Report. Water Resources Research Institute of the University of North Carolina, Department of Civil Engineering, North Carolina State University, Raleigh, NC.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

City of Austin, TX. 1991. *Design Guidelines for Water Quality Control Basins*. Public Works Department, Austin, TX.

City of Austin, TX. 1996. Evaluation of Non-Point Source Controls: A 319 Grant Project. Draft Water Quality Report Series, Public Works Department, Austin, TX.

Cullum, M. 1985. Stormwater Runoff Analysis at a Single Family Residential Site. Publication 85-1. University of Central Florida, Orlando, FL. pp. 247.256.

Dorman, M.E., J. Hartigan, R.F. Steg, and T. Quasebarth. 1989. *Retention, Detention and Overland Flow for Pollutant Removal From Highway Stormwater Runoff.* Vol. 1 Research Report. FHWA/RD 89/202. Federal Highway Administration, Washington, DC.

Driscoll, E.D. 1983. *Performance of Detention Basins for Control of Urban Runoff Quality.* Presented at the 1983 International Symposium on Urban Hydrology, Hydraulics and Sedimentation Control, University of Kentucky, Lexington, KY.

Emmerling-Dinovo, C. 1995. Stormwater detention basins and residential locational decisions. *Water Resources Bulletin*, 31(3):515.52.

Gain, W.S. 1996. *The Effects of Flow Path Modification on Water Quality Constituent Retention in an Urban Stormwater Detention Pond and Wetland System.* Water Resources Investigations Report 95-4297. U.S. Geological Survey, Tallahassee, FL.

Galli, F. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Prepared for the Maryland Department of the Environment, Baltimore, MD, by the Metropolitan Council of Governments, Washington, DC.

Holler, J.D. 1989. Water quality efficiency of an urban commercial wet detention stormwater management system at Boynton Beach Mall in South Palm Beach County, FL. *Florida Scientist* 52(1):48.57.

Holler, J.D. 1990. Nonpoint source phosphorous control by a combination wet detention/filtration facility in Kissimmee, FL. *Florida Scientist* 53(1):28.37.

Horner, R.R., J. Guedry, and M.H. Kortenhoff. 1990. *Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control.* Final Report. Washington State Transportation Commission, Olympia, WA.

Kantrowitz, I., and W. Woodham. 1995. *Efficiency of a Stormwater Detention Pond in Reducing Loads of Chemical and Physical Constituents in Urban Streamflow, Pinellas County, Florida.* Water Resources Investigations Report 94-4217. U.S. Geological Survey, Tallahassee, FL.

Martin, E. 1988. Effectiveness of an urban runoff detention pond/wetland system. *Journal of Environmental Engineering* 114(4):810.827.

Oberts, G.L. 1994. Performance of stormwater ponds and wetlands in winter. *Watershed Protection Techniques* 1(2):64.68.

Oberts, G.L., P.J. Wotzka, and J.A. Hartsoe. 1989. *The Water Quality Performance of Select Urban Runoff Treatment Systems.* Publication No. 590-89-062a. Prepared for the Legislative Commission on Minnesota Resources, Metropolitan Council, St. Paul, MN.

Oberts, G.L., and L. Wotzka. 1988. The water quality performance of a detention basin wetland treatment system in an urban area. In *Nonpoint Source Pollution: Economy,* *Policy, Management and Appropriate Technology*. American Water Resources Association, Middleburg, VA.

Occoquan Watershed Monitoring Laboratory. 1983. Metropolitan Washington Urban Runoff Project. Final Report. Prepared for the Metropolitan Washington Council of Governments, Washington, DC, by the Occoquan Watershed Monitoring Laboratory, Manassas, VA.

Ontario Ministry of the Environment. 1991. *Stormwater Quality Best Management Practices.* Marshall Macklin Monaghan Limited, Toronto, Ontario.

Saunders, G. and M. Gilroy. 1997. *Treatment of Nonpoint Source Pollution With Wetland/Aquatic Ecosystem Best Management Practices.* Texas Water Development Board, Lower Colorado River Authority, Austin, TX.

Schueler, T. 1997a. Comparative pollutant removal capability of urban BMPs: A reanalysis. *Watershed Protection Techniques* 2(4):515.520.

Schueler, T. 1997b. Influence of groundwater on performance of stormwater ponds in Florida. *Watershed Protection Techniques* 2(4):525.528.

Urbonas, B., J. Carlson, and B. Vang. 1994. Joint Pond-Wetland System in Colorado. Denver Urban Drainage and Flood Control District, Denver, CO.

U.S. Environmental Protection Agency (USEPA). 1995. *Economic Benefits of Runoff Controls*. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems.* Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC, by the Watershed Management Institute, Ingleside, MD.

Wu, J. 1989. Evaluation of Detention Basin Performance in the Piedmont Region of North Carolina. Report No. 89-248. North Carolina Water Resources Research Institute, Raleigh, NC.

Yousef, Y., M. Wanielista, and H. Harper. 1986. Design and Effectiveness of Urban Retention Basins. In *Urban Runoff Quality.Impact and Quality Enhancement Technology.* B. Urbonas and L.A. Roesner (Eds.). American Society of Civil Engineering, New York, New York. pp. 338.350.

Information Resources

Center for Watershed Protection (CWP). 1995. *Stormwater Management Pond Design Example for Extended Detention Wet Pond*. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Denver Urban Drainage and Flood Control District. 1992. *Urban Storm Drainage Criteria Manual.Volume 3: Best Management Practices*. Denver Urban Drainage and Flood Control District, Denver, CO.

Galli, J. 1992. *Preliminary Analysis of the Performance and Longevity of Urban BMPs Installed in Prince George's County, Maryland.* Prince George's County, Maryland, Department of Natural Resources, Largo, MD.

MacRae, C. 1996. Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection? In *Effects of Watershed Development and Management on Aquatic Ecosystems*. American Society of Civil Engineers. Snowbird, UT. pp. 144.162.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual.* [http://www.mde.state.md.us/environment/wma/stormwatermanual EXIT Disclaimer]. Accessed May 22, 2001.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas: Best Management Practices*. Minnesota Pollution Control Agency, Minneapolis, MN.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Click here to comment on this fact sheet

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												
	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
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/m^3 of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m^3	Life-Cycle [a] Cost/m^3
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.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

LIST OF APPENDICES

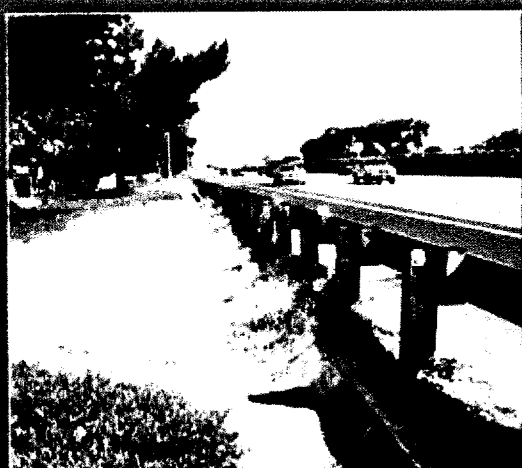
Note: The appendices to this final report are contained on two CD-ROMs attached to the inside back cover of this document. The CD-ROMs contain the following appendices:

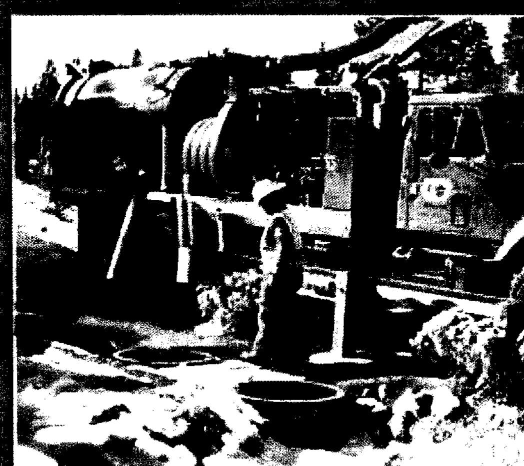
CD-ROM No. 1 :

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

June 2007

- **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

FWHA/IN/JTRP-2006/5

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
Project No: C-36-78V
File No: 4-7-22
SPR-2853

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

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.

Area Requirements – Linear or non-linear area requirements.
Soils – Evaluation of soils is based on USDA or NRCS hydrological soils group at the site.
Water Table – Indicates the minimum depth to the seasonally high water table from the bottom or floor of a BMP.
Drainage Area – Refers to the drainage area that is considered typical for the BMP.
Head – Estimate of the elevation difference needed at a site (from inflow to outflow).
Ultra-Urban Sites –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.

Water Quantity – Effectiveness of the BMP to control the rate and volume of stormwater runoff.
Water Quality – Indicates a BMPs ability to remove Total Suspended Solids (TSS), Phosphorus (P), Nitrogen (N), Metals, and fecal Coliform from stormwater runoff.
Accept Hotspot Runoff – 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

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

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

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

Virginia DCR, 1999

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:

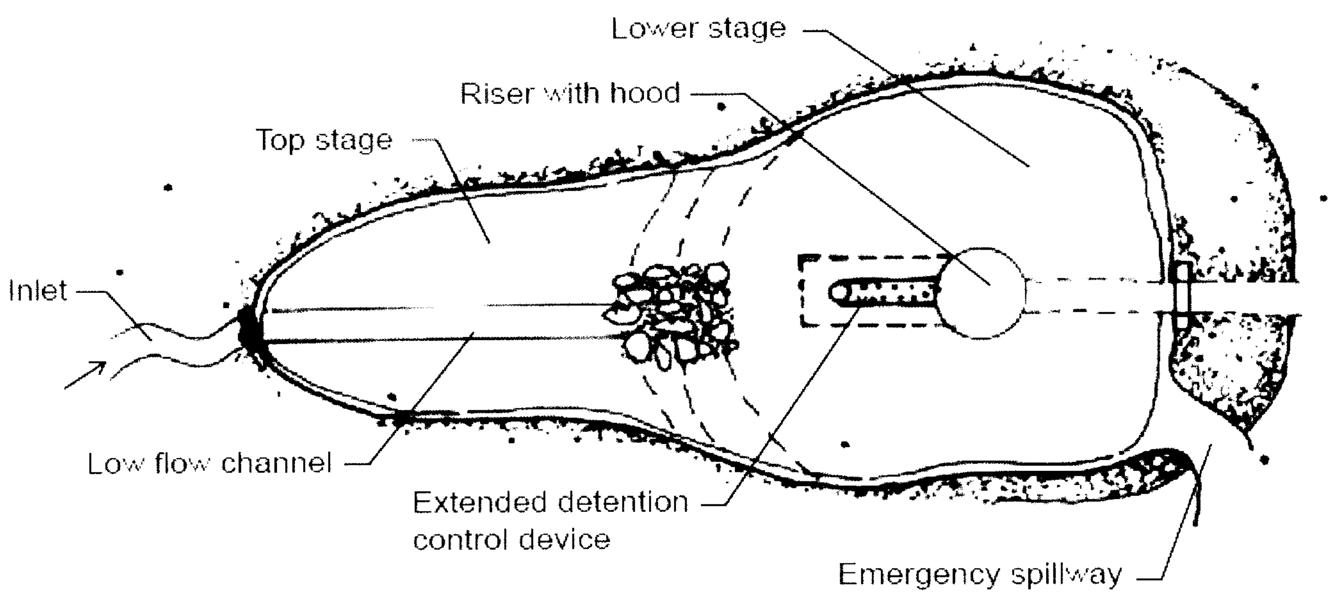


Figure 1: Dry Extended Detention Pond – Plan View
(NRCS, 2003)

Dry Pond

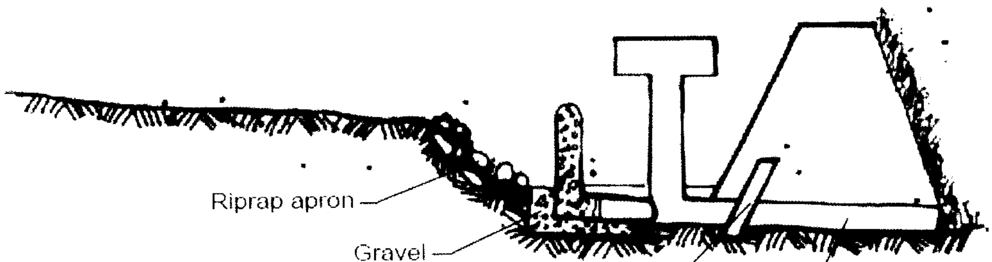


Figure 2: Dry Extended Detention Pond – Section View
(NRCS, 2003)

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

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

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:

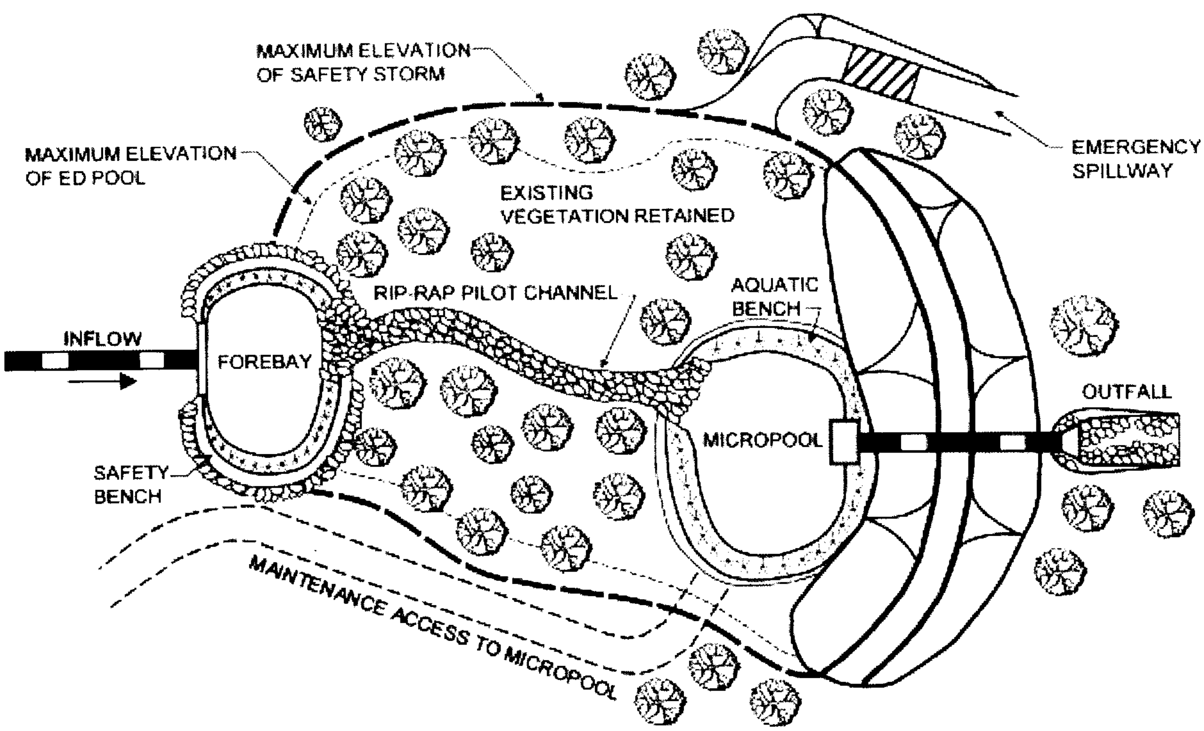


Figure 1: Typical Extended Wet Detention – Plan View (with shallow wetland and micropool options)
(Georgia Stormwater Management Manual, 2001)

Extended Detention Pond With Micropool

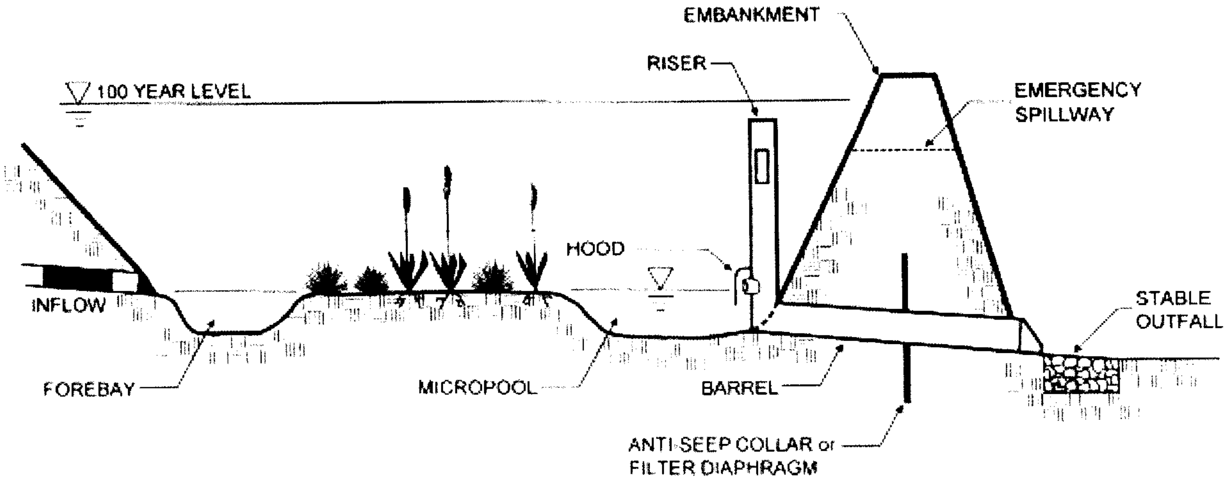


Figure 2: Typical Extended Wet Detention – Section View (with shallow wetland and micropool options)
(Modified from Georgia Stormwater Management Manual, 2001)

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/

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Wet Pond

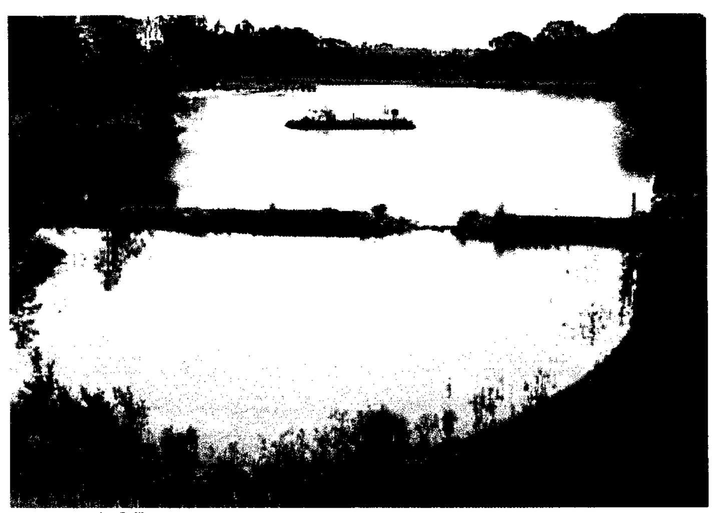
When to use:
- In hydrologic soil types C and D or with clay liner
- In low lying areas
- Water table is at least 3 feet below the pond bottom
- Drainage area of at least 2 acres
- Hydraulic head of 3 to 6 feet
- Not practical for use in ultra urban settings
- Cannot be placed on steep or unstable slopes

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:

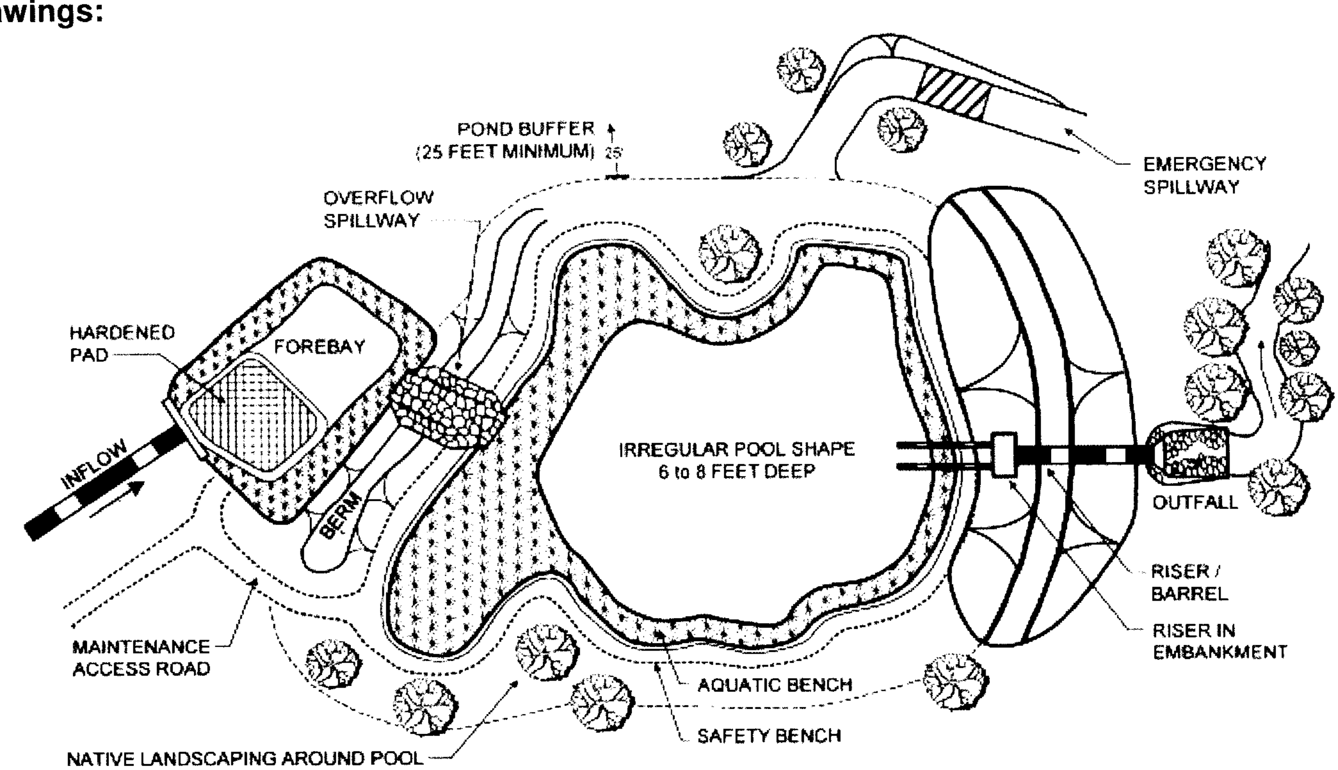


Figure 1: Typical Wet Pond with Wetland Perimeter – Plan View
(Georgia Stormwater Management Manual, 2001)

Wet Pond

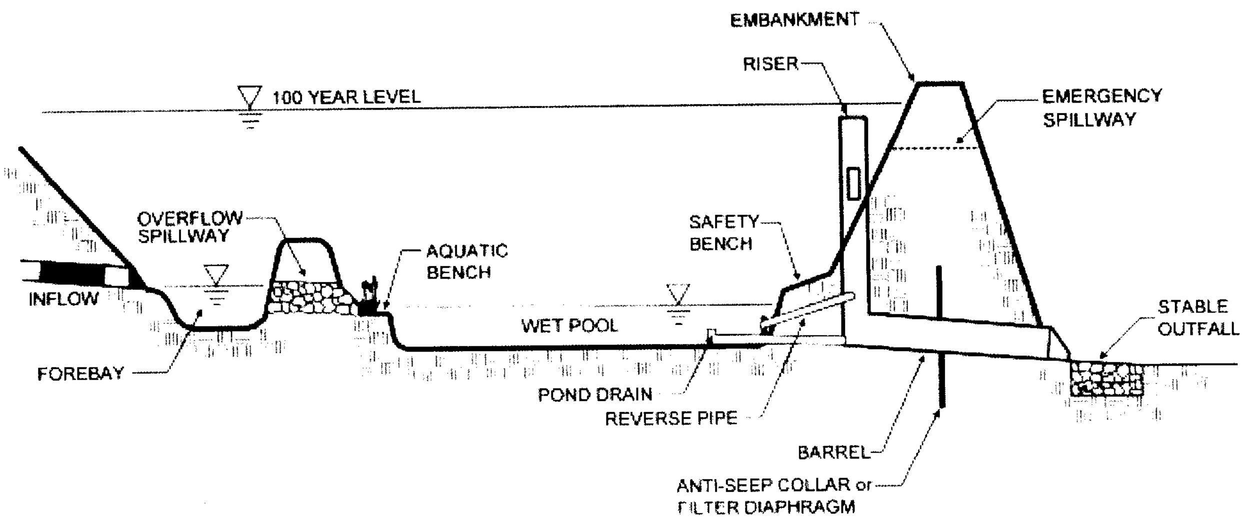


Figure 1: Typical Wet Pond – Section View
(Modified from Georgia Stormwater Management Manual, 2001)

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

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

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:

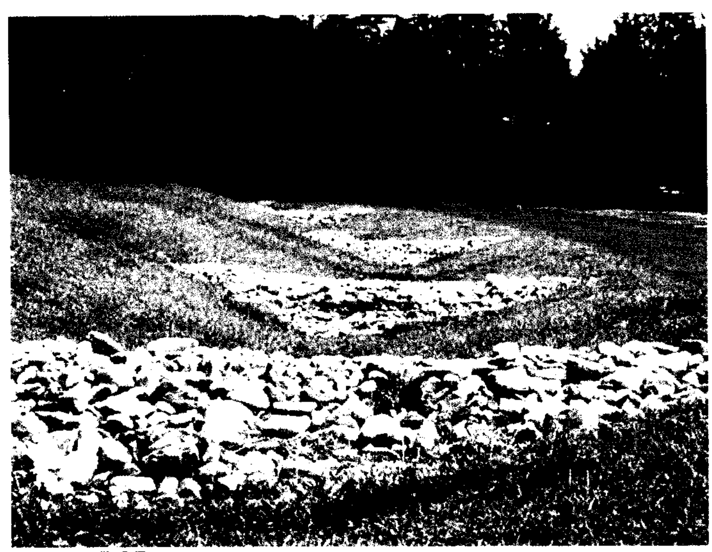
- Can achieve 80% TSS removal as a stand alone BMP
- Can accept pollutants from offsite hotspots
- Low construction cost
- Low maintenance cost
- Moderate community acceptance
- Relatively easy to design, install and maintain

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:

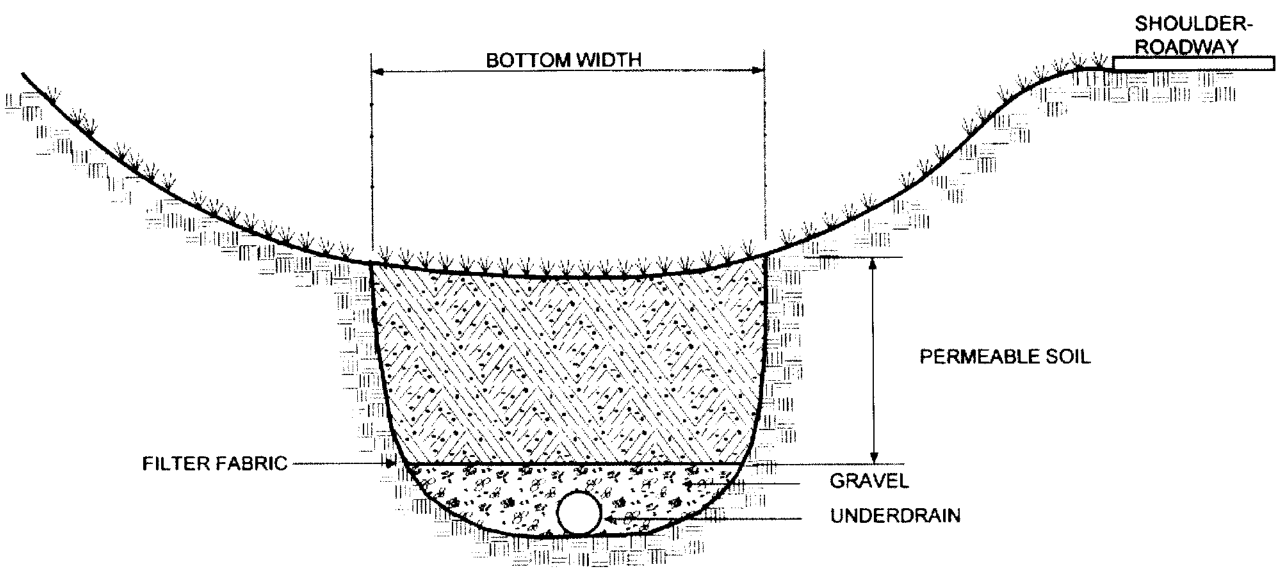


Figure 1: Typical Swale Configuration – Section View
(Modified From Center for Watershed Protection)

Dry Swale

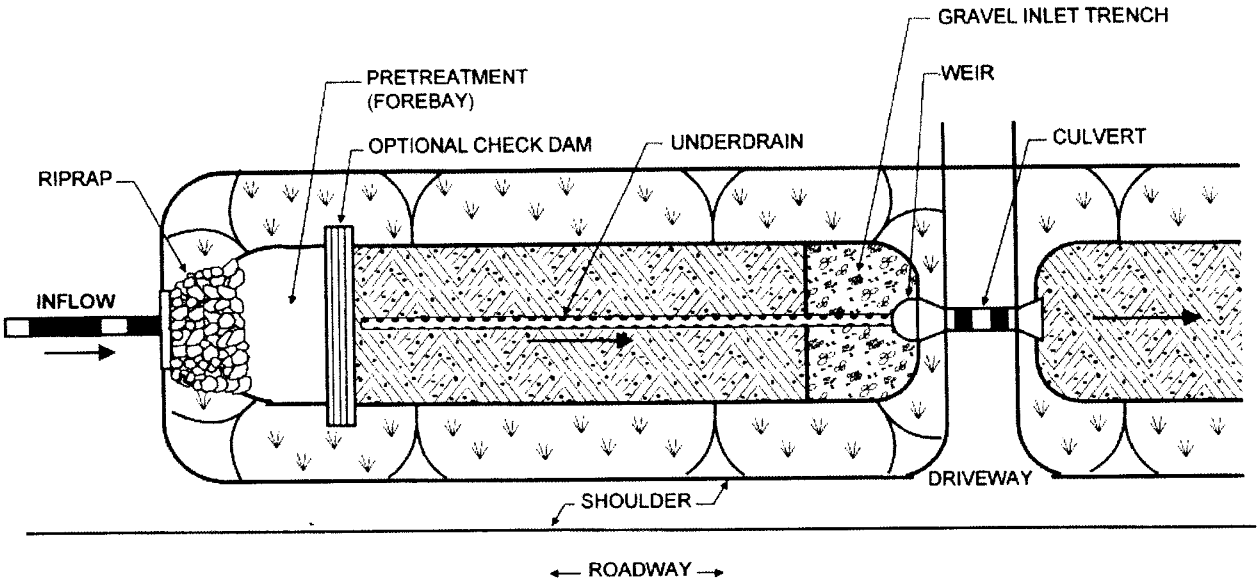


Figure 2: Typical Swale Configuration – Plan View
(Modified From Center for Watershed Protection)

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

INDIANA DEPARTMENT OF TRANSPORTATION

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:

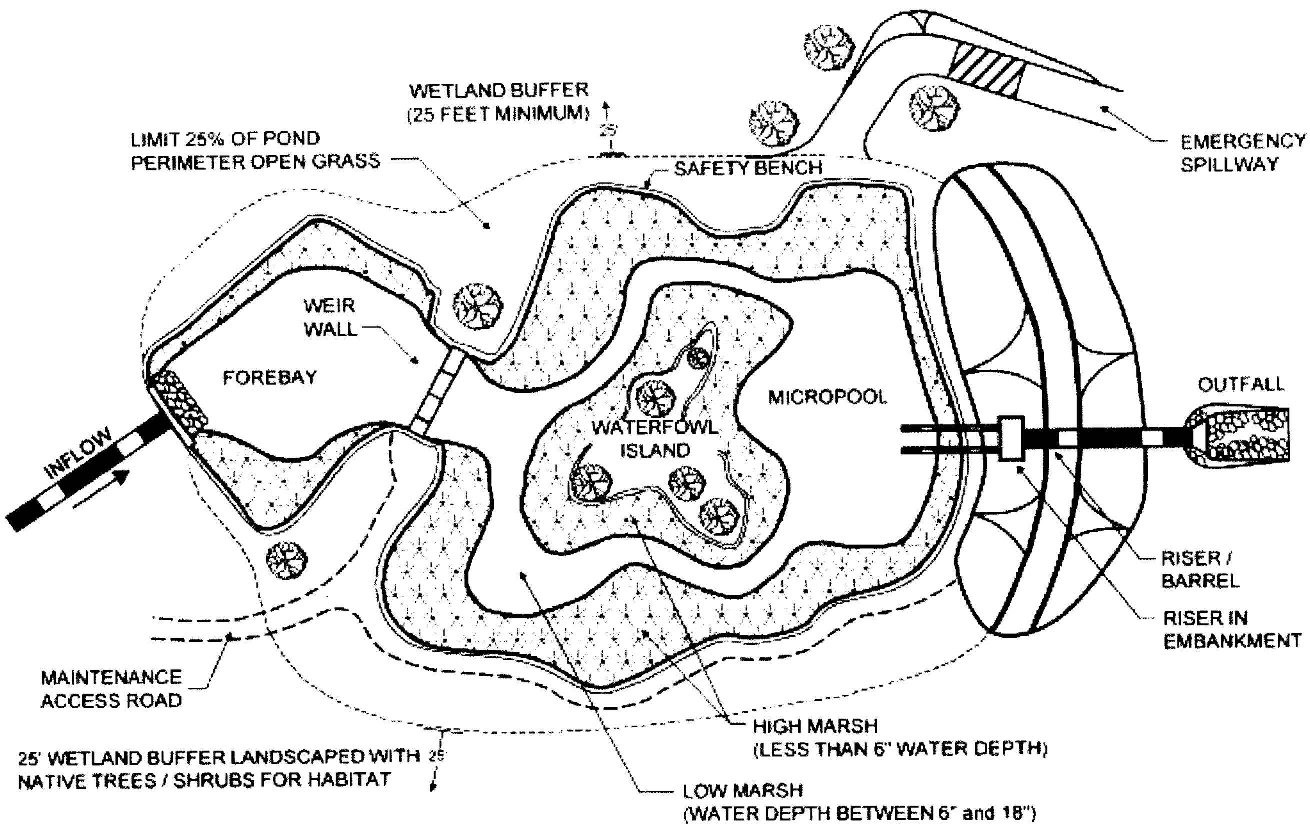


Figure 1: Constructed wetland plan view
(Georgia Stormwater Management Manual, 2001)

Stormwater Wetlands

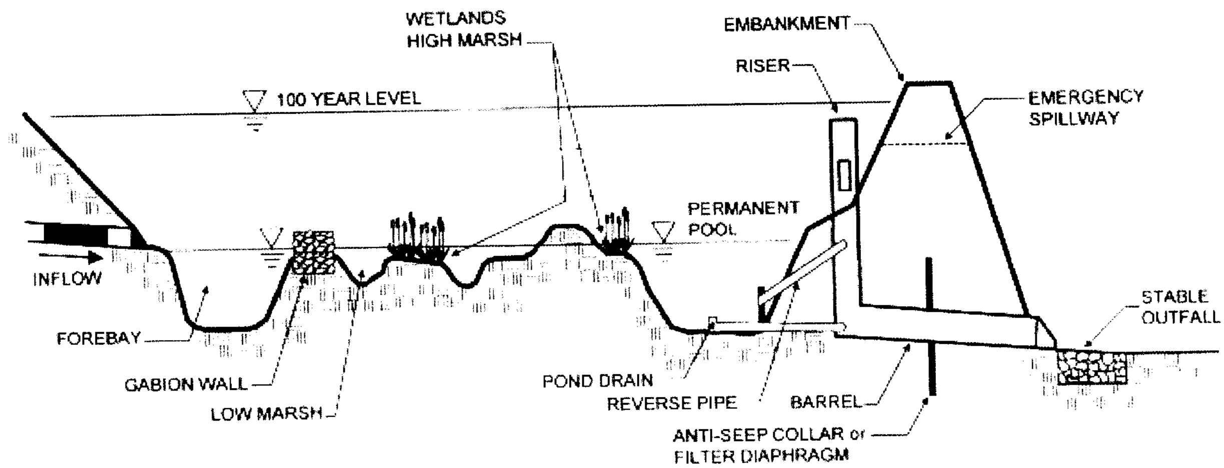


Figure 2: Constructed wetland section view
(Georgia Stormwater Management Manual, 2001)

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

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:

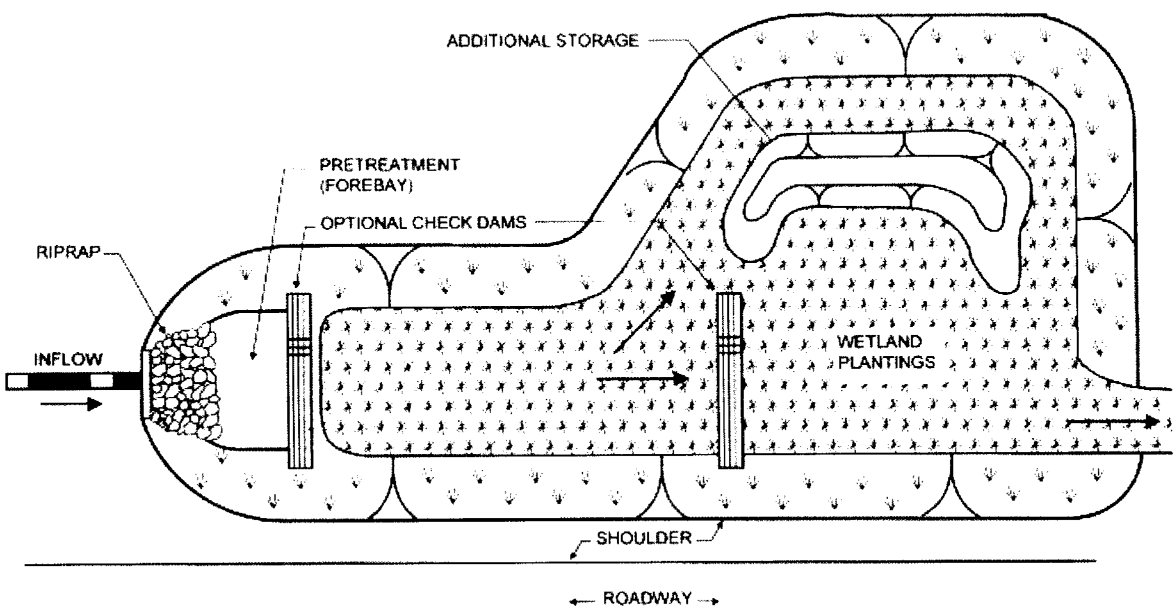


Figure 1: Plan View of a Wet Swale
(Center for Watershed Protection)

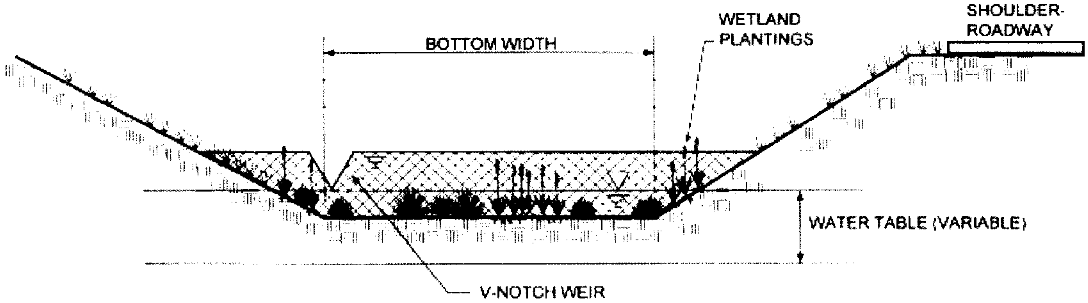


Figure 2: Section view of a wet swale with optional check dam (Modified from Center for Watershed Protection)

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

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

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:

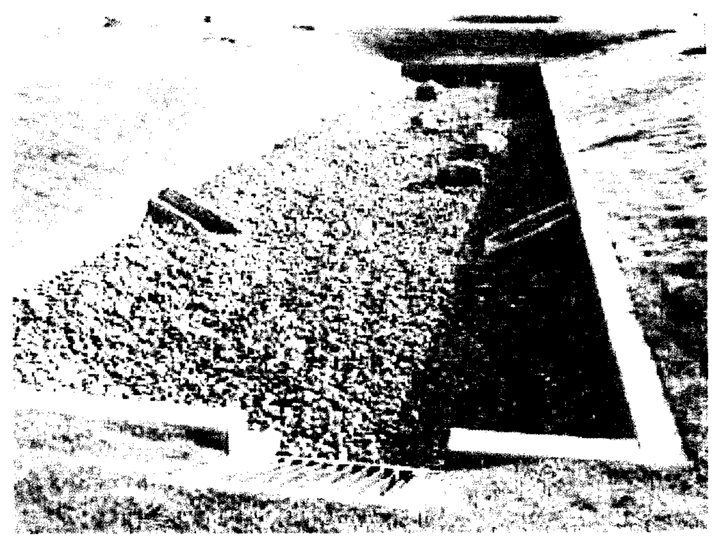
- Can achieve 80% TSS removal rates as a stand alone BMP
- Highly efficient removal of pollutants of concern
- Low to moderate maintenance cost
- Moderate to high community acceptance
- Provides water quantity benefit in the form of runoff volume control
- Provides groundwater recharge

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:

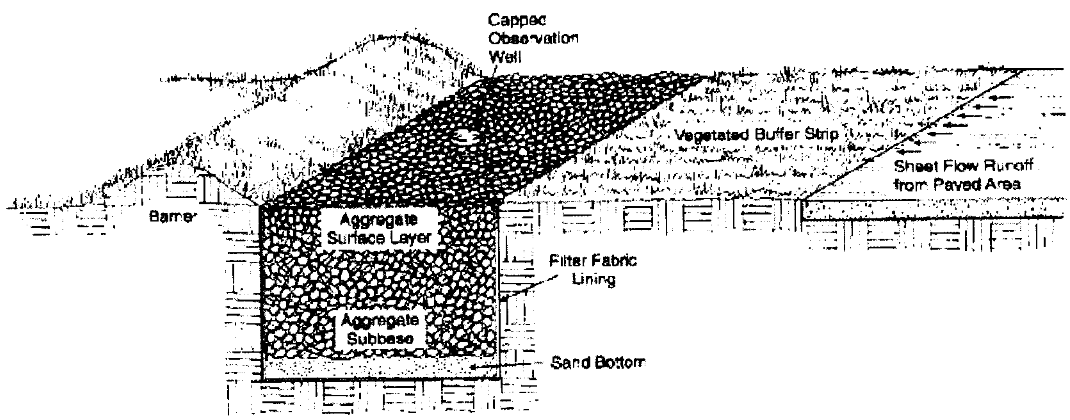


Figure 1: Typical Above Ground Infiltration trench Configuration
(Modified from Georgia Stormwater Management Manual, 2001

Infiltration Trench

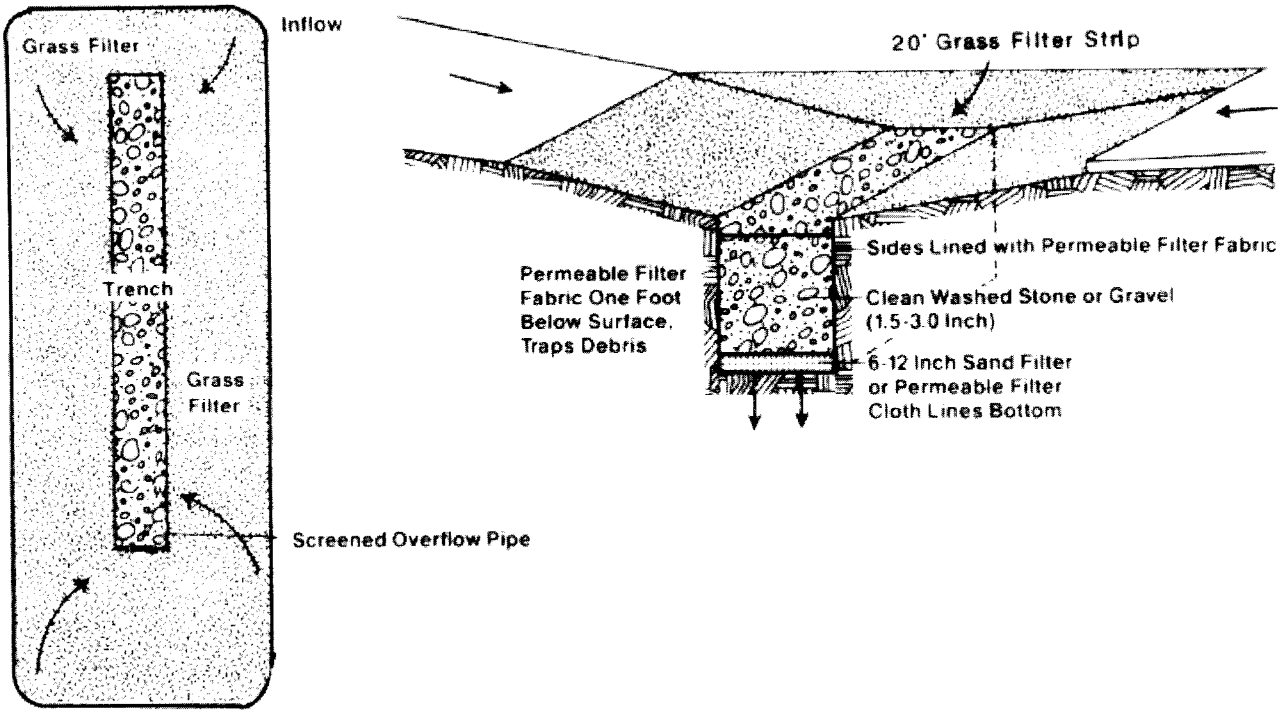


Figure 2: Infiltration Trench, Road Median Application – Plan and Section View
(Metropolitan Council, 2001)

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

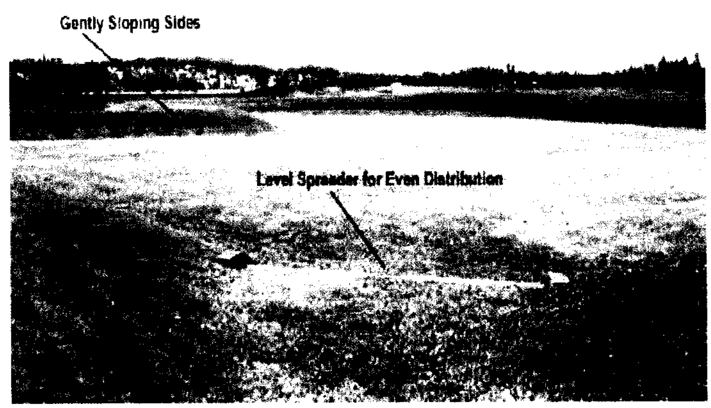
When to use:
- Should not be used in karst areas
- In soil types A and B
- Water table is at least 3 feet below the basin
- Drainage area of 2 to 20 acres
- Hydraulic head of 3 to 4 feet
- Not practical for use in ultra urban settings

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:

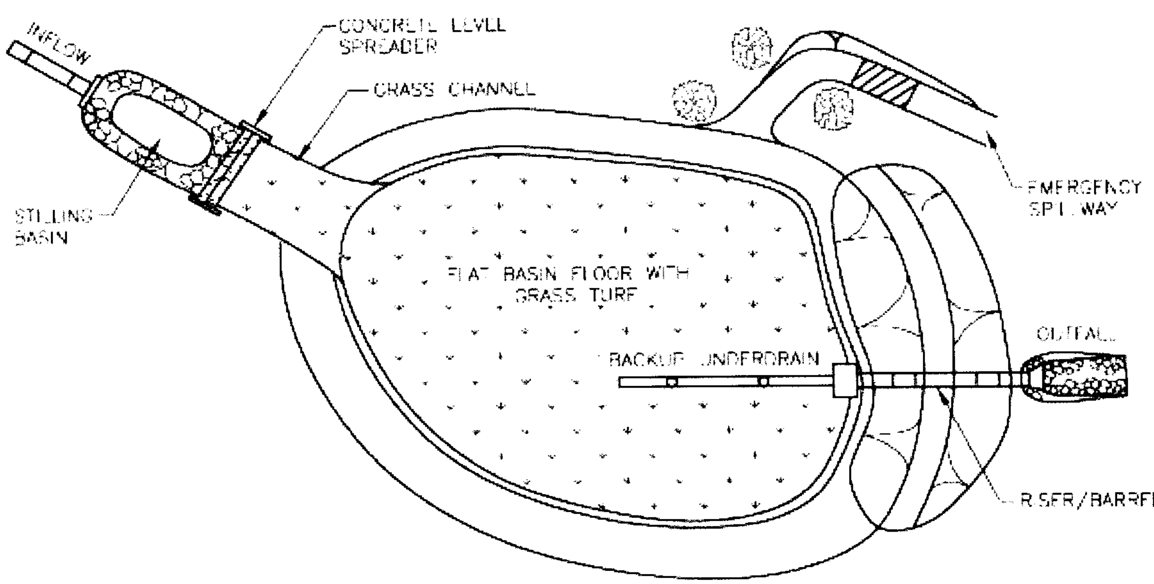


Figure 1 – Plan view of an infiltration basin
(PA SW Management Manual, 2005)

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

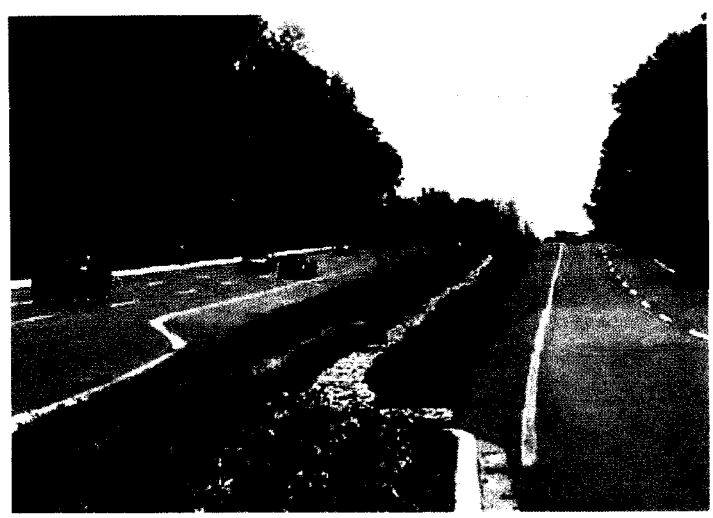
When to use:
- Any soil type
- Low lying areas
- Water table is at least 3 feet below the swale invert
- Drainage area of 2 to 4 acres
- Hydraulic head of 2 to 3 feet
- Can be used in ultra urban settings

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:

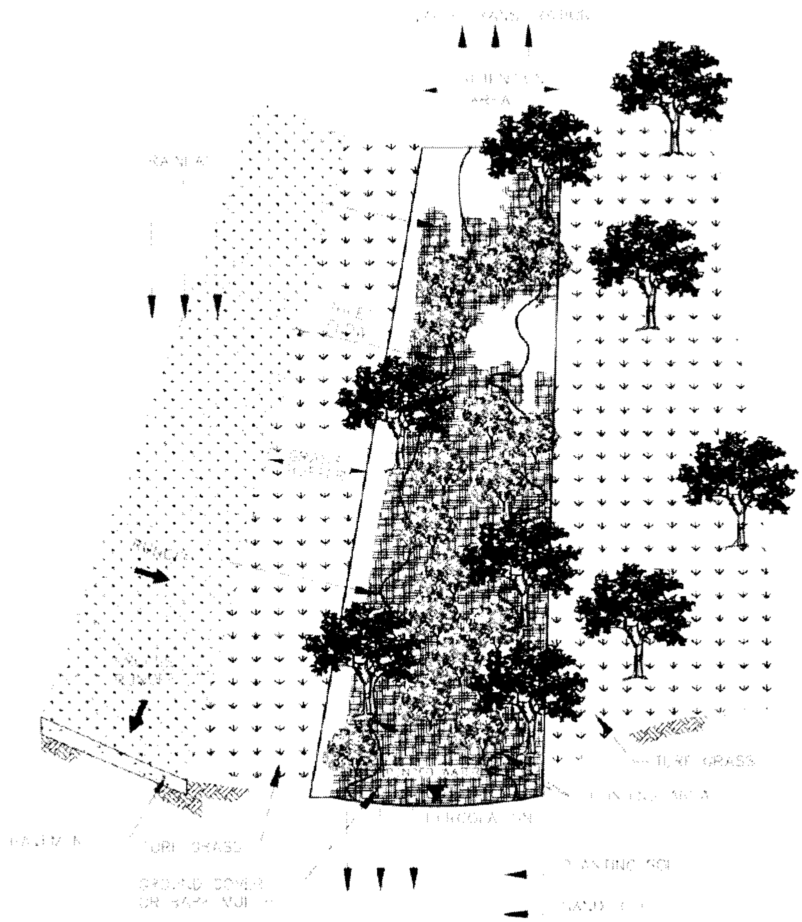


Figure 1: Bioretention Basin
(Virginia DCR, 1999)

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

INDIANA DEPARTMENT OF TRANSPORTATION

Stormwater Quality Best Management Practices
Post-Construction Stormwater Treatment

Filter Strip

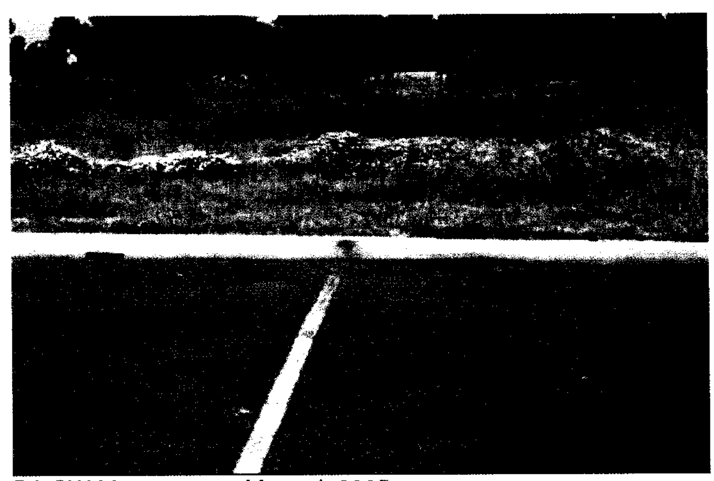
When to use:
- Any soil type
- Moderately sloping terrain
- Water table is at least 3 feet below the filter strip
- Drainage area of less than 5 acres
- Where sheet flow can be achieved
- Not practical for use in ultra urban settings

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:

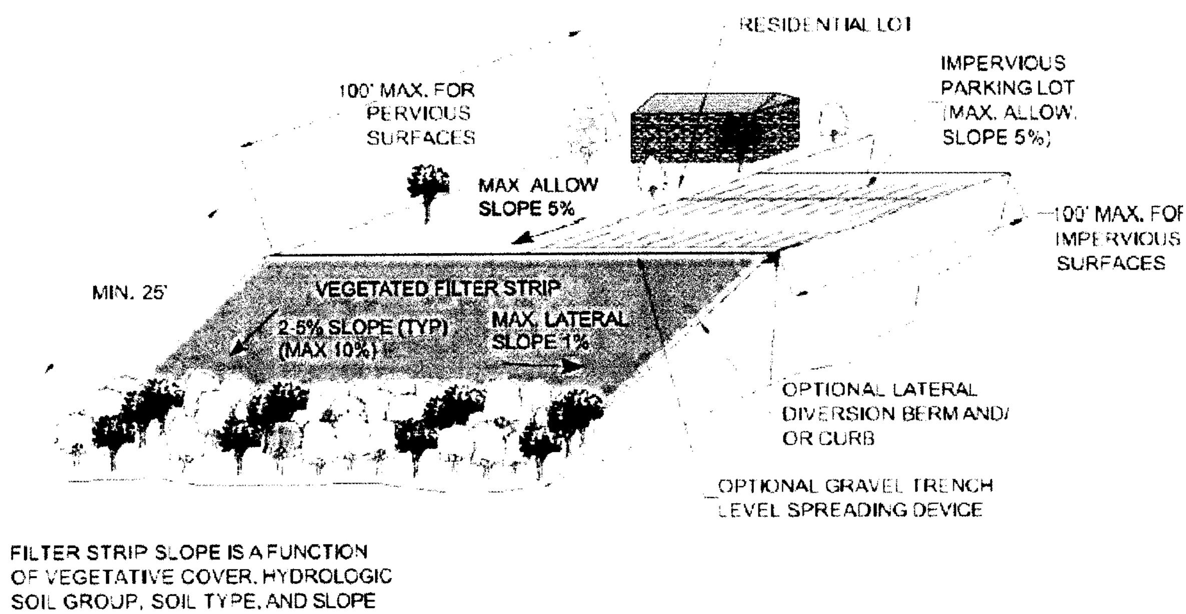


Figure 1: Filter Strip – Isometric View
(PA SW Management Manual, 2005)

Filter Strip

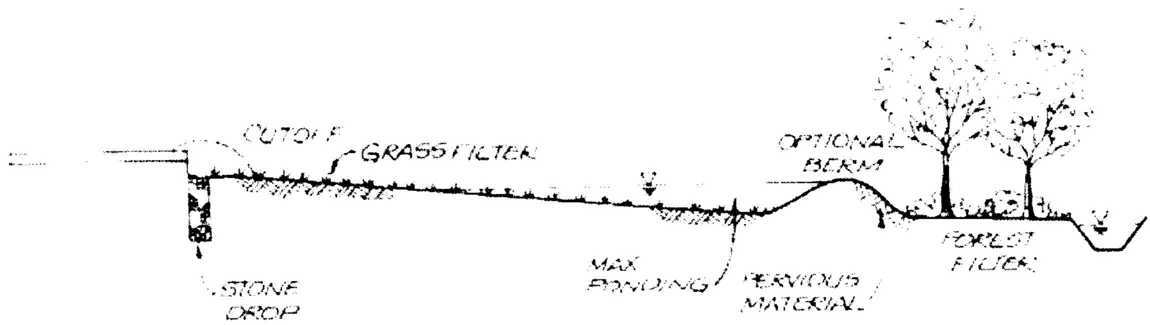


Figure 2: Filter Strip modified for quantity control
(Metropolitan Council, 2001)

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:

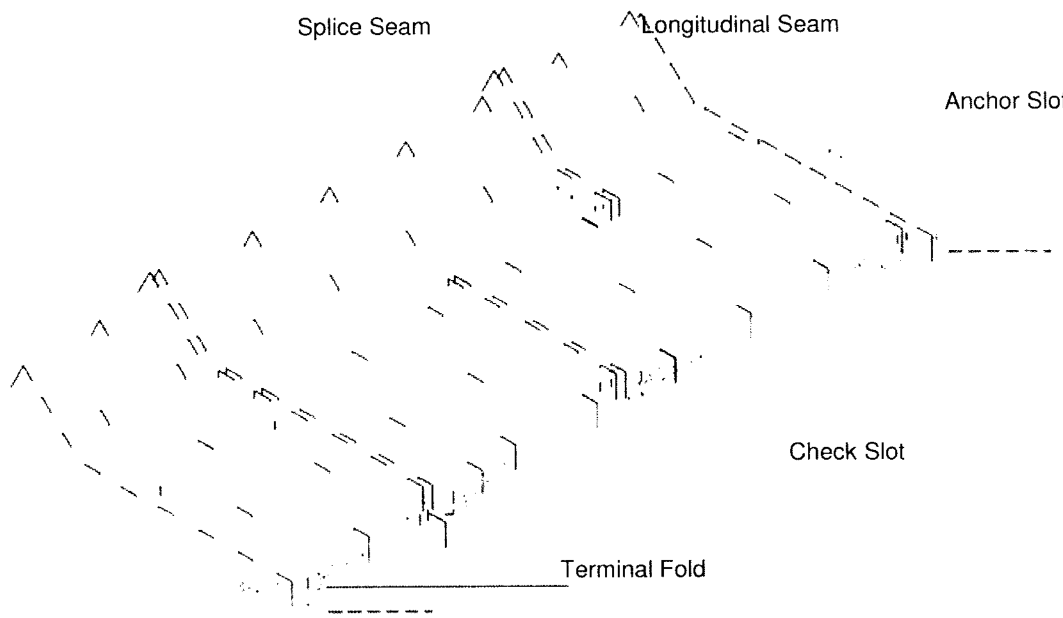


Figure 1: Channel Application
(TDOT, 2005)

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

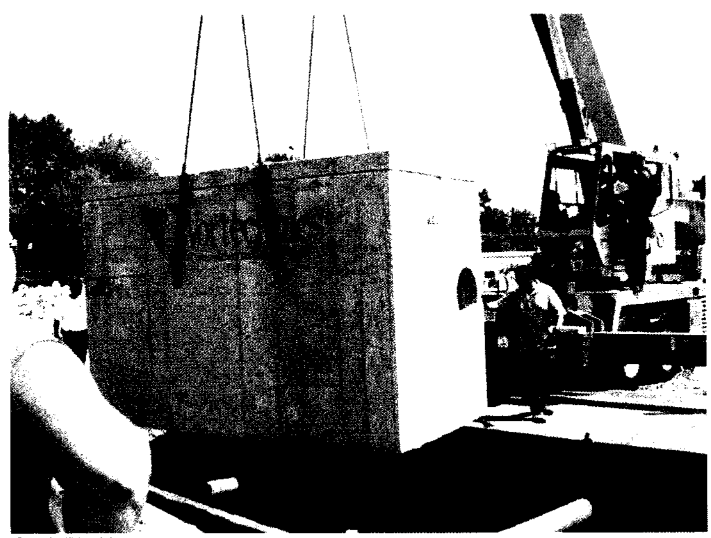
Hydrodynamic Separators

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



CBBEL file, 2005

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

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:

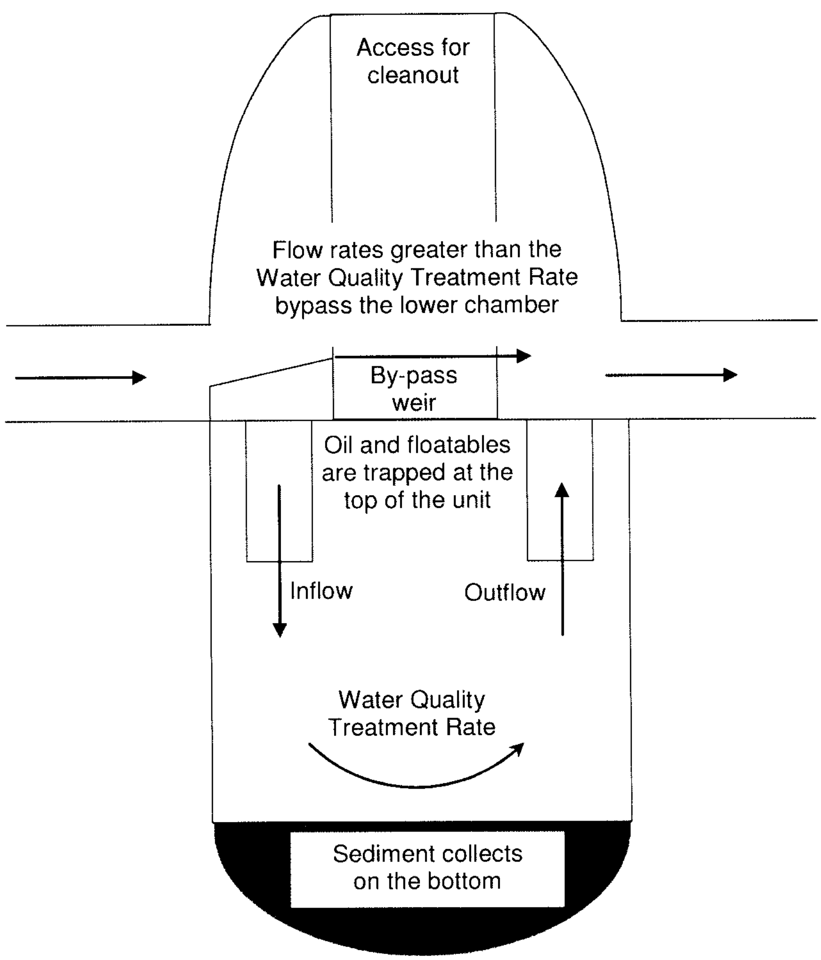


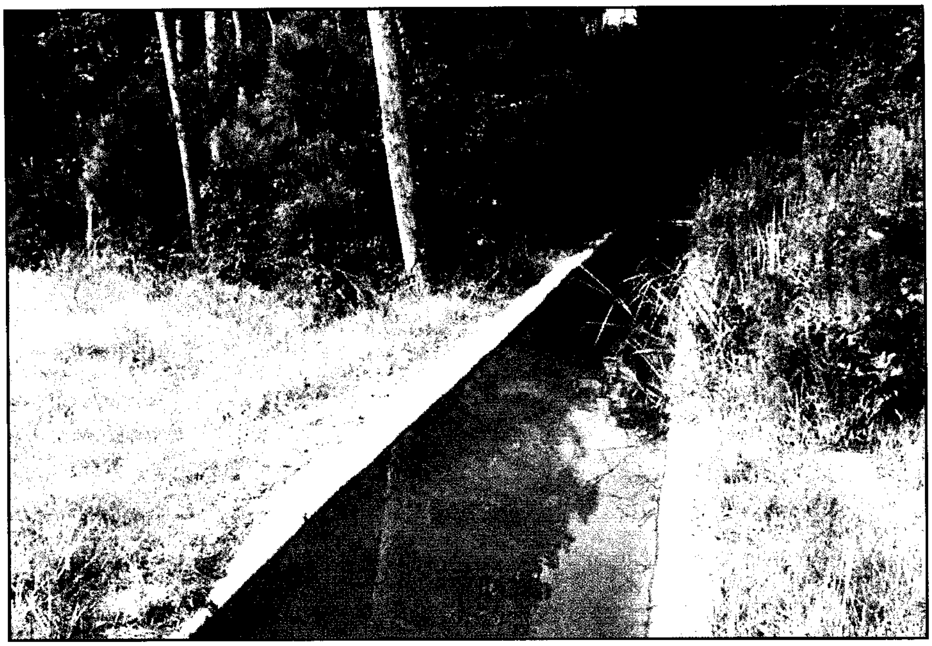
Figure 1: General Hydrodynamic Separator Schematic (CBBEL, 2005)

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.

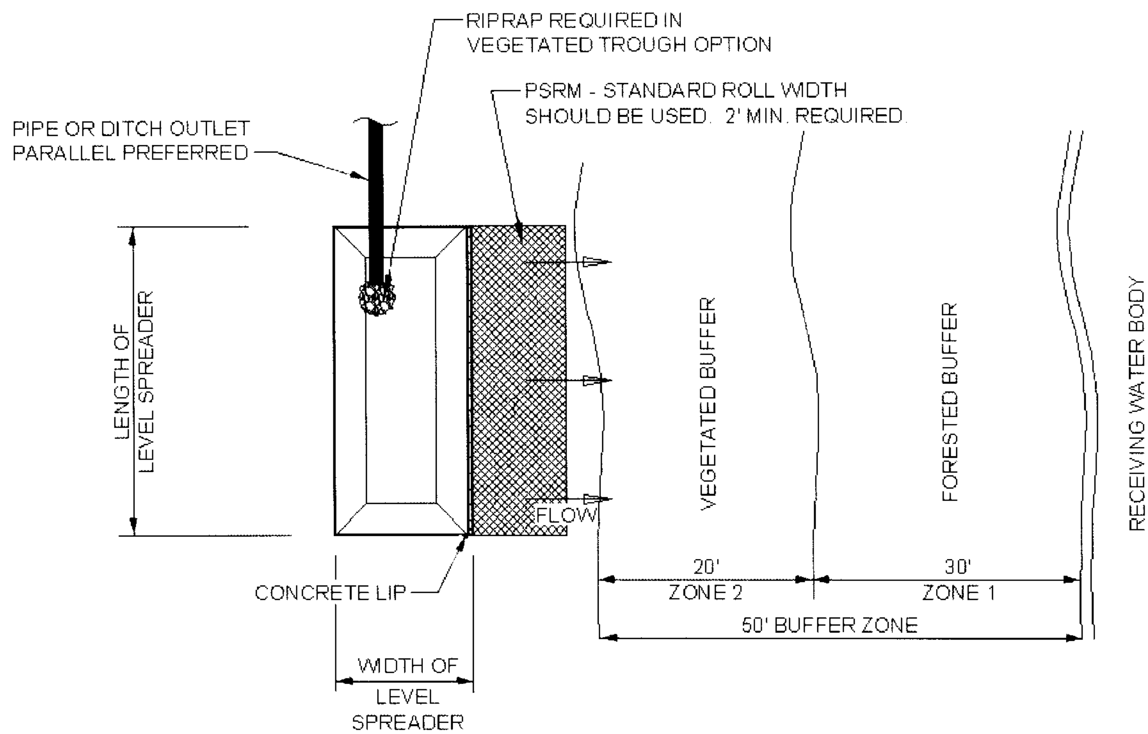


Figure 3-1. Typical level spreader layout and components

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.

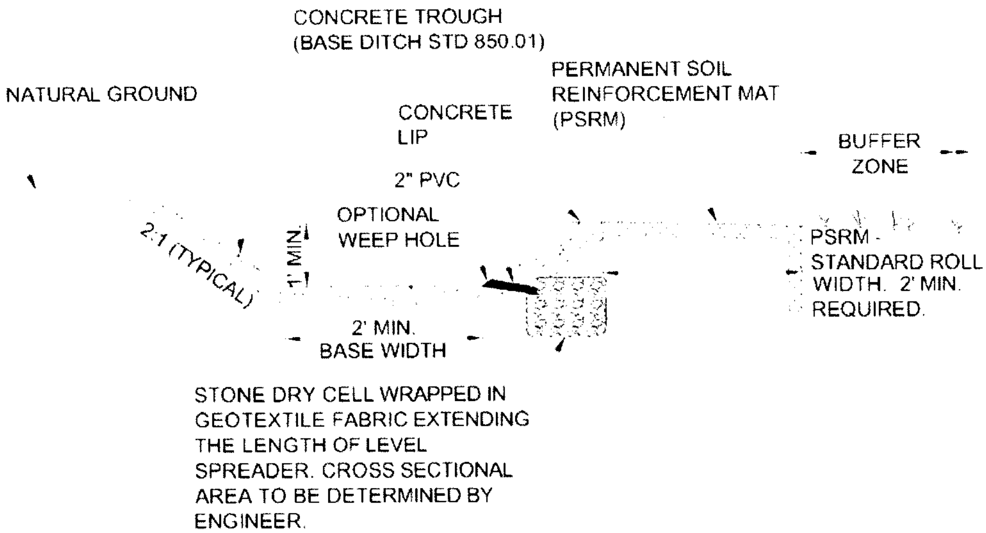


Figure 3-2. Level spreader with concrete trough

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.

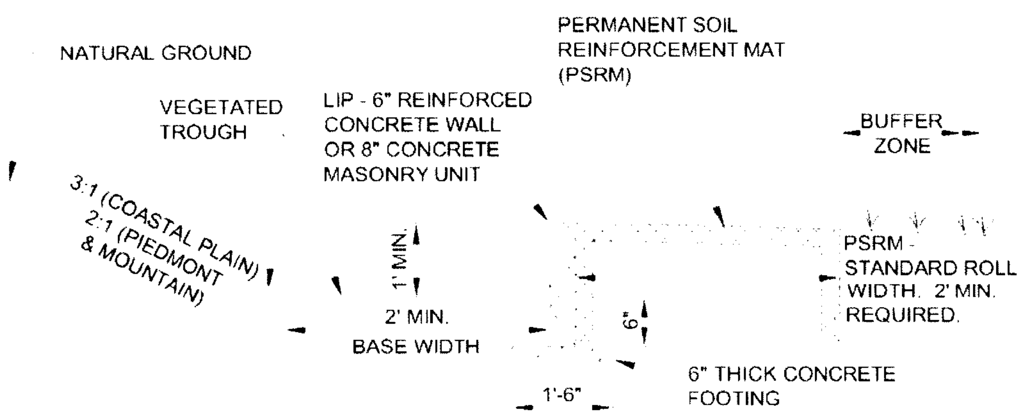


Figure 3-3. Level spreader with vegetated trough

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.

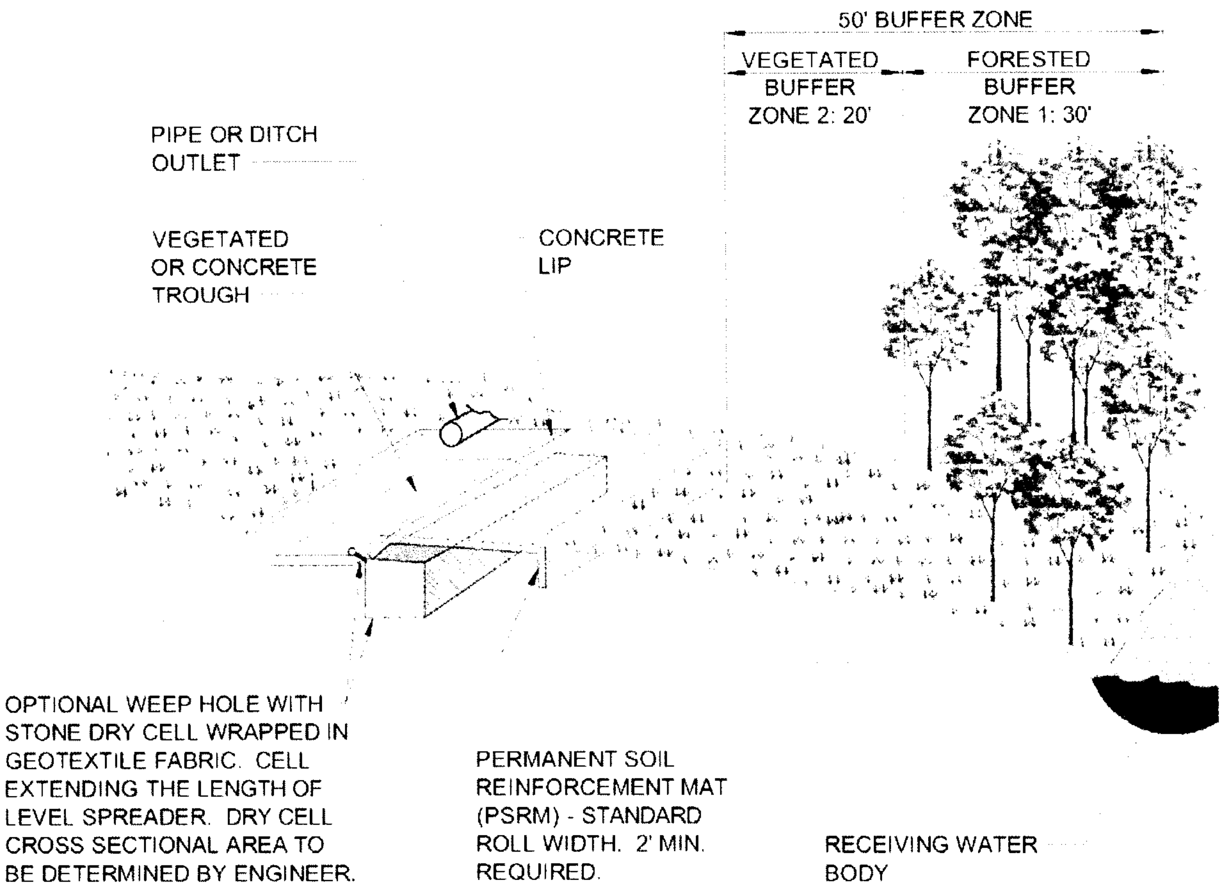


Figure 3-4. Typical level spreader with buffer

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.

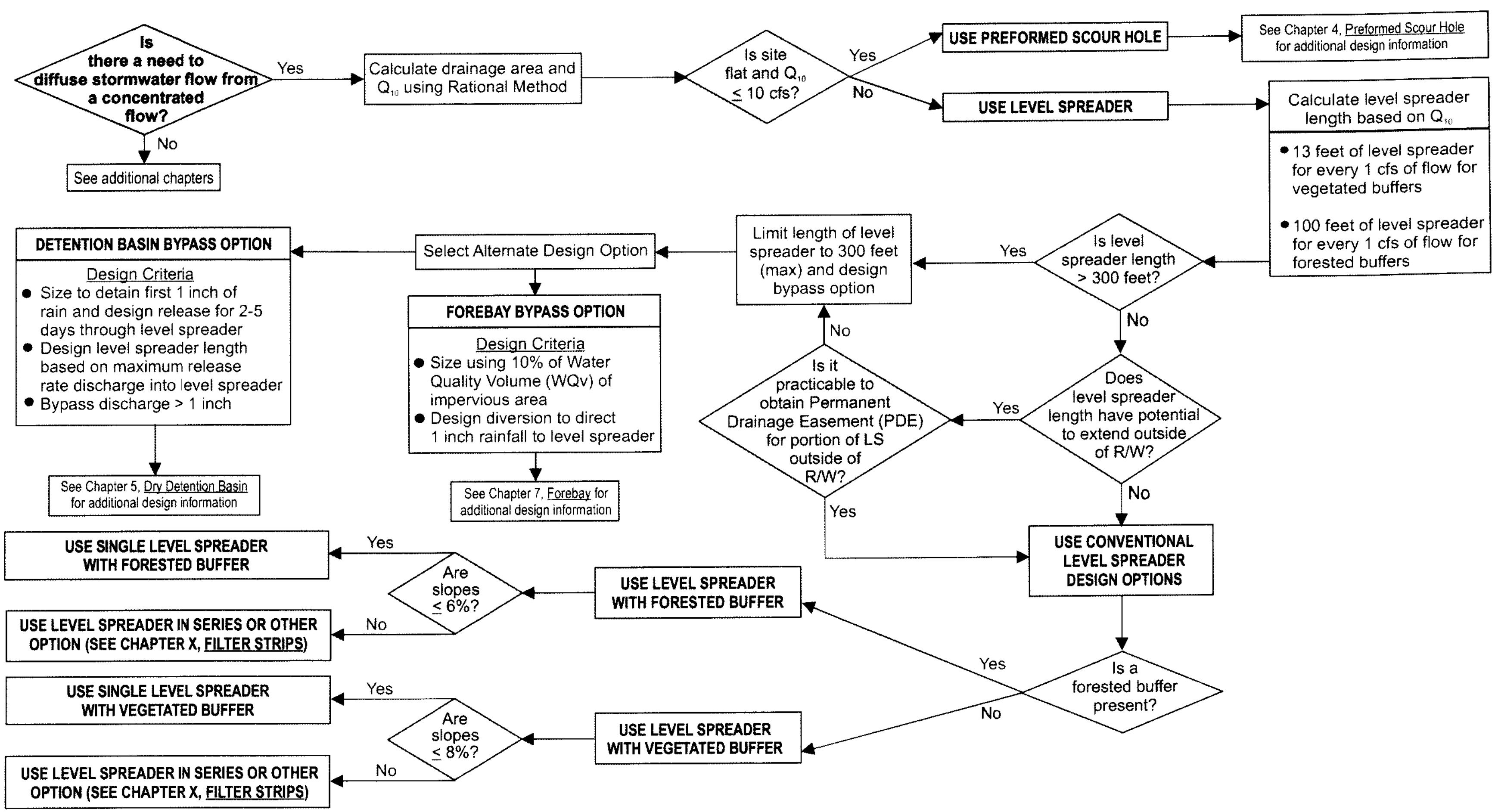


Figure 3-5. Level spreader design flowchart

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.

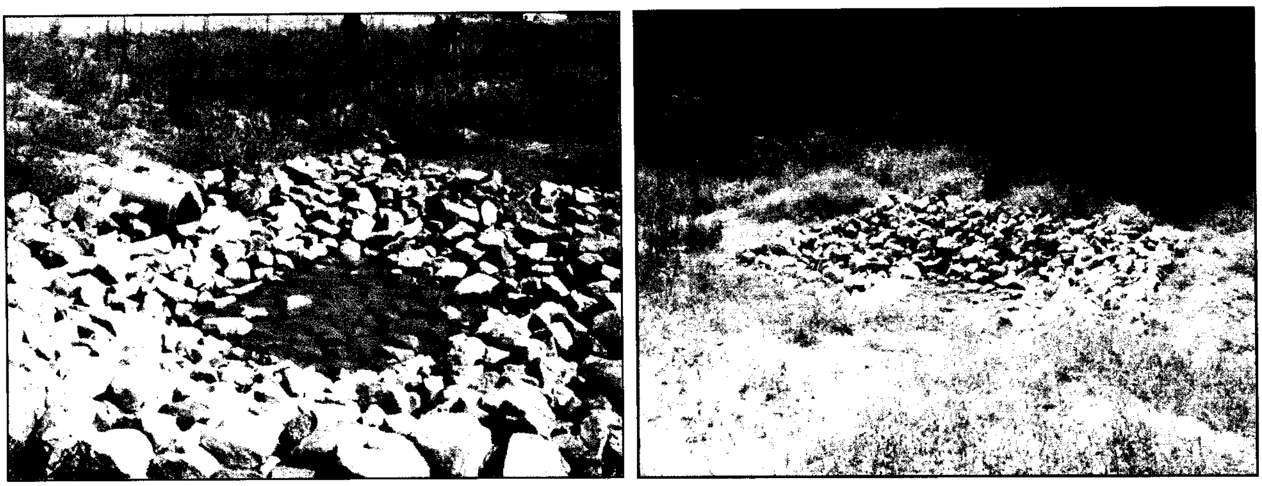


Figure 4-1. Preformed scour holes

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.

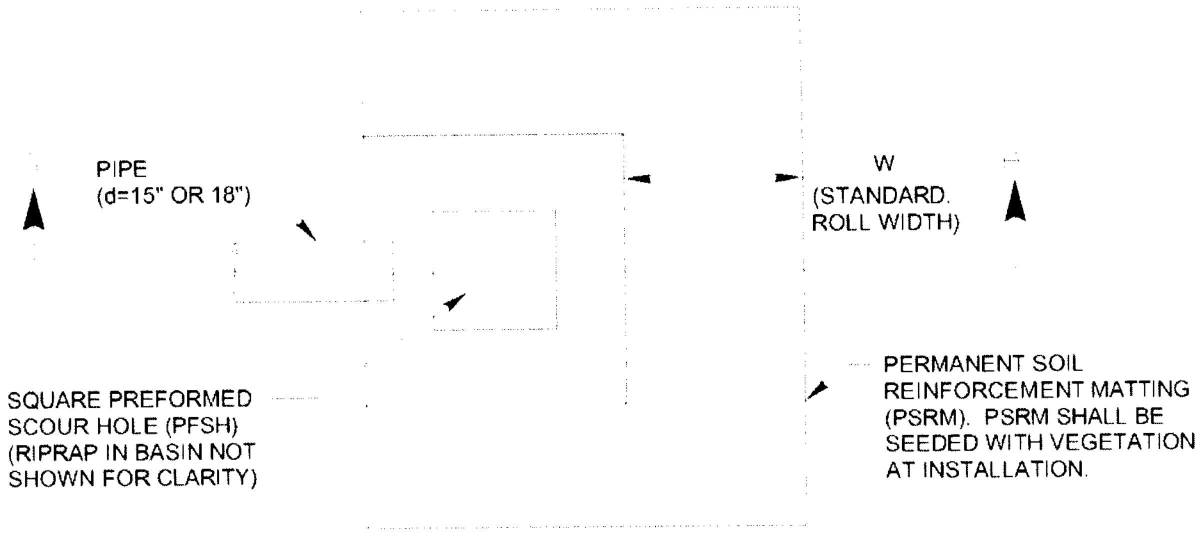


Figure 4-2. Typical preformed scour hole layout and components

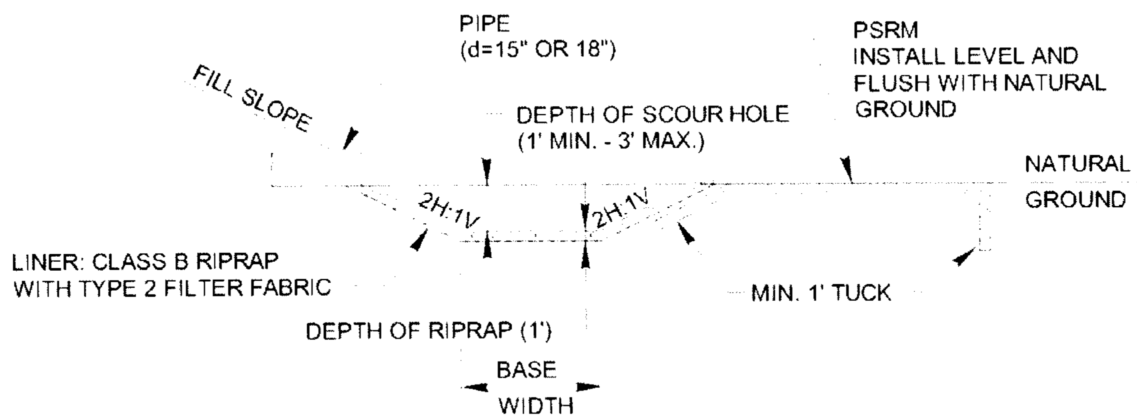


Figure 4-3. Preformed scour hole cross section

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.

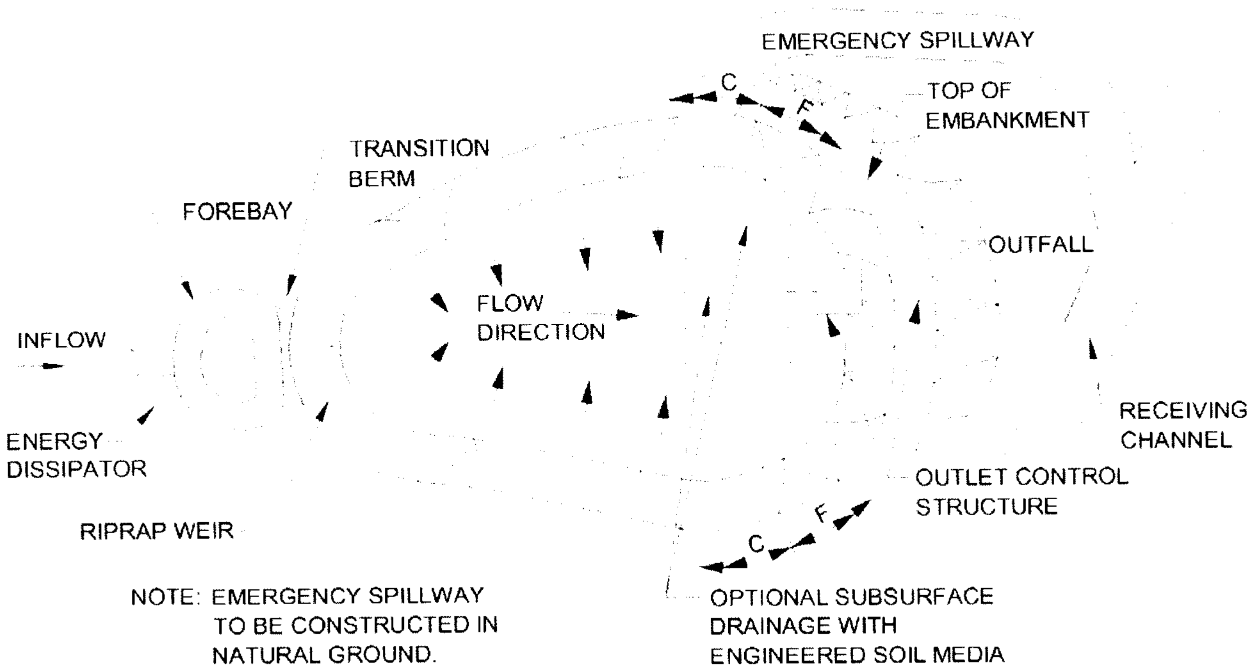


Figure 5-2. Typical dry detention basin layout and components

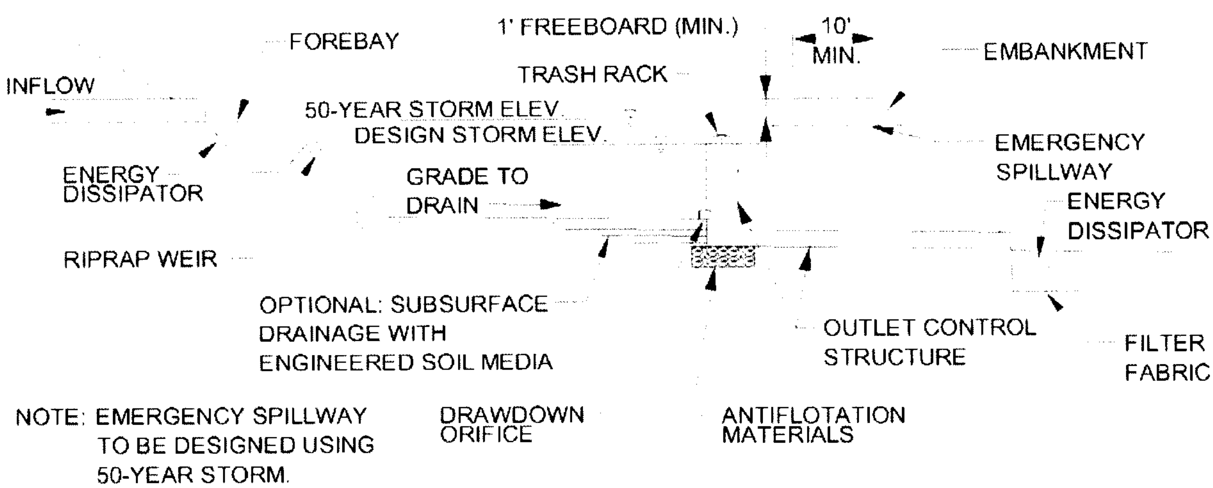


Figure 5-3. Dry detention basin cross section

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.

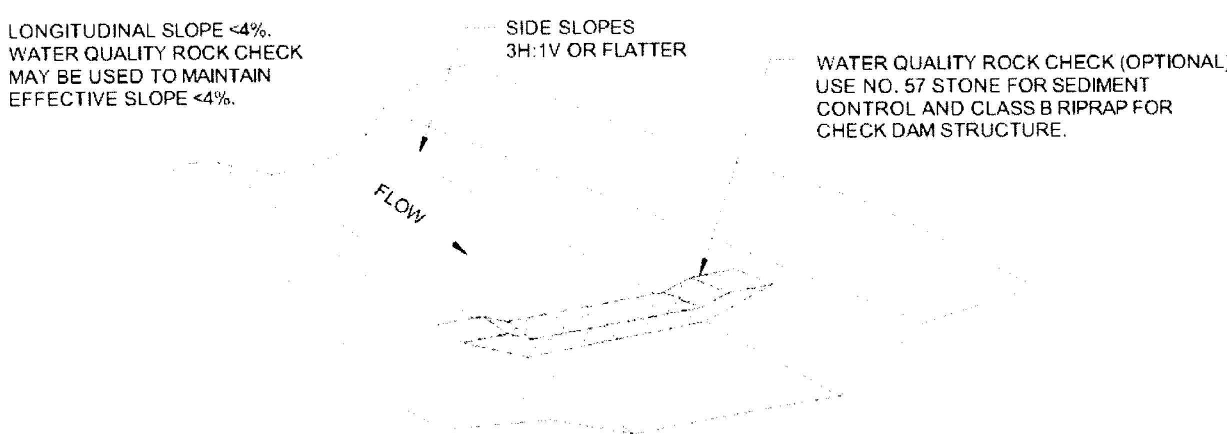


Figure 6-2. Isometric view of a grass swale with optional water quality rock check

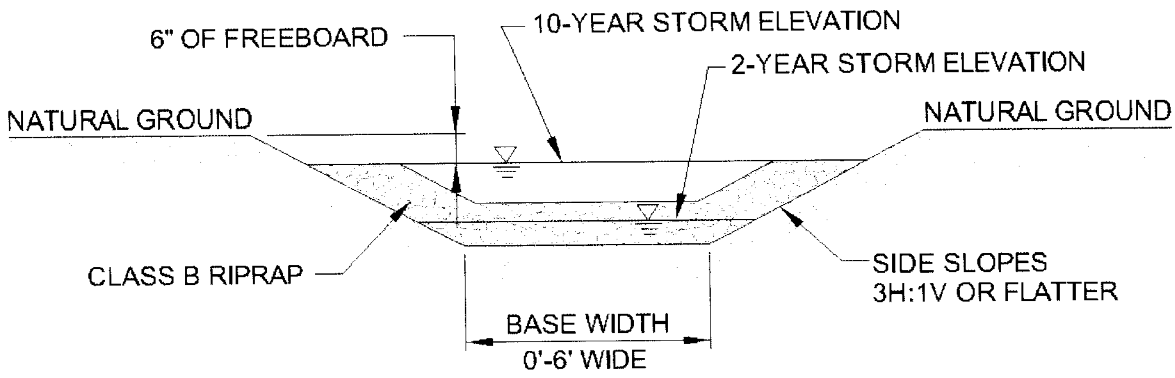


Figure 6-3. Grass swale cross section with optional water quality rock check

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.

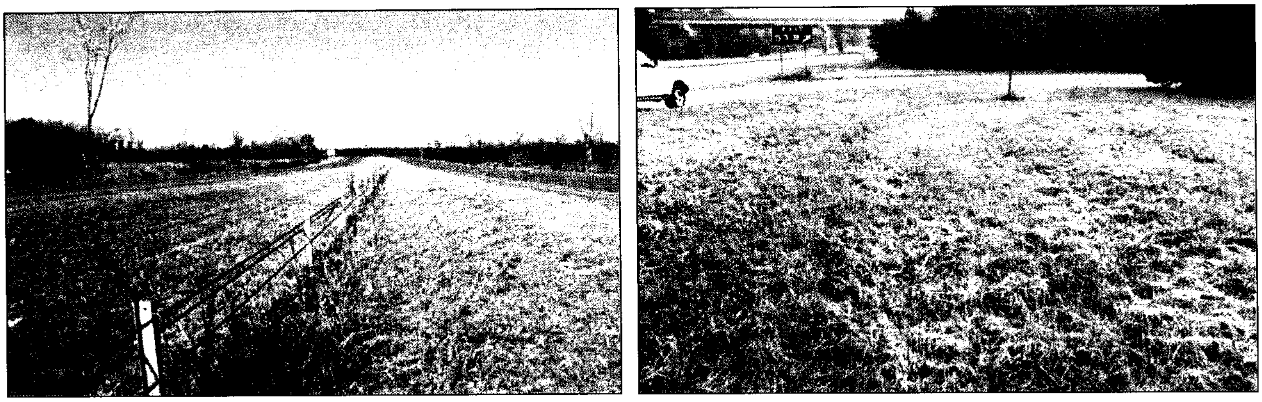


Figure 6-4. Linear highway applications of grass swales

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.

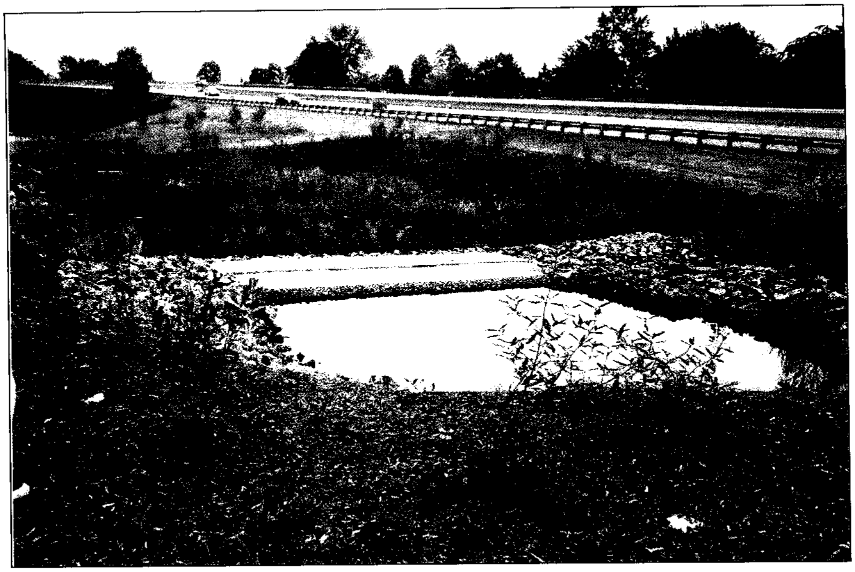
Figure 6-5. Grass swales without established vegetation

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.

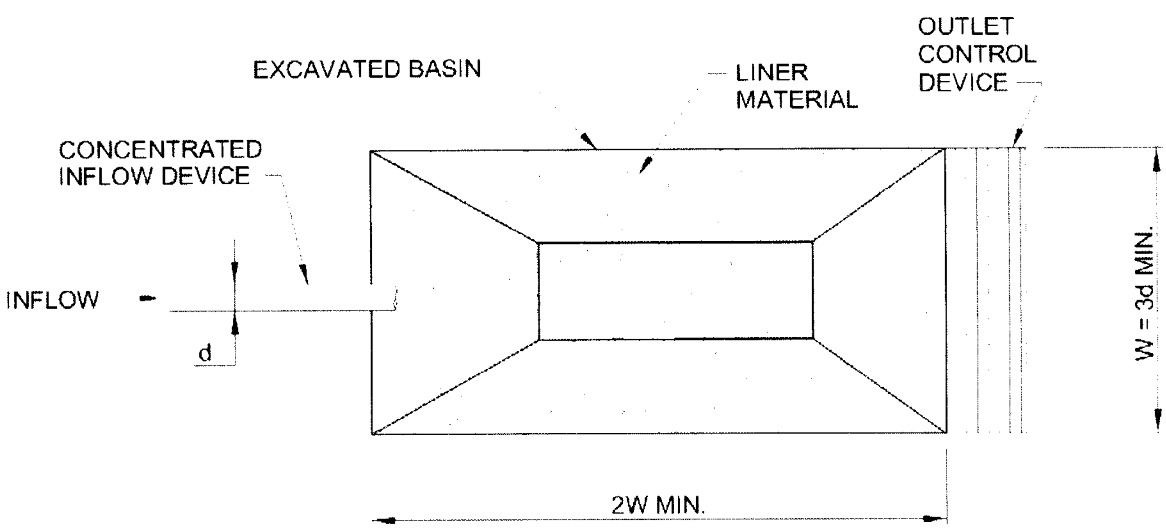


Figure 7-2. Typical forebay layout and components

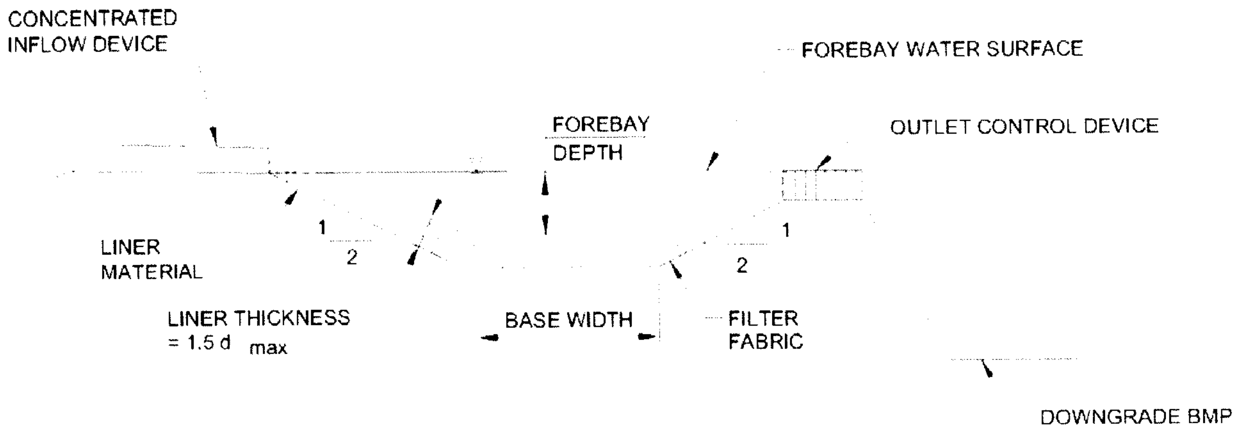


Figure 7-3. Forebay cross section

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.

Forebay

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)

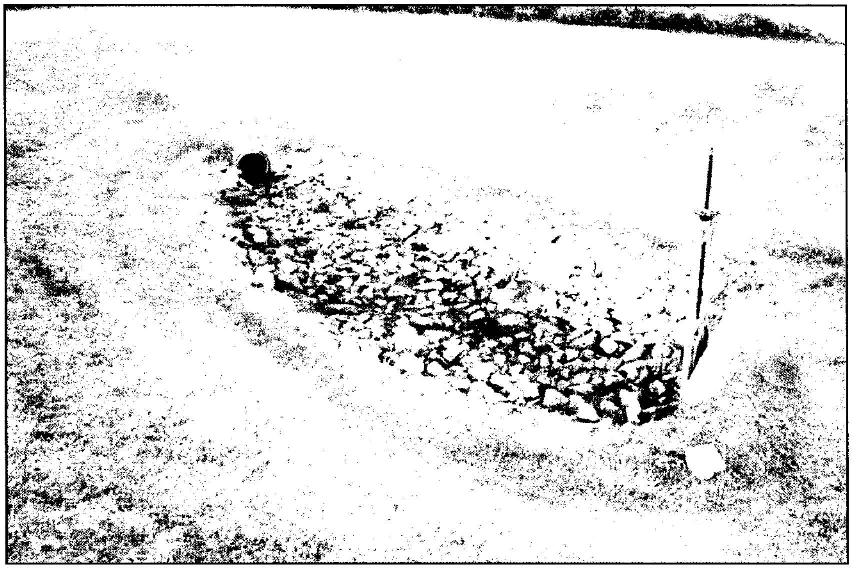
General inspection and maintenance recommendations are as follows:

- 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.

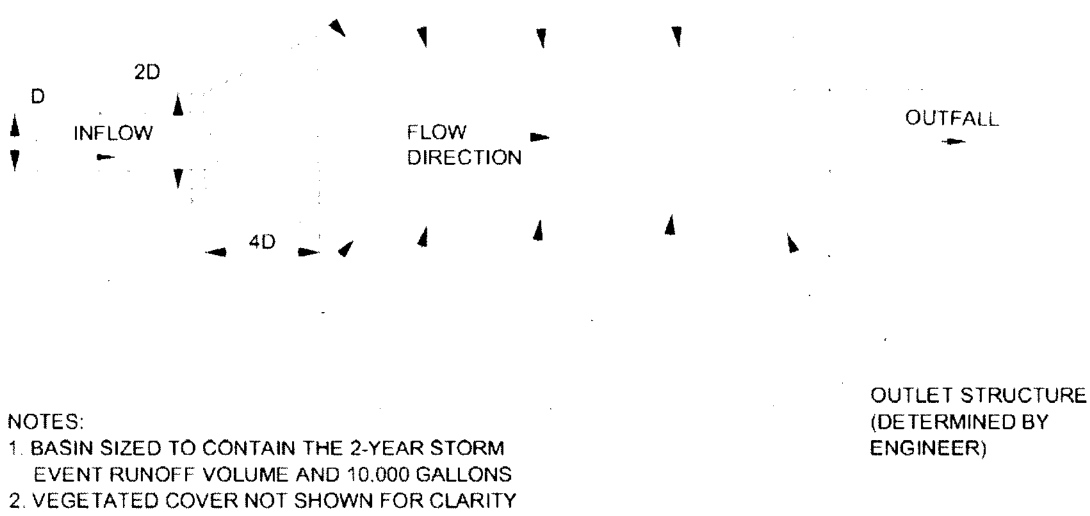


Figure 8-2. Typical hazardous spill basin layout and components

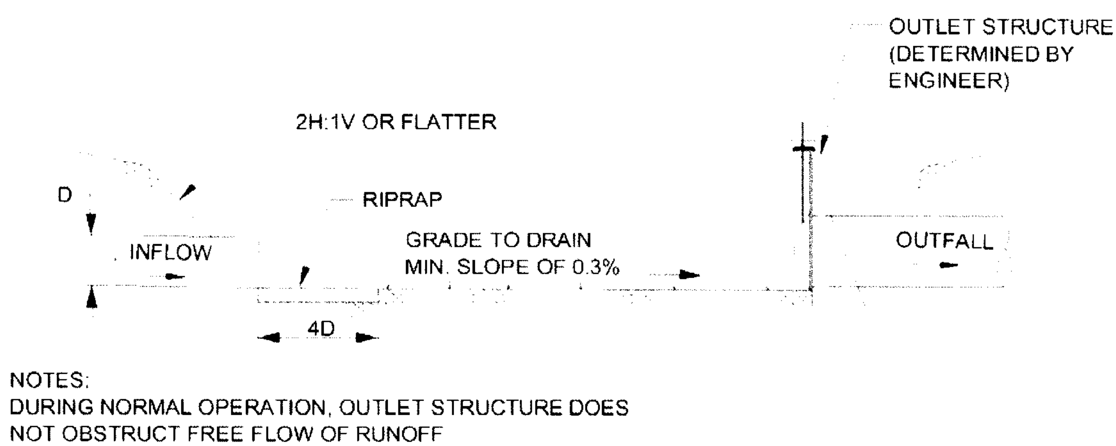


Figure 8-3. Hazardous spill basin cross section

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.

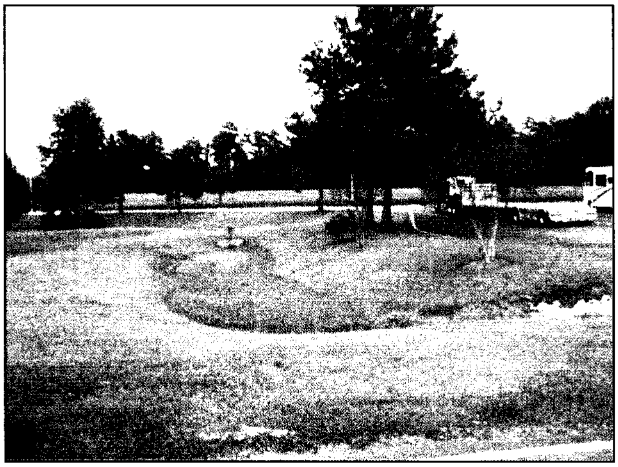


Figure 8-4. A hazardous spill basin at a rest area (left) and in a linear highway setting (right)

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.

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.

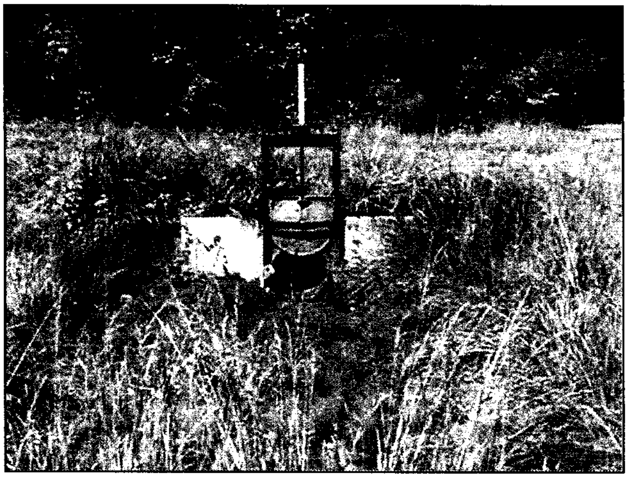


Figure 8-5. A sluice gate in a hazardous spill basin

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.

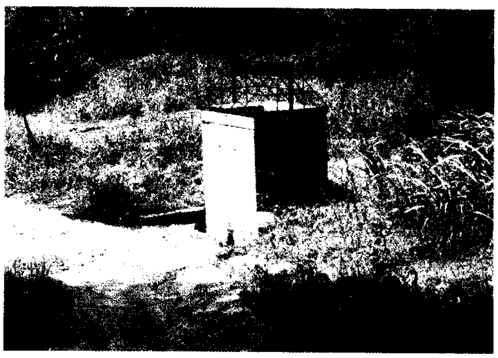
- Filtration basins may be shaped like ponds or channels.
- To improve pollutant removal, the basin may be covered with grass, wetland species, or landscaped vegetation (see Bioretention Basin).
- Sand filters are considered filtration basins.
- Filtration basins *may* have outlet control structures 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.

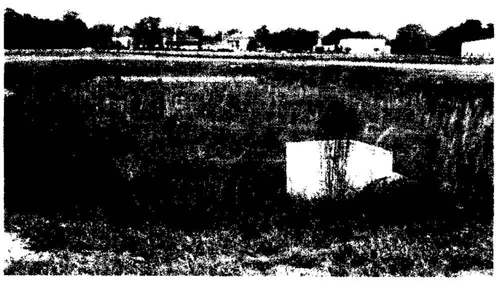
- Dry detention basins may be shaped like ponds or channels.
- The primary outlet control structure is located at the invert of the basin, allowing stormwater to drain slowly and completely between storm events.
- Dry detention basins are identified by the presence of an outlet control structure and 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

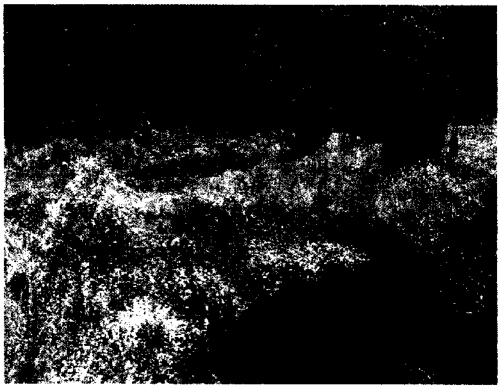
A SHALLOW BASIN WITH AN OUTLET CONTROL STRUCTURE THAT CAN BLOCK THE ENTIRE CROSS-SECTIONAL AREA OF FLOW

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.

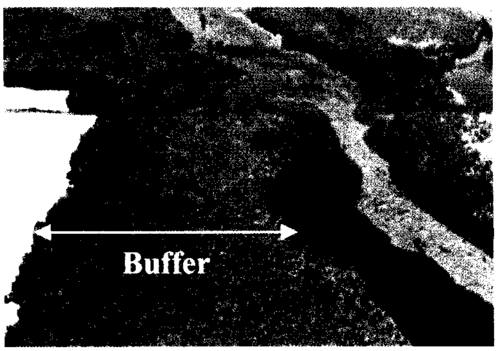
- Level spreaders are implemented upstream of buffers, swales, and basins to improve infiltration and biological uptake.
- Level spreaders are implemented downstream of stormwater controls to prevent stormwater from reconcentrating.
- Level spreaders are implemented on nearly flat grades to prevent reconcentration 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.

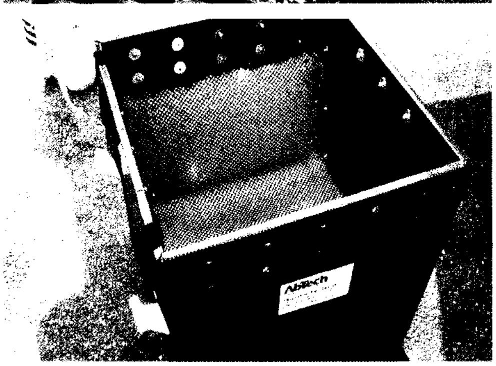
- The basins are reinforced with riprap to prevent erosion and scour.
- PFSH are used with pipe diameters of 18 inches or less.
- An apron of permanent soil reinforcement matting (PSRM) is required downgrade of PFSH to prevent scour.

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.



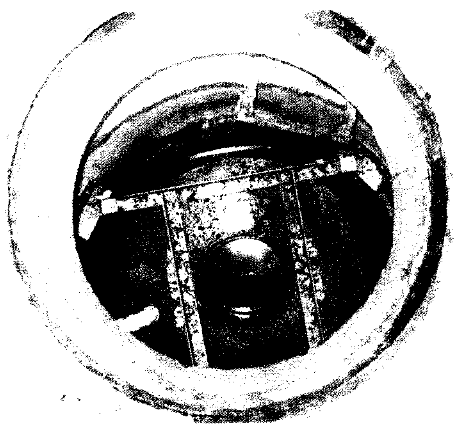
Catch Basin Insert

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.

NCDOT Highway Stormwater PROGRAM

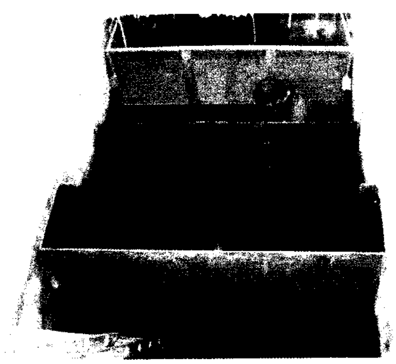


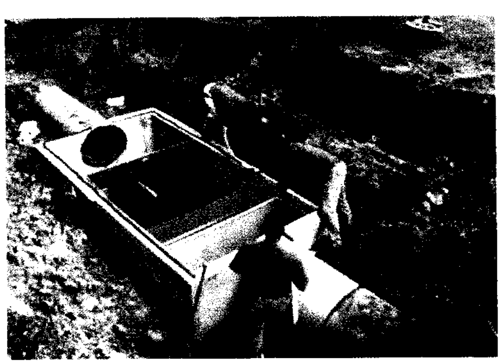
Swirl Concentrator

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 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. Provide 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	$3.3\text{x}10^{-3}$ to $3.3\text{x}10^{-1}$
Sand	$3.3\text{x}10^{-5}$ to $3.3\text{x}10^{-2}$
Silt	$3.3\text{x}10^{-9}$ to $3.3\text{x}10^{-5}$
Clay (saturated)	$< 3.3\text{x}10^{-9}$
Till	$3.3\text{x}10^{-10}$ to $3.3\text{x}10^{-6}$

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

INTERNET REFERENCES

International Stormwater BMP Database. Retrieved September 2007 from http://www.bmpdatabase.org/.

United States Department of Agriculture. National Resources Conservation Service. Urban Conservation Fact Sheets. Retrieved September 2007 from http://www.ia.nrcs.usda.gov/news/brochures/urbanfactsheets.html

Ohio Department of Transportation. *Ohio Location and Design Manual, Volume Two, Drainage Design.* Retrieved September 2007 from http://www.dot.state.oh.us/se/hy/LD2/entireL&Dbookmarked.pdf

Stormwater Authority. Best management practice fact sheets. Retrieved September 2007 from http://www.stormwaterauthority.org/bmp/

U.S. Environmental Protection Agency. National Pollutant Discharge Elimination System. Best management practice fact sheets. Retrieved September 2007 from http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

California Department of Transportation. Caltrans. *Phase I Gross Solids Removal Devices, Pilot Study: 2000-2002, Final Report.* (October 2003). CTSW-RT-03-072.31.22. Retrieved September 2007 from http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-03-072.pdf.

California Department of Transportation. Office of Storm Water Management - Design. *Storm Water Quality Handbook: Project Planning and Design Guide.* (May 2007). Retrieved September 2007 from http://www.dot.ca.gov/hq/oppd/stormwtr/Final-PPDG_Master_Document-6-04-07.pdf

Atlanta Regional Commission (ARC). *Georgia Stormwater Management Manual.* Retrieved September 2007 from http://www.georgiastormwater.com/.

Corson, Lynn A. (October 2006). Purdue University and Indiana Department of Transportation Joint Transportation Research Program Final Report. FWHA/IN/JTRP-2006/5. *Assessment and Selection of Stormwater Best Management Practices for Highway Construction, Retrofitting, and Maintenance*. Retrieved September 2007 from http://rebar.ecn.purdue.edu/JTRP_Completed_Project_Documents/SPR_2853/FinalReport/SPR_2853_Final/SPR_0605.pdf

Florida Department of Environmental Protection. *The Florida Stormwater, Erosion, and Sedimentation Control Inspector's Manual.* Retrieved September 2007 from http://www.dep.state.fl.us/WATER/nonpoint/ero_man.htm

DOCUMENTS

North Carolina Department of Transportation, Hydraulics Unit. (January 2007). *Best Management Practices Toolbox*.

Richardson, Aimee. URS Corporation. (April 6, 2007). Memorandum with the Subject: Stormwater Controls Naming Convention. Included as part of the memorandum, *Structural Stormwater Control Field Guide.*

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