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16. Abstract

This document is a revision of the *VDOT Manual of Practice for Planning Stormwater Management* prepared in 1991. The objective of this revised manual is to provide updated information regarding the management of stormwater at VDOT projects and facilities. This manual is significantly different from the previous manual, since this revision highlights differences in stormwater management practices as they are applied to both linear projects (i.e., roads) and facility projects (i.e., maintenance areas).

This document purposely does not duplicate information easily found in other manuals such as the *VDOT Erosion and Sediment Control and Stormwater Management Manual* and the *VDOT Drainage Manual* but instead provides up-to-date findings on relevant federal, state, and local regulations and requirements and the latest data regarding the selection, design, and use of best management practices.

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FINAL CONTRACT REPORT

VDOT MANUAL OF PRACTICE FOR STORMWATER MANAGEMENT

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NOTICE

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REFERENCES

ABBREVIATIONS AND ACRONYMS

BEHI	-	Bank Erosion Hazard Index
BMP	-	Best Management Practice
cfs	-	Cubic feet per second
CN	-	Runoff Curve Number
CBLAB	-	Chesapeake Bay Local Assistance Board
CBLAD	-	Chesapeake Bay Local Assistance Department
CBPA	-	Chesapeake Bay Preservation Areas
CWA	-	Clean Water Ac
CZMA	-	Coastal Zone Management Act of 1972
CZARA	-	Coastal Zone Act Reauthorization Amendments of 1990
DOT	-	Departments of Transportation
ESC	-	Erosion and Sediment Control
ESC/SWM	-	VDOT Erosion and Sediment Control and Stormwater Management
FWPCA	-	Federal Water Pollution Control Act
GUI	-	Graphical User Interface
HEC	-	Hydrologic Engineering Center
IACM	-	Inter-agency Coordination Meeting
IIM-LD-	-	Instructional and Informational Memoranda
LID	-	Low Impact Development
FAP	-	Floating Aquatic Plant
FHWA	-	Federal Highway Authority
FWS	-	Free Water Surface
IMP	-	Integrated Management Practice
MCTT	-	Multi-chambered Treatment Trains
MS4s	-	Municipal Separate Storm Sewer Systems
NEH	-	National Engineering Handbook
NPDES	-	National Pollutant Discharge Elimination System
NRCS	-	Natural Resources Conservation Service
P.L.	-	Public Law
RPA	-	Resource Protection Areas
SCS	-	Soil Conservation Service
SF	-	Surface Flow
SHA	-	Maryland State Highway Authority
SIC	-	Standard Industrial Classification
SSF	-	Subsurface Flow
SSR	-	Subdivision Street Requirements
SWPPP	-	Storm Water Pollution Prevention Plan
Tc	-	Time of Concentration
TN	-	Total Nitrogen
TP	-	Total Phosphorus
TSS	-	Total Suspended Solids
U.S.C	-	United States Code
USDA	-	United States Department of Agriculture
USEPA	-	United States Environmental Protection Agency
VAC	-	Virginia Administrative Code
VDEQ	-	Virginia Department of Environmental Quality
VDCR	-	Virginia Department of Conservation and Recreation

VDOT	-	Virginia Department of Transportation
VESCL&R	-	Virginia ESC Law & Regulations
VPDES	-	Virginia Pollutant Discharge Elimination System
VS&WCB	-	Virginia Soil and Water Conservation Board
VSWM	-	Virginia Stormwater Management
WQI	-	Water Quality Inlets
WQv	-	Water Quality Volume

CHAPTER 1 INTRODUCTION

1.1 OVERVIEW

This Manual is a revision of the Virginia Department of Transportation (VDOT) Manual of Practice for Planning Stormwater Management prepared in 1991. The concepts provided in this manual represent state-of-the art stormwater management practices in terms of water quantity and flow, as well as in terms of water quality.

Traditionally, the purpose of all Departments of Transportation (DOT) stormwater management and drainage practices has been to remove stormwater runoff from roadways. This philosophy is still prevalent in DOT drainage manuals throughout the United States. However, concerns with pollutants in stormwaters, and the deleterious physical, chemical, and biological effects that stormwater drainage often have on receiving waters, have required DOTs to continually improve their traditional approach to stormwater management.

Unlike the previous Stormwater Management Handbook, this revision identifies differences in stormwater management practices applied to "Linear" projects and "Facility" projects. Linear projects are those that involve roads, highways, and other linear construction; facility projects are those that involve maintenance areas, rest stops, weigh stations, and other areas that consist primarily of parking. While many of the stormwater management practices and approaches are similar for both linear and facility projects, there are some fundamental differences.

One of the key stormwater management approaches introduced in this revision of the VDOT Manual of Practice is "Low-Impact Development," or LID. Although the concept of LID is mentioned and discussed in some DCR documents,[1] it has not been discussed in VDOT documents with respect to its implementation on transportation projects. An important component of the LID approach to facility planning and stormwater management is the use of so-called "ultra-urban" best management practices (BMPs). These ultra-urban BMPs can be used to achieve stormwater water quality and quantity goals when there is insufficient space available for larger, "traditional" BMPs. Again, some ultra-urban BMPs are described in Virginia Department of Conservation and Recreation (VDCR) stormwater documents,[2] but there is little discussion in VDOT publications regarding their use at VDOT facilities.

This revised manual also introduces the concept of "Natural Stream Protection" techniques as they may be applied to transportation projects. Specifically, this manual discusses the application of natural stream protection techniques as they may be applied to the design of culverts.

[1] See: Chapter 2 of the Virginia Stormwater Management (VSWM) Handbook and VSWM Technical Bulletin #1.
[2] See: Minimum Standard 3-15 of the VSWM Handbook and VSWM Technical Bulletin #6.

1.2 OBJECTIVES OF THIS MANUAL

The objective of this manual is to provide updated information regarding the management of stormwaters at VDOT projects and facilities. Much of the information contained in the previous version of this manual is now incorporated in several VDCR and VDOT manuals. This revised VDOT Manual of Practice does not seek to duplicate the information found elsewhere. Rather, it identifies the sources of now-standard information (see below, Section 1.3) and provides information on additional aspects of many of the now-standard practices.

It is also an objective of this manual to introduce concepts and techniques regarding stormwater management that have been developed or expanded since the previous version was written. These concepts and techniques augment those that are already identified and discussed in other VDCR and VDOT publications.

Specifically, the objectives of this manual are:

1. To document the relevant federal, state, and local regulations and requirements regarding stormwater management at VDOT projects and facilities;

2. To provide information regarding Best Management Practices in terms of the following;

   - Capability to control the quantity (and flow rate) of stormwater runoff
   - Efficiency in removing pollutants from stormwater runoff
   - Selection and design guidelines
   - Maintenance and safety considerations

3. To assist transportation engineers in planning, selecting and designing BMPs.

1.3 EXISTING RESOURCES

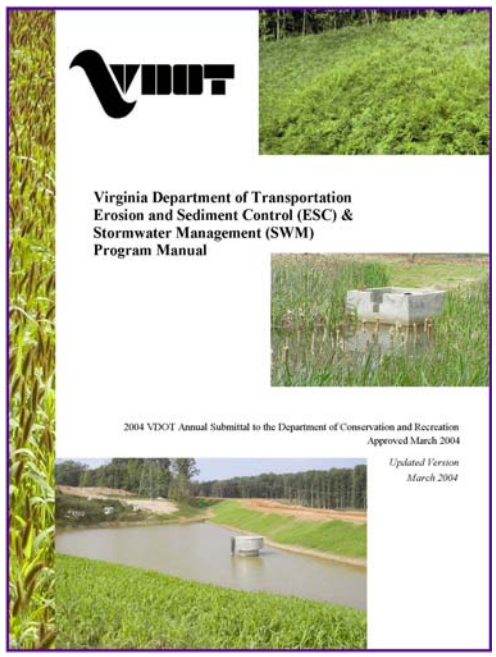
There are many resources currently available that describe stormwater management requirements and procedures that apply to VDOT projects. Other resources are available that provide guidance and information on stormwater practices. Some of these have been developed by VDOT, others have been developed by other Virginia agencies and departments. The following sections identify the primary sources of information regarding stormwater management for VDOT projects; stormwater regulations and other requirements are discussed in Chapter 2.

1.3.1 Virginia Department of Transportation

The Virginia Department of Transportation has developed several manuals that provide comprehensive information regarding stormwater policies and practices. The following paragraphs provide brief descriptions of these primary sources of information.

Erosion and Sediment Control (E&SC) and Stormwater Management (SWM) Program Manual

The VDOT Erosion and Sediment Control and Stormwater Management (ESC/SWM) Manual is revised annually and submitted to the VDCR. Approval of the ESC/SWM Manual by VDCR constitutes the approval of the VDOT ESC/SWM Program and allows VDOT to administer land disturbing activities in lieu of oversight by VDCR. The Manual was last updated in March, 2004.



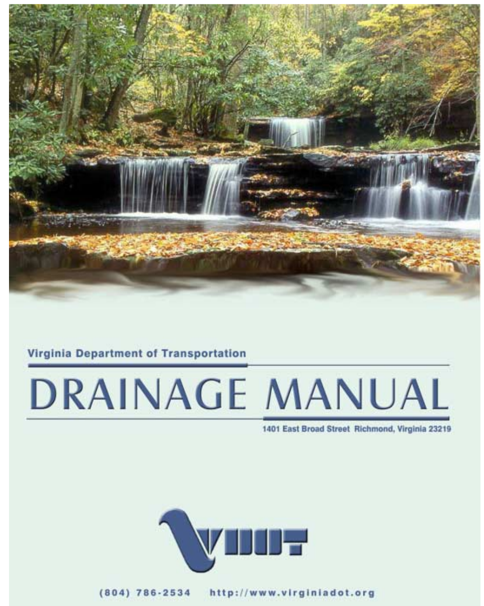
The 600-page ESC/SWM Manual is a compilation of all plan design/review processes, standards, specifications, and internal contract enforcement documents which are applied to all VDOT land disturbing/development activities. The twenty-one appendices of the manual provide a catalog of these documents. The appendices contain excerpts from the VDOT Road & Bridge Specifications, Road & Bridge Standards, I&I Memorandums, VDOT Drainage Manual, Road Design Manual, and other operational guidance. Appendices F, G, H, and I provide all guidance, standards, and specifications related to VDOT design and review of erosion and sediment control and stormwater management measures on all land disturbing/development project plans.

Drainage Manual

The fourth edition of the VDOT Drainage Manual was prepared in 2001. The objectives of the manual are to:

- Provide concise technical information for drainage designers
- Establish VDOT's policies and procedures for drainage design
- Provide an educational tool for aspiring drainage designers and instructors

- Provide technical information in electronic format, available on the World Wide Web for viewing and downloading
- Provide guidelines to enhance the quality of drainage design submittals to VDOT



The chapters most relevant to stormwater management at VDOT projects are:

Chapter 6 – Hydrology
Chapter 11 – Stormwater Management

Chapter 6 of the Drainage Manual, "Hydrology," deals with estimating stormwater runoff as the result of rainfall. Chapter 11 of the Drainage Manual, "Stormwater Management," describes VDOT's stormwater policies, criteria and concepts that, when applied to VDOT projects, will inhibit the deterioration of the aquatic environment by instituting a 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, and to limit the peak discharge to match the non-detrimental discharge capacity of the downstream drainage system.

Instructional and Informational Memoranda

Instructional and Informational Memoranda (IIM-LD-) are a means of providing instructions relating to new policies and procedures (i.e., revisions to specifications, units of measurement, pay items, new products, materials and construction methods). Revisions and additions to VDOT's Road and Bridge Standards are frequently issued as insertable sheets and addressed in an IIM-LD-.

Policies and procedures are frequently introduced as an IIM-LD- and subsequently moved to VDOT's Road Design Manual after procedures are well established. Design information (i.e., project development, design criteria, plan design layout) is typically not issued as an IIM-LD-, but originate in VDOT's Road Design Manual.

The IIMs that are most relevant to stormwater management are:

- IIM-LD-11.23 – Erosion and Sediment Control – revised June 26, 2003. This document supercedes IIM-LD-11.22.
- IIM-LD-195.5 – Management of Stormwater – revised February 12, 2003. This document supercedes IIM-LD-195.4.
- IIM-LD-223 – Drainage Instructions – revised April 5, 2001. This document supercedes IIM-LD-97 (D) 121.13, and is a supplement to the VDOT Drainage Manual.

There are numerous other IIMs that provide detailed, specific information regarding practices that may be relevant to certain aspects of stormwater management projects (including erosion and sediment control). These include the following final IIMs:

- IIM-LD-73.3 Riprap
- IIM-LD-110.16 General Notes
- IIM-LD-121.14 Pipe Criteria for Culverts and Storm Sewers

- IIM-LD-122.10 Roadside Development
- IIM-LD-146.1 Board Policies on Participation
- IIM-LD-166.3 Soil Stabilization Mat
- IIM-LD-173 Construction Access
- IIM-LD-221 General Criteria for Storm Sewer System Design
- IIM-LD-228 Sinkholes
- IIM-LD-229 Drainage Design at Railroads

and the following draft IIMs that are pending VDOT approval:

- IIM-LD-11.24 Erosion and Sediment Control
- IIM-LD-122.11 Roadside Development

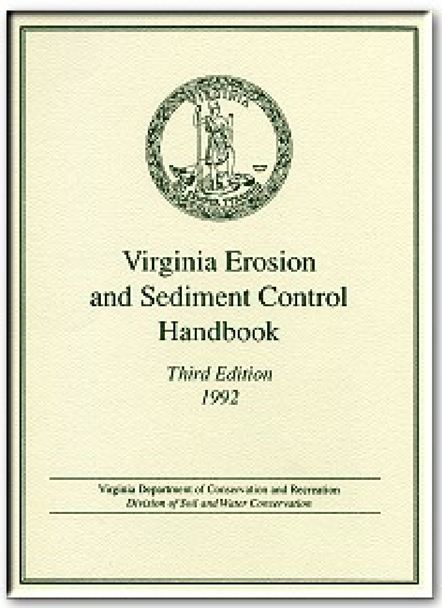
All IIMs are available on the VDOT Extranet Web site, and are incorporated into the ESC/SWM (described above) as Appendix F.

1.3.2 Virginia Department of Conservation and Recreation

The Virginia Department of Conservation and Recreation (VDCR) is the agency within the state that is responsible for developing erosion and sediment control (ESC) and stormwater management (SWM) programs, and for promulgating regulations under those programs. The requirements and regulations are briefly discussed in Chapter 2. The following paragraphs provide brief descriptions of the primary DCR documents related to erosion and sediment control, and to stormwater management.

Erosion & Sediment Control Manual

In 1992, VDCR published the Virginia Erosion and Sediment Control Handbook as the primary guidance document for all ESC programs. The handbook covers basic ESC concepts, ESC measure design, installation and maintenance, plan review procedures and administrative guidelines to support compliance with the Virginia ESC Law, Regulations and Certification Regulations (VESCL&R).

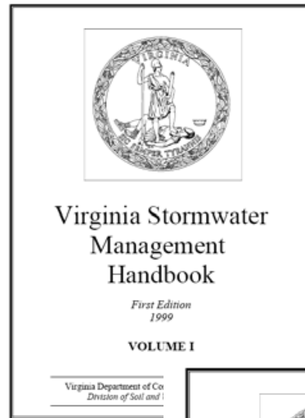


The ESC Manual provides detailed descriptions of the selection criteria, design, implementation, operation and maintenance of 39 "State Specifications". These are specifications for various ESC control practices.

In addition to the description of the State Specifications, the ESC Manual consists of chapters that describe:

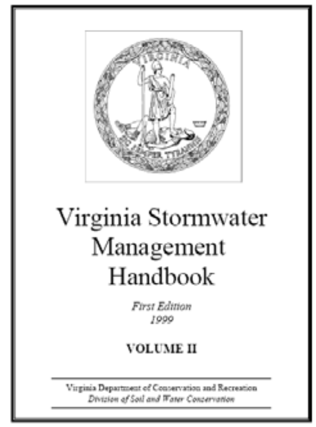
- Principles, Practices and Costs of ESC techniques,
- Stormwater runoff standards and the rationale behind those standards,
- Engineering calculations for estimating runoff, determining stormwater detention requirements, and designing and evaluating open channels to adequately convey stormwater,
- Preparation of ESC plans,
- Administrative guidelines, and
- The ESC Law and Regulations.

Stormwater Manual



In 1999, DCR published the Virginia Stormwater Management Handbook to serve as the primary guidance for SWM programs regarding basic hydrology and hydraulics, stormwater best management practice design and efficiency, and administrative guidelines to support compliance with state stormwater regulations.

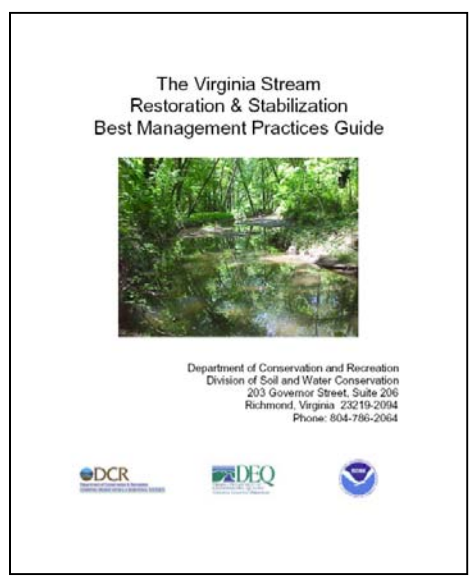
The manual is published in two volumes. Volume 1 contains chapters 1 through 3, and includes descriptions of the stormwater management program, best management practices sizing criteria, and stormwater management "Minimum Standards" which are structural elements to be used in the management of stormwaters. Volume 2 contains chapters 4 through 6, and includes descriptions and examples of hydrologic methods and engineering calculations.



Also available are several associated technical bulletins not addressed in the handbook. These are:[3]

- Technical Bulletin #1: Stream Channel Erosion Policy Guidance
- Technical Bulletin #2: Hydrologic Modeling and Design in Karst
- Technical Bulletin #3: Minimum Standard 3.10E - Plastic Chamber Systems
- Technical Bulletin #4: Performance- and Technology-Based Water Quality Criterion
- Technical Bulletin #6: Minimum Standard 3.11C – Filterra Bioretention Filter System
- Technical Bulletin #7: Minimum Standard 3.02 - Principal Spillway Trash Racks
- Technical Bulletin #8: Vector Control, Mosquitoes and Stormwater Management

The Virginia Stream Restoration & Stabilization Best Management Practices Guide



The Virginia Stream Restoration & Stabilization Best Management Practices Guide was developed to provide a technical resource for government, private, and non-profit organizations involved in permitting, designing, or constructing stream channel and bank stabilization and restoration projects.

This Best Management Practices guide describes geomorphological approaches to evaluating the processes involved in determining stream shape and stability. It also describes structural best management practices that can be used to restore and stabilize stream channels in lieu of using "traditional" bank armoring techniques, and the costs of these practices.

[3] Note: There is no Technical Bulletin #5.

CHAPTER 2

STORMWATER LAWS AND REGULATIONS

This chapter provides a brief review of several of the many laws, regulations and policies that govern transportation-related operations with regard to stormwater management. Other reviews of federal and state laws, regulations and policies are available from other sources. A review of federal and state rules related to drainage is available in Chapter 4 of the VDOT Drainage Manual. Reviews of state requirements for erosion and sediment control as well as for stormwater management are available as Appendix A and Appendix B of the VDOT ESC/SWM Program Manual.

2.1 FEDERAL LAWS AND REGULATIONS

Many of the requirements for stormwater management arise from regulations promulgated under federal statutes. The two federal statutes that are most important with respect to stormwater management at VDOT roads and facilities are the Clean Water Act (33 U.S.C. §§1251-1387) and the Coastal Zone Management Act.

2.1.1 Clean Water Act

The Federal Water Pollution Control Act (FWPCA), 33 U.S.C. Chapter 26, §§1251-1387, is the federal statute regulating the discharge of pollutants into the nation's waters. The FWPCA was originally enacted in 1948, and later amended by the Water Quality Act of 1965, which provided for the adoption of water quality standards for interstate waters. Major amendments were enacted in 1961, 1966, 1970, 1972, 1977, and 1987. With growing awareness of environmental degradation in general, and water pollution in particular, Congress passed the FWPCA Amendments in 1972 (P.L. 92-500). The goals of the Act were that "the discharge of pollution into the navigable waters be eliminated by 1985," "the discharge of toxic pollutants in toxic amounts be prohibited," and an "interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and ... recreation in and on the water ... by July 1, 1983." [CWA §101(a), 33 U.S.C. §1251(a)]. Section 402 of the 1972 amendments established the National Pollutant Discharge Elimination System (NPDES) to authorize issuance of discharge permits (33 U.S.C. 1342) by the United States Environmental Protection Agency (USEPA).

With the passage of amendments in 1977, the Act became known as the "Clean Water Act" (P.L. 95-217, "CWA"). The 1977 amendments extensively amended the FWPCA. Among the elements of particular significance were the following:

- Development of a "Best Management Practices" Program as part of the state areawide planning program (33 U.S.C. 1288)

- Authority for the Corps of Engineers to issue general permits on a state, regional, or national basis for any category of activities which are similar in nature, will cause only minimal environmental effects when performed separately, and will have only minimal cumulative adverse impact on the environment [33 U.S.C. 1344(e)]

In 1987, Congress amended the CWA to require implementation, in two phases, of a comprehensive national program for addressing storm water discharges.

The first phase of the CWA stormwater management program ("Phase I") was promulgated on November 16, 1990 (55 FR 47990). Phase I required NPDES permits for stormwater discharges from medium to large municipal separate storm sewer systems ("MS4s") for populations of 100,000 or more, and several industrial activity categories, including construction activity that disturbs five acres or more of land.

The second phase of the storm water program ("Phase II"), requires permits for storm water discharges from certain small MS4s, construction activities disturbing 1 to 5 acres of land, and certain industrial activities.

Permits for Land Disturbing activities

The operators of construction activities disturbing greater than 5 acres have been required to obtain NPDES permit coverage under Phase I of the U.S. EPA's stormwater management program since 1992. General permits for large construction activity require construction operators to develop and implement a storm water pollution prevention plan (SWPPP) to control erosion, sediment and other wastes on the site.

Phase II of the storm water program requires permits for storm water discharges from construction activity generally disturbing between 1 and 5 acres. However, the requirements for small construction activity (primarily activity disturbing between 1 and 5 acres of land) are not set forth in the Phase II regulation. Rather, the requirements are left to the discretion of the NPDES permitting authority when it develops the small construction activity permit. Since Virginia is a NPDES-authorized state, the requirements for stormwater management in Virginia are developed by the Department of Environmental Quality. Construction activities are considered an industry and are therefore regulated under the VPDES Permit for Industrial Activities. Since it is a very specific industry (different from permanent facility type activities) it is regulated by a separate permit. While the MS4 Permit program was expanded to include medium and small municipalities with the Phase II permit (with different requirements from the Phase I permits), the Construction Permit was simply amended to include small construction activities (1 to 5 acres) with the same requirements as the large construction activities. The requirements for land disturbing activities are discussed in further detail in Section 2.2.

Permits for Industrial Activities

Eleven categories of industrial activity are regulated under Phase I of the NPDES Storm Water Program. Under the Phase II Rule, no new categories of industrial activity are designated into the storm water program. The Rule does, however, include a revised no exposure exclusion that is available to all regulated categories of industrial activity (except category (x) - large construction activity) if the facility operator can certify that storm water runoff is not exposed to industrial activities.

The term "Storm Water Discharges Associated with Industrial Activity," is defined in federal regulations at 40 CFR 122.26(b)(14)(i)-(xi), and determines which industrial facilities are potentially subject to the NPDES storm water program. Transportation facilities classified as Standard Industrial Classifications (SIC) Codes 40, 41, 42 (except 4221 – 4225), 43, 44, 45, and 5171 are subject to permit requirements under the category of "runoff from industrial activities." Thus, stormwater discharges from industrial activities, including discharges from transportation facilities such as vehicle maintenance shops, equipment cleaning operations, material handling facilities, and general building or heavy equipment contractors will require a permit. Vehicle storage lots fall in one of the two following SIC Codes depending on the condition of the vehicles:

- Dead vehicle storage falls under Code Category 42. Motor, Transportation and Warehousing - 4226 - Special Warehousing and Storage.
- Automobile parking falls under Code Category 75. Automotive Repair, Services and Parking - 7521. Automobile parking.

Salt storage facilities fall under Code Category 37 - Transportation Equipment.

2.1.2 Coastal Zone Management Act

The Coastal Zone Management Act of 1972 ("CZMA"; 16 USC 1451-1464, Chapter 33; P.L. 92-583, October 27, 1972; 86 Stat. 1280) was passed in 1972 to encourage coastal states to develop and implement coastal zone management plans (CZMPs).

The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), required the development of Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters (USEPA, 1993). States with coastal zone management programs are required to develop coastal nonpoint pollution control programs consistent with these Management Measures. The "Existing Development Management Measure" of Chapter Four (Urban Areas) requires development and implementation of programs to reduce pollution from existing development. Areas addressed by the management measures for urban areas are:

- Roads, highways, and bridges
- Runoff from developing areas
- Runoff from construction sites
- Runoff from existing development
- On-site disposal systems
- General sources (households, commercial activities, and landscaping)

However, the 1993 Management Measures Guidance (page 4-4), states that "Any storm water runoff that ultimately is regulated under an NPDES permit will no longer be subject to" the guidance and is not required to be addressed in a state's/territory's coastal nonpoint control program. Further, EPA and NOAA have identified ten management measures that overlap in part or in full with the expanded (Phase II) NPDES storm water regulations. Transportation-related management measured included in this list are:

- New Development (geographically limited)
- Construction Site Erosion and Sediment Control
- Existing Development (geographically limited)
- Road, Highway and Bridge Construction Projects
- Road, Highway and Bridge Construction Site Chemical Control
- Road, Highway and Bridge Operation and Maintenance (geographically limited)
- Road, Highway and Bridge Runoff Systems (geographically limited)

Thus, state coastal nonpoint control programs are no longer required to include these management measures.

VDOT's compliance with Virginia's CZMP is through the acquisition of water quality permits, specifically in navigable (Section 10) waters. As part of VDOT's Inter-agency Coordination Meeting

(IACM) process, a copy of every VDOT water quality joint permit application is sent to DEQ for Federal consistency review and comment. When a written CZM clearance is necessary, upon obtaining all required permits, VDOT sends a memorandum to that effect to the Virginia Department of Environmental Quality (VDEQ), which responds with a letter indicating compliance with Virginia's CZMP.

2.2 STATE LAWS AND REGULATIONS

The primary state laws and regulations that address stormwater management at VDOT projects are:

- Virginia Stormwater Management Law and Regulations
- Virginia Erosion and Sediment Control Law and Regulations
- Virginia Water Control Law
- Chesapeake Bay Preservation Act
- Chesapeake Bay Preservation Area Designation and Management Regulations
- Virginia Dam Safety Act

In addition, certain goals regarding VDOT projects are established under the Chesapeake Bay Agreement. Each of these laws, regulation, and the Chesapeake Bay Agreement are briefly discussed below with respect to the requirements and goals they establish for stormwater management at VDOT projects.

2.2.1 Virginia Stormwater Management Law

The Virginia Stormwater Management Law is codified at Title 10.1, Chapter 6, Article 1.1 of the Code of Virginia. The Law allows local governments to adopt comprehensive stormwater management programs. Adopting such regulations is voluntary. As of January, 2002 only 17 local governments had adopted programs.

Section 10.1-603.8(B) of the Virginia Stormwater Management Law provides an exception for linear development projects if certain conditions are met. Linear development projects are exempt from stormwater management regulations provided that (i) less than one acre of land will be disturbed per outfall or watershed, (ii) there will be insignificant increases in peak flow rates, and (iii) there are no existing or anticipated flooding or erosion problems downstream of the discharge point.[4]

2.2.2 Virginia Stormwater Management Regulations

Stormwater Management Regulations are found at Section 4VAC3-20 of the Virginia Administrative Code. These regulations establish requirements for land disturbing activities to prevent water pollution, stream channel erosion, deplete groundwater resources, and to abate more frequent localized flooding to protect property value and natural resources. A “regulated land disturbing activity,” as defined by the Virginia SWM Law and Regulations, is one that disturbs one acre or more of land. This land disturbance threshold requires that a SWM Plan be developed to prevent the degradation of land and water resources by addressing potential water quality, stream channel erosion, and localized flooding impacts related to the development. The Virginia Stormwater Management Regulations states that linear development projects are exempt from requirements with respect to the control of post-developed stormwater runoff for flooding, except in accordance with a watershed or regional stormwater management plan [4 VAC 3-20-85(D)].

[4] Note: Linear development projects are *not* exempt from the Erosion and Sediment Control Regulations, and so must comply with Minimum Standard 19.

The state regulations, which are voluntary for local governments, assume that a local government must adopt the regulations in their entirety in order to demonstrate clear enabling authority for a local stormwater management program. The state regulations require the control of stormwater pollution and peak flows discharged by new development. The stormwater pollution control requirements specify minimum standards for structural BMPs to support three goals. These are: Water Quality, Stream Channel Erosion, and Flooding.

In terms of water quality, the regulations allow pollutant reduction goals to be met by establishing criteria by either of two procedures; performance-based criteria and technical-based criteria. Performance-based criteria are established by using the Simple Method of estimating existing pollutant loadings. Post-development stormwater controls must, in certain circumstances, limit pollutant discharges (in terms of phosphorus) to no more than the existing levels. Pollution goals can be met using the technology-based criteria by implementation of certain best management practices that are selected based on the post-development imperviousness of the site.

Copies of the Virginia Stormwater Management Regulations are provided in the VDOT ESC/SWM Program document as well as in the Virginia SWM Handbook.

2.2.3 Virginia Erosion and Sediment Control Law

The Virginia Erosion and Sediment Control Law is codified at Title 10.1, Chapter 5, Article 4 of the Code of Virginia. The Virginia Erosion and Sediment Control Law establishes the regulated land disturbing activities that will be subject to Virginia Erosion and Sediment Control Regulations and, among other things, requires an approved erosion and sediment control plan before land disturbing activities are initiated.

2.2.4 Virginia Erosion and Sediment Control Regulations

The Virginia Erosion and Sediment Control Regulations (4VAC 50-30), are enforced by VDCR, and specify minimum standards for the control of soil erosion and sediment deposition from construction sites. The regulations specify structural and nonstructural controls for construction site conditions. These regulations are mandatory for all new development in Virginia.

The ESC Program regulates only construction activities that constitute land-disturbing activities under the VESCL&R. Thus, it is essential to fully understand this definition. A land-disturbing activity is

> any land change on private or public land that may result in soil erosion from water or wind and the movement of sediments into state waters or onto lands in the commonwealth, including, but not limited to, clearing, grading, excavating, transporting, and filling of land.

This definition includes land-disturbing activities equal to or exceeding 10,000 square feet in area (or 2,500 ft^2 or more of land within Resource Protection Areas (RPAs) of Tidewater, Virginia); however, 13 activities are specifically exempt from the definition. Several of these exempted activities are relevant to VDOT. These exempted activities include:

- Installation, maintenance or repair of underground public utility lines when such activity is confined to an existing hard surfaced road, street or sidewalk;[5]
- Repair or rebuilding of the tracks, right-of-way, bridges, communication facilities and other related structures, and facilities of a railroad company;

[5] Note: Any land disturbing activity disturbing 10,000 ft^2 or more, or 2,500 ft^2 or more within RPAs of Tidewater VA, even maintenance activities, must have an ESC Plan in accordance with VDOT's approved Specifications.

- Installation of fence, sign, telephone, electric, or other kinds of posts or poles;
- Emergency work to protect life, limb or property, and emergency repairs.

All regulated land-disturbing activities must comply with the 19 Minimum Standards (MS) specified in Section 4VAC50-30-40 of the regulations that are applicable to the specific project. Further, all land-disturbing activities on *state agency land* must be covered by an ESC plan or annual ESC "specifications," including identification of a Responsible Land Disturber, approved by the DCR. Individuals holding Virginia Professional Engineer Licenses, Virginia Land Surveyor Licenses, Virginia Landscape Architect Licenses, Virginia Architect Licenses, Combined Administrator Certification, Administrator Certification, Plan Reviewer Certification, Inspector Certification, and Contractor Certification are qualified as Responsible Land Disturbers without further certification. The VDOT ESC & SWM Program Specifications fulfills the requirement for ESC "specifications."

Copies of the Virginia Erosion and Sediment Control Regulations are provided in the VDOT ESC/SWM Program document as well as in the Virginia ESC Handbook.

2.2.5 Virginia Water Control Law

Virginia is an authorized state under the federal permitting program. VDEQ administers the federal program as the Virginia Pollutant Discharge Elimination System (VPDES) permit program, which is authorized under the state Water Control Law. The Virginia Pollutant Discharge Elimination System Permit Regulation (9 VAC 25-31) sets forth the policies and procedures that are followed in the administration of the permit program. As mandated by the Clean Water Act and USEPA's Phase 1 (11/16/90) and Phase 2 (12/8/99) storm water regulations, VDEQ issues permits to dischargers of storm water from: (1) Industrial Activities (including Construction Activities), and (2) Municipal Separate Storm Sewer Systems (MS4s). The federal permitting requirements are incorporated into the Permit Regulation in sections 9 VAC 25-31-120 and 121.

The key aspect of the Virginia Water Control Law with respect to VDOT is the requirement for VPDES Construction Permits for regulated land disturbing activities. A "regulated land disturbing activity," as defined by the VPDES Permit Regulation, is one that disturbs one acre or more of land.[6] This threshold requires that a project specific ESC and SWM Plan (also referred to as a Stormwater Pollution Prevention Plan, or SWPPP) be developed consistent with Permit Conditions. However, the Plan requirements and the conditions of the Permit are satisfied by compliance with the VDOT ESC & SWM Program Specifications.

To comply with the permitting requirements the VDOT Resident Engineer is issued a Residency-Wide VPDES Construction Permit. VDOT provides VDEQ a monthly "active projects list" that identifies new projects commencing in the coming month, as well as a list of projects that have been completed, stabilized, and therefore terminated. Note: this procedure is subject to change. The user of this Manual should verify the procedure for complying with VPDES permitting requirements.

2.2.6 Chesapeake Bay Preservation Act

The Virginia General Assembly enacted the Chesapeake Bay Preservation Act (Bay Act) in 1988 as a partnership between the state and 84 of Virginia's eastern-most localities that are located in the Chesapeake Bay watershed. Figure 2.1 shows "Tidewater Virginia" as defined by the Bay Act.

[6] The exception to this threshold is maintenance activities that are performed to maintain the original line and grade, hydraulic capacity or original purpose of the facility; these activities are exempt from the VPDES Permit. However, a permit is required if any maintenance activity requires a disposal area or borrow pit that is greater than one acre in size.

The primary focus of the Bay Act is to guide local land use decisions in a manner that promotes the water quality of the Bay and its tributaries. A key component of the Bay Act requires localities to designate and protect Chesapeake Bay Preservation Areas (CBPAs) using performance criteria established by the Chesapeake Bay Local Assistance Board (CBLAB). In addition, the Code of Virginia authorizes local governments to use their police and zoning powers, including civil penalties, to enforce violations of their local programs. The Code also allows localities outside the Tidewater region to incorporate elements of the Bay Act program into their comprehensive plans and land use ordinances. However, according to Chesapeake Bay Local Assistance Department (CBLAD) staff, Albemarle County is the only non-Tidewater locality to adopt elements of the Bay Act program.

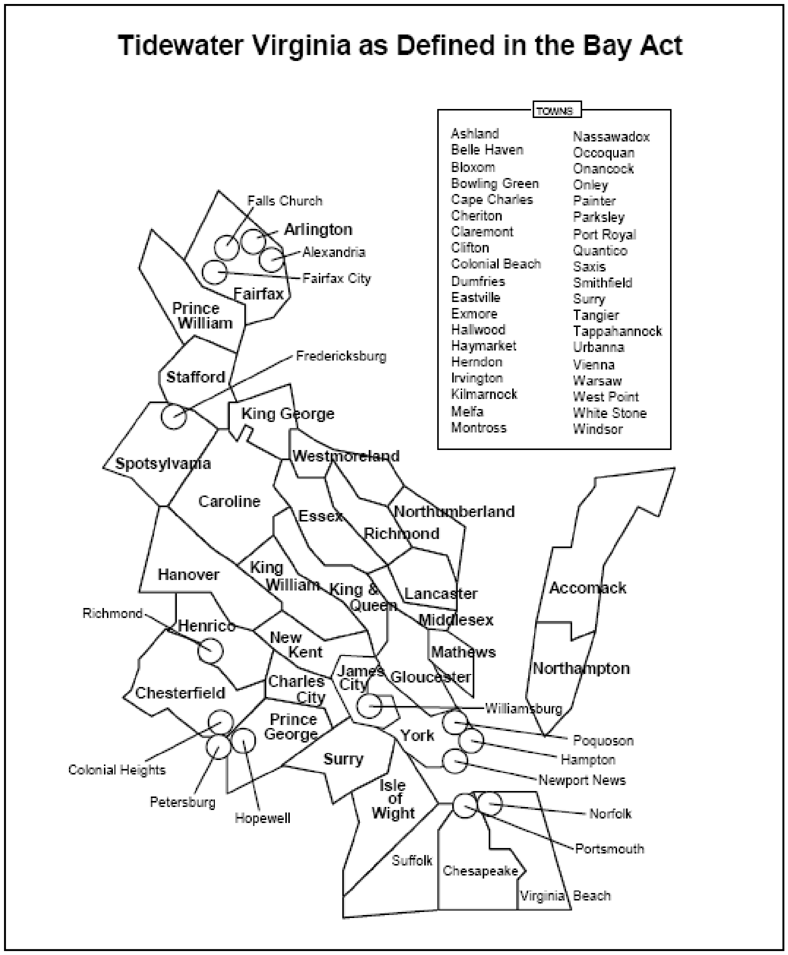


Figure 2.1 - Tidewater Virginia as Defined by the Bay Act.

To facilitate local implementation of the Bay Act, CBLAB established a "three-phase implementation process" that localities follow to develop Bay Act programs. In Phase I, localities designate CBPAs and adopt CBLAB performance criteria to protect these areas. In Phase II, localities incorporate water quality protection measures into their comprehensive plans, and in Phase III, localities achieve initial completion of their Bay Act programs by revising all land use ordinances to make certain they are consistent with the Bay Act and board regulations. Virtually all localities have now achieved initial consistency with Phase II requirements.

One key element of the CBPAs is the designation of Chesapeake Bay Preservation Areas that consist of Resource Management Areas (RMAs) and Resource Protection Areas (RPAs). RPAs consist of environmentally sensitive lands along shorelines or perennial streams that serve as "filters" by removing pollutants from runoff before they enter the Bay and its tributaries (see Figure 2.2). CBLAB regulations strictly limit development activities from encroaching into the RPAs due to the important function these areas perform in reducing nonpoint source pollution.

2.2.7 Chesapeake Bay Preservation Area Designation and Management Regulations

The Chesapeake Bay Preservation Area Designation and Management Regulations were adopted in 1990 and amended in December 2001. The revised regulations took effect in March of 2002 and localities had until December 31, 2003 (per the resolution adopted at the February 18, 2003 CBLAB meeting), to revise their local ordinances to become consistent with the new language.

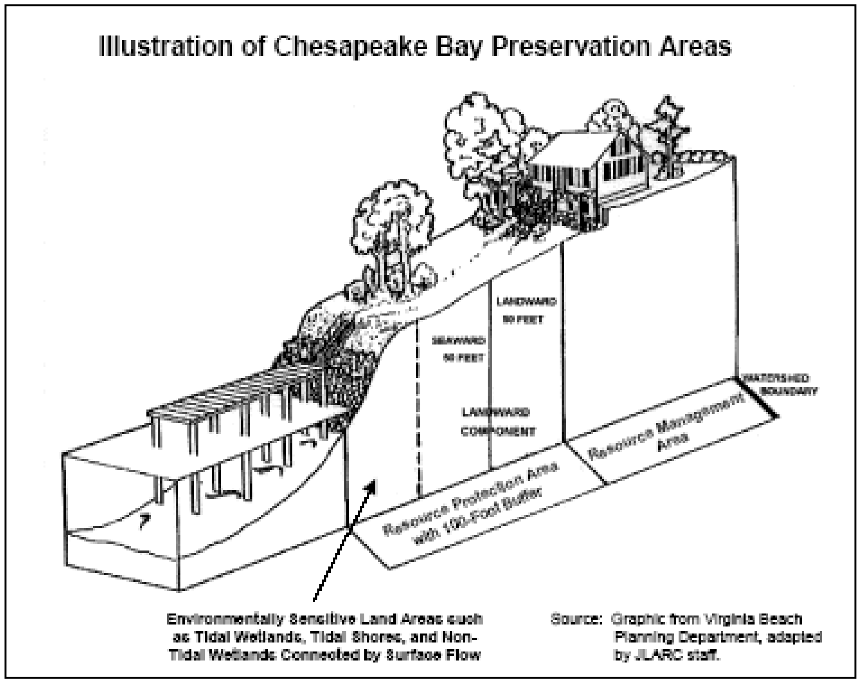


Figure 2.2 - Illustration of Chesapeake Bay Preservation Areas

The purpose of the regulations is to achieve the goals of the Bay Act by establishing criteria to implement the following objectives: 1) prevent a net increase in nonpoint source pollution from new development and development on previously developed land where the runoff was treated by a water quality protection best management practice, 2) achieve a 10% reduction in nonpoint source pollution from development on previously developed land where the runoff was not treated by one or more water quality best management practices, and 3) achieve a 40% reduction in nonpoint source pollution from agricultural and silvicultural uses. In order to achieve these goals and objectives, the regulations establish performance standards to minimize erosion and sedimentation potential, reduce land application of nutrients and toxics, maximize rainwater infiltration, and ensure the long-term performance of the measures employed.

Under section 9 VAC 10-20-40 - Definitions, the term "Development" is defined to include construction or substantial alteration of transportation or utility facilities or structures. However, there is no specific reference to transportation facilities such as vehicle storage lots or salt storage areas. Development activities are covered under the following sections of CBPA Regulations:

- 9 VAC 10-20-120. General Performance Criteria.
- 9 VAC 10-20-130. Development Criteria for Resource Protection Areas.
- 9 VAC 10-20-150. Nonconformities, Exemptions, and exceptions.

Each of these sections are briefly described below.

9 VAC 10-20-120. General Performance Criteria.

Through their applicable land use ordinances, regulations and enforcement mechanisms, local governments shall require that any use, development or redevelopment of land in Chesapeake Bay Preservation Areas meets the following performance criteria:

1. No more land shall be disturbed than is necessary to provide for the proposed use or development.

2. Indigenous vegetation shall be preserved to the maximum extent practicable, consistent with the use or development proposed.

3. Where the best management practices utilized require regular or periodic maintenance in order to continue their functions, such maintenance shall be ensured by the local government through a maintenance agreement with the owner or developer or some other mechanism that achieves an equivalent objective.

4. All development exceeding 2,500 square feet of land disturbance shall be accomplished through a plan of development review process consistent with § 15.2-2286 A 8 of the Code of Virginia and subdivision e of 9 VAC 10-20-231.

5. Land development shall minimize impervious cover consistent with the proposed use or development.

6. Any land disturbing activity that exceeds an area of 2,500 square feet (including construction of all single family houses, septic tanks and drainfields, but otherwise as defined in § 10.1-560 of the Code of 27 Virginia) shall comply with the requirements of the local erosion and sediment control ordinance.

9 VAC 10-20-130. Development Criteria for Resource Protection Areas.

Land development may be allowed in the Resource Protection Area, subject to approval by the local government, only if it (i) is water dependent; (ii) constitutes redevelopment; (iii) constitutes development or redevelopment within a designated Intensely Developed Area; (iv) is a new use established pursuant to subdivision 4 a of this section; (v) is a road or driveway crossing satisfying the conditions set forth in the regulations; or (vi) is a flood control or stormwater management facility satisfying certain conditions set forth in the regulations. There are several exemptions for roads and driveways. These exemptions are discussed in the following subsection.

Non-exempt roads and driveways may be constructed in or across Resource Protection Areas if each of the following conditions is met:

(1) The local government makes a finding that there are no reasonable alternatives to aligning the road or driveway in or across the Resource Protection Area;

(2) The alignment and design of the road or driveway are optimized, consistent with other applicable requirements, to minimize (i) encroachment in the Resource Protection Area and (ii) adverse effects on water quality;

(3) The design and construction of the road or driveway satisfy all applicable criteria of this chapter, including submission of a water quality impact assessment; and

(4) The local government reviews the plan for the road or driveway proposed in or across the Resource Protection Area in coordination with local government site plan, subdivision and plan of development approvals.

9 VAC 10-20-150. Nonconformities, Exemptions, and Exceptions.

Construction, installation, operation, and maintenance of public roads and their appurtenant structures in accordance with regulations promulgated pursuant to the Erosion and Sediment Control Law (§ 10.1-560 et seq. of the 48 Code of Virginia) and the Stormwater Management Act (§ 10.1-603.1 et seq. of the Code of Virginia), in conformance with an erosion and sediment control plan and a stormwater management plan approved by the VDCR, or in conformance with a local water quality protection criteria at least as stringent as the above state requirements is deemed to be in compliance with this the requirements of the Chesapeake Bay Preservation Area Designation and Management Regulations. In addition, public roads are exempt from the requirements of the Chesapeake Bay Preservation Area Designation and Management Regulations only if:

(a) Optimization of the road alignment and design, consistent with other applicable requirements, to prevent or otherwise minimize

(i) encroachment in the Resource Protection Area and
(ii) adverse effects on water quality; and

(b) Local governments may choose to exempt

(i) all public roads as defined in 9 VAC 10-20-40, or
(ii) only those public roads constructed by VDOT.

2.2.8 Chesapeake Bay Agreement

The Chesapeake Bay Agreement addresses "transportation" in general terms under the section "Sound Land Use." There is no specific clause that refers to transportation facilities per se (i.e., vehicle storage and maintenance facilities, or salt storage facilities). With respect to transportation, the Chesapeake Bay Agreement has the following goals:

- By 2002, the signatory jurisdictions will promote coordination of transportation and land use planning to encourage compact, mixed use development patterns, revitalization in existing communities and transportation strategies that minimize adverse effects on the Bay and its tributaries.

- By 2002, each state will coordinate its transportation policies and programs to reduce the dependence on automobiles by incorporating travel alternatives such as telework, pedestrian, bicycle and transit options, as appropriate, in the design of projects so as to increase the availability of alternative modes of travel as measured by increased use of those alternatives.

- Consider the provisions of the federal transportation statutes for opportunities to purchase easements to preserve resource lands adjacent to rights of way and special efforts for stormwater management on both new and rehabilitation projects.

- Establish policies and incentives that encourage the use of clean vehicle and other transportation technologies that reduce emissions.

- Work with communities and local governments to encourage sound land use planning and practices that address the impacts of growth, development and transportation on the watershed.

- By 2002, develop analytical tools that will allow local governments and communities to conduct watershed-based assessment of the impacts of growth, development and transportation decisions.

2.2.9 Virginia Dam Safety Act and Regulations

Some stormwater impoundments may be regulated under the Virginia Dam Safety Act, Article 2, Chapter 6, Title 10.1 (10.1-604 et seq.) of the Code of Virginia and Dam Safety Regulations established by the Virginia Soil and Water Conservation Board (VS&WCB).

All dams in Virginia are subject to the Dam Safety Act unless specifically excluded. A dam may be excluded if it:

- is less than 6 feet in height;
- has a capacity less than 50 acre-feet and is less than 25 feet in height;
- has a capacity of less than 15 acre-feet and is more than 25 feet in height;
- is used for primarily agricultural purposes and has a capacity less than 100 acre-feet (should use or ownership change, the dam may be subject to regulation);
- is owned or licensed by the Federal Government; or
- is operated for mining purposes under 45.1-222 or 45.1-225.1 of the Code of Virginia.

Dams are classified with a hazard potential depending upon the downstream losses anticipated in event of failure. Hazard potential is not related to the structural integrity of a dam but strictly to the potential for adverse downstream effects if the dam were to fail.

- Class I - dams which upon failure would cause probable loss of life or excessive economic loss
- Class II - dams which upon failure could cause possible loss of life or appreciable economic loss
- Class III - dams which upon failure would not likely lead to loss of life or significant economic loss
- Class IV - dams which upon failure would not likely lead to loss of life or economic loss to others

Periodic inspections by an engineer are required at the following frequency:

- Class I - each two years
- Class II - each three years
- Class III - each six years upon renewal of the certificate

In addition, the owner must inspect the dam in those years when an engineer's inspection is not required. Certificates are not required for Class IV dams, but the owner must file an inventory report each six years and an inspection report each year.

CHAPTER 3 STORMWATER MANAGEMENT – BASIC CONCEPTS

The previous VDOT Manual of Practice was written in 1991. Since then, many new concepts have entered the practice of stormwater management, and the emphasis placed on some of the older concepts have had changed. This Chapter discusses some of the basic concepts that underlie current stormwater management practices, and which should form the basis of stormwater management practices employed at VDOT projects and facilities.

3.1 STORMWATER QUANTITY AND QUALITY CONTROL

Perhaps one of the major changes to stormwater management principles that has occurred in the past decade is the emergence of the improvement in stormwater quality as a key function of stormwater management techniques. The management of stormwater quantity has remained an important issue, but the approach to the management of stormwater quantity also has changed over the past decade. The following paragraphs briefly discuss these changes.

3.1.1 Water Quantity Management

Traditionally, stormwater management has involved the design of stormwater management structures mainly as quantity-control, or flow-control structures. In Virginia, the key design criterion is associated with Minimum Standard 19 of the Virginia Erosion and Sediment Control Regulations (4VAC50-30-40.19). Minimum Standard 19 requires, in part:

> Properties and waterways downstream from development sites shall be protected from sediment deposition, erosion and damage due to increases in volume, velocity and peak flow rate of stormwater runoff for the stated frequency storm of 24-hour duration in accordance with the following standards and criteria:
>
> a. Concentrated stormwater runoff leaving a development site shall be discharged directly into an adequate natural or man-made receiving channel, pipe or storm sewer system. For those sites where runoff is discharged into a pie or pipe system, downstream stability analyses at the outfall of the pipe or pipe system shall be performed.
>
> b. Adequacy of all channels and pipes shall be verified in the following manner:
>
> (1) The applicant shall demonstrate that the total drainage area to the point of analysis within the channel is one hundred times greater than the contributing drainage area of the project in question; or
>
> (2)
>
> (a) Natural channels shall be analyzed by the use of a two-year storm to verify that stormwater will not overtop channel banks nor cause erosion of channel bed or banks; and
>
> (b) All previously constructed man-made channels shall be analyzed by the use of a ten-year storm to verify that stormwater will not overtop its banks and by the use of a two-year storm to demonstrate that stormwater will not cause erosion of channel bed or banks; and
>
> (c) Pipes and storm sewer systems shall be analyzed by the use of a ten-year storm to verify that stormwater will be contained within the pipe or system.

c. If existing natural receiving channels or previously constructed man-made channels or pipes are not adequate, the applicant shall:
   (1) Improve the channel to a condition where a ten-year storm will not overtop the banks and a two-year storm will not cause erosion to the channel bed or banks; or
   (2) Improve the pipe or pipe system to a condition where the ten-year storm is contained within the appurtenances; or
   (3) Develop a site design that will not cause the pre-development peak runoff rate from a two-year storm to increase when runoff outfalls into a natural channel or will not cause the pre-development peak runoff rate from a ten-year storm to increase when runoff outfalls into a man-made channel; or
   (4) Provide a combination of channel improvement, stormwater detention or other measures that is satisfactory to the plan-approving authority to prevent downstream erosion.

Thus, Minimum Standard 19 draws a distinction between man-made receiving structures and natural channels in terms of the quantity (related to overtopping) and the flow (related to erosion) of water to be handled.[7] In general, 19(c)(3) is used to design stormwater management facilities. That is, the post-development 2-year, 24-hour storm peak flow is controlled to be no greater than the pre-development 2-year, 24-hour storm.

The selection of a 2-year storm is based on the general observation that the bankfull stage of most streams is the discharge volume that most controls the shape and form of natural channels, and that the bankfull stage is controlled by the 1.5 to 2-year return frequency storm (Leopold et al., 1964). However, as pointed out in VDCR Stormwater Technical Bulletin No. 1, while stormwater controls may be implemented to reduce the peak *rate* of runoff, the increase in runoff volume dictates that the *duration* of the peak rate will increase, as well as the occurrence *frequency* of the peak rate.

Figure 3.1 shows typical hydrographs from pre-development site conditions, post-development site conditions, and from a detention basin. The pre-development hydrograph shows a peak discharge rate that has a very short, almost instantaneous duration. On the other hand, the discharge from the detention basin, while no greater than that of the pre-development condition, lasts significantly longer. Thus, the stream is subjected to longer duration of maximum erosive-force flows when detention basins are used as stormwater flow control devices.

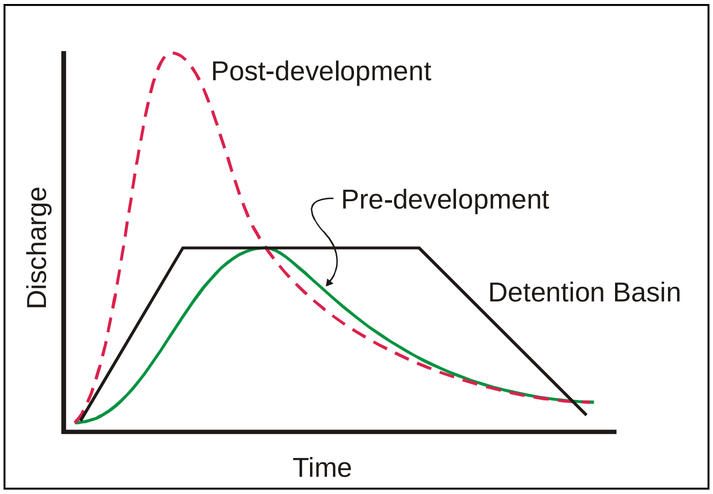


Figure 3.1 - Typical Hydrographs

The frequency of discharge of the maximum flow is also increased when detention basins are used to manage water quantity. Schueler (1987) presents an analysis of bankfull flooding frequencies for various rainfall intensities, times of concentration, and basin storage volumes. The analysis demonstrated that streams receiving stormwater discharges from conventional detention ponds designed to keep post-development discharge within the banks (i.e., the pre-development two-year flood level) may experience two to ten bankfull floods each year instead of one every other year. Thus, bankfull flooding is from 4 to 20 times more frequent.

[7] DCR Stormwater Technical Bulletin No. 1 - Stream Channel Erosion Control Policy Guidance discusses, among other things, the interpretation of each clause of Minimum Standard 19.

Schueler (1987) concluded that extended detention storage equivalent to the runoff produced by a 0.75 to 1.00-inch storm should be capable of reproducing the natural, pre-development frequency of the bankfull floods. He suggests using a larger design storm as an added measure of safety (i.e., 1.0 to 1.5 times the "C" value of the post-development condition).

The VDCR Stormwater Technical Bulletin No. 1 indicates that one potential solution to simply design flow controls based on the 2-year peak flow is to reduce the flow rate sufficiently so as to minimize the level of reaction by the channel. The amended SWM Regulations (4 VAC 3-20-81.C) provide one such alternative design criteria: extended detention of the runoff from the 1-year frequency storm event. Extended detention of the 1-year storm decreases the flow rate and velocity from the basin sufficiently so as to offset the increases in volume, frequency, and duration of the discharge. (The extended detention of the 1-year storm event is in lieu of the detention of the 2-year frequency storm, released at the pre-developed rate.)

The above alternative, however, may not necessarily solve the channel erosion concern. Rather, a comprehensive analysis of the geomorphology of the channel, including the natural sediment bed load, would be needed to accurately determine the appropriate design storm and release rate for maintaining the natural level of erosion and sedimentation to support the natural channel equilibrium. There are several methods that consider geomorphological information in assessing natural channel equilibrium, including the Pfankuch method (Pfankuch, 1975) and the BEHI (Bank Erosion Hazard Index; Rosgen, 1996).

3.1.2 Water Quality Management

Early water pollution control laws and regulations focused efforts on removal of pollutants from point sources. As the nations waterways became less polluted it became clear that non-point sources of pollution are now the predominant threat to water quality. Thus, attention was focused on the removal of pollutants from the major sources of non-point pollution, including stormwater runoff.

In Virginia, control of non-point sources of pollution, including stormwater runoff, is required under several legislative and regulatory authorities. These include: 1) The Chesapeake Bay Preservation Act (CBPA), 2) the associated Chesapeake Bay Preservation Act Regulations, 3) the Virginia Pollution Discharge Elimination System (VPDES), 4) the Virginia Stormwater Management Law, and 5) the Virginia Stormwater Management Regulations. Section 4 VAC 3-20-71 addresses water quality requirements. This section states:

A. Compliance with the water quality criteria may be achieved by applying the performance based criteria or the technology-based criteria to either the site or a planning area.

B. Performance-based criteria. For land development, the calculated post-development nonpoint source pollutant runoff load shall be compared to the calculated pre-development load based upon the average land cover condition or the existing site condition. A BMP shall be located, designed, and maintained to achieve the target pollutant removal efficiencies specified in Table 1 to effectively reduce the pollutant load to the required level based upon the following four applicable land development situations for which the performance criteria apply:

   1. Situation 1 consists of land development where the existing percent impervious cover is less than or equal to the average land cover[8] condition and the proposed improvements will create a total percent impervious cover which is less than the average land cover condition. Requirement: No reduction in the after development pollutant discharge is required.

[8] "Average land cover condition" means a measure of the average amount of impervious surfaces within a watershed, assumed to be 16%. Note that a locality may opt to calculate actual watershed-specific values for the average land cover condition based upon 4 VAC 3-20-101. (footnote not in original)

2. Situation 2 consists of land development where the existing percent impervious cover is less than or equal to the average land cover condition and the proposed improvements will create a total percent impervious cover which is greater than the average land cover condition.

   Requirement: The pollutant discharge after development shall not exceed the existing pollutant discharge based on the average land cover condition.

3. Situation 3 consists of land development where the existing percent impervious cover is greater than the average land cover condition.

   Requirement: The pollutant discharge after development shall not exceed (i) the pollutant discharge based on existing conditions less 10% or (ii) the pollutant discharge based on the average land cover condition, whichever is greater.

4. Situation 4 consists of land development where the existing percent impervious cover is served by an existing stormwater management BMP that addresses water quality.

   Requirement: The pollutant discharge after development shall not exceed the existing pollutant discharge based on the existing percent impervious cover while served by the existing BMP. The existing BMP shall be shown to have been designed and constructed in accordance with proper design standards and specifications, and to be in proper functioning condition.

C. Technology-based criteria. For land development, the post-developed stormwater runoff from the impervious cover shall be treated by an appropriate BMP as required by the postdeveloped condition percent impervious cover as specified in Table 1. The selected BMP shall be located, designed, and maintained to perform at the target pollutant removal efficiency specified in Table 1. Design standards and specifications for the BMPs in Table 1 that meet the required target pollutant removal efficiency will be available at the department.

Table 1*

Water Quality BMP	Target Phosphorus Removal Efficiency	Percent Impervious Cover
Vegetated filter strip Grassed swale	10% 15%	16 – 21%
Constructed wetlands Extended detention (2 x WQ Vol) Retention basin I (3 x WQ Vol)	30% 35% 40%	22 – 37%
Bioretention basin Bioretention filter Extended detention –enhanced Retention basin II (4 x WQ Vol) Infiltration (1 x WQ Vol)	50% 50% 50% 50% 50%	38 – 66%
Sand filter Infiltration (2 x WQ Vol) Retention basin III (4 x WQ Vol with aquatic bench	65% 65% 65%	67 – 100%

* Innovative or alternate BMPs not included in this table may be allowed at the discretion of the local program administrator or the Department. Innovative or alternate BMPs not included in this table that target appropriate nonpoint source pollution other than phosphorus may be allowed at the discretion of the local program administrator or the Department.

Thus, water quality is an important consideration in developing any stormwater management program for both VDOT linear projects and VDOT facilities. VDOT's IIM 195 requires that a water quality management plan be prepared for all outfalls and watersheds where one acre or more of land is disturbed, and one acre or more of impervious surface is added.[9]

[9] Where one acre or more of land is disturbed, but less than one acre of impervious surface is added, a site-specific evaluation is made to determine the opportunity for water quality measures.

Virginia has chosen phosphorous to be the “keystone” pollutant, but other pollutants may be controlled at the discretion of the local program administrator or by VPDES permit conditions. Phosphorous was selected because it exhibits some of the characteristics of particulate pollutants, as well as those of soluble pollutants, making it a good indicator of urban pollutants in general. Compliance with pollutant reduction requirements can be determined on a “performance” basis or on a “technology” basis. These two approaches are further discussed in Virginia SWM Technical Bulletin No. 4.

Performance-based compliance is determined based on an evaluation of the “existing” discharge of pollutants. The performance-based criteria, based on the Simple Method (Refer to Section 10 of Chapter 5 of the Stormwater Management Handbook[10]), has been in use for the purposes of pollutant calculations and BMP implementation as required by the Chesapeake Bay Preservation Act. The method assumes the amount of runoff, and the corresponding pollutant loads, are directly proportional to the degree of impervious cover. Figure 3.2 shows the assumed phosphorus loading rate with different percent imperviousness. BMPs with given pollutant removal efficiencies are applied to the site to reduce post-development loads to pre-development levels associated with an average land cover condition.

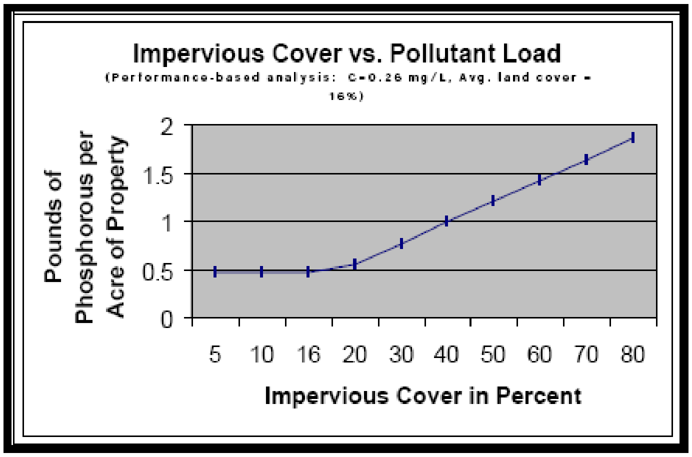


Figure 3.2 - Impervious Cover vs. Pollutant Load (from VA SWM Bulletin No. 4)

Technology-based compliance is based on the installation of one of the management practices identified in the regulations (or an approved alternative) appropriate to the percent impervious surfaces of the post-developed area. Note that there are some limitations to the application of the technology-based approach. This method may not provide the most appropriate water quality assessment in situations such as:

- Multiple drainage areas on a site (not individually treated by the technology approach);
- When multiple BMPs are employed to obtain compliance with a Regional (watershed-wide) Stormwater Analyses;
- Sites that include: buffer equivalency calculations, redevelopment, subdivided parcels, etc.

In such instances, the performance-based approach should be employed.

[10] A more detailed discussion and derivation of the Simple Method can be found in *Appendix A* of *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*, published by the Metropolitan Washington Council of Governments.

3.2 VOLUME AND FLOW CONSIDERATIONS

The requirements for stormwater management set forth in Virginia regulations require a no net increase in pollutant load from developed sites. Most traditional BMPs are volume-based and thus the designs of such BMPs are based on a water quality volume. With regard to stream protection, stormwater management units are designed to detain a certain volume of water, which is determined by the peak pre-development discharge rate, the time of concentration of the drainage area, and the 2-year or 10-year 24-hour storm intensity. With regard to water quality considerations, stormwater management units are required to store and treat the appropriate water quality volume.

Volume-based stormwater management units require significant open land area. In general, at least 2 percent of the drainage area must be available for the installation of volume-based units. This is a problem in areas where open land is not available, where “ultra-urban” best management practices must be used (or where they are planned to be used to augment volume-based units).

Ultra-urban stormwater management units are generally flow-based. That is, they are designed to treat stormwaters at a certain rate of input rather than a certain total volume. In instances where ultra-urban BMPs are proposed, the engineer, designer, or plan reviewer must determine if the flow-based BMP fulfills the goal established by volume-based regulatory requirements. At least three approaches have been developed to help determine appropriately sized flow-based units needed to fulfill water quality goals. These are: 1) a rainfall/hydrograph approach developed by Lenhart and Battiata (1999), 2) the maximum first flush intensity approach developed by Adams (undated), and 3) the surface area/drainage area ratio approach. These two approaches are discussed below.

3.2.1 Rainfall/hydrograph approach

Lenhart and Battiata (1999) used rainfall data for Richmond, Virginia and the Santa Barbara Unit Hydrograph model to establish a design methodology for flow-based systems by developing a statistical relationship between volume and flow. The relationship is based on the fact that the integral of a hydrograph between the onset of runoff and any given time is equal to the volume of rainfall that is discharged during that time span. Further, the rate of discharge can be obtained from the hydrograph at the time the discharge volume equals any set amount. In this case the discharge volume of interest is the “first-flush” or water quality volume, defined in Virginia as the first ½-inch of runoff from the impervious surfaces.

Lenhart and Battiata (1999) used the Santa Barbara Unit Hydrograph Model (a SCS TR55 model modified to be more representative of urban runoff hydrographs by reflecting a faster and sharper peak discharge) to generate hydrographs given a Type II rainfall distribution, a set of fixed watershed parameters (curve number, time of concentration, etc.), and different storm volumes. The analysis found that for the given inputs, the peak rate (cfs) of runoff associated with the first ½ inch volume (ft^3) was found to be 0.91cfs and occurred during a 24-hour rainfall event of 0.88 inches. Therefore, given a Type II distribution, the minimum treatment flow in Richmond, VA, required to ensure that the water quality volume (first ½ inch) is treated is 0.88 inches in 24 hours.

Recognizing that flow-based units treat not only the first flush volume, but the entire storm volume, and noting that the treatment efficiency of flow-based units often changes with the concentration of the pollutants in the stormwater, Lenhart and Battiata (1999) developed an equation to determine the composite TP removal efficiency for a flow-based BMP treating not only the first flush volume, but also the subsequent flow-paced flows. They called this equation the “Equivalent Efficiency Equation,” which is:

$$\text{Equivalent Efficiency} = (A+B)/C$$

where:

A = (% Runoff First ½ inch)(100% TP First Flush Conc)(% Removal First Flush)
B = (% Runoff Flow Paced)(% TP Flow Paced Conc)(% Removal Flow Paced)
C = (%Runoff First ½ inch)

and:

% Runoff First ½ inch	=	Percentage of total annual runoff within the first ½ inch of rainfall
100% TP First Flush Conc	=	100 percent of the concentration of TP associated with the first ½ inch of runoff
% Removal First Flush	=	Pollutant removal efficiency of the flow-based BMP treating the first ½ inch of runoff
% Runoff Flow Paced	=	Percentage of runoff being treated over and above the first ½ inch
% TP Flow Paced	=	Percentage of TP relative to the concentration of the first ½ inch
% Removal Flow Paced	=	Pollutant removal efficiency of the flow based BMP treating flows over and above the first ½ inch of runoff

The results of the analysis lead Lenhart and Battiata (1999) to recommend the following procedure for translating a volume-based regulation into a flow-based regulation:

1. Allow for the sizing of flow-based stormwater treatment facilities using the Santa Barbara Urban Hydrograph with a 24-hour, 0.88 inch storm, and a Type II rainfall distribution.

2. Use the Equivalent Efficiency Equation, if necessary, to demonstrate equivalent pollutant removal efficiencies for flow-based stormwater treatment facilities. However, this may require having data showing BMP performance during flow-paced flows as well as first-flush flows.

3. Using Richmond as a basis, adjust the design storm depth by multiplying 0.88 inch by the ratio of the storm intensities of the area where the facility is being designed to the intensities in Richmond using the design Tc and the 2-year storm.

3.2.2 First flush intensity approach

Adams (undated) evaluates a standard unit hydrograph and notes that that the runoff rate produced by the first inch of rain will never be more than when that inch of rain falls in a period of time equal to the catchment time of concentration (Tc), and furthermore, that the runoff rate produced by any first flush depth of rain will never be more than when that first flush depth of rain falls in a period of time equal to the catchment time of concentration. Based on this observation Adams (undated) proposes a method to calculate the design rainfall intensity assuming that the entire first flush falls in the drainage area's time of concentration, then he uses the Rational Method to calculate the runoff rate to size the flow-based BMP. In mathematical terms:

$$I_{FF} = P_{FF}/Tc$$

where:
P_{FF} = first flush depth, (inches)
I_{FF} = maximum first flush intensity, (inches per hour)
Tc = time of concentration (hours)

and

$$Q_{FF} = C \bullet A \bullet I_{FF}$$

where: Q_{FF} = first flush peak runoff rate, (CFS)
C = runoff coefficient (unitless)
A = drainage area (acres)

3.2.3 Area Ratio Approach

This approach is described in the Virginia Stormwater Management Program's Technical Bulletin No. 6, and addressed the design of bioretention units. The current Minimum Standard 3.11: Bioretention Practices, establishes a target ratio of bioretention surface area to contributing impervious area of 2.5%. Technology-specific evaluations of the performance of flow-based BMPs to optimize the flow / pollutant removal characteristics of the unit may significantly reduce this ratio.

To establish the sizing criteria for a particular BMP technology, examine the rainfall distribution and frequency data from the mid-Atlantic region and size the filter surface area to treat 90% of the total annual rainfall volume. Establish filter surface area and drainage area relationships with respect to pollutant removal data. For the Filterra™ unit described in Technical Bulletin No. 6, the optimum filter surface area to drainage area ratio was found to be 0.33%. For example, the required minimum size Filterra™ filter for ¼-acre of impervious surface would be 36 square feet of filter surface area or one 6 ft. by 6 ft. filter box.

The pollutant removal rates for the Filterra™ also varied as a function of the filter surface area to drainage area. At the minimum 0.33% filter surface/impervious surface ratio, filtering of 90% of the annual runoff is expected to result in pollutant removal rates as shown below. It is not recommended that a ratio of less than 0.33% be used.

Expected Pollutant Removal (at 0.33% filter surface area/drainage area)

Total Suspended Solids Removal = 85%
Total Phosphorous Removal = 74%
Total Nitrogen Removal = 68%
Total Metal Removal = 82%

Higher pollutant removal rates are possible by increasing the ratio of filter surface area to drainage area.

3.3 LINEAR PROJECTS AND FACILITY STORMWATER MANAGEMENT

Stormwater management for VDOT projects has traditionally emphasized the design of facilities for linear development projects. A "linear development project" is defined in Virginia SWM and ESC regulations as a land development project that is linear in nature such as, but not limited to, (i) the construction of electric and telephone utility lines, and natural gas pipelines; (ii) construction of tracks, rights-of-way, bridges, communication facilities and other related structures of a railroad company; and (iii) highway construction projects.

There has been significant effort devoted to developing stormwater management practices for linear projects. In general, linear projects are situated in areas that otherwise would provide sufficient open space to implement "traditional" best management practices, such as swales, detention ponds, retention basins, constructed wetlands, and other measures that require a significant percentage of the drainage area be available for use. These traditional measures are discussed in Chapter 4 of this manual. However, the use of traditional BMPs on linear projects can be very expensive since VDOT typically must purchase additional right-of-way or easements in order to fit a basin adjacent to the right-of-way needed simply for the road or highway. Without the additional right of way or easement there is no room for traditional BMPs such as basins, wetlands, and ponds. (The use of grass swales as a BMP is being proposed based on previous Virginia Transportation Research Council research.)

Further, in more urbanized areas drainage from the roadway may or may not be separate from the drainage of the adjacent development. VDOT often spends additional money on drainage in order to keep these flows separate. Ideally, these activities should be a partnership since the adjacent development will typically represent a larger share of the over all developed condition runoff and facilities (to include site developments in general) are much more suited to stormwater management practices due to the ability to manipulate the drainage characteristics. Drainage characteristics for linear transportation projects, where the vertical and horizontal alignment, drainage requirements, and other features are established by strict guidelines, often cannot be readily manipulated to benefit stormwater management goals.

While stormwater management for linear projects remains a key element of VDOT's stormwater management program, there is a need also to emphasize the management of stormwaters generated by VDOT facilities. VDOT "facilities" include non-linear development projects such as truck weigh stations, welcome areas, vehicle maintenance facilities, and salt (and other materials) storage facilities. These facilities are generally characterized by parking and rooftop areas rather than (or in addition to) roadways.

Facilities are more often than linear project placed in areas where there is little open space in the drainage area to place traditional best management practices. Thus, facility stormwater management strategies rely on ultra-urban BMPs to a greater extent than linear projects. In addition, facilities are more amenable to the use of Low-Impact Development (LID) approaches to stormwater management. These newer stormwater methods and concepts are discussed in Chapter 5 of this manual.

3.4 ULTRA-URBAN AND "TRADITIONAL" APPROACHES

Best management practices are used to mitigate the effects of highways and roads on local conditions, in terms of both water quantity and water quality effects. Best management practices are used to reduce peak flows, to reduce runoff volumes, and to reduce the magnitude and concentrations of constituents in runoff. Numerous studies have been done on the effectiveness of BMPs, although past studies have emphasized more traditional BMPs such as wet and dry ponds and vegetative practices.

Linear projects generally emphasize the use of traditional stormwater management approaches and technologies. Traditional approaches to stormwater management focus on strategies suitable to locations where there is sufficient space to construct stormwater management facilities that generally require from 2 to 20% of the impervious surface that contributes runoff to the facilities in the watershed.[11]

A concept that has emerged in the past decade is the one of the "ultra-urban" environment. The "ultra-urban" environment (a term coined by the city of Alexandria, Virginia) has been used to describe metropolitan areas of the country where space for stormwater BMP implementation is limited. These heavily urbanized areas present special challenges to those responsible for stormwater management. Stormwater management in these ultra-urban areas may require retrofits to existing stormwater control and conveyance systems (FHWA, undated).

[11] Filter strips can require 100% of the impervious surface area.

The Federal Highway Authority (FHWA) compiled a comprehensive database of information about ultra-urban BMPs.[12] The FHWA used the following factors to distinguish between ultra-urban BMPs and urban BMPs:

- Limited space available for BMP implementation (less than 0.5 ha [1 ac]).
- Drainage area imperviousness greater than 50 percent.
- Property value of land over $215 per square meter ($20 per square foot).
- Location of BMP in right-of-way (only available space).
- Existence of build-out conditions at the site (lot-line to lot-line development).

Stormwater management at VDOT projects and facilities must now recognize the important distinction between "traditional" approaches and techniques and "ultra-urban" approaches and techniques. The approach and techniques used should be appropriate to the physical situation and the goal(s) of the stormwater management strategy.

3.5 BEST MANAGEMENT PRACTICES

Stormwater management strategies for both water quality and water quantity control consist of measures generally known as best management practices, or BMPs. According to EPA's Preliminary Data Summary of Urban Storm Water Best Management Practices, an urban stormwater BMP is a "technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of storm water runoff in the most cost-effective manner." These can be either structural practices such as ponds, swales, and proprietary units, or they can be non-structural management measures such as street sweeping, good housekeeping, and other measures to reduce stormwater quantity or the pollutants in the runoff.

The Virginia Stormwater Management Handbook provides descriptions of many typical structural BMPs, but does not discuss non-structural BMPs. There are many other structural BMPs in addition to those discussed in the Virginia Stormwater Management Handbook. Table 3.1 provides a list of BMPs developed by the Chesapeake Bay Program's Urban Stormwater Workgroup. They are arranged in seven general categories. All of these BMPs are potentially applicable to various VDOT linear and facility projects, depending on the goal of the BMP and site conditions.

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[12] The undated report, titled: "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring" is available at the time of publication of this revised manual on the Internet at: http://www.fhwa.dot.gov/environment/ultraurb/index.htm.

Table 3.1 – Definitions of Best Management Practices	
Best Management Practice	Definition
Category A: Wet Ponds and Wetlands	Practices that have a combination of a permanent pool, extended detention or shallow wetland equivalent to the entire water quality storage volume. Practices that include significant shallow wetland areas to treat urban storm water but often may also incorporate small permanent pools and/or extended detention storage.
Wet pond	A storm water management pond designed to obtain runoff and always contains water.
Wet extended detention pond	Combines the pollutant removal effectiveness of a permanent pool of water with the flow reduction capabilities of an extended storage volume.
Multiple pond system	A group of ponds that collectively treat the water quality volume.
"Pocket" pond	A wetland that has such a small contributing drainage area that little or no baseflow is available to sustain water elevations during dry weather. Water elevations are highly influenced, and in some cases, maintained by a locally high water table.
Shallow wetland	A wetland that provides water quality treatment entirely in a wet shallow marsh.
Extended detention wetland	A wetland system that provides some fraction of the water quality volume by detaining storm flows above the mash surface.
Pond/wetland system	A wetland system that provides a portion of the water quality volume in the permanent pool of a wet pond that precedes the marsh for a specified minimum detention time.
"Pocket" wetland	A storm water wetland design adapted for the treatment of runoff from small drainage areas (< 5 acres) and which has little or no baseflow available to maintain water elevations and relies on groundwater to maintain a permanent pool.
Submerged gravel wetland	One or more treatment cells that are filled with crushed rock designed to support wetland plants. Stormwater flows subsurface through the root zone of the constructed wetland where pollutant removal takes place.
Constructed wetland	Constructed wetlands are systems that perform a series of pollutant removal mechanisms including sedimentation, filtration, absorption, microbial decomposition and vegetative uptake to remove sediment, nutrients, oil and grease, bacteria and metals. Wetland systems reduce runoff velocity thereby promoting settling of solids. Plant uptake accounts for removal of dissolved constituents. In addition, plant material can serve as an effective filter medium and denitrification in the wetland can remove nitrogen.
Retention pond (wet)	Surface pond with a permanent pool.
Wetland basin with open water surfaces	Similar to retention ponds except that a significant portion (usually 50% or more) of the permanent pool volume is covered by emergent wetland vegetation.
Retention basin	Capture a volume and retain that volume until it is displaced in part or in total by the next runoff event. Maintains a significant permanent pool volume of water between runoff events.
Category B: Dry Detention, Hydrodynamic Structures	Practices used to moderate flows and remains dry between storm events.
Dry Pond	Designed to moderate influence on peak flows and drains completely between storm events.

Table 3.1 – Definitions of Best Management Practices

Best Management Practice	Definition
Underground dry detention facility	Designed to dry out between storms and provides storage below ground in tanks and vaults.
Category C: Dry Extended Detention	A storm water design feature that provides gradual release of volume of water in order to increase settling of pollutants and protects downstream channels from frequent storm events.
Dry extended detention pond (peak quantity control only)	Dry extended detention ponds (a.k.a. dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins whose outlets are designed to detain the stormwater runoff from a water quality "storm" for some minimum duration (e.g., 24 hours) which allow sediment particles and associated pollutants to settle out. Unlike wet ponds, dry extended detention ponds do not have a permanent pool. However, dry extended detention ponds are often designed with small pools at the inlet and outlet of the pond, and can also be used to provide flood control by including additional detention storage above the extended detention level.
Extended detention basin	An impoundment that temporarily stores runoff for a specified period and discharges it through a hydraulic outlet structure to a downstream conveyance system. An extended detention basin is usually dry during non-rainfall periods.
Enhanced extended detention basin	An enhanced extended detention basin has a higher efficiency than an extended detention basin because it incorporates a shallow marsh in the bottom. The shallow marsh provides additional pollutant removal and helps to reduce the resuspension of settled pollutants by trapping them.
Category D: Infiltration Practices	Practices that capture and temporarily store the water quality volume before allowing it to infiltrate into the soil.
Infiltration Trench	An excavated trench that has been back filled with stone to form a subsurface basin. Storm water runoff is diverted into a trench and stored until it can be infiltrated into the soil. (
Infiltration Basin	Relatively large, open depressions produced by either natural site topography or excavation. When runoff enters an infiltration basin, the water percolates through the bottom or the sides and the sediment is trapped in the basin. The soil where an infiltration basin is built must be permeable enough to provide adequate infiltration. Some pollutants other than sediment are also removed in infiltration basins.
Porous Pavement	Pavement that allows storm water to infiltrate into underlying soils promoting pollutant treatment and recharge.
Category E: Filtering Practices	Practices that capture and temporarily store the water quality volume and pass it through a filter bed.
Filtering and Open Channel Practices	Practices that capture and temporarily store the water quality volume and pass it through a filter bed of sand, organic matter, soil or other media are considered to be filtering practices. Filtered runoff may be collected and returned to the conveyance system. Vegetated open channels that are explicitly designed to capture and treat the full water quality volume within dry or wet cells formed by checkdams or other means.
Surface sand filter	Both the filter bed and the sediment chamber are above ground. The surface sand filter is designed as an off-line practice, where only the water quality volume is directed to the filter.
Underground sand filter*	A modification of the surface sand filter, where all of the filter components are underground. An off-line system that receives only the smaller water quality events.

Table 3.1 – Definitions of Best Management Practices	
Best Management Practice	Definition
Perimeter sand filter	Includes the basic design elements of a sediment chamber and a filter bed. In this design, however, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is the only filtering option that is on-line, with all flows entering the system, but larger events bypassing treatment by entering an overflow chamber.
Organic media filter*	Essentially the same as surface filters, with the sand media replaced with or supplemented with another medium. The assumption is that these systems will have enhanced pollutant removal for many compounds due to the increased cation exchange capacity achieved by increasing the organic matter.
Pocket sand filter	Diverts runoff from the water quality volume into the filter by pipe where pretreatment is by means of concrete flow spreader, a grass filter strip and a plunge pool. The filter bed is comprised of a shallow basin containing the sand filter medium. The filter surface is a layer of soil and a grass cover. In order to avoid clogging the filter has a pea gravel "window" which directs runoff into the sand and a cleanout and observation well.
Bioretention areas (aka “Rain gardens”)	Primarily for water quality control. These are planting areas installed in shallow basins in which the storm water runoff is treated by filtering through the bed components, biological and biochemical reactions within the soil matrix and around the root
Swale	In general a swale (grass channel, dry swale, wet swale, water quality swale) refers to a series of vegetated open channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. It is treated through filtering by the vegetation in the channel, filtering through a subsoil matrix, and/or infiltration into the underlying soils.
Dry swale	A type of grassed swale. Controls quality AND volume (Prince George’s LID). An open drainage channel explicitly designed to detain and promote the filtration of storm water runoff through an underlying fabricated soil media.
Infiltration swale	Planted areas designed specifically to accept runoff from impervious areas (i.e., parking lots) providing temporary storage and onsite infiltration.
Wet swale (aka “water quality swale”)*	A type of grassed swale. Uses residence time and natural growth to reduce peak discharge and provide water quality treatment before discharge to a downstream location (Prince George’s LID). An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.
Dry well	Dry well – small excavated pit, backfilled with aggregate, usually pea gravel or stone. Function as infiltration systems used to control runoff from building rooftops
Category F: Roadway Systems (sheet flow to median)	Using a BMP to reduce the total area of impervious cover, thereby reducing the pollutant and sediment load in a given area.
Sheet flow discharge to stream buffers	Sheet flow is water flowing in a thin layer of the ground surface. Filter strips are a strip of permanent vegetation above ponds, diversions and other structures to retard the flow of runoff, causing deposition of transported material, thereby reducing sedimentation.

Table 3.1 – Definitions of Best Management Practices	
Best Management Practice	Definition
Category G: Impervious Surface Reduction	Using a BMP to reduce the total area impervious area and therefore encouraging stormwater infiltration.
Natural area conservation	Maintaining areas such as forests, grasslands and meadows that encourage stormwater infiltration.
Disconnection of rooftop runoff	Disconnecting the rooftop drainage pipe and allowing it to infiltrate into the pervious surface thereby reducing the impervious area.
Disconnection of non-rooftop impervious area	Directing sheet flow from impervious surfaces, i.e., driveways and sidewalks, to pervious surfaces instead of stormwater drains.
Rain barrels	Rain barrels retain a predetermined volume of rooftop runoff
Green roofs	A multi-layer construction material consisting of a vegetative layer that effectively reduces urban storm water runoff by reducing the percentage of impervious surfaces in urban areas. (
Category H: Street Sweeping, Catch Basin Inserts	A variety of BMPs that provide stormwater treatment for trash, litter, coarse sediment, oil and other debris before proceeding through the stormwater system.
On-line storage in the storm drain network	A management system designed to control storm water in the storm drain network.
Catch basin inserts	Small, passive, gravity-powered devices that are fitted below the grate of a drain inlet. Intercept and contain significant amounts of litter, vegetation, petroleum hydrocarbons and coarse sediments.
Oil/grit separators	Oil/grit separators – systems designed to remove trash, debris and some amount of sediment, oil and grease from storm water runoff based on the principles of sedimentation for the grit and phase separation for the oil.
Hydrodynamic structures	A variety of products for storm water inlets known as swirl separators, or hydrodynamic structures 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. These designs allow sediment to settle out as stormwater moves in this swirling path. Additional compartments or chambers are sometimes present to trap oil and other floatables.
Water quality inlets	Also known as oil and grit separators, provide removal of floatable wastes and suspended solids through the use of a series of settling chambers and separation baffles.
Street sweeping	Seeks to remove the buildup of pollutants that have been deposited along the street or curb, using a vacuum assisted sweeper truck.
Deep sump catch basins	Storm drain systems designed to catch debris and coarse sediment.
Category I: Stream Restoration	A BMP used to restore the natural ecosystem by restoring the stream hydrology and natural landscape.
Stream restoration	Return of an ecosystem to a close approximation of its condition prior to disturbance. The establishment of predisturbance aquatic functions and related physical, chemical and biological characteristics. A holistic process.

*May not be applicable to linear transportation projects.

Source: Chesapeake Bay Program Internet Site (http://www.chesapeakebay.net/pubs/subcommittee/nsc/uswg/BMP_Definitions.PDF) . Last accessed 9/12/04.

3.6 SELECTION OF APPROPRIATE BEST MANAGEMENT PRACTICES

The sections below discuss the selection of appropriate Best Management Practices.

3.6.1 Narrative Criteria

FHWA (undated) describes a three-step approach to the evaluation and selection of ultra-urban BMPs. The approach, however, is applicable to other types of BMPs. The FHWA three-step process consists of:

Step 1: Scoping
Step 2: Evaluation
Step 3: Selection

The first step consists of a "base" analysis of alternative BMPs. The analysis involves considering the characteristics of the BMP, the management goals and objectives of the project, site characteristics, as well as the source and type(s) of contaminant(s). The questions to be answered in the scoping phase of the selection process are:

- Is the BMP suitable or does it have demonstrated success in addressing the targeted sources at similar conditions?
- Can the BMP completely or partially achieve program objectives?

The second step consists of a more detailed evaluation of site physical constraints, the demonstrated effectiveness of the BMP, and the manageability of the BMP treatment train. The questions to be answered in the evaluation phase of the selection process are:

- Can the structural BMP be implemented within the physical site constraints?
- Does the BMP have a superior effectiveness?
- What management alternative can be developed based on compatible BMP combinations to maximize control and minimize maintenance?

The third step consists of an evaluation of cost, public acceptance, and any benefits provided by the BMP in addition to those identified in Steps 1 and 2. The questions to be answered in the final selection phase of the selection process are:

- Is the management alternative cost-effective? (compare alternatives based on cost)
- Does the alternative have additional environmental values? (e.g., aesthetics, recreation, public support, etc.)
- What are the risks associated with the alternative not meeting the objectives? (compare short-term and long-term overall performance).

FHWA (undated) discusses each of these steps in detail.

Claytor and Schueler (1996) have examined a variety of filter BMPs and have identified which of these types of BMPs is most appropriate for applications generally encountered at DOT projects. The following table gives the results of their evaluation.

Table 3.2 Most Appropriate Filter Options for Different Transportation-Related Land Uses

Filter System	Ultra-Urban or Retrofit	Parking Lots	Roads and Highways	Rooftops
Surface Sand	Yes	Depends	Depends	Yes
Underground Sand	Ideal	Yes	No	Yes
Perimeter Sand	Yes	Depends	Depends	Yes
Organic	Depends	Yes	No	Yes
Pocket Sand	Yes	Yes	Depends	Yes
Grass Channel	No	No	Depends	Depends
Dry Swale	No	Depends	Ideal	Depends
Wet Swale	No	Depends	No	Depends
Bioretention	Depends	Ideal	Yes	Yes
Filter Strip	No	Depends	Yes	Yes
Gravel Filter	Yes	Yes	No	Depends

Adapted from Claytor and Schueler, 1996.
Ideal – Physically and economically the best alternative for a site
Depends – May be suitable under certain conditions (space, soils, water table, etc.)
Yes – Generally suitable for most development projects within category.
No – Seldom or never suitable.

3.6.2 Synthetic Key to Select Best Management Practices

Selection of best management practices is often controlled by physical factors at the site. The predominant physical factors are: 1) drainage area, 2) the hydrologic soil group as it represents the infiltration capabilities of the soils, 3) the slope of the area in which the BMP will be constructed, 4) the depth to bedrock (or to the ground water table), and 5) downgradient distance to potable water wells. The following "synthetic key" is useful for using these criteria to select appropriate BMPs based on the physical characteristics of the area.

To use the key, start with the drainage area. After finding the appropriate section according to drainage area select the appropriate subsection according to the predominant soil hydrologic group. After finding the appropriate subsection according to the hydrologic soil group, find the next category according to the slope of the land where the BMP will be constructed. Then, locate a subcategory according to the depth of bedrock (or water table). Finally, locate the subcategory based on downgradient distance to a potable water well (if applicable). Note that not all of the above criteria are relevant in all circumstances. For instance, for a drainage area of 0 – 5 acres, soil group A, and a slope between 5 and 15% the applicable BMPs would be a *sand filter* or a *water quality inlet*. The depth to bedrock or distance to downgradient potable well are not relevant with respect to selecting appropriate BMPs in this particular physical situation.

SYNTHETIC KEY TO BEST MANAGEMENT PRACTICES

AREA: 0 - 5 ACRES

Soil Group: A or B

- ***Slope: <5 %***
  - Depth to Bedrock: 0 – 4 feet
    - *Filter Strip*
    - *Grassed Swale*
    - *Sand Filter*
    - *Water Quality Inlet*
  - Depth to Bedrock > 4 feet
    - Distance to Well: 0 – 100 feet
      - *Filter Strip*
      - *Grassed Swale*
      - *Sand Filter*
      - *Water Quality Inlet*
    - Distance to Well: > 100 feet
      - *Filter Strip*
      - *Grassed Swale*
      - *Infiltration Trench*
      - *Porous Pavement*
      - *Sand Filter*
      - *Water Quality Inlet*
- ***Slope: 5 – 15%***
  - *Sand Filter*
  - *Water Quality Inlet*

Soil Group: C

- ***Slope: <5 %***
  - *Filter Strip*
  - *Grassed Swale*
  - *Sand Filter*
  - *Water Quality Inlet*
- ***Slope: 5 - 15 %***
  - *Sand Filter*
  - *Water Quality Inlet*

Soil Group: D

- *Sand Filter*
- *Water Quality Inlet*

AREA: 5 - 10 ACRES

Soil Group: A or B

- ***Slope: <5 %***
  - Depth of Bedrock: 0 – 4 feet
    - *Extended Detention Basin*
    - *Grassed Swale*
    - *Sand Filter*
  - Depth of Bedrock > 4 feet
    - Distance to Well: 0 – 100 feet
      - *Extended Detention Basin*

Grassed Swale
Sand Filter
Distance to Well: > 100 feet
Extended Detention Basin
Grassed Swale
Infiltration Basin
Infiltration Trench
Porous Pavement
Sand Filter
Slope: 5 - 15 %
Extended Detention Basin
Sand Filter
Soil Group: C
Slope: <5 %
Extended Detention Basin
Grassed Swale
Sand Filter
Slope: 5 - 15 %
Extended Detention
Sand Filter
Soil Group: D
Extended Detention Basin
Sand Filter

AREA: 10 - 50 ACRES
Soil Group: A
Slope: <2 %
Distance to Bedrock: 0 – 4 feet
Extended Detention Basin
Sand Filter
Distance to Bedrock > 4 feet
Distance to Well: 0 – 100 feet
Extended Detention Basin
Sand Filter
Distance to Well: > 100 feet
Extended Detention Basin
Infiltration Basin
Sand Filter
Slope 2 – 15%
Extended Detention Basin
Sand Filter
Soil Group: B
Slope: <2 %
Distance to Bedrock: 0 – 4 feet
Constructed Wetlands
Extended Detention Basin
Sand Filter
Wet Pond
Distance to Bedrock: > 4 feet
Distance to Well: 0 – 100 feet
Constructed Wetlands

Extended Detention Basin
Sand Filter
Wet Pond
Distance to Well: > 100 feet
Constructed Wetlands
Extended Detention Basin
Infiltration Basin
Sand Filter
Wet Pond

Slope: 2 - 5 %
Constructed Wetlands
Extended Detention Basin
Sand Filter
Wet Pond

Slope: 5 - 15 %
Extended Detention
Sand Filter

Soil Group: C
Constructed Wetlands
Extended Detention Basin
Sand Filter
Wet Pond

Soil Group: D
Extended Detention Basin
Sand Filter

AREA: 50 – 100 ACRES

Extended Detention Basin

CHAPTER 4 STORMWATER MANAGEMENT FOR LINEAR PROJECTS

A linear project is one that is linear in nature such as rights-of-way, bridges, and highway construction projects.[13] These projects often consist of long paved, impervious areas. In urban areas the pavement is bordered by traditional "curb and gutter," but in rural areas the pavement may be bordered by crushed stone or vegetated pervious areas.

Virginia is one of only a few states that manage the maintenance and operations of local streets. In localities where VDOT maintains the local streets, after the locality has accepted the new streets, the governing body may ask VDOT to assume the responsibility to operate and maintain the new streets. The Subdivision Street Requirements (SSRs; 24 VAC 30-91-10 et seq.) establish the criteria governing VDOT's acceptance of new roads.[14] Drainage facilities for subdivision streets are required to be designed in accordance with VDOT's Drainage Manual and supplemental directives.

With regard to stormwater management, VDOT considers storm water management associated with the construction of new subdivision streets to be under the authority of the local governing body. Consequently, VDOT does not require storm water management in the construction of subdivision streets. However, storm water management, including the construction of detention or retention facilities, or both, is recognized as an available design alternative. Where the developer is required by regulations promulgated by an agency or governmental subdivision other than VDOT, or where the developer chooses to use storm water management facilities in the design of a subdivision, the governing body shall, by formal agreement, and as a prerequisite for the transfer of jurisdiction over the street to VDOT, acknowledge that VDOT is neither responsible nor liable for the storm water detention facility.

Subdivision streets are generally part of a site plan. The stormwater management requirements for subdivision streets often form a part of the stormwater management requirements for the entire development site, of which the road may only be a small portion. A subdivision layout designed and constructed by a private developer is very different from a linear transportation project designed and constructed by VDOT.

Chapter 2 of the Virginia Stormwater Management Manual identifies seven traditional practices whose major purpose is to control the quantity and flow of stormwaters. The traditional practices identified in the Virginia Stormwater Management Manual are:

- Primary goal is water quantity and flow control
  - Extended detention

- Secondary goal is water quantity and flow control
  - Extended detention (enhanced)

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[13] Virginia Stormwater Management regulations define: "Linear development project" means a land development project that is linear in nature such as, but not limited to, (i) the construction of electric and telephone utility lines, and natural gas pipelines; (ii) construction of tracks, rights-of-way, bridges, communication facilities and other related structures of a railroad company; and (iii) highway construction projects. (4VAC3-20-10)

[14] In late 2004 VDOT completed the most comprehensive revision of the Department's Subdivision Street Requirements since they were first adopted in 1949. The revised SSRs will be effective January 1, 2005.

  - Retention basin
  - Detention

- Potential secondary goal is water quantity and flow control if design modifications are made
  - Infiltration basin
  - Grassed Swale (with check dams)
  - Constructed Wetlands

The following sections discuss stormwater management practices that are generally applicable for linear transporation projects. The first section addresses stormwater management practices that have the management of water quantity and flow as their primary function. The second section addresses stormwater management practices that have the removal of stormwater pollutants as their primary function.

4.1 STORMWATER MANAGEMENT PRACTICES FOR WATER QUANTITY CONTROL

The following paragraphs will briefly describe traditional stormwater management practices that have water quantity control as their primary or main secondary goal, and will identify further sources of information regarding their selection, design, construction, operation and maintenance. Those practices that have water quantity control as a potential secondary goal will be described below in Section 4.2.

4.1.1 Extended and Enhanced Extended Detention Basins

Extended and Enhanced Extended Detention Basins are discussed in Chapter 3 of the Virginia Stormwater Management Handbook as Minimum Standard 3.07. An extended-detention basin is an impoundment that temporarily stores runoff for a specified period and discharges it through a hydraulic outlet structure to a downstream conveyance system. An extended-detention basin is usually dry during non-rainfall periods. An extended-detention basin can be designed to provide for one, or all, of the following: a) water quality enhancement, b) downstream flood control, and c) channel erosion control. An Enhanced Extended Detention Basin is an Extended Detention Basin that has been modified to incorporate a marsh area to improve water quality performance.

VDOT policies regarding extended detention basins are discussed in Chapter 11 of the VDOT Drainage Manual. Engineering drawings of extended detention basins are found in Chapter 3 of the Virginia Stormwater Management Manual and in Appendix 11G of the VDOT Drainage Manual.

Application

Extended detention basins are designed for areas generally having between 22 and 37% impervious area. With respect to VDOT projects the impervious area refers to new impervious area within the site or per outfall. The minimum contributing drainage area for an extended-detention basin varies with the required extended-detention volume and draw down period and the resulting orifice size.

Design

The design of an extended detention basin for water quantity control varies somewhat from the design of an extended detention basin for water quality control (discussed in Section 4.2.2). With respect to the design of extended detention basins for water quantity purposes Virginia's Stormwater Management Regulations recommend 24-hour extended detention of the runoff from the 1-year frequency storm as an alternative to the 2-year peak discharge reduction required by MS-19 of the VESCR. Chapter 11 of the VDOT Drainage Manual provides a procedure for estimating the channel erosion control volume requirement and calculating other design elements of extended detention basins, such as the discharge orifice.

Siting

All extended-detention basins should be a minimum of 20 feet from any structure or property line, and 100 feet from any septic tank/drainfield. Extended-detention basins should also be a minimum of 50 feet from any steep slope (greater than 15%). Other siting considerations include:

Soils	–	highly permeable soils are not suited for extended detention basins
Bedrock	–	bedrock should not be so close to the surface that blasting will be required
Utilities	–	most utility companies will not allow a permanent or temporary pool to be installed over their underground lines or rights-of-way.

Maintenance

All extended detention basins are required to be inspected and maintained in perpetuity. VDOT has developed a stormwater basin inspection form. The form is found in Appendix K of the 2003 VDOT ESC&SWM Manual.

4.1.2 Retention Basin

A retention basin is a stormwater facility that includes a permanent impoundment, or pool of water, and, therefore, is normally wet, even during non-rainfall periods. Inflows from stormwater runoff may be temporarily stored above this permanent pool for downstream flood control and channel erosion control.

Retention Basins are discussed in Chapter 3 of the Virginia Stormwater Management Handbook as Minimum Standard 3.06.

Application

Wet ponds are cost-effective in larger, more intensively-developed sites. If properly sized and maintained, retention basins can achieve a high removal rate of sediment, BOD, organic nutrients and trace metals. Retention basins are unique in that they truly can be a multi-purpose BMP, providing stormwater management, pollutant removal, and landscaping/habitat improvement.

Design

Retention basins can be designed to provide both water quality benefits and water quantity controls. The following paragraphs discuss these two design elements.

Quality – for water quality purposes the SWM regulations state that the permanent poll should be at least 3 times the water quality volume. The theory behind this requirement is that incoming runoff displaced old stormwater from the pond, and the new runoff is detained until it is displaced by runoff from the next storm. A permanent pool of 3 times the Water Quality Volume (WQv) should then provide an adequate detention time for the stormwater. In addition to the volume of the basin, several other design considerations can be made to enhance pollutant removal. Some of these design considerations are briefly discussed in the following paragraphs.

The shape of the basin can significantly affect the pollutant removal efficiency of a wet pond. The shape of the basin can promote or reduce short-circuiting of the water. Short-circuiting occurs when incoming water does not displace the existing water, but rather moves directly to the discharge point, thus reducing the actual retention time. To minimize the probability of short-circuiting the length-to-width ratio should be at least 3:1. Baffles and different shapes can be used to achieve this length-to-width ratio if the land area or topography does not allow a long, narrow basin or if additional width-to-length ratio is desired.

The depth of the pond is also a key design element that affects the ability of a retention basin to remove pollutants. Settling column studies and modeling analyses indicate that shallow ponds have higher removal efficiencies than deeper ones, but extremely shallow ponds are susceptible to resuspension of sediments, and thus will achieve a lower pollutant removal. Therefore, retention ponds should be designed to be between 3 to 6 feet deep. Ponds should not be deeper than 8 feet, and should be no shallower than 2 feet unless they are stabilized with aquatic vegetation.

Other water quality enhancements include establishing a sediment forebay to remove larger sediments before they fill the basin and including perimeter vegetation to increase biological uptake of nutrient pollutants.

Quantity – for quantity purposes the retention basin should be designed to reduce the peak flow from a 2- and 10-year storm, and be able to pass a 100-year storm safely. Routing these storms through the retention basin can be accomplished in many ways. The VDOT Drainage Manual provides examples of these calculations.

Table 4.1 presents a summary of design considerations for retention basins.

Table 4.1 – Summary of Design Considerations for a Retention Basin

Purpose	Design
Quality control	Permanent poll volume 3 x WQv; Perimeter vegetation; Sediment forebay
Quantity control	Control 2- and 10-year peak flows
Prevent short-circuiting	3:1 length-to-width ratio
Maintenance	Valve to be included to drain the pond
Safety	Fence; Shallow (< 2 feet) safety ledge around pond Post signs
Other	Side slopes (3h:1v) for maintenance access

Siting

Several site-specific conditions affect the feasibility of constructing retention basins. These are:

- Drainage area – construction of a wet pond (retention basin) is not generally feasible in watersheds less than ten acres in size, unless a natural spring occurs on-site (Schueler, 1987).

- Permeable soils – soils in hydrologic soil groups A and B may result in pond drawdown. This problem can be minimized by constructing a less permeable liner of clay soil or synthetic fabric.
- Bedrock – bedrock close to the surface may prevent the required depth from being easily met.
- Land requirements – retention ponds generally require as much as 10% of the watershed area (in small drainage areas), but land required by the pool and buffer area generally is approximately 5% of the drainage area.
- Utility easement – most utility companies will not allow existing underground pipes to be submerged under a permanent pool of water.

Maintenance

It is important that detention ponds be properly maintained. The entire area of the dam and any grass around the basin should be mowed at least 2 times per year to prevent woody growth. If there is vegetation in the pond, it should be harvested so that the bottom of the basin does not fill up with decaying organic matter. The sediment on the bottom should be removed every 10 to 20 years, depending on the loading rate.

4.2 STORMWATER MANAGEMENT PRACTICES FOR WATER QUALITY

Chapter 2 of the Virginia Stormwater Management Manual identifies ten traditional practices and six proprietary systems whose major purpose is to control the quality and flow of stormwaters. The traditional practices identified in the Virginia Stormwater Management Manual are:

- Primary goal is water quantity and flow control
    - Vegetated filter strip
    - Grassed Swale (with check dams)
    - Constructed wetlands
    - Enhanced Extended detention
    - Bioretention
    - Retention basins
    - Sand filters
    - Infiltration
- Secondary goal is water quantity and flow control
    - Extended detention
    - Infiltration basin

The following paragraphs will briefly describe the traditional practices with water quality and flow control as their primary or main secondary function, and will identify further sources of information regarding their selection, design, construction, operation and maintenance.

4.2.1 Vegetated Filter Strip

A vegetated filter strip is a densely vegetated strip of land, similar to grassed swales, but engineered to accept runoff from upstream development only as *overland sheet flow*. It may adopt any naturally vegetated form, from grassy meadow to small forest. Vegetated filter strips are discussed in Chapter 3 of the Virginia Stormwater Management Handbook as Minimum Standard 3.14.

Application

Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. The Virginia SWM Handbook indicates that vegetated filter strips are technology-based BMPs when the imperviousness of a drainage area is between 16 and 21%.

A vegetated filter strip also may be used as a pretreatment BMP in conjunction with a primary BMP.

Design

Vegetated filter strips need the following elements to work properly:

- a device such as a level spreader that ensures that runoff reaches the vegetated filter strip as a sheet flow (berms can be used for this purpose if they are placed at a perpendicular angle to the vegetated filter strip area to prevent concentrated flows);
- a dense vegetative cover of erosion-resistant plant species;
- a gentle slope of no more than 5 percent; and
- a length at least as long as the adjacent contributing area (Schueler, 1987).

If these requirements are met, vegetated filter strips have been shown to remove a high degree of particulate pollutants.

Engineering drawings of vegetated filter strips are found in Chapter 3 of the Virginia Stormwater Management Manual.

Siting

The Virginia SWM Handbook indicates that the following site conditions should be considered when selecting a vegetated filter strip as a water quality BMP:

1. Soils – Vegetated filter strips should be used with soils having an infiltration rate of 0.52 inches/hour; (sandy loam, loamy sand). Soils should be capable of sustaining adequate stands of vegetation with minimal fertilization.

2. Topography – Topography should be relatively flat to maintain sheet flow conditions. Filter strips function best on 5 percent or less.

3. Depth of Water Table – A shallow or seasonally high groundwater table will inhibit the opportunity for infiltration. Therefore, the lowest elevation in the filter strip should be at least 2 feet above the water table.

Effectiveness

Several studies of vegetated filter strips show that they improve water quality and can be an effective management. Research results show that vegetative filter strips are most effective at sediment removal, with rates generally greater than 70 percent. The published results on the effectiveness of vegetative filter strips in nutrient removal are more variable, but nitrogen and phosphorus removal rates are typically greater than 50 percent. However, the Virginia SWM Handbook indicates that the phosphorus removal efficiency is only 10%.

Maintenance

To increase the functional longevity of a vegetated filter strip, the following practices are recommended:

- regular removal of accumulated sediment,
- periodic reestablishment of vegetation in eroded areas or areas covered by accumulated sediment,
- periodic weeding of invasive species or weeds, and
- periodic pruning of woody vegetation to stimulate growth.

Shorter vegetated filter strips should be mowed 2 to 3 times per year. However, the transformation from grass to meadow to second growth forest will enhance, rather than detract form the performance of longer filter strips. Thus, mowing is not recommended for longer filter strips.

4.2.2 Enhanced (Ecological) Extended Detention Basins

An extended-detention basin is an impoundment that temporarily stores stormwater runoff for a specified period of time and discharges it through a hydraulic outlet structure and a downstream conveyance system to receiving waters. An extended-detention basin is usually dry during non-rainfall periods. An enhanced, or ecological extended-detention basin has a higher efficiency than an extended-detention basin because it incorporates a shallow marsh, or wetland system, in its bottom. The wetland provides additional pollutant removal through wetland plant uptake, absorption, physical filtration, and decomposition. The wetland vegetation also helps to reduce the resuspension of settled pollutants by trapping them (VDCR, 1999). Figure 4.1 shows a typical enhanced extended detention basin. Extended Detention Basins and Enhanced Extended Detention Basins are discussed in Chapter 3 of the Virginia Stormwater Management Handbook as Minimum Standard 3.07.

Figure 4.1 - Enhanced Extended Detention Basin (VADCR, 1999).

Application

Although wetlands have been used as a treatment component of stormwater management systems in the United States since the 1970s, the technology is still considered to be an experimental BMP. The major categories of treatment wetland systems include natural wetlands, surface flow (SF, or FWS) wetlands, subsurface (SSF) flow wetlands, and floating aquatic plant (FAP) systems.

In most cases, the application of wastewater to natural wetlands is not engineered, but the study of these systems led to the development of constructed wetland treatment systems. Many states, however, do not allow direct discharges of wastewater to natural wetlands unless treated to a minimum of either secondary or tertiary levels.

Effectiveness

Ecological processes inherent in such wetland stormwater treatment systems include sedimentation, adsorption of pollutants to sediments vegetation and detritus, physical filtration, microbial uptake of pollutants, uptake of pollutants by wetland plants, uptake of pollutants by algae, and other physico-chemical processes. The combination of ecological processes make wetlands relatively effective in removing pollutants normally found in stormwaters. Table 4.2 compares the median pollutant removal efficiencies of several stormwater practices.

Table 4.2 - Median Pollutant Removal (%) of Stormwater Treatment Practices (Center for Watershed Protection, 2000)

	TSS	TP	Sol P	TN	NOx	Cu	Zn
Stormwater Dry Ponds	47	19	- 6.0	25	4.0	26[1]	26
Stormwater Wet Ponds	80	51	66	33	43	57	66
Stormwater Wetlands	76	49	35	30	67	40	44
Filtering Practices[2]	86	59	3	38	- 14	49	88
Infiltration Practices	95[1]	70	85[1]	51	82[1]	N/A	99[1]
Water Quality Swales[3]	81	34	38	84[1]	31	51	71

[1] Fewer than 5 data points
[2] Does not include vertical sand filters and filter strips
[3] Refers to open channel practices designed for water quality
N/A = Data are not available
TSS = Total suspended solids; TP = Total phosphorus; Sol P = Soluble phosphorus;
TN = Total nitrogen; NOx = Nitrate and nitrite; Cu = copper; Zn = Zinc

In addition to pollutant removal, surface flow wetlands offer the most potential for creating the ancillary benefits of wildlife habitat, public recreational uses such as bird watching and nature study, and surface runoff flow retention.

Design

Surface flow wetland treatment systems are typically shallow constructed basins which usually contain marshes densely vegetated by a variety of rooted emergent plant species such as bulrush, cattails, and others. The SF wetlands can be further categorized into four major types (Schueler, 1992). These are: 1) shallow marsh systems that have large surface areas and require reliable sources of baseflow or groundwater to support emergent plants, 2) pond/wetland systems that consist of a wet pond to trap sediments and a separate shallow marsh cell, 3) extended detention wetland systems where extra runoff storage is created above the shallow marsh by temporarily detaining runoff, and 4) pocket wetland systems which serve sites from one to ten acres (0.4 to 4 ha) in size, and exhibit widely fluctuating water levels.

Figure 4.2 shows a schematic drawing of a “typical” extended-detention shallow wetland stormwater treatment system. Approximately 45% of the surface area of this system is high marsh, 35% is low marsh, and 20% of the surface area is deep pool. As much as 50% of the total treatment volume can be provided as extended-detention storage, which helps to protect downstream channels from erosion, and reduce the wetland’s space requirement.

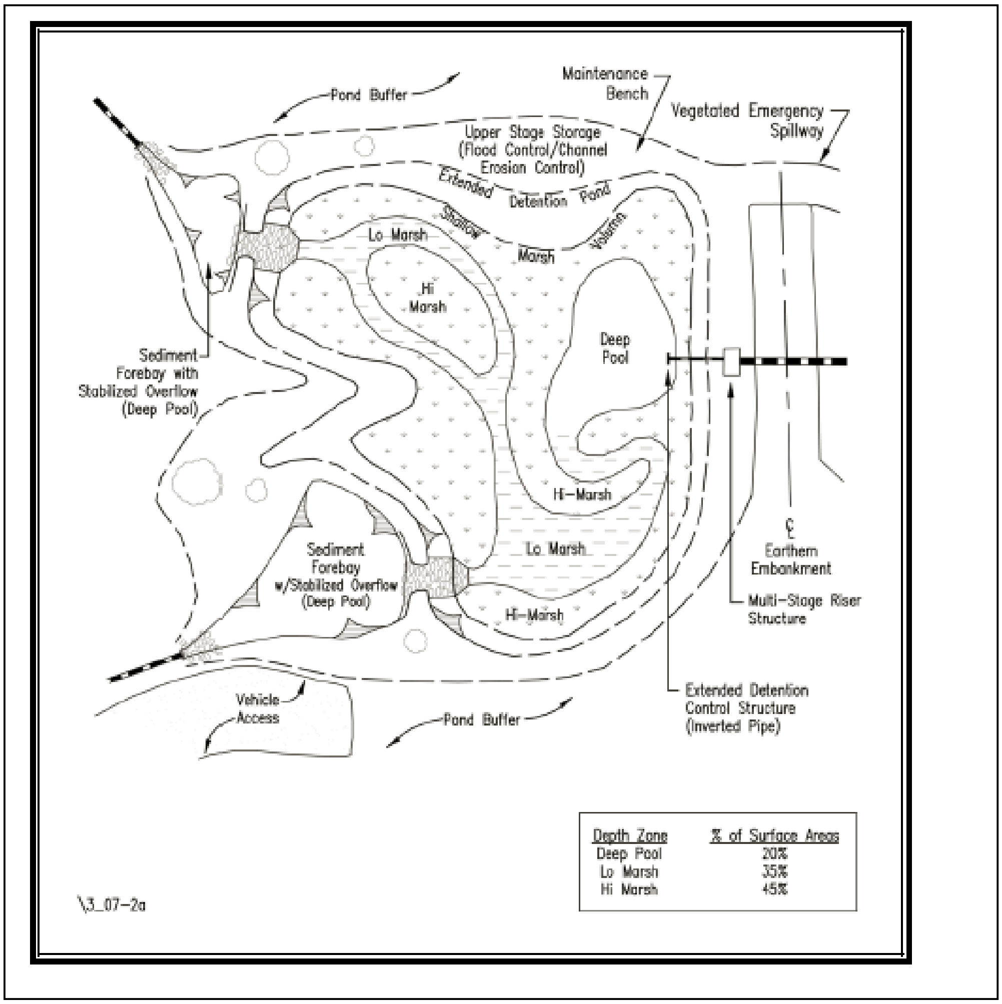

Figure 4.2 - Enhanced Extended Detention Basin

Traditional engineering design and ecological engineering come together to enhance the pollutant removal efficiency of wetland treatment systems. Typical techniques involve:

- Increasing the volume of runoff treated by capturing a greater percentage of annual runoff and providing a longer residence time for the captured runoff,
- Increasing the surface area to volume ratio by increasing the total area of the wetland or by increasing complexity of the internal structure of the wetland,

- Increasing the flow path through the wetland by locating the inlet and outlet structures farther apart, by increasing the sinuosity of the water flow through the system, or by using multiple cells within the system,
- Providing runoff pre-treatment and energy dissipation, and
- Designing redundant pollutant removal pathways.

Siting

All extended-detention basins should be a minimum of 20 feet from any structure or property line, and 100 feet from any septic tank/drainfield. Extended-detention basins should also be a minimum of 50 feet from any steep slope (greater than 15%). Other siting considerations include:

- Soils – Highly permeable soils are not suited for extended-detention basins.

- Rock – The subsurface investigation should also identify the presence of rock or bedrock. Excavation of rock may be too expensive or difficult with conventional earth moving equipment.

- Existing Utilities – Most utility companies will not allow a permanent or temporary pool to be installed over their underground lines or right-of-ways.

Maintenance

The basin's side slopes, embankment and emergency spillway should be mowed at least twice a year to discourage woody growth. More frequent mowing may be necessary in residential areas for aesthetic purposes.

Specific plant communities may require different levels of maintenance. Upland and floodplain terrace areas, grown as meadows or forests, require very little maintenance, while aquatic or emergent vegetation may need periodic thinning or reinforcement plantings.

Sediment deposition should be continually monitored in the basin. Removal of accumulated sediment is extremely important. Unless unusual conditions exist, it is anticipated that accumulated sediment will need to be removed from the basin every 5 to 10 years (Schueler, 1987). More frequent cleaning of the area around the low flow or extended-detention orifice may be required.

4.2.3 Grassed Swale

Swales are grassy depressions in the ground designed to collect storm water runoff from streets, driveways, rooftops and parking lots. Two general types of grassed swales are generally designed: 1) a dry swale, which provides water quality benefits by facilitating stormwater infiltration, and 2) a wet swale, which uses residence time and natural growth to treat stormwater prior to discharge to a downstream surface water body. Both dry and wet swales demonstrate good pollutant removal, with dry swales providing significantly better performance for metals and nitrate. (FHWA, no date). The primary pollutant removal mechanism for both wet swales and dry swales is through sedimentation of suspended materials.

Procedures for the evaluation, design, operation and maintenance of grassed swales are presented as Minimum Standard 3.13 in the Virginia Stormwater Management Handbook. The Virginia Stormwater Management Handbook distinguishes two types of grassed swales: a simple grass swale, and a “water quality” swale. A simple grassed swale is a broad and shallow earthen channel vegetated with erosion resistant and flood-tolerant grasses. Check dams are strategically placed in the swale to encourage ponding behind them. A water quality swale is a broad and shallow earthen channel vegetated with erosion resistant and flood tolerant grasses, and underlain by an engineered soil mixture.

Application

The purpose of grassed swales and water quality swales is to convey stormwater runoff at a non-erosive velocity in order to enhance its water quality through infiltration, sedimentation, and filtration. Check dams are used within the swale to slow the flow rate and create small, temporary ponding areas. A water quality swale is appropriate where greater pollutant removal efficiency is desired.

Effectiveness

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 (FHWA, No date). Table 4.3 shows the pollutant removal efficiencies for some grassy and vegetated swales used for stormwater conveyance and treatment in the United States.

Table 4.3 - Pollutant removal efficiencies for grassy swales (from FHWA, No date)

Design	Pollutant Removal Efficiencies (%)					
	TSS	Metals	Nutrients			Source
			TN	NO_3	TP	
Grassed channel	68		23	-2	43	City of Austin (1995)[1]
Vegetated swale (61-m)	21-95	-	-	-	32-85	Yu et al., (1993)[2]
Vegetated swale (30-m)	49	13	-	-	33	Yu et al., (1994)[2]
Grassed swale	30	11	-	-	Neg.	Yu and Kaighn (1995)[1]
Grassed swale	-	(-25)-92	(-14)-25	-	(-48)-48	Yousef et al., (1985)[1]
Grassed swale (61-m)	83	30-72	-	-	29	Kahn et al., (1992)[2]

[1] Removal efficiencies based on concentrations.
[2] Removal efficiencies based on mass loading.

The Virginia Stormwater Management Handbook indicates that an expected phosphorus removal effectiveness of approximately 15% can be expected for simple grassed swales, and an expected phosphorus removal effectives of approximately 35% can be expected for water quality swales.

Design

Marsh (1996) performed an extensive review of the literature regarding the design of grassy swales and found the following guidelines with respect to the various variables important in designing grassy swales.

- Infiltration
  - Infiltration rates should be greater than 0.27 inches per hour (0.69 cm/hr)
  - Groundwater contamination from swales is sometimes possible
  - Ponded water should infiltrate within 24 (or sometimes 48) hours

- Hydraulics
  - Maximum velocity should be less than 1.5 foot per second (45.7 cm/s) for quality control applications
  - Maximum flow depth should be 4 inches (10 cm) or should not exceed the height of vegetation
  - Minimum residence time in the swale should be approximately 9 minutes
  - Flow should be less than 5 cubic feet per second (11 m^3/min)

- Channel Configuration
  - Side slopes should never be steeper than 3:1
  - Minimum top width should be 10 feet (3 m), where possible
  - Minimum length should be 100 feet (30 m), where possible
  - Slopes should be between 0.2 and 8%

- Vegetation
  - Wetland species should be planted if the water table is high enough to support growth
  - Top soil layer of 12 inches (30.5 cm) should be added
  - Slow growing vegetation should be used

The above elements of the design of grassed swales, and others, are presented in Minimum Standard 3.13 of the Virginia Stormwater Management Handbook.

Siting

Grassed swales are commonly used instead of curb and gutter drainage systems in low- to moderate density (16 to 21% impervious) developments. Dry swales are distinguished from a simple drainage/grassed channel by the addition of carefully selected, highly permeable soil (usually sandy loam), check dams (spaced 15 to 30 m. apart), and an underdrain system (see Figure 4.3). These design features ensure that infiltration of stormwater will not depend only on the infiltration rate of the existing natural soils.

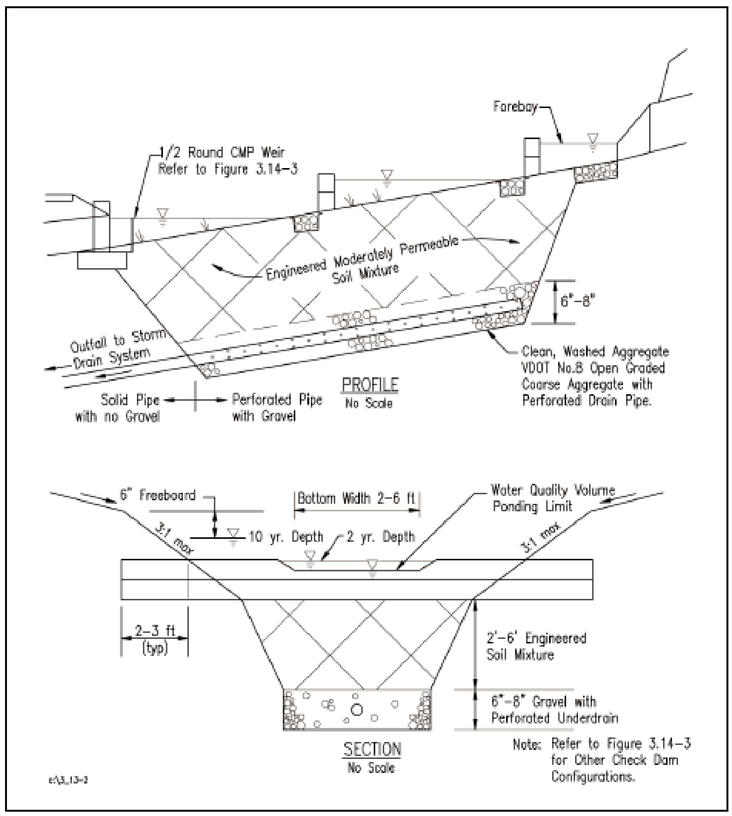

Figure 4.3 - Grassy Swale (VDCR, 1999)

Wet swales are generally located in areas of relatively high water table, and differ from the simple drainage/grassed channel by design features (including check dams and weirs) 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 not desired in a wet swale because it would likely result in conditions that would not support wetland vegetation.

Maintenance

Maintenance of grassed swales includes upkeep of the vegetative cover and preservation of the swale's hydraulic properties.

- Vegetation – dense and vigorous grass cover should be maintained in a grassed swale. This will be simplified if the proper grass type is selected in the design. Periodic mowing is required to keep the swale operating properly.
- Debris and Litter Removal – The accumulation of debris (including trash, grass clippings, etc.) in the swale can alter the hydraulics of the design and lead to additional maintenance costs.
- Sediment Removal –The sediment that accumulates within the swale should be manually removed and the vegetation reestablished.

4.2.4 Infiltration

Infiltration practices for linear DOT projects generally take the form of infiltration basins or infiltration trenches. An infiltration basin consists of a shallow, flat basin in pervious soil, with an inlet structure and an outlet structure to regulate emergency overflow. It functions by retaining runoff in the basin, where it then percolates into the soil. An infiltration trench consists of a long, narrow subgrade gravel bed, where runoff is stored until it is infiltrated. Figure 4.4 shows a typical infiltration trench. Infiltration basins and trenches are discussed as Minimum Standard 3.10A and 3.10B, respectively, in the Virginia SWM Handbook.

Figure 4.4 - Infiltration Trench (Center for Watershed Protection)

Application

Infiltration trenches and basins capture and treat small amounts of runoff, but do not control peak hydraulic flows. Infiltration facilities achieve some removal of sediment, heavy metals, toxic materials, floatable materials, oxygen demanding substances, oil and grease, bacteria, and viruses. Infiltration facilities also control runoff volume. Tributary areas to infiltration devices shall not exceed 50 acres. Land uses for which infiltration is appropriate include residential, commercial, and institutional land uses.

Effectiveness

Infiltration trenches function similarly to rapid infiltration systems that are used in wastewater treatment. Estimated pollutant removal efficiencies from wastewater treatment performance and modeling studies are shown in Table 4.4 (U.S. EPA, 1999; source of data Schueler, 1992).

Table 4.4 -Typical Pollutant Removal Effectiveness for Filtration Practices

Pollutant	Removal Effectiveness
Sediment	90%
Total Phosphorus	60%
Total Nitrogen	60%
Metals	90%
Bacteria	90%
Organics	90%
BOD	70 – 80%

Design

Infiltration trench and basin designs vary considerably, depending on site constraints and the preferences of the designer and community. There are some features, however, that should be incorporated into every infiltration trench design. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping. The Virginia SWM Handbook discusses design procedures in detail.

Siting

Infiltration facilities are suitable for use where the subsoil is sufficiently permeable to provide a reasonable rate of infiltration. They are also practical where the water table is sufficiently lower than the design depth of the facility to prevent pollution of the groundwater. Infiltration is not recommended for areas underlain by karst topography.

The key element in siting infiltration basins is identifying sites with appropriate soil and hydrogeologic properties, which is critical for long term performance. In one study conducted in Prince George's County, Maryland (Galli, 1992), all of the infiltration basins investigated clogged within 2 years. It is believed that these failures were for the most part due to allowing infiltration at sites with rates of less than 0.5 in/hr, basing siting on soil type rather than field infiltration tests, and poor construction practices that resulted in soil compaction of the basin invert.

Infiltration practices are generally suited for low- to medium-density development (38% to 66% impervious cover).

Maintenance

Typical maintenance activities for infiltration trenches include the following (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, as well as 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 to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate limit Excavate trench walls to expose clean soil.	Upon Failure
Source: Center for Watershed Protection	

4.2.5 Constructed Wetlands

Stormwater wetlands are structural practices similar to stormwater ponds 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 also offer aesthetic value. While 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 both in terms of plant and animal life.

Figure 4.5 - Stormwater Constructed Wetlands (VDCR, 1999)

The Virginia SWM Handbook discusses constructed wetlands in Chapter 3 as Minimum Standard 3.09.

Application

A constructed stormwater wetland can achieve high removal rates of particulate and soluble pollutants (nutrients) through gravitational settling, wetland plant uptake, absorption, physical filtration, and biological decomposition. The pollutant removal efficiency of a constructed wetland is dependent on various design criteria relating to the size and design of the pool area.

Effectiveness

The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data, modeling and professional judgment. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or "treatment train" approach.

- Total Suspended Solids – 80%
- Total Phosphorus – 40%
- Total Nitrogen – 30%
- Fecal Coliform – 70% (if no resident waterfowl population present)
- Heavy Metals – 50%

The Virginia SWM Manual indicates that constructed wetlands are approximately 30% effective with respect to removing phosphorus.

Design

Although the Virginia SWM Handbook describes a single design of stormwater treatment wetland, there are actually several design variations, with each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. Below are descriptions of each design variant:

- Shallow Wetland – In the shallow wetland design, most of the water quality treatment 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 of this design is that, since the pool is very shallow, a relatively large amount of land is typically needed to store the water quality volume.

- Extended Detention (ED) Shallow Wetland – The extended detention (ED) shallow wetland design is the same as the shallow wetland; however, part of the water quality treatment volume is provided as extended detention above the surface of the marsh and released over a period of 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 both wet and dry periods need to be specified in the ED zone.

- Pond/Wetland Systems – The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland, where stormwater flows receive additional treatment. Less land is required for a pond/wetland system than for the shallow wetland or the ED shallow wetland systems.

- Pocket Wetland – A pocket wetland is intended for smaller drainage areas of 5 to 10 acres and typically requires excavation down to the water table for a reliable water source to support the wetland system.

Siting

The minimum watershed drainage area for constructed stormwater wetlands should be 10 acres. However, this minimum should be confirmed based on the watershed's hydrology and the presence of an adequate base flow to support the selected vegetation. Similar to retention basins, a drainage area of 15 to 20 acres or the presence of a dependable base flow is most desirable to maintain a healthy wetland. Other siting criteria include:

- Site Slope – There should be no more than 8% slope across the wetland site.

- Minimum Head – Elevation difference needed at a site from the inflow to the outflow: 3 to 5 feet; 2 to 3 feet for pocket wetland.

- Minimum Depth to Water Table – If used on a site with an underlying water supply aquifer or when treating a hotspot, a separation distance of 2 feet is recommended between the bottom of the wetland and the elevation of the seasonally high water table; pocket wetland is typically below water table.

- Soils – Permeable soils are not well suited for a constructed stormwater wetland without a high water table. Underlying soils of hydrologic group “C” or “D” should be adequate to maintain wetland conditions. Most group “A” soils and some group “B” soils will require a liner. Evaluation of soils should be based upon an actual subsurface analysis and permeability tests.

Maintenance

Maintenance of stormwater wetlands should include the following at a minimum:

- Inspect the wetland twice a year and after major storm events. Initially, determine if it is working according to design, look for signs of eroding banks or excessive sediment deposits and insure that plant growth is occurring as expected. Routine inspections should include looking for clogged outlets, dike erosion and nuisance animals. Be sure to specify what measures to take to correct any defects.

- Determine what the maximum sediment accumulation in the forebay and micropool can be from the design. Sediment accumulation should not reduce the treatment volume to less than 10% of the total wetland treatment volume. Specify how to measure the sediment accumulation, how to remove excess sediment and where to dispose of it.

- Remove floatables and trash as necessary.

- Inspect structures such as riprap or concrete for signs of damage. Inspect and test any mechanical structures such as gates, valves or pumps.

- Mow the banks and access roads at least twice per year to prevent the growth of woody vegetation.

- Harvesting (the periodic annual or semiannual cutting and removal of wetland vegetation) is necessary to maintain the capability of the wetland to remove soluble nutrients and pollutants. Harvesting the vegetation promotes plant growth and thereby the uptake of soluble nutrients and pollutants from stormwater. A written harvesting procedure should be prepared by a qualified wetland scientist. The plan should include how to dispose of harvested material.

- Harvesting vegetation within a natural wetland is often difficult due to the topography and thick organic soils present. However, a constructed wetland can be designed in a manner that decreases harvesting and maintenance practices and associated costs.

CHAPTER 5 STORMWATER MANAGEMENT FOR FACILITIES

Transportation facilities include rest stops, welcome stations, park and ride areas, vehicle maintenance yards, salt storage areas, and any areas where there are buildings, parking lots, and other structures that are not roads or streets. These facilities require stormwater control measures that may be similar to those used for linear projects, but stormwater management for facilities also include measures that are fundamentally different from stormwater control measures used on linear projects. It should be noted that BMPs both for linear projects and facilities all are based on the same general pollutant removal pathways of settling, filtering, and to a much lesser degree, biological processes. Many of the BMPs used at DOT facilities are similar to those used for linear projects, with possible variations in the physical constraints and/or pollutants of concern.

Management of stormwater at transportation facilities involves the capture, transport, storage and discharge of runoff largely from impervious areas such as rooftops, parking lots, and sidewalks. Traditional stormwater management practices have consisted of roof drains, drop inlets, curb inlets, stormwater sewers, detention ponds, and discharge to natural receiving waters. The following sections discuss both traditional methods of stormwater management at facilities as well as new methods. The section begins with a discussion of a relatively new stormwater management paradigm that is generally known as Low-Impact Development, or “LID.”

5.1 LOW IMPACT DEVELOPMENT

Storm water has long been regarded as a “nuisance” to construction and a hazard to existing facilities rather than a resource to be protected. Traditional stormwater management has emphasized the removal of precipitation as quickly and completely as possible from developed areas to the detriment of ecosystem functions.

Although it provides a convenient environment for construction, removing stormwaters in the traditional way from developed areas, and discharging the removed stormwaters into nearby receiving watercourses, has resulted in numerous unintended problems, including:

- Increased flooding hazard
- Stream instability
- Impaired stream water quality, including increased temperature
- Insufficient groundwater recharge
- Reduced base flow and increased peak flow (i.e., “flashiness”)

Project-specific approaches to stormwater management that address runoff only from the small area occupied by the facility are gradually giving way to more comprehensive watershed-based approaches that consider the interplay of all (or at least many) of the ecological processes that combine to create and maintain stable ecosystems.

Low-Impact Development is an innovative technological approach to stormwater management and ecosystem protection where hydrologic controls are integrated into every aspect of a site’s design to mimic the predevelopment hydrology hydrologic regime (Coffman, 2001). Low-Impact Development focuses on the design of stormwater management systems that maintain ecosystem and hydrologic functions. Low-Impact Development maintains or restores the hydrologic regime and manages stormwater by modifying or replacing conventional site design with designs that create an environmentally and hydrologically functional landscape that mimics all natural watershed hydrologic functions (volume, frequency, recharge, evaporation and discharge).

Low-Impact Development techniques are simple and effective, and are significantly different from conventional engineering approaches which emphasize the piping of water to low spots removed from the development area as quickly as possible. Instead, LID uses micro-scale techniques (sometimes known as “ultra-urban” techniques when space is extremely limited) to manage precipitation as close to where it hits the ground as possible. However, LID approaches and technologies can also provide adequate removal or stormwater runoff so that public safety concerns (e.g., flooding and ponding) are also addressed.

5.1.1 Basic Principles of Low-Impact Development

The basic principles of Low-Impact Development include:

- Restore/Conserve Natural Hydrologic Processes
- Hydraulically Disconnect Impervious Surfaces
- Disburse Runoff
- Integrated Micro-scale Management
  - Retain
  - Detain
  - Recharge
  - Treat
- Increase Flow Paths
- Upland Phytoremediation Systems
- Unique Watershed Storage
- Minimize Imperviousness
- Multifunctional Landscaping

The following paragraphs will briefly discuss the key principles.

Restore/Conserve Natural Hydrologic Processes

One of the primary principles of LID is to conserve the natural hydrologic processes as areas are being developed, and to restore natural hydrologic processes to already-developed areas. The Low-Impact Development approach to stormwater management focuses on the following hydrologic components (Prince George’s County, 1999):

- Runoff Curve Number (CN). Minimizing changes in post-development hydrology by reducing impervious areas and preserving more trees and meadows. This reduces the storage requirements in order to maintain the pre-development runoff volume.

- Time of Concentration (T_c). Maintaining the pre-development T_c in order to minimize the increase of the peak runoff rate after development by lengthening surface flow paths and reducing the length of the below-ground runoff conveyance systems.

- Retention. Providing retention storage for volume and peak control, as well as water quality control in order to maintain the same storage volume as the predevelopment condition.

- Detention. Providing additional detention storage, if required, to maintain the same peak runoff rate and/or prevent flooding.

Table 5.1. Hydrologic Processes Affected by Various LID Techniques (Prince George's County, 1999)

LID Hydrologic Component	Low-Impact Development Techniques															
	Flatten slope	Increase flow path	Increase sheet flow	Increase roughness	Minimize disturbance	Flatten slopes on swales	Infiltration swales	Vegetative filter strips	Constricted pipes	Disconnected impervious areas	Reduce curb and gutter	Rain barrels	Rooftop storage	Bioretention	Revegetation	Vegetation preservation
Lower Post-development CN					✓		✓	✓		✓	✓			✓	✓	✓
Increase Tc	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Retention							✓	✓				✓	✓	✓	✓	✓
Detention						✓			✓			✓	✓			

Hydraulically Disconnect Impervious Surfaces

Often, transportation facilities are characterized by an interconnected series of impervious areas. Rooftops drain to parking lots, which in turn drain to streets. Water from the streets enters storm sewers and flows either directly to a receiving stream, or to a detention basin before being released to the stream. The imperviousness does not allow the water to infiltrate into the surface soils; the connectedness of these impervious areas ensures that the maximum amount of water will be drained from the area in the minimum time. These goals have, for a long time, formed the basis for stormwater management, but it has been shown that alone, they are in direct opposition to good, sustainable environmental planning.

An important principle and technique of low-Impact development is to disconnect those impervious surfaces. When roofs, parking lots and streets are disconnected, the discharge hydrograph is at least partially restored.

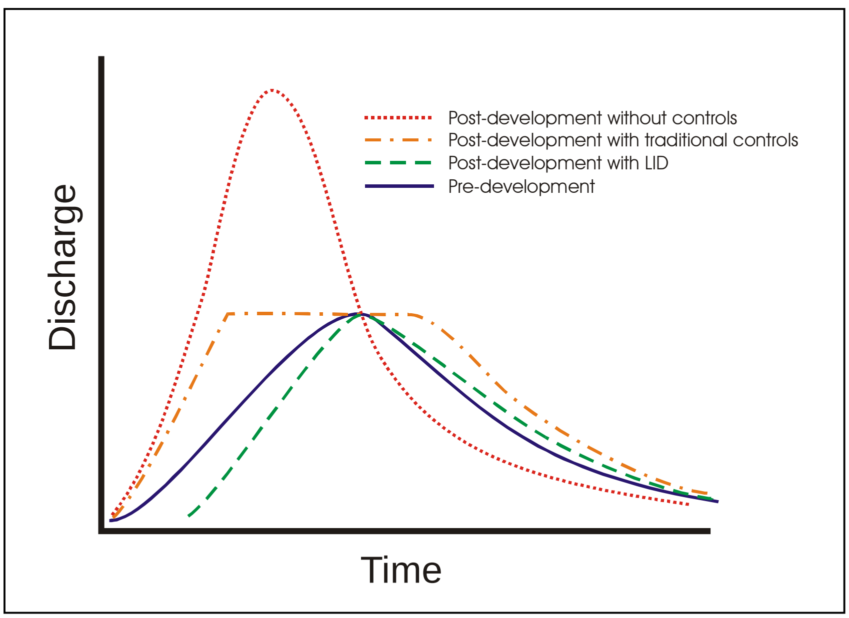

Figure 5.1 - Typical Stormwater Hydrographs

Figure 5.1 shows some typical stormwater hydrographs from pre- and post-urbanized areas. The solid blue line shows a normal stormwater hydrograph from a natural area. Post-development hydrographs have an increased peak discharge, which occurs earlier in the runoff cycle due to the decreased time of concentration.

Traditional controls (e.g., detention basins) reduce the peak discharge of runoff to pre-development rates, but result in the discharge of runoff to receiving waters at the peak rate for a longer time. Thus, even though the peak discharge is at pre-development rates, the potential for stream erosion is increased. When LID techniques are used the hydrograph is closer to the natural hydrograph. The initial discharge is somewhat delayed due to the use of increased biofiltration techniques for water quality improvement. The peak discharge is roughly the same magnitude and occurs at roughly the same time due to the maintenance (to the extent possible) of the original time of concentration. Importantly, the receiving water receives the peak discharge only for a brief period, as in the natural hydrograph, so the potential for erosion is greatly reduced.

Upland Phytoremediation Systems

A key principle of LID is to disaggregate stormwater management facilities and to redistribute them into the upland urbanized area, rather than to concentrate stormwater management facilities at the end of the stormwater sewer pipe. These distributed units serve two purposes: (1) to maintain or restore the hydrology of the area, and (2) to improve water quality before it is discharged into the receiving stream.

Low-impact development relies greatly on upland phytoremediation systems to control the hydrology and to improve runoff water quality. Such techniques as bioretention units (aka "rain gardens"), buffer strips, swales and other vegetative components are used in LID. Specific examples of these techniques, and their effectiveness was discussed in the previous section of this manual.

Minimize Imperviousness

It is clear that there is a correlation between the amount of impervious area in a drainage basin and the quality of the receiving waters (both groundwater and surface waters) as well as the quantity of ground water resources (Stephenuck et al., 2002, Schueler, 1994). Therefore, a key principle of LID is to minimize the amount of impervious area.

Imperviousness can be minimized by a wide variety of techniques, including the use of porous pavement in parking areas, and the use of porous pavers for patio areas and sidewalks.

Multifunctional Landscaping

The low-impact development "multi-functional landscape" emulates the predevelopment temporary storage (detention) and infiltration (retention) functions of the developed area. This functional landscape is designed to mimic the pre-development hydrologic conditions through runoff volume control, peak runoff rate control, flow frequency/duration control, and water quality control.

Rather than creating a landscape based purely on aesthetics, LID landscapes integrate aesthetics with function, and include such techniques as varying the topography to increase the time of concentration, use of phytoremediation units for stormwater catchments and infiltration, increased use of plants to improve micrometeorological aspects of the area, and others.

Integrated Micro-scale Management

Instead of using "hard" engineering strategies for stormwater management, LID strategies integrate green space, native landscaping, natural hydrologic functions, and various other techniques to generate less runoff from developed land. This involves strategic placement of linked lot-level controls, such as bioretention cells, swales, and other ultra-urban BMPs that are designed to address specific pollutant loads as well as stormwater timing, flow rate, and volume issues. The Virginia Stormwater Management Handbook refers to this strategy as "Green Alleys."

5.1.2 Costs

Results of completed LID projects indicate that the higher initial landscaping costs of LID might be offset by reductions in the infrastructure and site preparation work associated with conventional approaches. Estimates from pilot projects and case studies suggest that LID projects can be completed at a cost reduction of 25-30% over conventional projects—in decreased site development, stormwater fees, and site maintenance (Hager, 2003).

5.1.3 Operation and Maintenance

Operation and maintenance is a real consideration in the selection, design and implementation of any stormwater utility. Any steps taken to simplify and minimize operation and maintenance requirements will help ensure the continued effectiveness of stormwater controls, and will contribute to the cost-effectiveness of the system.

Many of the techniques employed by LID do not involve maintenance. Such aspects of LID as those taken by the architects, planners and engineers in the initial layout and construction of facilities, including conservation, maximizing disconnection of impervious surfaces, saving infiltratable soils, and amending soils to have more assimilative capacity do not require ongoing operation and maintenance. Mr. Larry Coffman, of the Prince George's County (Maryland) Department of Environmental Services notes that with the dozens of techniques available to implement LID, even a loss of 30-40% of installed rain gardens over time will be offset by the redundancy of the other techniques (Hager, 2003).

5.1.4 Additional Information Resources

There are many additional sources of information related to Low Impact Development. These sources include printed reports and Internet sites. The following is a brief description of some of the key sources of additional information regarding LID.

Reports and Manuals

The initial documents that developed the planning and engineering aspects of LID were prepared by the Prince George's County (Maryland) Department of Environmental Resources. These two documents are:

Low-Impact Development Design Strategies – An Integrated Design Approach: This document was issued in June 1999. The manual describes how LID can achieve stormwater control through the creation of a hydrologically functional landscape that mimics the natural hydrologic regime.

Low-Impact Development Hydrologic Analysis: This document was issued in June 1999. This document describes low-impact development (LID) hydrologic analysis and computational procedures used to determine low-impact development stormwater management requirements. The hydrologic analysis presented is based on the Soil Conservation Service (SCS) TR-55 hydrologic model (SCS, 1986). Design concepts are illustrated by the use of runoff hydrographs that represent responses to both conventional and low-impact development. Low-impact development site planning and integrated management practices (IMPs) are defined and categorized into components of low-impact development objectives. Computational procedures for determining IMP requirements are demonstrated through design examples.

The Federal Highway Administration has prepared a comprehensive, Internet-based document that provides a review of many ultra-urban best management practices that promote the LID concept. This document, titled: "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring" can be found at http://www.fhwa.dot.gov/environment/ultraurb/index.htm.

Organizations and Associations

Several organizations and associations have been formed to promote LID implementation. Some of the key organizations and associations are:

Low Impact Development Center, Inc.

http://www.lowimpactdevelopment.org

The Low Impact Development Center is a non-profit water resources research group with a mission of conducting research and training on LID and sustainable stormwater management. Resources include publications, pictures, and other resources.

Center for Watershed Protection

http://www.stormwatercenter.net/

The Stormwater Center offers resources to technically assist decision-makers and the public on stormwater management issues. Resources include publications and manuals, slide shows, ordinance information, monitoring and assessment methods, and best management practices fact sheets.

Prince George's County, Maryland, Department of Environmental Resources

http://www.co.pg.md.us/Government/AgencyIndex/DER/PPD/lid.asp?h=20&s=&n=50&n1=160

The LID page of the Programs and Planning Division offers information on links to on-line information on watershed management and low impact design concepts.

5.2 TRADITIONAL STORMWATER MANAGEMENT PRACTICES

Like any stormwater management program, stormwaters originating at facilities must be managed in accordance with Virginia's stormwater regulations. These regulations, as discussed in Section 2, require that the quantity of stormwater be managed so that the discharge of collected runoff to receiving streams does not cause channel erosion, and does not cause flooding.

In addition, facilities have requirements with respect to the quality of released stormwaters. In Virginia the "keystone" pollutant to be controlled principally to improve the quality of the Chesapeake Bay, is phosphorus. However, other pollutants are often found in stormwaters from transportation-related areas and traditional stormwater management practices also are being used to remove these other pollutants.

The following sections discuss two traditional practices for the management of stormwater quantity and their effectiveness with respect to water quality: bioretention and infiltration. These practices are regarded as "traditional" because they have been used in various forms for many years to provide management of stormwaters for linear projects. However, many of the design and operation features of these "traditional" approaches have been modified to make them effective stormwater management techniques in smaller, facility situations.

5.2.1 Bioretention

One of the key water quality stormwater management techniques is bioretention (sometimes referred to as "rain gardens"). Bioretention is a terrestrial-based (up-land as opposed to wetland), water quality and water quantity control practice using the chemical, biological and physical properties of plants, microbes and soils for removal of pollutants from storm water runoff. Some of the processes that may take place in a bioretention facility include sedimentation, adsorption, filtration, volatilization, ion exchange, decomposition, phytoremediation, bioremediation, and storage capacity (Prince George's County, 2002). Figure 5.2 shows a typical bioretention system in a parking lot.

Figure 5.2 - Typical "Rain Garden" Bioretention System

The design, operation and maintenance of bioretention units are described in Minimum Standard 3.11 of the Virginia Stormwater Management Handbook. The Virginia Stormwater Management Handbook describes two types of bioretention units: 1) rain garden-type units are called "Bioretention Filters" in the Virginia Stormwater Management Handbook to emphasize the primary pollutant reduction mechanism related to phosphorus and heavy metals, and 2) "Green Alleys" are networks of bioretention basins/infiltration trenches or bioretention filters that provide both redundant water quality management and stormwater conveyance to other stormwater management facilities.

Application

Bioretention units can be applied to many situations that arise at VDOT facilities. Perhaps the most often-used application would be to capture and treat stormwater from parking lots. These could be located at truck weigh stations, park-and-ride facilities and welcome stations. Other applications include the treatment of runoff from rooftops, and from streets.

Effectiveness

There have been only a few studies of the effectiveness of bioretention units on stormwater quality, and many of those studies have been laboratory-based rather than field-based. Therefore, there are almost no data regarding the effectiveness of these units on water quality, and the results of the studies that have been performed are sometimes inconsistent. The Virginia Stormwater Management Manual indicates the following effectiveness of bioretention units in reducing phosphorus concentrations in stormwaters.

Description	Target Phosphorus Removal Efficiency
Bioretention basin with capture and treatment volume equal to 0.5 inches of runoff from the impervious area.	**50%**
Bioretention basin with capture and treatment volume equal to 1.0 inches of runoff from the impervious area.	**65%**

Laboratory and field studies performed by the University of Maryland have shown that bioretention is very efficient at removing heavy metals such as copper, lead and zinc, and organic compounds such as ammonia and phosphorus (decreased by 60-80%). Also there was a marked decrease in thermal pollution, a form of pollution often forgotten when dealing with run-off. Unfortunately, the removal rates for nitrates were lower than ideal. Other studies of bioretention units by the University of Maryland (Davis et al., 1998) show the following effectiveness.

Typical Pollutant Removal Rates at Bioretention Units	
Pollutant	Pollutant Removal (%)
TSS	81
TP	29
TN	49
NO_x	38
Metals	51-71
Bacteria	-58

However, it is important to note that the ability of bioretention to handle different types and degrees of pollutant loading is design-specific, and the different bio-chemical-physical processes described above can be modulated to achieve the desired result. For example, adding an anaerobic zone will promote the growth of denitrifying bacteria, which volatilize nitrates. The latter design feature can easily be incorporated into a site where excessive nitrate runoff is anticipated.

Design

Bioretention systems are more than simply creative landscaping. They are engineered systems that have been designed and installed to promote the biological, physical and chemical treatment of stormwater runoff, as well as to promote the infiltration of stormwater runoff in order to help restore the character of the natural hydrologic cycle of the area. The key design factor for bioretention units is the area of bioretention with respect to the drainage area. In general, the Virginia Department of Forestry recommends that the size of the bioretention area should be 5% to 7% of the drainage areas multiplied by the crop "C" coefficient (the ground cover type). Bioretention cells are comprised of six basic components (U.S. EPA, 1999a). These are:

- Grass buffer strips that reduce runoff velocity and filter particulate matter.
- Sand bed that provides aeration and drainage of the planting soil and assists in the flushing of pollutants from soil materials.
- Ponding area that provides storage of excess runoff and facilitates the settling of particulates and evaporation of excess water.
- Organic layer that performs the function of decomposition of organic material by providing a medium for biological growth (such as microorganisms) to degrade petroleum-based pollutants. It also filters pollutants and prevents soil erosion.
- Planting soil that provides the area for stormwater storage and nutrient uptake by plants. Often the planting soils contain some clays that adsorb pollutants such as hydrocarbons, heavy metals and nutrients. Virginia DCR and the Virginia Department of Forestry recommend a soil mixture of top soil (20-30%), leaf compost (20-30%) and coarse-grained sand (50%) which produces an ideal filter media to maximize infiltration, filtration and storage (hydrologic loading) capacity.
- Vegetation (plants) that function in the removal of water through evapotranspiration and pollutant removal through nutrient cycling.

Figure 5.3 shows a schematic drawing of a typical bioretention cell constructed to transport stormwater runoff from a parking lot. Note that the runoff is first collected in a stone-filled trench and is spread evenly across a grassy filter strip (at least 20 feet, or 6 meters long) before entering the bioretention area. Drawings of other configurations of bioretention units can be found in Minimum Standard 3.11 of the Virginia Stormwater Management Handbook.

Siting

Bioretention can be applied on many sites, with its primary restriction being the need to apply the practice on small sites. The following paragraphs provide additional information regarding siting of bioretention units

- Drainage Area - Bioretention areas should usually be used on small sites (i.e., five acres or less). When used to treat larger areas, bioretention units may 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% or less).

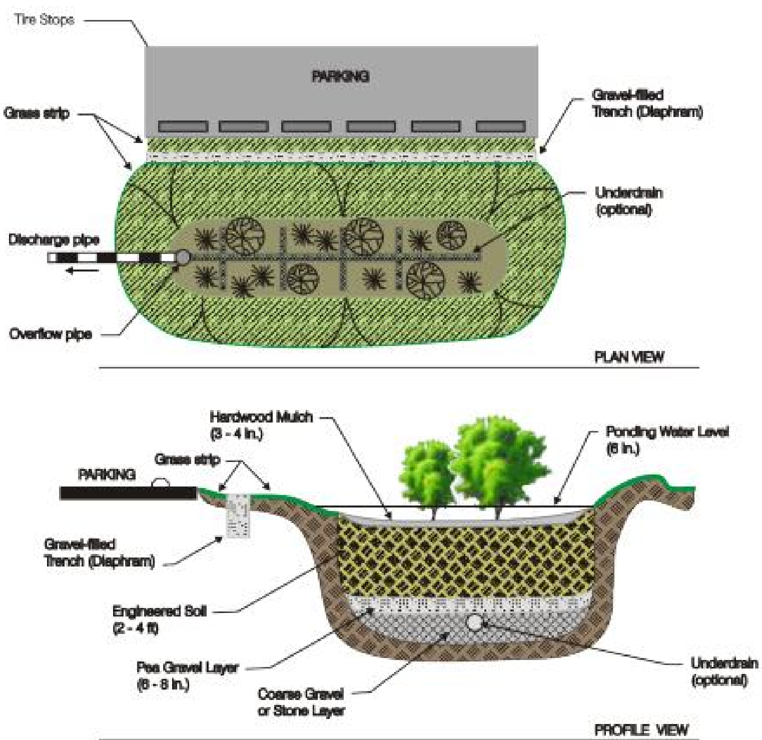

Figure 5.3 - Schematic Drawing of a Typical Bioretention Unit.

- Soils /Topography - Bioretention areas can be applied in almost any soils or topography. Generally, for free infiltration soils should be in hydrologic soil groups A or B. Otherwise, bioretention units can be constructed using a man-made permeable soil bed with an underlying drainage system that returns filtered stormwaters to a conventional stormwater system.

- Groundwater - Bioretention should be separated from the water table by at least 3 to 4 feet to ensure that the groundwater never intersects with the bottom of the bioretention area.

Maintenance

There are no specific operation and maintenance requirements for bioretention units other than routine plant maintenance (e.g., trimming, mulching, weeding, etc.). The maintenance of bioretention units can be performed by landscape contractors hired to perform other landscape maintenance tasks. The Center for Watershed Protection's Stormwater Center recommends the following maintenance schedule:

Typical Maintenance Activities for Bioretention Areas	
Activity	Schedule
• Remulch void areas • Treat diseased trees and shrubs	As needed
• Water plants daily for two weeks	At project completion
• Inspect soil and repair eroded areas • Remove litter and debris	Monthly
• Inspect soil and repair eroded areas • Remove litter and debris	Once yearly
• Add additional mulch • Replace tree stakes and wire	Twice yearly
Source: Center for Watershed Protection	

5.2.2 Infiltration

Infiltration practices for linear projects are described in Chapter 4; this section discusses other infiltration practices that are better suited for smaller applications, such as those encountered at VDOT facilities. In general, a stormwater filter refers to units that use either artificial media (such as sand, peat, grass, soil, or compost) to filter out pollutants in stormwaters. These filters are designed to remove pollutants from the "first flush" or other water quality volumes, and bypass larger flows. Claytor and Schueler (1996) identify three broad groups of filters. These are: 1) sand filters (comprised of surface, underground, perimeter, organic and pocket designs), 2) bioretention, and 3) vegetated channels (including grass channels, dry swales, wet swales, and filter strips). Bioretention was discussed above. Some of the sand filter units are described in the next subsection. This subsection will discuss the more "traditional" infiltration units; the organic sand and pocket sand filters, as well as infiltration trenches. A comprehensive review of all of the various types of infiltration systems can be found in Claytor and Schueler (1996).[15]

Application

Like bioretention units, infiltration units can be applied to many situations that arise at VDOT facilities. The most often-used applications would be to capture and treat stormwater from parking lots. These could be located at truck weigh stations, park-and-ride facilities and welcome stations. Other applications include the treatment of runoff from rooftops, and from streets. These systems generally are applied to smaller drainage areas, usually less than 5 acres. Pocket sand filters are often used for drainage areas less than 2 acres.

Effectiveness

The following table shows the pollutant removal effectiveness for various types of infiltration systems suitable for use at VDOT facilities.

[15] This publication is available as a downloadable manual as of the date of this publication from: http://centerforwatershedprotection.goemerchant7.com/. Click the link to "Other Downloadable Resources" Cost: $25.

Estimated Pollutant Removal Effectiveness of Infiltration Units					
Filtering System	TSS	TP	TN	NO_3	Other Pollutants/comments
Organic Sand Filter[1]	95	40	35	neg	Hydrocarbons: 90% Soluble Phosphorus: negatives Metals: 85+%
Pocket Sand Filter[1]	Presumed to be comparable to surface sand filter (Austin Filter); discussed in next section.				
Infiltration Trench[2]	90	60	60	--	Organics: 90% Bacteria: 90% Metals: 90% Biochemical oxygen demand: 70 – 80%

[1] From Claytor and Schueler, 1996
[2] From USEPA, 1999b (source of data: Schueler, 1992)

Design

The pocket sand filter consists of a flow splitter inlet structure to capture the water quality volume, a vegetative filter strip (or suitable alternative, such as a small stilling basin at a storm drain pipe outfall) and an above-ground sand filter bed (18 – 24 inches) over a gravel underdrain system. Figure 5.4 shows a plan view of a typical pocket sand filter; Figure 5.5 shows a typical profile view. Both of these figures are adapted from Claytor and Schueler, 1996.

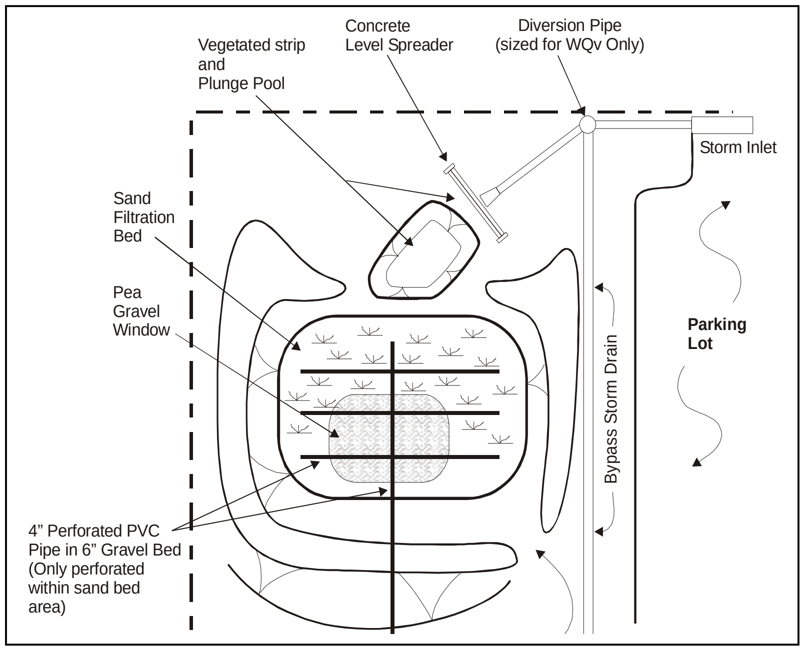

Figure 5-4 Pocket Sand Filter - Plan View (after Claytor and Schueler, 1996).

Organic sand filters have the same basic design, but use an organic additive to the sand to increase pollutant removal efficiencies. The most-used organic additives are peat and leaf compost. Claytor and Schueler (1996) indicate that the type of peat used in the filtration bed is extremely important. A fibric peat, where the undecomposed fibrous organic matter is easily identifiable is preferred; a hemic peat, where more material is decomposed may also be used. However, in no case should a sapric peat, which is made up of mostly decomposed material, be used.

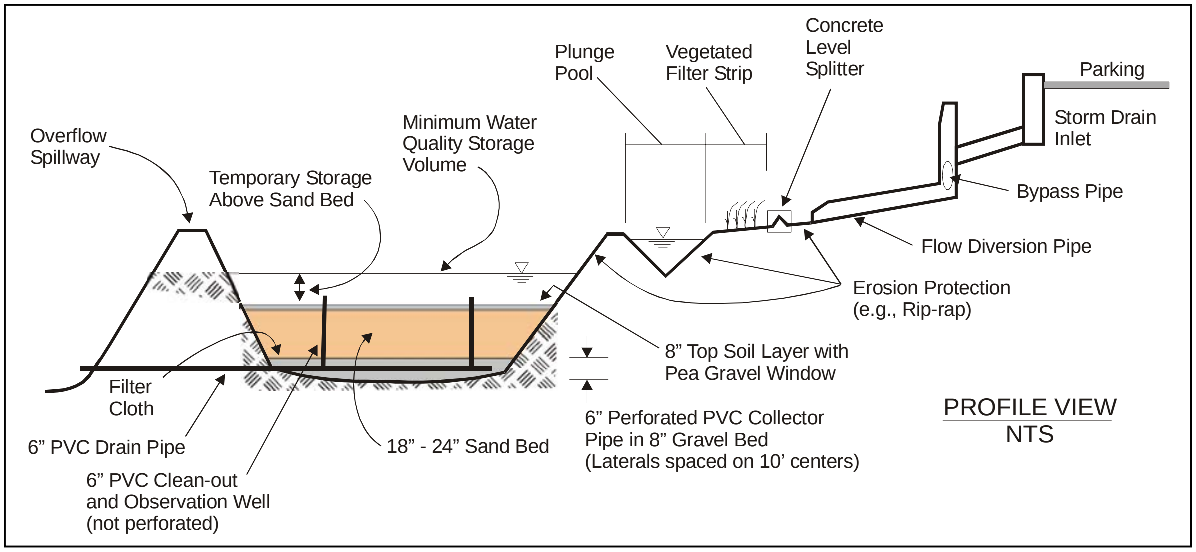

Figure 5-5. Pocket Sand Filter - Profile View (after Claytor and Schueler, 1996)

As with the bioretention units, the key factor in the design of sand filtration units is the surface area. The necessary surface area is a function of the permeability of the filter medium, the bed depth, the hydraulic head (i.e., the height of water above the bed), and the sediment loading. The City of Austin developed an equation that can be used to size the sand filter bed based on Darcy's Law. This equation is:

$$A_f = WQ_v \bullet \frac{d_f}{\left[k \bullet (h_f + d_f)(t_f)\right]}$$

where:

	A_f	=	surface area of the sand filter bed (ft^2)
	WQ_v	=	water quality volume (ft^3)
	d_f	=	sand filter bed depth (ft)
	k	=	coefficient of permeability for sand bed (ft/day)
	h_f	=	average height of water above the sand bed (ft)
	t_f	=	time required for the WQ_v to filter through the sand bed (days)

The sand bed depth can vary, but should not be greater than 24 inches (18 inches is a typical depth). The height of water above the sand bed should not be greater than 6 feet. The rated of infiltration through the sand bed were found by City of Austin field staff to range between approximately 0.5 to 2.7 ft/day. Claytor and Schueler (1996) recommend using a *k* value of 3.5 ft/day for sand media, a value of 2 ft/day for a sand-peat mixture, and a value of 8.7 ft/day for leaf compost media.

Other design elements involve: (1) design of the piping system to regulate flow, (2) design of pretreatment systems to remove excess sediments (includes, for instance, sedimentation basins, vegetative filter strips, grass swales, storm drain structures, oil/grit separators, etc.), and (3) overflow elements. The design and construction of these elements are described in Claytor and Schueler (1996).

Siting

The key factors that affect the siting of pocket sand filters are: (1) the available land area, and (2) the difference in elevation from the drainage area to the filter. In general, pocket sand filters require approximately 2% of the drainage area. This is actually one of the lesser land requirements among all types of filter systems, so a pocket filter should be generally applicable for small drainage areas. A pocket sand filter requires approximately 5 feet of vertical distance (head, or fall) from the drainage area (e.g., parking lot) to the filter bed in order to drive water through the entire filtering system by gravity.

Maintenance

Maintenance requirements for pocket sand filters are generally modest and straightforward. The following table identifies suggested maintenance activities.

Suggested Maintenance Activities for Pocket Sand Filters (after Claytor and Schueler, 1996)

General Maintenance Elements		Specific Maintenance Elements	
Sedimentation Bed	*Filtration Bed*	*Peat-Sand Filter*	*Compost Filter*
• Should be cleaned when sediment depth > 12 inches • Remove accumulated trash every 6 months (or as needed)	• Grass clippings should be removed to prevent clogging of filter	• Periodic mowing • Grass clippings should be removed	• Removal of accumulated sediment – annually
• Vegetation should be limited to 18 inches in height	• Silt should be removed when it exceeds ½-inch	• Regular inspections – especially during the first year	• Rototilling compost media - annually
• Corrective maintenance for off-design draw-down times • Perforated standpipe should be checked and cleaned as needed	• Filter should be inspected regularly according to the following: o Debris cleanout – quarterly o Vegetation – monthly during growing season; otherwise quarterly o Filter bed chamber – semi-annually o Sedimentation chamber – semi-annually o Structural components – annually o Outlets/overflow – annually	• Reseeding of areas with sparse grass coverage	• Compost should be replaced every 3 to 4 years, or when (if) heavy metal concentra-tions exceed the USEPA's 503 Sewage Sludge Requirements for "clean sludge"
• Corrective action for sediment trap if it does not drain at the design rate	• If stormwater contains high amounts of oil/grease – semi-annual cleanout of sedimentation chamber		
• Access manways, gate valves, flumes, etc.. should be kept clean	• Vegetation growing within the basin should not exceed 18 inches in height.		

5.3 URBAN AND ULTRA-URBAN PRACTICES

Management of stormwater quality is a relatively new field, and many innovative products have been developed over the past several years. Those products that are most readily implemented in transportation facilities are often referred to as "ultra-urban" best management practices since they can be employed in areas where there is very little open space. Table 5.2 gives a summary of many of the new ultra-urban BMP products.

They can be classified into five major groups:

1. Catch basin inserts
2. Water quality inlets
3. Hydrodynamic separators
4. Filtration units
5. Porous pavement.

Each of these major groups of ultra-urban BMPs is discussed below.

5.3.1 Catch Basin Inserts

Catch basins are chambers or sumps, usually built at the curb line, which allow surface water runoff to enter the stormwater conveyance system. Catch basin inserts are generally designed to catch and remove coarse sediments, oils, grease, litter and debris from storm water. These units are especially suited for parking lots, vehicle maintenance yards, and other areas where impervious surfaces drain directly into the stormwater conveyance system.

5.3.2 Water Quality Inlets

Water Quality Inlets (WQIs) include oil/water separators, multi-chambered treatment trains (MCTTs), and other public-domain and proprietary design units.[16] WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other best management practices (BMPs). A typical WQI, as shown in Figure 5.6, consists of a sedimentation chamber, an oil separation chamber, and a discharge chamber. The basic WQI design is often modified to improve performance.

Water quality inlets are good for small roadside areas, parking lots, gas stations, rest areas, and weigh stations, and are effective in treating runoff containing high density sediment loads and hydrocarbons. The Federal Highway Authority has previously not recommended the use of water quality inlet BMPs such as oil/grit separators for highway applications, although they may perform adequately in maintenance yards with proper maintenance after installation (FHWA, 2004).

[16] Note: According to the 1996 Sand Filtration Addendum to the Northern Virginia BMP Handbook, water quality inlets (oil/grit separators) and underground extended detention are no longer acceptable BMPs in participating Northern Virginia jurisdictions unless specifically required. Conditions requiring oil/grit separators for spill control will not be affected. Additionally, underground detention for the sole purpose of peak shaving continues to be acceptable.

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
Catch Basin Inserts							
Sorbant™	Sorbant Environmental Corp. Aventura, FL.	Flow cascades over 3 tiers of sorbent pads. Primarily for hydrocarbon removal	Structure drops into standard inlets.	ND	ND	Sorbs 16 to 22 times its weight in hydrocarbons. Does not leach in flooded conditions.* (Corcoran and Rich, 1995)	Catch basin or curb inlet design.
BMP Filter "CB" Series Catch Basin Insert	StormWater Compliance International Oroville, CA (www. stormwatercompintl.com/)	Insert directs flow through mesh screens for sediment removal, then through proprietary media filters.	Applied to catch basins or curb inlets. Overflow allows up to 0.63 cfs through the system.	Hydrocarbon media changes color when saturated. Replacement of other media filters every 6 months. More frequent cleaning of debris.	$900	Oil and grease removal to less than 5 mg/L. Neutral pH: 6-8, BOD & COD reduced to less than 50 mg/L; TSS removal over 90%.*	Company also manufactures oil/water separators, curb inlet filters, inline filters.
Hydro-Kleen™ Filtration System	Hydro Compliance Management, Inc. Brighton, MI (www. hydrocompliance.com/)	Multi-chambered system. Flow through sedimentation chamber to 2 media filters: proprietary material for hydrocarbon removal then activated carbon for final polishing.	Treats first-flush, with bypass available.	Filter change every 4-6 months. More frequent sediment cleanout by vacuum truck.	$1,200 - $2,500 per unit. Filter change: $400 including labor. Low installation cost.	Reduces hydrocarbons, pesticides, herbicides, VOCs to below detection limits.*	Can customize media for site-specific loads. Can be catch basin or burn inlet system. Vendor claims product satisfies structural BMP requirements for NPDES compliance.
Aqua-Guard™	AquaShield, Inc.	Flow through sedimentation chamber and filter media.	ND	Sediment removal by shop-vac or vacuum truck. Filter media changes color to black when replacement is needed.	ND	Effective removal of TSS, soluble and insoluble O&G, phosphorus, nitrogen, VOCs, sulfides, heavy metals. Certified by CA EPA 90-95% removal of dissolved petroleum and oils.*	Standard sizing for drop-in application.
StreamGuard™	Bowhead Manufacturing Co. Address: P.O. Box 80327 Seattle, WA 98108	The insert's universal skirt adapter is installed under a storm drain grate and provides water quality treatment through filtration.	Size based on flow rates from 20 to 40 gpm.	Remove trash and debris when accumulation becomes significant.	$56 to $93 each, depending on size.	Independent testing by King County Surface Water Management Division of	Installed at the U.S. Coast Guard Station in Chesapeake, VA.

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
		gravity settling and absorption.				Washington State demonstrated oil removal efficiencies of 88% when tested in a park-and-ride lot catch basin. Catch basin inserts installed at SeaTac International Airport's passenger pick-up area show average removal efficiencies for Total Suspended Solids of 80%, and for oil & grease of 94%.	
The SNOUT™	Best Management Products, Inc.	Simple hood covers outlet structure. Bottom of hood sites below static water level. Keeps floatables (including trash) above outlet.	ND	SNOUT itself does not require maintenance. Remove trash and debris when accumulation becomes significant.	Low hundreds	Inspections show significant accumulation of gross pollutants.*	Suitable for use with catch basins or water quality inlets. Can be equipped with flow restriction and/or odor control filter.
Filter bag inserts – general	*Multiple Vendors:* DrainPac™ by Drain Works; Drainguards by Ultra Tech; Ultra-Urban Filters by AbTech Industries.	Heavy filter fabric held in place by inlet grate.	Standard sizes for drop-in installation	Frequent inspection and cleanout	ND	Mainly designed to capture trash and sediment. Some also claim sorption of O&G. Can be effective if frequently maintained.	Improper installation causes leaks/bypass of runoff around filter media.
Water Quality Inlets							
Oil/Water Separator (OWS)	*Multiple Vendors:* Areo-Power®; Flo-Trends, Inc.; PSI International, Inc.	Coalescing plate or tube separator. Flow-through system.	Usually designed for specific applications.	ND	ND	Low to negative removal of TSS, TPH, and O&G. (Othmer et al., 2001)	General inability to reduce low levels of hydrocarbons. Not generally recommended.
MCTT (Multi-Chambered Treatment Train)	Developed at the University of Alabama-Birmingham. Specifications are given for cast-in-place construction.	Flow through 3 chambers: screening, tube settling, media filtration. Provides some detention. Customize	Surface area of unit typically 0.5 – 1.5% of the drainage area.	Six-month inspections. Replace sorbent pillows & clean catch basin	$10,000 - $20,000 per 0.25 acre. (Schueler, 1994)	Treats 95% of annual rainfall. Toxicity reduced by filtration. Flow restrictions can	May be able to customize system depending on site pollutant

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
		with aerators, sorbent pads, multi-media filters	Criteria can be expanded to include storm characteristics and anticipated loads.	every 6 – 12 months. Media replacement after 3 – 5 years. Ensure mosquito control.		provide up to 24 hrs settling (US EPA, 1999c)	characteristics.
BaffleBox	Multiple Vendors: Suntree Technologies, Inc., or Cast-in-place construction	Large sediment trap comprised of multiple concrete or fiberglass chambers separated by weirs. Usually with trash screens and skimmers.	Usually 10 – 15 ft. long by 6 – 8 ft. wide. (2 ft. wider than inlet pipe)	Monthly during wet season, 2 – 3 months during dry season.	Installation: $20,000 - $30,000 Maintenance: $0.24/kg removed (avg. $450 per event)	Approx. 2,500 – 3,800 kg/yr sediment removal but highly site-specific. Model performance: removed at least 90% sand or sandy clay, but reduced to only 28% for fly ash. Differences in accumulated material noted between chambers.	Better performance with larger boxes. Systems become septic and odorous without base flow. Many systems installed in Florida. Wash-out can be a problem with larger events.
Oil/Grit Separators (OGS)	Usually cast-in-place construction.	On-line system. Flow through three chambers: sediment & trash, oil containment, energy dissipation. Inverted elbow in oil chamber retains floatables.	Treat 0.1" runoff. Recommended as a last resort for treatment area less than 1 acre.	Quarterly	$5,000 - $16,000; average $8,500 (US EPA, 1999d)	Of 109 systems investigated, the average residence time was less than 30 minutes. Poor retainment of trash and debris. 10 – 40% solids removal with 1 hour detention time.	Used mainly at gas stations, fast food restaurants and other small, but highly-developed sites. Hundreds installed in the DC metro area. Better performance expected if size is increased and unit is placed off-line.
Hydrodynamic Separators							
V2B1	Kistner, Inc.	Swirl concentrator in 2 chambers. Second chamber collects floatables and has outlet. Maintains wet pool. Treats only first flush.	1 – 25 cfs treatment capability. Sized for local 2-month storm. Flows greater than first flush diverted directly to outlet.	Required only in first chamber if regular maintenance. Residuals removed by vacuum truck.	ND	80% TSS removal for first flush.	Floating pollutants isolated from peak storm flows.
Bay Saver®	Bay Saver, Inc.	Gravity treatment in 2 manholes connected by HDPE separator. Primary manhole in-line with the	Either according to flow rate or impervious area. Three units	Required in either chamber when accumulation reaches 2 ft.	$7,000 - $18,000 (materials only)	Designed to remove TSS, O&G, and debris,*	

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
		storm drain. First-flush or low-flow diverted to storage chamber for settling and O&G removal. Outflow from center of static wter column to retain floatables back to primary manhole. Maintains wet pool in storage chamber.	available correspond to range of treatable areas: 1.2 – 8.0 acres impervious area. Largest systems treats maximum up to 11 cfs.				
Stormceptor®	CSR America	Manhole-shaped device. First-flush or low flows divered beneath high-flow platform to settling chamber. Outflow from center of static water column to retain floatables. Maintains wet pool.	8 units available: 900 – 7,200 gal.; 0.55 – 6.7 acres of impervious area. Sized to treat 90% of annual rainfall.	Perform maintenance when stored material reaches 15% total system volume. Recommend quarterly inspections during first year to establish schedule.	Typical installation is $9,000 for 1 acre drainage area. Unit cost: $7,600 - $33,560 per unit. (US EPA, 1999e)	Varying reports. Vendor claims 50 – 80% removal of TSS based on field testing by contracted agencies. Canada ETV reports 81-94% TSS removal; 42-67% TKN removal.	Improper installation compromises system performance. Also, available with inflow configured for curb inlet or submerged application. Over 4,000 installations.
Stormvault™	Jensen Precast	Rectangular footprint. Interior baffles minimize horizontal velocity to enhance settling and prevent resuspension. Bypass available.	Variable sizes afforded by adding modular sections. Sized to treat 85% annual rainfall or runoff. Variable outlet structure allows extended detention.	Large footprint allows extended periods between maintenance. Recommended inspections to establish schedule.	ND	Laboratory testing indicates low horizontal velocity near vault bottom to minimize resuspension. Extensive evaluation provided in Brisbane et al., 2000	Several field monitoring studies are being performed.
Vortechs™	Vortechnics, Inc.	Rectangular footprint comprised of 3 chambers; swirl concentrator, O&G removal, underflow to energy dissipator. Maintains wet pool.	10 units available to treat maximum 10-yr design storms of 1.6 – 25 cfs without bypassing. On-line system sizing criteria based on 1 ft^2 grit chamber surface area per 100 gpm peak flow rate.	Monthly inspection during first year after installation or whenever loading have been high.	$10,000 - $40,000 per unit, not including shipping or installation (US EPA, 1999e)	Vendor claims 80% TSS removal for flow less than or equal to design events. Sediment storage capacity 0.75 – 7.0 yd^3 depending on model.*	Improper installation compromises system performance. 1998 US EPA Environmental Technology Innovator Award.
CDS®	CDS Technologies, Inc.	Non-mechanical screening system. Circular flow maintained within unit.	Treats first-flush with bypass option. Precast systems	3 – 4 times per year. Frequent inspection is required	$2,300 - $7,200 per cfs capacity (including	100% of particle size of mesh opening; Over 90% for	Vendor has won several engineering awards in Australia.

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
		Pollutants settle to sump or remain floating and trapped in center column. Radial flow cleans screens. Maintains wet pool.	available up to 62 cfs. Cast-in-place options can treat up to 300 cfs. Screen size and unit diameter determined for specific applications.	especially during first month after installment. Maintenance includes inspection of screens for damage and measurement of sediment depth.	installation)	particles ½ the size of opening; over 85% for particles 1/3 size of opening; 80-90% O&G using sorbent materials. Complete trash removal*	Installations in the US, Australia and New Zealand.
Downstream Defender™	H.I.L. Technology, Inc.	Swirl concentrator creates a 3D flow path. Sediment settles to bottom of storage area. O&G also stored outside treatment path to prevent re-entrainment. Maintains a wet pool.	4 units range from 0.74 to 13 cfs design flows with corresponding 3 – 25 ft^3 capacity.	Clean-out after 1 – 2.5 ft of sediment accumulates – or annually.	$10,000 - $35,000 per unit (including installation)	PSD trapped sediments 0.001 – 0.01 mm (over 95% measured less than 75 µm). Estimate total solids removal was over 80% for theoretical design flows. Oil storage capacity 70 – 1050 gal.; sediment storage capacity of 0.7 – 8.7 yd^3.	ND
Filtration Units							
Sand Filters	More than 7 varieties	Generally gravity flow through sand bed. Pre-treatment chambers to dissipate energy and remove trash and debris. Particular designs differ in surface area for treatment, head differential to maintain flow, and pre-treatment chambers.	Varies according to specific design, generally changing bed surface area requirements or draw-down time.	Inspect for clogging, mosquito breeding, pump repair. Remove sediments with accumulation exceeds 300 mm; remove upper layers of sand if drain time is greater than 48 hours.	High	Effective for removal of dissolved and particular pollutants.	Excessive sediment clogs filter media, so technology may not be appropriate at all sites (i.e., construction sites).
Storm Filter®	Stormwater Management, Inc.	Rectangular footprint contains multiple rechargeable media filters to tailor treatment for specific applications. Siphon action maintains flow. Bypass is	Customized depending on local requirements for flow or volume-based design. Peak design flow 15 gpm	Annual inspection. Used cartridges recharged with new material. Sediments removed from vault bottom. Services	ND	Treats soluble and insoluble fractions depending on filter media. TSS removal greater than 90%.*	External pre-treatment may be needed.

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
		available.	per cartridge; 8.5 ft^2 footprint per cartridge. 2.3 ft head differential between inlet and outlet is required.	may be provided by vendor.			
Combination Devices							
StormTreat™	StormTreat Systems, Inc.	4 feet high, 9.5 feet diameter recycled polyethylene tank. Flow into sedimentation chamber with skimmers pretreats runoff before entering subsurface flow constructed wetland. Outlet control for a maximum 5-day detention. Effluent released to subsurface for recharge if site conditions permit.	Usually treats first flush. Usually multiple units per site off central catch basin. Each unit serves 5-10% of the total drainage area, or 1-2 units per impervious acre. Sizing includes consideration of soil permeability, hydrologic group, and storm characteristics.	Annual inspection of skimmers and screens. Sediment clean-out every 3-5 years. Replace wetland after 10-20 years.	$6,500 per acre treated impervious area. Maintenance $80 - $120 for 3-5 years. (US EPA, 1999d)	Over 90% removal of TSS and fecal coliforms; over 80% removal of total phosphorus and TPH. Good performance attributed to subsurface flow wetland.	System can be closed off in event of a spill. 1999 EPA New England Environmental Technology Innovator Award winner. 52 units installed between 1994 and 1996.
Aqua-Filter™ Filtration System	Aquashield, Inc. Representative Water Services Inc. 1102 C. Montalona Rd. Dunbarton, NH 03046	Swirl concentrator precedes filtration. Filter bypass for storms exceeding capacity. The Aqua-Filter™ system utilizes a variety of natural media to filter fine sediments and water borne pollutants from the moving storm water.	Treats peak flows of 3.5 – 14.5 cfs; drainage areas 0.5 – 6.0 acres. Filter flow can treat up to 6 mo. to a 1-year design storm.	Filter media changes color to indicate the need for replacement. Remove sediment when accumulation reaches within 2 feet of water surface. For the Aqua-Filter™ Stormwater Filtration System to operate most efficiently, the unit must be maintained properly. Typically, inspection of the Swirl Concentrator	A 6 x 12 feet StormFilter™ (filters a flow-through volume of 0.3 cfs) will cost approximately $15,000; an 8 x 18 feet StormFilter™ (filters a flow-through volume of 0.8 cfs) will cost approximately $30,000. Larger units (filtering a flow-through volume of over 8	Oil storage capacity of 250 – 1000 gal.; sediment storage capacity 1.75 – 5 yd3 depending on the specific system. Extracts hydrocarbons, VOCs, heavy oils, PCBs, insecticides, herbicides, sulfides, organic acidic compounds, heavy metals, nutrients, fine silts and clays. High conductivity of filter material allows high treatment without compromising flow.*	Possible to install individual components of system for site-specific conditions. “Environmentally Preferred” technology since media is made of recycled material.

Table 5.2 Ultra-Urban Best Management Practices

System Type	Manufacturer	Operation	Sizing and/or Area Treated	Maintenance	Cost	General Performance	Comments
				and Filtration Chamber should be performed on a quarterly basis. Information gathered during the first year of service can be used to create a maintenance plan appropriate for the site.	cfs) range from $30,000 to $200,000. The catch basin system starts at $2500.	Third party testing has demonstrated TSS removals of greater than 80% and the effective removal of additional pollutants including hydrocarbons (i.e., light and heavy oils and grease); phosphorus, and various heavy metals (i.e., copper, zinc).	
Pressurized Filtration System	Arkal Filtration Systems	2-step pressurized filtration provided by external pump; commercial disk filters then series of sand filters. Redundant system allows backwashing and continual treatment. Requires power source and outlet for back wash discharge.	ND	Routine	$200,000 for cast-in-place construction.	Rapid filtration allows for more treatment than gravity filters.	ND

* Information supplied by vendor
ND - No Data
After Fassman, 2002

Advantages and Disadvantages

Some advantages of water quality inlets are:

- They do not require a supply of water (such as wet detention basins or wetlands);
- They can be placed underground as part of the storm drainage system;
- They are suitable for smaller catchments, including parking lots and roadways;
- Many types of filters are suitable for larger drainage areas up to 5 or 10 acres.

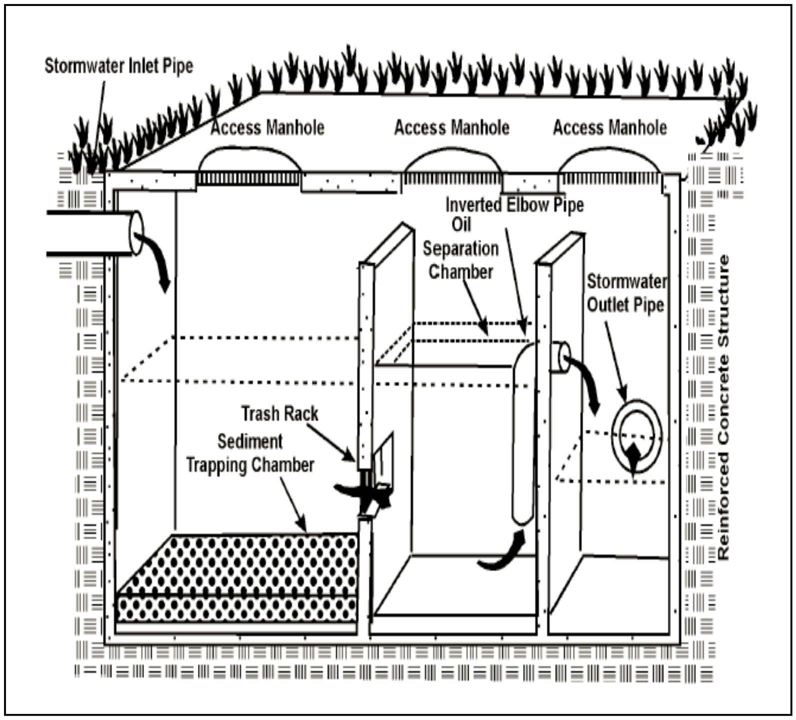

Figure 5.6 - Water Quality Inlet (from Berg, 1991)

Some potential disadvantages of water quality inlets are:

- Pollutant removal performance is uncertain due to lack of detailed studies
- May be expensive on the basis of cost per unit stored and treated.

Design Guidance

Drainage Area	The area served by a water quality inlet should generally be less than 0.4 ha (1 ac) (Schueler, 1987).
Storage Volume	The volume of the permanent pool within the inlet should be at least 28 m^3/ha (400 ft^3/ac) of wet storage (Schueler, 1987). This can be used as an initial sizing estimate.
Depth	The depth of the permanent pool should be at least 1.2 m (4 ft) (Schueler, 1987).One approach has been to use a depth of between 1 and 2.4 m (3 and 8 ft) (Camp, Dresser and McKee, 1993b).
Preventing Resuspension	Resuspension of deposited material can be reduced by installing vertical baffle plates on the chamber floors. Slightly sloping the chamber floor away from the outlet is another way to help reduce the resuspension of sediments accumulating on the floor of the chamber (Schueler, 1987).
Inverted Elbow	An inverted pipe with a 90-degree elbow should connect the second and third chambers of the inlet. The pipe should extend at least 1 m (3 ft) into the permanent pool, and should extend to 0.3 m (1 ft) from the bottom of

	the chamber (Northern Virginia Planning District Commission and Engineers and Surveyors Institute, 1992; Schueler, 1987). Two 0.45 m (1.5 ft) CMPs welded together at a right angle may be used for the elbow.
Infiltration	Inlets are a good pretreatment method for runoff before it enters an underground infiltration facility such as an infiltration trench. Inlets can also be designed to function as infiltration devices, as described later in this section. Information on infiltration trenches can be found earlier in this manual.
Trash Rack	A trash rack constructed of a half-round of aluminized CMP should be placed over the two 150 mm (6 in) orifices that lead to the second chamber. Large debris will be caught on this trash rack, and not clog the two orifices.
Access	Manholes should be provided for easy access to clean and maintain the water quality inlet. Step rings should also be installed for access to the chamber floor.
Hydraulic Design	The inlet should be able to pass the 2-yr design storm without hydraulic interference. This can be accomplished by placing a weir at least 0.3 m (1 ft) above the water level in each chamber, and with at least a 0.3 m (1 ft) gap to the top of the chamber. The structure can be constructed of reinforced concrete or corrugated metal and should be structurally sound.
Water Table	If the groundwater table is high, the structures should be designed to avoid floatation.

Maintenance

Although well suited for the ultra-urban environment, water quality inlets must receive frequent cleaning and inspection to maintain their effectiveness. A clean-out schedule should be developed which includes removal of accumulated sediment.

The ideal site is associated with responsive maintenance capability that can monitor the facility after storms and act accordingly. These devices tend to clog and if unattended can cause more harm than good. A centralized, current record of the location and status of each inlet is desirable. Water quality inlets may last as long as 20 yr with proper and frequent (several times a year) cleaning and maintenance. Isolated sites that are infrequently checked by maintenance workers are poor selections for the device.

One of two methods can be used to clean the inlet. The first method is to vacuum pump the contents of the inlet. The action of the pump creates sufficient turbulence that a slurry of water, oil, and sediment is created. This slurry can then be moved to a tank truck, and possibly disposed of in the sanitary sewer line. The slurry would then be treated at the sewage treatment plant.

The second method consists of siphoning of the permanent pool, followed by manual removal of the sediments. The fluid in the chamber must be carefully siphoned without creating a slurry. If not too oily, it can be allowed to infiltrate over a nearby grass area. Sediments can usually be disposed at a landfill; if toxicity is a concern, other avenues will need to be explored. This method does present some risk of groundwater contamination resulting from the on-site siphoning.

Cost

A standard, three-chamber water quality inlet costs approximately $5,000 to $15,000 (Schueler, 1987). Routine maintenance costs are fairly high because the sediments must be removed at frequent intervals (several times a year). Pre-cast inlets will generally be somewhat cheaper. The three-chamber water quality inlet can also be built as part of an underground detention system. Underground detention chambers, although sometimes necessary because of a limited amount of available land, are often the most expensive BMP with respect to cost per unit volume stored.

5.3.3 Hydrodynamic Separators

Hydrodynamic separators are flow-through structures with a settling or separation unit to remove sediments and other pollutants. The separation of sediments may be achieved either by the swirling action of flowing water or by indirect filtration. These systems are most effective at removing heavy particulates, which can be settled, or floatables, which can be captured. The five major types of hydrodynamic separator systems currently available from vendors include: (1) Continuous Deflective Separators (CDS); (2) Downstream Defender™; (3) Stormceptor®; (4) Vortechs Separator™; and (5) BaySaver™. The design, operation and maintenance of hydrodynamic separators are described in Minimum Standard 3.15 of the Virginia Stormwater Management Handbook.

Application

This technology may be used by itself or in conjunction with other storm water BMPs as part of an overall storm water control strategy. Hydrodynamic separators come in a wide size range and some are small enough to fit in conventional manholes. This makes hydrodynamic separators ideal for areas where land availability is limited.

Effectiveness

The Virginia SWM Handbook indicates that hydrodynamic systems are approximately 15 – 20% effective in removing phosphorus from storm waters.

Design

The designs of the units are unit-specific. The manufacturer should be consulted to assist with the design.

Maintenance

Hydrodynamic separators do not have any moving parts, and are consequently not maintenance intensive. Maintenance is important however, to ensure the system is operating as efficiently as possible. Proper maintenance involves frequent inspections throughout the first year of installation, especially after major storm events. The systems are considered full when the sediment level comes within one foot of the unit’s top, at which point it must be cleaned out. Removal of sediment can be performed with a sump vac or vacuum truck. Some hydrodynamic separator systems may contribute to mosquito breeding due to the presence of standing water between storms. The following table shows recommended routine inspection and maintenance activities.

Inspection and Maintenance Activities for Hydrodynamic Separators	
Activities	Suggested Frequency
Inspection	
Inspect for proper construction	Immediately following construction
Inspect for accumulated sediment and debris	As needed
Maintenance	
Removal of accumulated material with a vacuum truck. It may be necessary to remove and dispose of the floatables or absorbent oil pillows separately if petroleum products are present.	Annually, or more frequent as needed
See vendor's instructions for additional maintenance activities.	
Source: Center for Watershed Protection	

Cost

- CDS – The cost per unit (including installation) ranges from $2,300 to $7,200 per cfs capacity, depending on site-specific conditions and does not include any required maintenance.
- Downstream Defender – The approximate capital and installation costs, range from $10,000 to $35,000 per pre-cast unit.
- Stormceptor – Typically, the cost for installation of a unit for a one acre drainage area is $9,000. This cost will vary depending on site-specific conditions. Stormceptor units range from 900 to 7,200 gallons and cost between $7,600 and $33,560. Cleaning costs depend on several factors, including the size of the installed unit and travel costs for the cleaning crew. Cleaning usually takes place once per year and costs approximately $1,000 per structure.
- Vortechs – The cost for these units ranges from $10,000 to $40,000, not including shipment or installation.

5.3.4 Filtration Units

The primary type of filtration units being used in the management of stormwater from facilities are various types of sand filtration units and proprietary mixed media filtration units. Some proprietary filtration units combine filtration with other processes. The following paragraphs briefly describe sand filtration units, the StormFilter unit® and the StormTreat™ units. Fact sheets that describe these systems are also provided in Appendix A.

Sand Filtration Units

Sand filtration systems are relatively new to the field of stormwater quality control although the basic principles have been used extensively in the design of systems for water purification and sewage treatment. These systems have been modified to provide stormwater quality control and are particularly well adapted to highly impervious areas where space is at a premium and phosphorus removal rates must be maximized. The three basic types of sand filters are designated by the areas where they were first developed: Austin (Texas), Delaware, and the District of Columbia (D.C.). These sand filter designs were incorporated in the Alexandria Supplement to the Northern Virginia BMP Handbook. Sand filters are recommended for areas 1.5 acres or less and greater than 65% imperviousness.

The design, operation and maintenance of Austin, D.C., and Delaware sand filters are described in Minimum Standard 3.12 of the Virginia Stormwater Management Handbook and in the Sand Filter Addendum to the Northern Virginia BMP Handbook.

Other Media Filtration Units

Stormwater Management, Inc., (SMI) has developed a mixed natural and synthetic media filtration system known as "StormFilter.®" The SMI StormFilter system consists of an underground concrete vault housing filter canisters. An upstream manhole diversion structure would shunt the water to be treated to the filter unit and allow the flood flows to bypass the device. An initial chamber traps larger materials in the runoff. Stormwater pollutants are filtered out in the filter canisters. A system of float operated valves control the flow through the filters. The filters are designed so that particles on the filter surface slough off to the vault floor, thereby increasing the longevity of the filter.

The StormFilter cartridges (or canisters) are the heart of the StormFilter unit. The particular media to be used in any application is determined based on the nature of the potential pollutants. The cartridges are housed in the filtration bay of the StormFilter vault. The StormFilter vault is composed of three bays: a pretreatment bay, a filtration bay, and an outlet bay. Stormwater enters the pretreatment bay where heavy solids and floatable materials are trapped. The pretreated flows are then directed into the filtration bay. Flow passes through the filters into an under-drain manifold that discharges fully-treated flow to the outlet bay. The outlet bay collects flow from the under-drain manifold for discharge through a single outlet pipe.

Applications of the StormFilter have included:

- Parking lots for ultra-urban environments such as fast food restaurants, shopping malls, medical facilities, waste transfer stations, and light industrial developments.

- Roadways ranging from single-family residential to arterial roadways and major freeway systems.

StormTreat Systems, Inc., (STS) of Sandwich, Massachusetts has developed a unit called StormTreat. The system is a prefabricated unitary structure that provides sedimentation, oil and grease separation, sand filtration, and biological filtration. In the system, a chambered sedimentation unit and oil and grease separator is combined with a containerized biofilter. The system is designed as a recharge unit, or with controlled discharge to surface water or to a stormwater conveyance system (Closed Mode). The system is 9.5 feet in diameter and 4 feet deep. Several units can be installed in series if site conditions warrant.

5.3.5 Porous Pavement

An innovative BMP that has been in use for over 20 years is porous pavement. Porous pavement is a special type of pavement that allows rain and snowmelt to pass through it, thereby reducing the runoff from a site and surrounding areas.

In addition, porous pavement filters some pollutants from the runoff if maintained.

Application

Porous pavement may substitute for conventional pavement on parking areas, areas with light traffic, and the shoulders of airport taxiways a runways, provided that the grades, subsoils, drainage characteristics, and groundwater conditions are suitable. Slopes should be flat or very gentle. Soils should have field-verified permeability rates of greater than 1.3 centimeters (0.5 inches) per hour, and there should be a 1.2 meter (4-foot) minimum clearance from the bottom of the system to bedrock or the water table.

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. 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 crossovers on divided highways, and low-traffic roads (FHWA, undated). Some porous pavements such as porous asphalt have also been tested for use in highway projects (Hossain and Scofield, 1991).

Effectiveness

Porous pavement pollutant removal mechanisms include absorption, straining, and microbiological decomposition in the soil. An estimate of porous pavement pollutant removal efficiency is provided by two long-term monitoring studies conducted in Rockville, MD, and Prince William, VA. These studies indicate removal efficiencies of between 82 and 95 percent for sediment, 65 percent for total phosphorus, and between 80 and 85 percent of total nitrogen. The Rockville, MD, site also indicated high removal rates for zinc, lead, and chemical oxygen.

Design

There are several different designs of permeable pavement. These are:

Porous Asphalt – A great advantage to porous asphalt is that the same mixing and application equipment is used as for impervious asphalt. Only the formula for the paving material changes. Small stones are left out of the aggregate, and the amount of tar is reduced. The resulting surface has the same "blacktop" appearance, but contains spaces through which water can pass.

Porous Concrete – The same equipment may be used as for standard concrete. Larger pea gravel and a lower water-to-cement ratio is used to achieve a pebbled, open surface that is roller compacted. Expansion joints are cut using a roller with a welded steel flange.

Plastic Grid Systems – High strength plastic grids (often made from recycled materials) are placed in roadway areas. Some are designed to be filled with gravel on top of an engineered aggregate material, while others are filled with a sand/soil mixture on top of an aggregate/topsoil mix that allow grass to be planted on the surface. The grids provide a support structure for heavy vehicles, and prevent erosion. After heavy rains, the grids act as mini holding-ponds, and allow water to gradually absorb into the soil below. This paving material is often selected for gardens or recreational areas that must support vehicular or pedestrian traffic, but where a more natural appearance is desired. A porous grid system was installed more than ten years ago on East Executive Avenue at the White House in Washington DC to allow both green space and parking in this area.

Block Pavers – This material can be used to create a porous surface with the aesthetic appeal of brick, stone, or other interlocking paving materials. Traditional looking pavers can be specially designed with channels to funnel water between each block, into a substrate of sand and gravel for gradual soil filtration.

Maintenance

Porous pavements need to be maintained. Maintenance should include vacuum sweeping at least four times a year (with proper disposal of removed material), followed by high-pressure hosing to free pores in the top layer from clogging. Potholes and cracks can be filled with patching mixes unless more than 10 percent of the surface area needs repair.

Spot-clogging may be fixed by drilling 1.3 centimeter (half-inch) holes through the porous pavement layer every few feet. The pavement should be inspected several times during the first few months following installation and annually thereafter. Annual inspections should take place after large storms, when puddles will make any clogging obvious. The condition of adjacent pretreatment devices should also be inspected.

Cost

The costs for some of the permeable surfaces currently available are shown below, courtesy of the Center for Watershed Protection in Ellicott City, Maryland:

Product	**Manufacturer**	**Cost (Square Foot)**
Asphalt	Various	\$0.50 - \$1.00
Geoweb®	Presto Products, Inc.	\$1.00 - \$2.00

Grasspave™, Gravelpave™	Invisible Structures, Inc	$1.00 - $2.00
Grassy™ Pavers	RK Manufacturing	$1.00 - $2.00
Geoblock®	Presto Products, Inc	$2.00 - $3.00
Turfstone	Westcon Pavers	$2.00 - $3.00
UNI-Eco-stone	Uni-Group USA	$2.00 - $3.00
Checkerblock	Hastings Pavement Co.	$3.00 - $4.00

CHAPTER 6 STORMWATER MODELS AND MODELING TECHNIQUES

The design of most stormwater management facilities involves the use of models. These models can be relatively simple, like the Rational Method for determining peak flows, or they can be quite complex involving the determination of both water quality and quantity in complicated piping networks or in entire watersheds. Horner (1994) provides a simple classification of stormwater models that illustrate the range of complexity, shown below.

- Models based on simple empirical relationships such as the Rational Method for peak flows or the Simple Method (Schueler, 1987) for pollutant loading
- Models using regression equations (Driver and Tasker, 1990)
- Models incorporating site-specific or modeled flow data and either local or published concentrations
- Continuous simulation models, such as the Storage, Treatment, Overflow, and Runoff Model (STORM); Storm Water Management Model (SWMM); and Hydrologic Simulation Program-Fortran (HSPF)

The selection of which model to use during the design of a stormwater management facility depends on the level of complexity of the contributing watershed and the level of accuracy needed in the design.

Properly calibrated and verified models provide an accurate description of the changes in stormwater quantity and quality for given conditions. By using the models, one can investigate and compare design options and choose an optimal design. Models can also be used, for example, to estimate the impact of particular growth patterns on strategies for local stormwater master planning. The designer can assume various growth patterns and use the model to simulate their consequences.

There are several sources of information regarding stormwater and water quality modeling techniques and models on the Internet. Examples of these sources of information include:

- U.S.G.S. Surface Water and Water Quality Models Information Clearinghouse (http://smig.usgs.gov/SMIC/SMIC.html) - a database of the descriptions and features of environmental surface water and water quality models, and abstracts of projects using those models. Information regarding particular models can be obtained from a list of models or by key words.

- U.S. Bureau of Reclamation Hydrologic Modeling Inventory (http://www.usbr.gov/pmts/rivers/hmi/hmi.html) - a database of descriptions and features of hydrologic models. Models are searchable by name, or by words in the summary.

- U.S. Army Corps of Engineers Hydraulic Engineering Center (http://www.hec.usace.army.mil/) - provides descriptions and a source for the various HEC models.

6.1 HYDROLOGIC AND RUNOFF MODELS

Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow. In general, hydrologic models simulate some aspect or aspects of the hydrologic cycle and are based on the continuity equation and if routing is desired, on a storage equation. The following sections describe some of the better-known and most-used hydrologic and runoff models.

6.1.1 NRCS Technical Release (TR) Series

The Natural Resources Conservation Service has developed what is probably the "standard" hydrologic runoff models. These are Technical Release No. 20: Computer Program for Project Formulation Hydrology and Technical Release 55: Urban Hydrology for Small Watersheds. Technical Release 55 consists of two alternative methods; the graphic method and the tabular method. These Technical Releases are described below.

Technical Release No. 20: Computer Program for Project Formulation Hydrology (TR 20)

Description

The TR-20 hydrological modeling program was developed by the Soil Conservation Service (SCS, now the Natural Resources Conservation Service, or NRCS), an agency of the U.S. Department of Agriculture (USDA). It is a single event model that will compute direct runoff for a synthetic storm event, or it can be calibrated when rainfall records and hydrograph records are available. Up to nine storm events can be modeled with routings through a maximum of 200 stream reaches and 99 structures in a single run. The procedures used are described in the Soil Conservation Service National Engineering Handbook, Section 4, Hydrology and the TR-20 user's manual.

The program can distribute single-event synthetic rainfall through the use of six preprogrammed rainfall distribution tables, or the user may input a customized rainfall distribution table. Hydrographs are developed from the SCS dimensionless unit hydrograph based on time of concentration and runoff depth. The unit hydrograph can also be replaced with a user input unit hydrograph. Runoff depth is determined using SCS curve number theory, which also defines rainfall reductions due to infiltration and interception.

Stream reach routing is accomplished through the use of a Modified Attenuation-Kinematic (ATT-KIN) method. The ATT-KIN method develops a routing coefficient from a valley storage-discharge curve that represents the reach. The user must either input a cross section flow rate-elevation-cross sectional area rating table for the reach, or input the "x" and "m" variables that the program uses to calculate the routing coefficient (Q = xAm).

Routing through structures involves the balancing of mass inflow, mass outflow and changes in storage over incremental time intervals. A rating table for the structure, which includes elevation, storage and discharge, must be input by the user for structural routing. The definition of structure for the purpose of TR-20 is a detention basin, floodwater retarding dam with spillways, or other hydrograph attenuating facility.

The advantages of TR-20 are its simplicity of operation, its applicability to ungaged watersheds where gage data are lacking, and its input parameters are user-oriented. Two disadvantages of this particular program are that it is sometimes difficult to calibrate and match data where rainfall and hydrograph records are available; and some professionals contend that the SCS dimensionless hydrograph yields peak flow rates that are too high when compared to other methods.

Uses and Applications

Uses and applications for the TR20 model include:

- watershed-scale planning,
- design of water-management structures,
- surface water quantity routing,
- hydrograph development, and
- structure routing and approximate sizing.

Input Data and/or Model Components

The input data and components of the TR20 model include:

- rainfall amount and time distribution,
- land use data and soils for developing a runoff curve number (CN) for each subarea,
- time of concentration (T_c) for each subarea,
- stream reach length and typical cross section for reach-routing applications,
- structure stage/discharge/storage tables, and
- antecedent moisture condition.

Outputs Available

Outputs available from the TR20 model include:

- peak discharge,
- runoff volume,
- hydrographs,
- estimated elevations, and
- results of structure and stream-reach routings.

Limitations

- The TR20 model is a single-event model.
- Snowmelt inputs cannot be entered directly.
- Using the TR20 model requires an understanding of hydrologic processes.
- Three hundred time increments for hydrographs in the 1983 version (400 points in the newer version that is being developed).
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

Technical Release 55: Urban Hydrology for Small Watersheds (TR-55 - Graphical Method)

Description

The graphical method in Technical Release 55 (TR55) is used to determine the peak discharge for a single storm event on a watershed. The method applies to an urban or a rural watershed or one in transition. The method uses NRCS hydrology as described in National Engineering Handbook section 4, “Hydrology” (NEH-4), and was developed from hydrograph analysis using Technical Release 20: Computer Program for Project Formulation–Hydrology. The procedure calculates the runoff curve number (RCN) and time of concentration (T_c) based on measured watershed parameters.

Uses and Applications

Uses and applications for the TR55 Graphical Method model are:

- small-scale watershed planning, and
- comparison of “before” and “after” conditions for installation of structures or watershed-development actions.

Input Data and/or Model Components

Data to be input into the TR55 Graphical Method include:

- rainfall amount and choice of synthetic time distribution,
- land-use data and soils for developing a runoff curve number (RCN) for the watershed, and
- time of concentration using measured parameters or the lag equation.

Outputs Available

Outputs available from the TR55 Graphical Method model include:

- peak discharge, and
- runoff volume in watershed inches.

Limitations

- TR55 Graphical Method is a single-event model.
- Use of TR55 is limited to watersheds of less than 2,000 acres.
- Only a single homogeneous watershed may be simulated.
- Time of concentration must be less than 10 hours.
- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

Technical Release 55: Urban Hydrology for Small Watersheds (TR 55 -Tabular Method)

Description

This method was also developed by the USDA NRCS (formerly the SCS). The tabular method in Technical Release 55 (TR55) is used to determine the peak discharge and an approximate hydrograph for a single-event storm on a single watershed. The method applies to an urban or a rural watershed or one in transition. The model uses SCS hydrology as described in National Engineering Handbook section 4, “Hydrology” (NEH-4). The program will calculate the runoff curve number (RCN) and time of concentration (Tc) based on watershed parameters that are measured and entered into the program.

Uses and Applications

Uses and applications for the TR55 Tabular Method include:

- small-scale watershed planning,
- comparison of “before” and “after” conditions for installation of structures or watershed-development actions, and
- simple hydrograph development (limited detail).

Input Data and/or Model Components

Input data for the TR55 Tabular Method include:

- rainfall amount and choice of synthetic time distribution,
- land use data and soils for developing a CN for each subarea,
- time of concentration using measured parameters or the lag equation for each subarea, and
- travel times through subareas.

Outputs Available

Outputs available from the TR55 Tabular Method include:

- peak discharge for each subarea,
- runoff volume in watershed inches, and
- simple hydrograph.

Limitations

The TR55 Tabular Method has the following limitations:

- TR55 Tabular Method is a single-event model
- Watersheds must be less than 2,000 acres in size
- Watershed subareas must be hydrologically homogeneous
- Ten subacres or less
- Time of concentration less than two hours in each subarea
- Travel time of three hours or less in each subarea.

- The initial abstraction assumptions may not be valid for watersheds with a high percentage of impervious area when rainfall amounts less than 1.5 inches are used.

6.1.2 HEC 1

HEC-1 is a very flexible program for modeling the rainfall-runoff response of a watershed. This program was developed by the Hydrologic Engineering Center of the Corps of Engineers at Davis, California. A single computer run of HEC-1 can accommodate a multi-flood analysis that includes the simulation of up to nine ratios of a design flood for up to three different plans of a stream network.

The user has a wide selection of options in HEC-1. Rainfall and runoff can be input from actual gage measurements and the program calibrated, or a synthetic storm can be produced through input of National Weather Service point rainfall data. The rainfall loss rates due to interception and infiltration can be modeled through four methods: 1) Initial and uniform loss rate; 2) Exponential loss rate; 3) SCS curve number; and 4) Holtan loss rate. In addition to these options, there are three options for defining the discharge hydrograph from any area: 1) Clark Unit Hydrograph; 2) Snyder Unit Hydrograph; and 3) SCS Dimensionless Unit Hydrograph.

Hydrological flood routing within HEC-1 also gives the user several options for routing hydrographs through floodways, channels, overbank areas and reservoirs. The user can select the Muskingum, Modified Puls, Working R and D, Average-Lag or Kinematic Wave methods for routing through floodways and other channel segments. Routing through reservoirs is usually done by balancing mass inflow, mass outflow and storage over incremental time periods.

Although the HEC-1 flood hydrograph program gives the user considerable flexibility in modeling watersheds and storm events, the program does have its disadvantages. There is often difficulty in selecting certain required input parameters, particularly where there are insufficient watershed gage data to calibrate the model. Another disadvantage is the fact that the order of computation, and a possible lack of program input labels, can be difficult to decipher for those not involved in originally setting up the watershed simulation.

Limitations

Simulations provided by HEC-1 are limited to single-storm events because no provision is made for soil moisture recovery between storms. HEC-1 does not account for backwater effects from downstream reaches or reservoirs.

6.1.3 MIKE SHE/MIKE 11

MIKE SHE is based on the European Hydrological System that was developed in a joint effort by the Institute of Hydrology (United Kingdom), SOGREAH (France), and the Danish Hydraulic Institute. Since 1987, the SHE model has been further developed independently by the three respective organizations, which are now the University of Newcastle (United Kingdom), Laboratorie d'Hydraulique de France, and DHI, Inc. (DHI). MIKE SHE is one of the few hydrologic models that was initially developed to integrate surface water and groundwater modeling capabilities. With additional DHI programs (MIKE 11 and MOUSE) that are easily linked to MIKE SHE, the capabilities of MIKE SHE are further expanded.

MIKE SHE is used to simulate flow and transport of solutes and sediments in both surface water and groundwater. Areas of application include, but are not limited to, conjunctive water use, water resources management, irrigation management, wetland protection, surface and groundwater interaction, and contaminant transport (DHI, 1999a). The MIKE SHE model is proprietary software developed and distributed by DHI. Product support and training for MIKE SHE is readily available since the program is continually being enhanced by DHI.

Description

MIKE SHE is a distributed, physically based hydrologic modelling system for the simulation of all major processes occurring in the land phase of the hydrologic cycle, including interception, evapotranspiration, overland and channel flow, snow melt, unsaturated and saturated zone flow, and surface water/groundwater interactions.

MIKE SHE is applicable on spatial scales ranging from a single soil profile (infiltration studies) to large regions that include several river catchments.

MIKE SHE, coupled with MIKE 11, is capable of modeling open channel flow and closed pipe flow using the kinematic wave, diffusive wave, and dynamic wave approximation. MIKE 11 can simulate a full range of structures (dams, weirs, culverts, gates, etc.), many of which can be operated according to a known time series or dynamically based on logical rules driven by simulated hydraulic conditions. MIKE 11 is capable of simulating a range of water quality parameters. Overland flow is simulated using the diffusive wave approximation and special provisions are available for flow between the overland flow plane and channels that depend on channel bank geometry and user selected flooding options.

MIKE SHE utilizes three methods to simulate flow in the unsaturated zone but assumes that flow is vertical in all three methods. The basis for this assumption is flow is primarily vertical at the scale typically simulated with MIKE SHE (catchment scale). Once infiltrated water enters the surficial aquifer, the 3D ground water equations take over. Two of the available unsaturated zone methods in MIKE SHE are 1) the full Richard's equation and 2) a simplified Richard's equation that neglects capillary tension. The full and simplified Richard's equation methods use real soil properties and soil moisture-relationships that can be developed using Brooks and Corey or Van Genuchten relationships. A simplified wetland module that uses a linear relationship between depth to the water table and average soil moisture content and a linear infiltration equation can be used in place of the full and simplified Richard's equation modules.

MIKE SHE includes a 3D saturated zone model. Available boundary conditions are comparable to those available in MODFLOW (i.e., wells, drains, etc.). Groundwater quality in the overland, unsaturated, and saturated components can be explicitly modeled with MIKE SHE.

Interception and evapotranspiration can be simulated in combination with the full or simplified Richard's equation unsaturated zone modules using an empirical evapotranspiration module (Kristensen and Jensen, 1975). If the wetland unsaturated zone module is used, evaporation is determined using a top-down approach (interception storage, detention storage, unsaturated zone, and groundwater) until potential evaporation is satisfied, if possible, or water levels are below a specified seasonally- and spatially varying evapotranspiration extinction depth.

The overland, unsaturated, and saturated zone modules and MIKE 11 are explicitly coupled which allows the time step of each component to be determined based on the response time of the component processes. The explicit coupling allows simulations to be tailored to particular problems but requires extreme diligence to ensure that mass balance errors do not occur. Special provisions are available in MIKE SHE to adjust the time step during a simulation based on changes in input fluxes (i.e., rainfall). The rainfall time step can vary from 15 minutes to one hour to one day, and a mix of time steps is possible. Thus, one-day time steps can be used for most of the period, with a one-hour time step during critical rainfall periods.

Uses and Applications

MIKE SHE can be used for the analysis, planning and management of a wide range of water resources and environmental problems related to surface water and groundwater, such as:

- Surface water impact from groundwater withdrawal
- Conjunctive use of groundwater and surface water
- Wetland management and restoration
- River basin management and planning
- Environmental impact assessments
- Aquifer vulnerability mapping with dynamic recharge and surface water boundaries
- Groundwater management
- Floodplain studies
- Impact studies for changes in land use and climate
- Impact studies of agricultural practices including irrigation, drainage and nutrient and pesticide management with DAISY

Data Input and/or Model Components

MIKE SHE is comprised of two basic modules: MIKE SHE PP and MIKE SHE WM. MIKE SHE PP is the pre- and post-processing module. MIKE SHE WM is the water movement module that is comprised of five modules: evapotranspiration (ET), unsaturated zone flow (UZ), saturated zone flow (SZ), overland and channel flow (OC), and irrigation (IR). Several additional add-on modules are available for particle tracking, contaminant transport, soil plant systems, and other specialized modeling applications (DHI, 1999b).

The MIKE SHE program can be fully integrated with GIS and several applications (MIKE SHE converters, GeoEditor, UZ editor, Irrigation GIS, and DAISY GIS) are available. The GIS integration was developed in collaboration with Environmental Systems Research Institute, Inc. (ESRI) ArcView. MIKE SHE converters are available for conversion of ArcView data to model input. The GeoEditor is used for geologic interpretation and creation of three-dimensional geological models. UZ editor and Irrigation GIS are used to setup the MIKE SHE UZ and IR modules, respectively.

Finally DAISY GIS is used for defining and running MIKE SHE DAISY, a soil-plant simulation add-on module (DHI, 1999a).

6.2 OPEN-CHANNEL AND HYDRAULIC MODELS

Open channel and hydraulic routing models use mathematical equations to calculate results like flood stage and flow regimes. Hydraulic models generally employ the continuity equation and momentum equations.

6.2.1 The Hydrologic Engineering Center Models

The U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) has developed several hydraulic models. The original flood stage and routing model is known as HEC 2. This model has been updated and expanded. The updated version is the first of HEC's "Next Generation" of models and is known as HEC-RAS (HEC River Analysis System). These models are discussed below.

HEC 2

HEC-2 is a U.S. Army Corps of Engineers computer program for determination of open channel water surface profiles. The program was developed for the calculation of water surface profiles for steady, gradually varied flow (one-dimensional flow) in natural or man-made channels. Friction losses can be calculated by one of five alternative approaches, and one alternative is internally set as the default approach. The friction loss is calculated with Manning's equation and the trial energy gradient elevations are iteratively balanced to within ± 0.01-foot between iterations at the reach endpoints. The program is limited to fourteen profiles in a single run. The September 1990 version of the user's manual specifies a maximum number of 800 cross sections or reaches.

Input to HEC-2 is rather straightforward in regard to cross section ground elevations and distances. Distances can be entered as negative or positive numbers to indicate distances left or right of a channel survey base line. The engineer should be aware that negative cross-section distances can result in erroneous output where the program's encroachment subroutine is engaged.

In such instances the cross-section distances should be entered in increasing positive numbers from left to right across the section. Manning's "n" values for flow resistance can be varied across a cross section through a combination of input horizontal distances and elevations. Flow through bridges and culverts can be accommodated by HEC-2 through the appropriate normal bridge, special bridge or special culvert input card images.

HEC-2 has the advantages of being able to calculate either subcritical or supercritical water surface profiles, can be used for split flow routines and a variety of user-defined output tables can be specified in addition to the standard output tables. One disadvantage of HEC-2 is that defining bridges can be quite involved and confusing to infrequent users.

HEC-RAS

HEC-RAS (Hydrologic Engineering Center - River Analysis System), a Corps of Engineer program, is intended to be the successor to the current steady-flow HEC-2, as well as provide unsteady flow, sediment transport, and hydraulic design capabilities. The HEC-RAS program provides a steady-flow model with several significant advances over HEC-2.

HEC-RAS is an integrated hydraulics package, designed for interactive use in a multi-tasking environment (Windows™). The system uses a Graphical User Interface (GUI) for file management, data entry and editing, program execution, and output display. The current (1996) release provides steady-flow, subcritical, supercritical, and mixed-flow regime profile calculations for a river network.

Profile calculations are performed using the standard-step procedure. Overbank conveyance is computed incrementally at coordinate points (HEC-2 style) or at breaks in roughness (HEC-RAS default). Detailed hydraulic jump location and losses are not computed; however, the jump location is defined between two cross sections.

The program contains many improvements over HEC-2 including mixed subcritical and supercritical flow analysis, enhanced bridge and culvert routines, true stream network and confluence analysis, excellent cross section interpolation, and high quality graphics. Future features will include scour analysis, channel improvements and other design options, and unsteady flow.

6.2.2 P8 - Urban Catchment Model

The P8 Urban Catchment Model was developed by the Narragansett Bay Project (Providence, Rhode Island). It is used to predict the generation and transport of stormwater-runoff pollutants in small urban watersheds (Walker, 1990).

Description

P8 incorporates the algorithms of existing stormwater-runoff models, such as HSPF, SWMM, DR3M, STORM and TR20. Runoff from impervious areas is calculated directly from rainfall once depression storage is exceeded. Particle build-up and wash-off processes are obtained using equations derived primarily from the SWMM program. The SCS curve number equation is used to predict runoff from pervious areas. Water balance calculates percolation from the pervious areas. Baseflow is simulated by a linear reservoir. Without calibration, use of model results should be limited to relative comparisons. This menu-driven computer program runs on IBM-compatible personal computers, and includes extensive user interfaces, such as on-line help and look-up tables for input parameters.

Uses and Applications

The P8 Urban Catchment Model can be used for:

- selecting and sizing BMPs,
- surface water quantity routing,
- small urban area assessments,
- watershed-scale land-use planning,
- site planning and evaluation for compliance,
- simplified watershed-scale pollutant generation and transport simulations, and
- routing through control structures.

Input Data and/or Model Components

The following are input data and/or components needed to run the P8 Urban Catchment Model:

- time series meteorological data
- land area
- impervious fraction
- SCS curve number

- BMP characteristics
- device (hydraulic) parameters for pond, basin, buffer, pipe, splitter and aquifer
- depressional storage

Outputs Available

Outputs available from the P8 Urban Catchment Model include:

- water and mass balances, removal efficiencies, mean inflow/outflow concentrations and statistical summaries by device and component;
- comparison of flow, loads and concentration across devices;
- peak elevation and outflow ranges for each device;
- sediment accumulation rates by device; and
- violation frequencies for event mean concentrations.

Limitations

The P8 Urban Catchment Model has some limitations:

- No snowfall, snowmelt, or erosion is calculated.
- Effects of variations in vegetation type/cover on evapotranspiration are not considered.
- Watershed lag is not simulated.
- Quantitative analysis should be checked using another method.

6.3 WATERSHED MODELS

Watershed models are integrated models that usually consist of various sub-models that simulate various components of a watershed. The following paragraphs discuss some of the better-known watershed-scale models.

6.3.1 HSPF

The HSPF (Hydrological Simulation Program – FORTRAN) is available for free from the U.S. EPA (http://www.epa.gov/ceampubl/swater/hspf/). The current version as of the date of this manual is Version 11.00.

Description

HSPF (Hydrological Simulation Program – Fortran) is a comprehensive package for simulation of watershed hydrology and water quality. It is an integrated program that simulates the hydrology and the behavior of conventional and organic pollutants in surface runoff and receiving waters. The Agricultural Runoff Management (ARM) model is used to describe the processes that affect the fate and transport of pesticides and nutrients from agricultural lands. Several main application modules are contained in HSPF: The PERLLND (pervious land) and IMPLND (impervious land) modules perform soil simulation for land surfaces and the RCHRES (reach/reservoir) model simulates the processes that occur in a single reach and at the bed sediments of a receiving water body (a stream or well-mixed reservoir). Extensive and flexible data management and statistical routines are available for analyzing simulated or observed time series data. The modules are arranged in a hierarchical structure that permits the continuous simulation of a comprehensive range of hydrologic and water-quality processes.

Use and Application

There have been hundreds of applications of HSPF all over the world. The largest application is the 62,000 square mile tributary area to the Chesapeake Bay.

HSPF is the only available model that can simulate the continuous, dynamic event or the steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed. The model is unusual in its ability to represent the hydrologic regimes of a wide variety of streams and rivers with reasonable accuracy. Thus, the potential applications and uses of the model are comparatively large and include:

- flood mapping,
- urban drainage studies,
- river basin planning,
- studies of sedimentation and water erosion problems, and
- in-stream water quality planning.

In addition to the above, HSPF:

- can perform continuous hydrologic simulation.
- integrates the loading from nonpoint sources (including alternative control practices) and receiving water quality simulation into a single package.
- analyzes both point- and nonpoint-source loading.
- provides the option of using simplified or detailed representation of nonpoint-source runoff.
- performs risk analysis due to the exposure of aquatic organisms to the toxic chemicals present in receiving waters.
- incorporates agricultural management practices by changing parameter values.

Input Data and/or Model Components

HSPF requires extensive data along with meteorological and hydrologic data, including;

- Meteorologic records of precipitation and estimates of potential evapotranspiration are required for watershed simulation.
- Air temperature, dew point temperature, wind, and solar radiation are required for snowmelt.
- Air temperature, wind, solar radiation, humidity, cloud cover, tillage practices, point sources, and (or) pesticide applications may be required for water-quality simulation.
- Physical measurements and related parameters are required to describe the land area, channels, and reservoirs.

Outputs Available

The output of HSPF includes system variables, temporal variation of pollutant concentrations at a given spatial distribution, and annual summaries describing pollutant duration and flux. A summary of time-varying contaminant concentration is provided along with the link between simulated receiving water pollutant concentration and risk assessment.

Limitations

- HSPF needs calibration before it can be applied to a particular site.

- HSPF requires extensive data along with meteorological and hydrologic data.
- Two to three months are required to learn HSPF's operational details.
- Cost associated with different BMPs is not linked to pollutant delivery.
- Computer costs for model operation and data storage can be a significant fraction (10-15%) of total application costs, depending on the extent to which the model will be used.

6.3.2 SWMM

SWMM was originally developed for the EPA between 1969 and 1971 (Metcalf and Eddy, 1971) and was the first comprehensive model of its type for urban runoff analysis. Maintenance and improvements to SWMM led to Version 2 in 1975, Version 3 in 1981 and now Version 4 (Huber and Dickinson, 1988; Roesner et al., 1988). Both single-event and continuous simulation may be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. The latest edition of Version 4.4, currently Version 4.4h, is the recommended version of this comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. However, EPA SWMM5 is a completely revised and updated release of SWMM, which has been available since June 2003. It is recommended for new users, except that the June 2003 release is not fully functional in terms of all SWMM4 capabilities.

SWMM is available for free from several sources. Version 4.4h is available from Oregon State University (http://ccee.oregonstate.edu/swmm/), and the beta test version of SWMM5 is available from the U.S. EPA (http://www.epa.gov/ednnrmrl/swmm/).

Description

The USEPA's Storm Water Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Extran Block solves complete dynamic flow routing equations (St. Venant equations) for accurate simulation of backwater, looped connections, surcharging and pressure flow.

SWMM5, which is currently in the beta testing stage of development as of the publication of this document, will be a significant modification of the previous SWMM models. The changes to the SWMM model to be implemented in SWMM5 involve:

- Revision of the architecture of the SWMM computational engine, using object oriented programming (OOP) techniques, to enhance the ability of the model to be maintained, upgraded, and interfaced with other software.
- Provision of a rudimentary graphical user interface (GUI) to the engine to improve the usability of the model.
- Removal of obsolete features, improvement of key computational aspects, and addition of new computational capabilities to the model where warranted.
- Development of guidelines on how SWMM can be used to model more recently developed Best Management Practices (BMP) for runoff control.

Uses and Applications

SWMM can be used for both planning and design. The modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snowmelt, surface and subsurface runoff, flow routing through drainage network, storage and treatment.

Input Data and/or Model Components

The SWMM-Windows interface was developed to assist the user in data input and model execution to make a complex model user friendly.

Outputs Available

Basic SWMM output consists of hydrographs and pollutographs (concentration vs. time) at any desired location in the drainage system. Depths and velocities are also available, as are summary statistics on surcharging, volumes, continuity and other quantity parameters. Additional quality output includes loads, source identification, continuity, residuals (e.g., sludge) and other parameters.

Most output is tabular. Microcomputer graphics are accessed through exports to spreadsheets or other graphics packages and through third party software for pre- and post-processing. The latter includes options for dynamic plots of the hydraulic grade line produced by the Extran Block. Linkages have also been prepared to geographic information systems.

Limitations

Technical limitations include lack of subsurface quality routing (a constant concentration is used), no interaction of quality processes (apart from adsorption), difficulty in simulation of wetlands quality processes (except as can be represented as storage processes), and a weak scour-deposition routine in the Transport Block.

The biggest impediment to model usage is the user interface, with its lack of menus and graphical output. The model is still run in a batch mode (the user constructs an input file with an editor). Third-party software that can greatly facilitate pre- and post-processing is available.

6.3.3 SLAMM

The Source Loading and Management Model (SLAMM) was originally developed to better understand the relationships between sources of urban runoff pollutants and runoff quality. It has been continually expanded since the late 1970s and now includes a wide variety of source area and outfall control practices (infiltration practices, wet detention ponds, porous pavement, street cleaning, catch basin cleaning, and grass swales).

SLAMM was subsequently refined through additional field studies and program support by the Ontario Ministry of the Environment, WDNR, USEPA, and others. The principal authors of SLAMM are Dr. Robert Pitt and John Voorhees. The current version of SLAMM is a Windows, 32-bit application called WinSLAMM. WinSLAMM is available from PV & Associates, Inc., at http://www.winslamm.com. Copies of WinSLAMM cost $200. As of the publication of this manual the most recent version of WinSLAMM is Version 8.7.0 (12/28/2003).

Description

SLAMM is based on actual field observations, with minimal reliance on theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control. Special emphasis has been placed on small storm hydrology and particulate washoff in SLAMM.

Many currently available urban runoff models have their roots in drainage design where the emphasis is with very large and rare rains. In contrast, stormwater quality problems are mostly associated with common and relatively small rains. The assumptions and simplifications that are legitimately used with drainage design models are not appropriate for water quality models. SLAMM therefore incorporates unique process descriptions to more accurately predict the sources of runoff pollutants and flows for the storms of most interest in stormwater quality analyses. However, SLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water quality controls on drainage design.

SLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rains, development characteristics, and control practices. As with all stormwater models, SLAMM needs to be accurately calibrated and then tested (verified) as part of any local stormwater management effort.

Uses and Applications

- SLAMM can analyze an urban drainage area with up to 6 different land use and 14 source area types per land use (those most applicable to transportation projects are shown in italics).
  - Land uses are: Residential, Institutional, Commercial, Industrial, Open Space, *Freeways*
  - Source areas are: Roofs, *Undeveloped Areas*, *Paved Parking/storage*, Small Landscaped Areas, Unpaved Parking/Storage, *Other Pervious Areas*, Playgrounds, *Driveways*, *Freeway Lanes / Shoulders*, Sidewalks / Walks, *Large Turf Areas*, *Street Areas*, Large Landscaped Areas, Other Areas

- SLAMM's BMPs include: catch basins, swales, infiltration devices, porous pavement, wet detention ponds, street sweeping and user-defined devices.

- SLAMM can run batch mode that permits the simulation of additional subareas and/or different management scenarios.

- For additional wet detention pond analysis or design, SLAMM output can be entered into the DETPOND model.

- SLAMM is a continuous sequential event based model. SLAMM simulates rainfall runoff; snowmelt may be modeled with a modified rain file.

- SLAMM simulates runoff volume and loading for ten standard and six user-defined pollutants.

- SLAMM is ideally suited for pollutant source area identification and source area BMP evaluation. It is also useful for water balance studies in conjunction with DETPOND.

Input Data and/or Model Components

Required Data consists of:

- Land Use:
  Land use codes must be related to the Standard Land Use categories defined in SLAMM.

- Sewersheds:
  Sewersheds define the study boundaries. They can be created from analysis of topography (such as a digital elevation model) and the storm sewer network.

Data Input files consist of the following:

- Rain Events (*.RAN file)
  Necessary rain information includes rain depths, durations, and interevent time periods. This information can be recorded from rainfall records or generated stochastically from rainfall statistics.

- Runoff Coefficients (*.RSV file)
  Runoff coefficients, when multiplied by rain depths, land use source areas, and a conversion factor, determine the runoff volumes. RSV coefficients are a function of:
  - Source area type (9 types, such as roof, pervious, impervious, streets)
  - Rainfall depth (17 levels, from 1 to 125 mm)
  - Drainage Efficiency Factor (3 levels for how directly runoff connects to storm sewer)

- Particulate Solids Concentration (*.PSC file)
  Particulate solids concentration values, when multiplied by source area runoff volumes and a conversion factor, calculate particulate solids loadings (in pounds). PSC values are a function of:
  - Land use (6 classes)
  - Source area type (13 types)
  - Rainfall depth (14 levels, from 1 to 80 mm)

- Pollutant Probability Distribution (*.PPD file)
  Pollutant probability distribution values determine, when multiplied by either a source area runoff volume or source area particulate loading, the pollutant loading from a source area. These concentrations are ideally based on measurements specific to the study area. SLAMM calculates pollutant loadings for nine particulate and ten filterable pollutants. The user may define up to six other pollutants in both particulate and filterable forms. PPD values are a function of:
  - Land use (6 classes)
  - Source area type (14 types – PSC types, plus streets)

- Particulate Residue Reduction (*.PRR file)
  This describes the fraction of total particulates that remains in the drainage system (curbs and gutters, grass swales, and storm drainage) after rain events end due to deposition. Residue reduction is a function of:
  - Type of drainage system (grass swales; undeveloped roadside; curb & gutters, “valleys”, or sealed swales)
  - Condition of curb and gutter (poor/flat, fair, or good/steep)

- Rainfall depth (14 levels, from 1 to 80 mm)

- Particle Size (*.CPZ file – only for detention pond analysis)
  This information describes the size distribution of urban runoff particulates that enter a detention pond. Particle size determines the amount of settling in the pond, and how much particulate will continue as runoff.

Outputs Available

- Output source areas by land use and outfall for each rain - complete printout.

  Output consists of runoff, concentration, and loading values, by rain event, for all source areas in each land use, and outfall totals for each rain event.

- Output source area totals and outfall summaries.

  Output consists of runoff, concentration, and loading value totals for all rain events, for all source areas in each land use, and outfall value totals for entire model run.

- Output outfall data only for each rain.

  Output consists of outfall runoff, concentration, and loading values, by rain event.

- Default option - Output outfall summaries only.

  Output consists of outfall runoff, concentration, and loading value totals for entire model run.

- Runoff & Flow Summary

  One line data summary per event.

- Outfall Hydrograph Data

  Three time increment options – 6, 15, or 60 minute.
  Output a component of SLAMM integration with SWMM

Limitations

The SLAMM model requires that several "data input" files be created. These data input files, which include rainfall statistics, washoff statistics, pollutant probability distributions, etc., must be developed on an area-specific basis. These files may not be available for Virginia, and must be developed.

6.3.4 BASINS

The BASINS “Model” is actually a collection of models linked together with a GIS interface. It was developed by the U.S. Environmental Protection Agency.

Description

Better Assessment Science Integrating point and Nonpoint Sources (BASINS) is a multipurpose environmental analysis system for use by regional, state, and local agencies in performing watershed and water quality based studies. This new software makes it possible to quickly assess large amounts of point source and nonpoint source data in a format that is easy to use and understand. Installed on a personal computer, BASINS allows the user to assess water quality at selected stream sites or throughout an entire watershed. It is an invaluable tool that integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to environmental protection.

Uses and Applications

BASINS supports the development of total maximum daily loads (TMDLs), which require a watershed-based approach that integrates both point and nonpoint sources. It can support the analysis of a variety of pollutants at multiple scales, using tools that range from simple to sophisticated.

Beside BASINS' primary role in creating TMDL analysis, it has been useful in identifying impaired surface waters from point and nonpoint pollution, wet weather combined sewer overflows (CSO), storm water management issues, and drinking water source protection. BASINS also has been used in urban/rural land use evaluations, animal feeding operations, and habitat management practices. Another unexpected use of BASINS is providing schools and educational institutions with a quick, free resource of GIS and surface water data for the United States.

Input Data and/or Model Components

The heart of BASINS is its suite of interrelated components essential for performing watershed and water quality analysis. These components are grouped into several categories:

- nationally derived environmental and GIS databases (the 48 continuous states and the District of Columbia);
- assessment tools (TARGET, ASSESS, and DATA MINING) for evaluating water quality and point source loadings at a large or small scales;
- utilities including local data import and management of local water quality observation data;
- two watershed delineation tools;
- utilities for classifying elevation (DEM), land use, soils, and water quality data;
- an in-stream water quality model (QUAL2E);
- a simplified GIS based nonpoint source annual loading model (PLOAD);
- two watershed loading and transport models (HSPF and SWAT);
- a postprocessor (GenScn) of model data and scenario generator to visualize, analyze, and compare results from HSPF and SWAT; and
- many mapping, graphing, and reporting formats for documentation.

Outputs

The Watershed Characterization Reporting tools are designed to assist users in summarizing key watershed information in the form of standard and automated reports. These tools can be used to make an inventory and characterize both point and nonpoint sources at various watershed scales. The results are presented in table, chart and/or map layout formats. These reports allow users to quickly evaluate and define data availability for the selected watershed(s). Eight different types of watershed characterization reports are included in BASINS:

- Point Source Inventory Report
- Water Quality Summary Report
- Toxic Air Emission Report
- Land Use Distribution Report
- Land Use Distribution Report (Grid)
- State Soil Characteristics Report
- Watershed Topographic Report
- Watershed Topographic Report (Grid)

6.3.5 AGNPS and AnnAGNPS

The AGricultural Non-Point Source Pollution Model (AGNPS) is a joint USDA-Agricultural Research Service and Natural Resources Conservation Service system of computer models developed to predict non point source pollutant loadings within agricultural watersheds. The term "AGNPS" now refers to the system of modeling components instead of the single event AGNPS, which was discontinued in the mid-1990's.

AGNPS can be obtained for free by downloading it from http://www.sedlab.olemiss.edu/AGNPS.html.

Description

The AGNPS system contains a continuous simulation, surface runoff model designed to assist with determining BMPs, the setting of TMDLs, and for risk & cost/benefit analyses. The set of computer programs consist of: (1) input generation & editing as well as associated databases; (2) the "annualized" science & technology pollutant loading model for agricultural-related watersheds (AnnAGNPS); (3) output reformatting & analysis; and (4) the integration of more comprehensive routines (CCHE1D) for the stream network processes; (5) a stream corridor model, the CONservational Channel Erosion Pollutant Transport System, or “CONCEPTS”; (7) an instream water temperature model (SNTEMP); and (8) several related salmonid models (SIDO, Fry Emergence, Salmonid Total Life Stage, & Salmonid Economics). Not all of the models are electronically linked but there are paths of common input/output that, with the use of standard text editors, can be linked.

Uses and Applications

The AGNPS model was developed to analyze and provide estimates of runoff water quality resulting from single storm events from agricultural watersheds ranging in size from a few hectares to 20,000 ha. Because of its ease of use, flexibility, and relative accuracy, AGNPS is widely applied throughout the world to investigate various water quality problems.

AGNPS is a single-event model. Early in its development, this was recognized as a serious model limitation. In the early 1990's, a cooperative team of ARS and NRCS scientists was formed to develop an annualized continuous-simulation version of the model, AnnAGNPS. AnnAGNPS is a continuous-simulation, watershed-scale model intended to be used as a tool to evaluate non-point source pollution from agricultural watersheds ranging in size up to 300,000 ha.

Input Data and/or Model Components

AnnAGNPS includes 34 different categories of input data. These can be further grouped into the following major classifications: climate, land characterization, field operations, chemical characteristics, and feedlot operations. The climatic data consist of precipitation, maximum and minimum air temperature, relative humidity, sky cover, and wind speed. Land characterization data include soil characterization, curve number, RUSLE parameters, and watershed drainage characterization.

Input is facilitated by an input editor that is currently available with the model. The input editor provides for data input in a page type format, with each of the 34 major data categories on a separate input page. Input and output can be in either all English or all metric units. The input programs include: (1) a GIS-assisted computer program (TOPAZ with an interface to AGNPS) to develop terrain-following cells with all the needed hydrologic & hydraulic parameters that can be calculated from readily available DEM's; (2) an input editor to initialize, complete, and/or revise the input data; and (3) an AGNPS-to-AnnAGNPS converter for the input data sets of the old single-event versions of AGNPS (4.03 & 5.00).

AnnAGNPS can be operated in two different modes. The standard mode (AnnAGNPS) allows for continuous simulation of a watershed using a daily time step. A more limited mode (AGNPS) will run a single day simulation based on input data converted from AGNPS5.0 input data set.

Outputs

Outputs related to soluble & attached nutrients (nitrogen, phosphorus, & organic carbon) and any number of pesticides are provided. Water and sediment yield by particle size class and source are calculated. A field pond water & sediment loading routine is included for rice/crawfish ponds that can be rotated with other land uses. Nutrient concentrations from feedlots and other point sources are modeled. Individual feedlot potential ratings can also be derived using the model.

The application of CCHE1D for stream networks and CONCEPTS for stream corridors include more detailed science for the channel hydraulics, morphology, and transport of sediments and contaminants.

Limitations

The following limitations to the model are acknowledged by the developers:

- All runoff and associated sediment, nutrient, and pesticide loads for a single day are routed to the watershed outlet before the next day simulation begins (regardless of how many days this may actually take);
- There are no mass balance calculations tracking inflow and outflow of water;
- There is no tracking of nutrients and pesticides attached to sediment deposited in stream reaches from one day to the next;
- Point sources are limited to constant loading rates (water and nutrients) for entire simulation period;
- Preprocessing software (flow net generator and input editor) are written in Visual Basic for a Windows environment so they will not operate on a DOS-only system;
- There is no allowance for spatially variable rainfall.

6.3.6 WinVAST

WinVAST is the Windows™-compatible version of the Virginia Stormwater Model, or VAST.

Description

The Virginia Stormwater model for Windows (WinVAST) is an integrated collection of subroutines that simulate stormwater runoff, non-point source pollution and pollutant transport. It is an event-oriented model that can be applied to multiple catchment basins. WinVAST combines widely-used techniques to: 1) compute rainfall abstractions, 2) generate overland flow hydrographs, 3) route outflow from upstream subbasins through downstream subbasins (including detention ponds), 4) compute non-point source pollutant wash-off from subbasins, and 5) route pollutants downstream and through selected best management practices (BMPs).

Uses and Applications

The WinVAST model is an event model and can be applied to model hydrologic response to rainfall events in multiple basins. The model simulates stormwater runoff, pollutant loadings of suspended solids, settleable solids, BOD, total nitrogen, orthophosphate, fecal coliforms, and has the capability to model up to four user-defined pollutants.

WinVAST can also simulate the effect of several BMPs on water quantity and quality. Currently, WinVAST can simulate detention ponds and swales.

Input Data and/or Model Components

WinVAST provides the user the capability of selecting a variety of approaches to model the various hydrologic processes in a watershed. The available modeling approaches include:

- PRECIPITATION
    - Total Precipitation
    - Net Precipitation
    - Regional Hyetograph
    - Kiefer & Chu (or "Chicago") Hyetograph

- ABSTRACTION
    - Constant Rate Loss
    - HEC1 Rate Loss Formula
    - Horton's Equation

- RUNOFF
    - Read Unit Hydrograph
    - SCS Unit Hydrograph
    - Clark Unit Hydrograph
    - Actual Hydrograph

- ROUTING
  - Muskingum Method
  - Muskingum-Cunge Method
  - Kinematic Method

Outputs

WinVAST calculates hydrographs of stream reaches that comprise the watershed as well as pollutographs of the various pollutants. Output can be either graphical or tabular.

Limitations

The primary limitation is that WinVAST is currently an event model. The developers are currently updating the model to perform continuous simulation.

6.4 ALGORITHMS AND SPECIALTY MODELS

The following paragraphs describe some of the more common algorithms used in stormwater management, and specialty models offered by independent vendors.

6.4.1 Rational Method

Description

Approximates the peak flow that results from a given rainfall intensity and duration. Used widely around the world on small rural and urban drainage basins.

Use and Applications

The Rational Formula is used to estimate the peak runoff flow. The Rational Formula is quite simple; it is generally given as:

$$Q = kCIA$$

where Q = discharge in cfs, k = a conversion factor, C is a dimensionless "runoff coefficient", I = rainfall intensity in inches/hour, and A = contributing drainage area in acres. The conversion factor, k, is equal to 1.008 when I is in inches/hour and A is in acres (i.e., inches/hour • ft/12 inches • hour/3600 seconds • 43,560 ft^2/acre • acres = cfs, or 1.008 • inches/hr • acres = cfs). In practice, the conversion factor is ignored and the units are "rationalized", thus giving the equation its name.

Occasionally, the Rational Formula is expressed as:

$$Q = C \cdot C_a \cdot I \cdot A$$

where C, I and A have their "conventional" definitions, and are constant for all return periods. Now, the "C" value given in most standard tables are appropriate for the 2-year to 10-year storms. Less frequent higher intensity storms will require the use of higher "C" coefficients because infiltration and other losses have a proportionally smaller effect on runoff. Thus, "C_a" is a coefficient that varies to account for the less frequent, higher intensity storms. Generally, C_a takes the following values:

- 1.0 for 2 to 10-yr events
- 1.1 for 25-yr event
- 1.2 for the 50-yr event, and
- 1.25 for the 100-yr event.

The analyst must ensure, however, that the product of C and C_a is not greater than 1, since that would imply the amount of runoff is greater than the rainfall.

The Rational Method should generally be used for watersheds that are smaller than 200 acres.

Input data and/or model components:

- QP = peak flow rate (cfs)
- C = runoff coefficient for drainage area
- I = rainfall intensity (inches/hour)
- A = drainage area (acres).

Outputs Available

Specific results of the Rational Method are peak flow from solving the equation, although software exists that incorporates this method with routines providing more output options.

Limitations

The following are shortcomings of the classic rational method:

- In practice, runoff coefficient is only related to type of terrain; however, in reality, it is also related to storm event frequency (intensity/duration).
- Assumes no temporary storage (basin or stream) within watershed.
- Published coefficients are valid only for two- to 10-year storm events.
- Calculates peak Q only.
- Does not produce a hydrograph.
- Usually does not account for soil conditions or antecedent rainfall.
- Results are unreliable for areas greater than 100 acres.

6.4.2 Modified Rational Method

The Rational Method, discussed above has a significant limitation in that it provides only an estimate of the peak rate of runoff. In many instances stormwater engineers must develop estimates of the volume of runoff to manage. The Modified Rational Method is sometimes used to develop the volume estimate. The Modified Rational Method differs from the Rational Method in that it assumes a storm *duration*. Use of the Modified Rational Method is described in detail in Chapter 5 of the Virginia SWM Handbook.

Description

The first step in determining the critical storm duration is to use the post-developed time of concentration, t_c , to generate a post-developed runoff hydrograph. Rainfall intensity averaging periods, T_d , representing time periods incrementally longer than the t_c , are then used to generate a "family" of runoff hydrographs for the same drainage area. These hydrographs will be trapezoidal with the peak discharges, Q_i , based upon the intensity, I, of the averaging period, T_d . The trapezoid having the greatest area represents the volume needed to be detained in the detention pond.

Use and Application

The Modified Rational Method uses the critical storm duration to calculate the maximum storage volume for a detention facility. This critical storm duration is the storm duration that generates the greatest volume of runoff and, therefore, requires the most storage. In contrast, the "standard" Rational Method produces a triangular runoff hydrograph that gives the peak inflow at time = t_c and falls to zero flow at time = $2.5t_c$. In theory, this hydrograph represents a storm whose duration equals the time of concentration, t_c , resulting in the greatest peak discharge for the given return frequency storm. The volume of runoff, however, is of greater consequence in sizing a detention facility. A storm whose duration is longer than the t_c may not produce as large a peak rate of runoff, but it may generate a greater volume of runoff.

Inputs

Same as for the Rational Formula with the addition of a storm event duration.

Outputs

Calculation of the volume of runoff generated during various storm durations.

6.4.3 Haestad Methods, Inc. Modeling Programs

Haestad Methods, Inc. has developed several models that address various aspects of stormwater facilities design. These models include PondPack, Culvert Master and Flowmaster. These proprietary models are discussed in the following paragraphs.

PondPack

PondPack, is Windows-based software developed for modeling general hydrology and runoff from site development. The program analyzes pre- and postdeveloped watershed conditions and sizes detention ponds. It also computes outlet rating-curves with consideration of tailwater effects, accounts for pond infiltration, calculates detention times and analyzes channels.

Rainfall options are unlimited. The user can model any duration or distribution, for synthetic or real storm events. Several peak discharge and hydrograph computation methods are available, including SCS, the Rational Method and the Santa Barbara Unit Hydrograph procedure. Infiltration can be considered, and pond and channel routing options are available as well. Like TR-55, PondPack allows the user to calculate hydrologic parameters, such as the time of concentration, within the program.

PondPack has limited, but useful hydraulic features, using Manning's equation to model natural and man-made channels and pipes. A wide variety of detention pond outlet structure configurations can be modeled, including low flow culverts, weirs, riser pipes, and even user-defined structures.

CulvertMaster

CulvertMaster is an easy-to-use, Windows-based culvert simulation and design program. The program can analyze pressure or free surface flow conditions and in subcritical, critical and supercritical flow conditions, based on drawdown and backwater. A variety of common culvert shapes and section types are available. Tailwater effects are considered and user can enter a constant tailwater elevation, a rating curve, or specify an outlet channel section. Culvert hydraulics are solved using FHWA methodology for inlet and outlet control computations. Roadway and weir overtopping are checked in the solution of the culvert.

CulvertMaster does have a hydrologic analysis component to determine peak flow using the Rational Method, SCS Graphical Peak Methods. The user also has the option of entering a known peak flow rate. The user must enter all rainfall and runoff information (e.g., IDF data, rainfall depths, curve numbers, C coefficients, etc).

Flowmaster

FlowMaster, also developed by Haestad Methods, Inc., is a Windows-based hydraulic pipe and channel design program. The user enters known information on the channel section or pipe, and allows the program to solve for the unknown parameter(s), such as diameter, depth, slope, roughness, capacity, velocity, etc. Solution methods include Manning's equation, the Darcy-Weisbach formula, Hazen-Williams formula, and Kutter's Formula. The program also features calculations for weirs, orifices, gutter flow, ditch and median flow and discharge into curb, grated, and slot inlets.

CHAPTER 7

OTHER STORMWATER MANAGEMENT ISSUES

In addition to the laws, regulations, policies, practices and designs of stormwater management programs presented in previous chapters, there are several issues involved with the planning and design of stormwater facilities that should be considered. The following sections discuss two of the most important of these new issues: (1) the design of culverts in such a way as to protect the stream, its flood plain, wetlands and associated habitat, and (2) the operation and maintenance of stormwater facilities in order to reduce the potential for them to become problems in terms of disease.

7.1 NATURAL STREAM DESIGN FOR CULVERTS

There are a great many design manuals that provide information for the design of culverts to pass stream waters beneath roadways.[17] Most of these manuals base the design of culverts on their ability to transport a given volume of water at a rate sufficient to prevent overtopping of the roadway. There is very little, or no consideration of the effect of the culvert on the geomorphology or the habitat of the downstream receiving waters. As a consequence, these otherwise properly-designed culverts have contributed to erosion and loss of habitat.

Culverts are normally designed to collect flood flows upstream of the highway crossing from the channel and flood plains, convey the flow under the highway and discharge it into the downstream channel. However, this action of collecting the upstream flow and discharging it in a concentrated jet into the downstream channel can have an effect on the stream morphology. A small culvert that severely constricts the flow can initiate degradation and lead to the creation of an unstable channel downstream of the highway.

One way to minimize this effect is to install *additional culverts* on the flood plain to convey the flood plain flows from one side of the highway to the other and thereby reduce the collection and concentration of flow by the main channel culvert into the downstream channel.

The Maryland State Highway Authority (SHA) has developed a procedure for the design of roadway culverts that incorporates *floodplain culverts* which potentially reduce the adverse effects of roadway main (or channel) culverts.[18] They base this procedure on appropriate stream geomorphological considerations. This section provides an overview of the Maryland SHA culvert design procedure with respect to those elements needed to protect downstream stream resources.

[17] See, for instance:

1. AASHTO Highway Drainage Guidelines, Chapter 4, Hydraulic Design of Highway Culverts, 1994.
2. AASHTO Model Drainage Manual, Chapter 9, Culverts
3. Federal Highway Administration, Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts, September 1985.
4. Federal Highway Administration, HY-8, FHWA Culvert Analysis, Version 6, 1996.

[18] Maryland SHA. 2000. Guidelines for the Selection and Design of Culvert Installations [draft].

7.1.1 Objectives

The Maryland SHA has identified two groups of objectives that relate to the structure of the culvert and the effect of the culvert on the stream. These objectives are:

Group 1: Objectives relating to the structure itself such as it's structural, geotechnical and hydraulic design and the overall effect of the design on safety, maintenance and traffic operations. This includes minimizing any effects of the stream on the structure, the highway and related flood hazards.

1. Provide for the safety of the public; structure to remain stable for worst-case flood conditions.

2. Provide a cost-effective and maintainable design.

3. Meet state requirements for strength and durability.

4. Minimize potential for uplift, piping and pressure forces on culverts.

5. Minimize maintenance problems with inorganic and organic debris.

6. *Meet requirements for flood plain management.

7. Maintain the natural stream channel stability of dimension, pattern and profile so that over time the channel features are maintained and the channel neither aggrades nor degrades. (Select culvert installation to maintain bankfull geometry of width and depth).

8. Control scour, erosion and degradation of bed and banks at culvert inlet and outlet and in downstream channel; control deposition of material in culvert barrel.

Group 2: Objectives relating to minimizing the effect of the structure on the stream, its flood plain, wetlands and associated habitat.

1. Provide for passage of fish and wildlife

2. Maintain and enhance fish and wildlife habitat

3. Create an aesthetic design

4. See objectives 6-8 above.

7.1.2 Stream Inventory and Classification

One of the key elements in the culvert evaluation and design is to perform a stream inventory and classification. The protocols developed by the Fish and Wildlife Service are to be used for measurements and inventories of stream characteristics. The stream should be classified in accordance with the Rosgen classification system (See: Rosgen, 1996 and 1998). Figure 7.1 shows the different stream classifications in the Rosgen system.

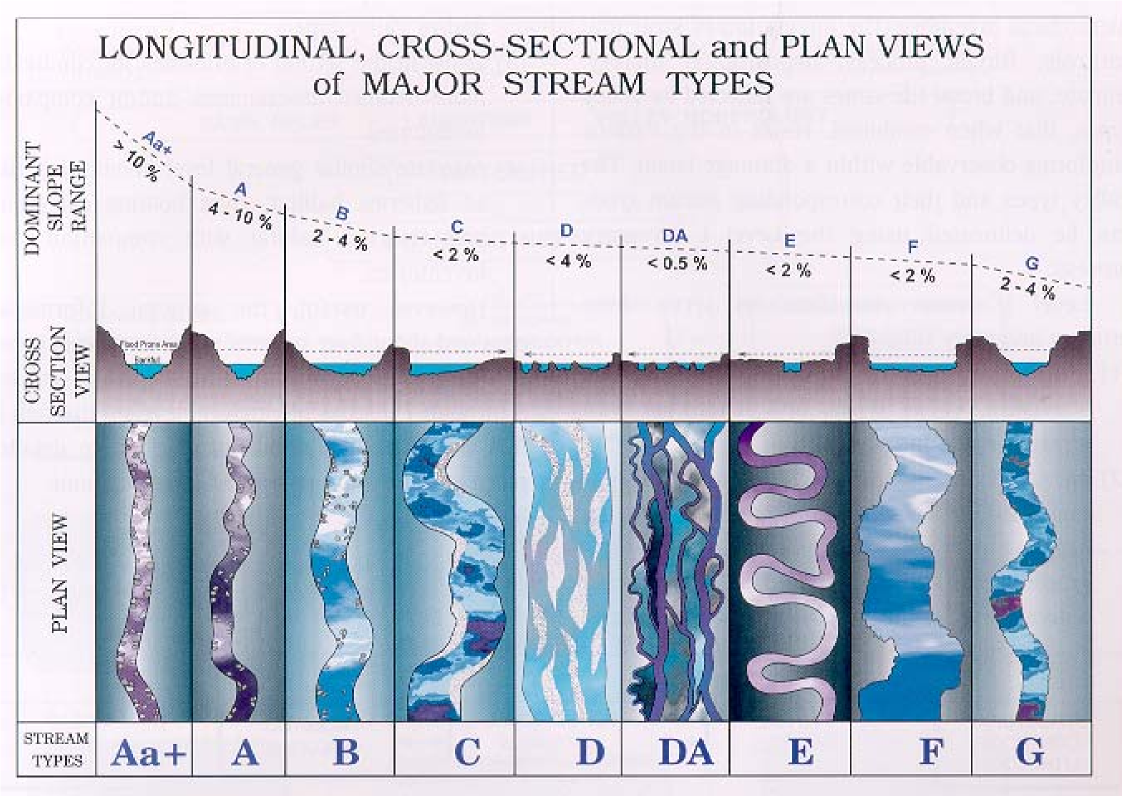

Figure 7. 1 - Rosgen Stream Classification System (Rosgen, 1996). Reprinted with permission from Wildland Hydrology, Inc., Fort Collins, Colorado.

The above stream Types are further classified with respect to the size of the materials that form the channel. The further classification is indicated by a number ranging from 1 to 6 that follows the alphabetical type indication. The numerical designations are:

1 – Bedrock
2 – Boulders
3 – Cobbles
4 – Gravel
5 – Sand
6 – Silt/Clay

Thus, a C-Type stream that has a sandy channel is designated as a C5 stream; a B-Type stream that has boulder-sized materials in the channel is designated as a B2 stream.

The stream stability and geomorphology study will normally need to address the following considerations:

- Stream and flood plain characteristics at the proposed highway crossing, and when necessary stream and flood plain characteristics at a reference reach determined to be a stable reach that is typical of the stream morphology in the vicinity of the highway crossing.

- Cross-sections of the channel and flood plain to provide necessary input for the preparation of water surface profiles using HEC-RAS. Note that if a "bottomless culvert" alternative is to be considered, cross-section elevations should be taken high enough to encompass the 500-year flood.

- A preliminary assessment regarding the stability of the stream bed and banks, adverse effects of urbanization, actual or potential aggradation, degradation or lateral migration, etc.

- Preparation of a Stream Inventory and Classification Report to summarize the results of the field and office studies. Particular attention is directed towards obtaining measurements of bankfull width and depth. The bankfull depth elevations and channel bank elevations need to be plotted on the stream profile and cross-sections in the reach of the stream under study.

7.1.3 Culvert Design

The Maryland culvert design draft guidance distinguishes between the procedures to be used on Type B, C, and E streams where the culverts located on a riffle or on a comparatively straight channel reaches, and other types of streams. In general, the design process involves the following considerations:

- design of the main channel culvert to accommodate bankfull flow with minimum change in the hydraulic characteristics of unit discharge, width, depth and velocity,

- design of an upstream transition to the culvert entrance to achieve, within practical limits, a streamlined continuity of the flow and to maintain sediment transport characteristics of velocity and shear so as to avoid deposition of material or scouring,

- design of the culvert installation, including additional flood plain culverts as appropriate, to accommodate the design discharge in the channel and on the flood plain, and

- design of the main channel culvert outlet to minimize impacts to the downstream channel and to stabilize flow conditions for passage of fish.

Design of Culverts on Type B, C and E Streams

The B-Type streams are moderately entrenched, have moderate width to depth ratios (> 12), and are moderately sinuous. They have channel slopes between 2 and 4%. They usually form in narrow, moderately steep colluvial valleys with gentle sloping side slopes, but can also be located on stable, well-vegetated alluvial fans. The B-Type streams are generally found in mountain and piedmont regions, in valleys with steep, highly-dissected fluvial slopes. Figure 7.2 shows a typical B3-Type stream.

Figure 7.2 - Type B3 Stream

The C-Type streams are slightly entrenched, low gradient (< 2%), meandering, point-bar, riffle/pool streams with broad, well-defined flood plains. These types of streams have a high width to depth ratio. They are usually found in broad alluvial valleys. The C-Type stream is one of the most common streams found in Virginia. Figure 7.3 shows a typical C4-Type stream.

Figure 7.3 - Type C4 Stream

The E-Type streams are low-gradient (< 2%), meandering, riffle/pool streams with low to very low width to depth ratios (< 12). These streams tend to be hydraulically efficient, maintaining a high sediment transport capacity, with little deposition. These types of streams are generally very stable unless the streambanks are disturbed. They are found in broad valleys and meadows with well-developed floodplains. The E-Type stream is very common in Virginia. Figure 7.4 shows a typical E5-Type stream.

Figure 7.4 - Type E5 Stream

The recommended general approach is to design the culvert width to match the bankfull width of the upstream approach channel. This approach will tend to stabilize the channel since the culvert invert will serve to control the upstream channel elevation. There may not be a need for an upstream transition to the culvert entrance.

Main Channel Culvert

The culvert width should be about the same as the bankfull width for the reference section. Where practicable, accommodate the bankfull flow in a single pipe or box culvert cell. Where provision is to be made for fish passage, the main channel culvert(s) should be depressed two feet below the existing channel bed.

Use HEC-RAS to run the water surface profile for the bankfull discharge; adjust culvert slope, type, roughness and dimensions by a trial and error process to maintain continuity, to the extent practicable, of bankfull flow widths, depths and velocities upstream of, through and downstream of the culvert.

Flood Plain Culverts

The following elements are involved in planning and designing flood plain culverts:

Location - The flood plain culvert should be positioned on the flood plain well beyond the channel banks. This location avoids the higher velocity and boundary shear stress in the near bank region of the flood plain, and moves the culvert away from the area of convergence of the flood plain flow into the culvert. It also minimizes the chance for clogging with debris that is carried in the main channel. The upstream flood plain culvert invert is to be set at the water surface elevation of the bankfull flow.

Size - A primary goal is to design the main channel culvert installation to convey the main channel flows and the flood plain culvert installation(s) to convey the flood plain flows.

Culvert Outlets

The design of the main channel culvert outlet is a critical aspect of the culvert installation with regard to minimizing the impact of the culvert on the stream. When flood plain culverts are effectively used, they serve to relieve the main channel culvert of much of the hydraulic load. This in turn simplifies the problem of energy dissipation at the culvert outlets. Normally, energy dissipation at the outlets of the flood plain culverts can be handled with riprap pads since the velocities of flow on the flood plain tend to be low. However, culvert outlet protection needs to be tailored for the specific conditions at the site, and no single “standard” method will be appropriate for all locations.

Design of Culverts in other Stream Types

In some cases, particularly for A, DA, F and G Type streams, stream morphology becomes of paramount importance to the culvert design, requiring the services of engineers with specialized experience and knowledge. The following paragraphs briefly identify design issues associated with culverts in those types of streams.

Culverts in Type A streams

The A-type stream is a steep, entrenched and confined channel step-pool systems with stream slopes in the range of 4 to 10% or more. It tends to occur mostly in small drainage basins in the mountainous regions of Virginia. The recommended general concept for a highway structure on an A type stream is to span the entire channel, placing the structure footings beyond the limits of the channel banks.

Culverts in Type DA streams

The DA stream types are highly interconnected channel systems (anastomosed) that develop in gentle relief terrain areas exhibiting wetland environments with stable channel conditions. The stream channels have highly variable width to depth ratios, highly variable sinuosities, flat slopes (< 0.005), low bedload and stable banks.

Such streams are encountered mostly in the coastal physiographic regions. The recommended general concept for a highway structure on such streams is to maintain the existing channel system to the extent feasible. This can be accomplished by providing:

- a combination of bridges and culverts at the crossing (preferred approach),
- culverts to carry each of the individual stream channels under the highway, or
- a bridge to span the entire channel system.

Culverts in Type F streams

The F stream type is an entrenched, meandering riffle/pool channel on a low gradient with a high width to depth ratio. Type F streams tend to be laterally unstable with high bank erosion rates. Depositional features (central and transverse bars) are common, and are related to the high sediment supply from streambanks and the high width-to-depth ratios. Vegetation plays a minor role in the stability of F-Type streambanks because the very high bank heights typically extend beyond the rooting depth of riparian plants. Figure 7.5 shows a typical F4-Type stream.

Figure 7.5 - Type F3 Stream

Because of the potential for the lateral instability of the F channel, a thorough investigation should be made of the stream reach upstream and downstream of the proposed highway crossing. Design alternatives for a highway stream crossing include:

1. A stream rehabilitation project to modify the Type F channel to a more stable channel form such as a Type C channel.
2. A bridge to span the main channel with abutments set back from the channel banks and, if necessary, placement of circular piers in the channel.
3. A culvert installation. The most feasible approach would be to consider the evolutionary cycle of the F channel and to design the installation with a main channel culvert (to match the lower width to depth ratio of the re-established channel) and with flood plain culverts (Alternative 1 above). If this approach cannot be worked out, a wide culvert should be provided with a width equal to or greater than the bankfull width of the F channel.

Culverts in Type G streams

The “G” or gully stream type is an entrenched narrow and deep step/pool channel with a low to moderate sinuosity. Channel slopes are moderate, and generally range from 2% to 4% although “G” channels may be associated with gentler slopes where they occur as “down-cut” gullies in meadows. With the exception of channels containing bedrock and boulders, the “G” stream types have very high bank erosion rates and a high sediment supply.

A culvert design on a “G” type stream should be approached with caution in recognition of the potential problems with bank erosion and sediment discharge. A bridge may be a better alternative in some cases. Prior to selecting a culvert installation for a “G” type stream, a detailed study should be conducted of the stream reach to determine whether work is necessary to stabilize the channel upstream and downstream of the culvert. In general, the stability problems with “G” type channels become more difficult as the culvert length increases. A bridge alternative has the advantage of spanning the stream entirely, thereby avoiding changes to the stream regime.

7.2 DISEASE VECTORS (E.G., MOSQUITOES)

Ponded waters, such as constructed stormwater management facilities (detention areas, storm sewers, and stormwater ditches), have the potential to foster mosquito reproduction. However, stormwater management is crucial to protect our environment and downstream properties and communities.

There are approximately 55 species of mosquitoes present in Virginia. Currently, a survey of mosquito populations associated with stormwater management facilities has not been conducted. There are two basic groups of mosquitoes that may use aquatic habitats in the urban environment: permanent water species and floodwater species. Permanent water species lay their eggs directly on the water surface or on the leaves of aquatic plants. Floodwater species deposit eggs on moist soil or the substrate around aquatic systems, and the eggs hatch only when submerged by rising water levels. It is estimated that six mosquito species breed in temporary bodies of water, of which a majority are potential vectors of the West Nile virus. Also, it is estimated that 4 mosquito species breed in permanent bodies of water, of which none are known to carry the West Nile virus. Finally, there are 2 mosquito species that breed in both permanent and temporary bodies of water that may be vectors of the West Nile virus.

The number of pesticides available for mosquito control are dwindling fast, and biological-control agents (e.g., mosquito fish) often have limited application. Neither approach generally provides a long-term solution.

Stormwater Management Technical Bulletin No. 8 describes site design procedures that minimize the use of stormwater management structures that promote mosquito breeding. The Bulletin outlines seven elements of site design. These are:

- Reduce the need for stormwater management facilities
- Improve designs of permanent pools
- Select stormwater management measures based on site -specific conditions
- Take special care for ponds that temporarily impound water
- Take care in the design of storm sewer systems
- Require “as-builts,” which provide assurance that stormwater management facilities are effectively minimizing mosquito propagation
- Require and comply with a written maintenance agreement

Better site design is coupled with better designs of the management units themselves. Metzger et al. (2002) identify measures to take to improve the design of stormwater management units to minimize the potential for supporting the development of mosquito populations. They suggest that the best solution to minimizing vector production is through prevention, by "engineering them out" of structural devices and enforcing proper and regular maintenance. The measures that they suggest are:

- Dry Systems

  1. Structures should be designed such that they do not hold standing water for more than 72 hours to prevent mosquito development. Provisions to prevent or reduce the possibility of clogged discharge orifices (*e.g.*, debris screens) should be incorporated into the design. The use of weep holes is not recommended due to rapid clogging.

  2. The hydraulic grade line of each site should be a primary factor in determining the appropriate BMP that will allow water to flow by gravity through the structure. Pumps are not recommended because they are subject to failure and often require sumps that hold water.

Structures that do not require pumping should be favored over those that have this requirement.

3. Designs should avoid the use of loose riprap or concrete depressions that can hold standing water.

4. Distribution piping and containment basins should be designed with adequate slopes to drain fully and prevent standing water. The design slope should take into consideration buildup of sediment between maintenance periods.

5. The use of barriers or diversions that results in standing water should be avoided.

- Systems With Sumps or Basins

  1. Structures designed with sumps or basins that retain water permanently or longer than 72 hours (e.g., CDS, Delaware-type sand media filters) should be sealed completely to prevent entry of adult mosquitoes. Adult female mosquitoes can use openings as small as 1/16 in. to access water for egg laying. Screening can be used to exclude mosquitoes but is subject to damage and is not a method of choice.

  2. Structures should be designed with the appropriate pumping, piping, valves, or other necessary equipment to allow for easy dewatering of the unit if necessary.

  3. If the sump or basin is completely sealed, with the exception of the inlet and outlet, the inlet and outlet should be fully submerged to reduce the available surface area of water for mosquitoes to lay eggs (female mosquitoes can fly through pipes).

- Permanent Ponds

  1. Permanent ponds should maintain water quality sufficient to support surface-feeding fish such as mosquito fish (*Gambusia affinis*), which feed on mosquito larvae.

  2. Permanent pond shorelines should be accessible to both maintenance and vector-control crews for (1) periodic maintenance and/or control of emergent and pond-edge vegetation and (2) routine monitoring of mosquito immatures and abatement procedures if necessary. Emergent plant density should be controlled so that mosquito predators are not inhibited or excluded from pond edges (i.e., fish should be able to swim between plant bases).

  3. If possible, permanent ponds should be maintained with depths in excess of 4 ft. to preclude invasive emergent vegetation such as cattails. Emergent vegetation provides mosquito larvae with refuge from predators and increases nutrient availability. The pond edges below the water surface should be as steep as practicable and uniform to discourage dense plant growth and reduce favorable mosquito habitat.

  4. Concrete or liners should be used in areas where vegetation is not necessary to prevent unwanted plant growth.

  5. Permanent ponds should be designed to allow for easy dewatering of the basin when needed.

- General-Access Requirements

  1. All BMP structures should be easily and safely accessible, without the need for special requirements (*e.g*., Occupational Safety & Health Administration requirements for "confined space"). This will allow vector-control personnel to effectively monitor and, if necessary, abate vectors.

  2. If covers are used, the design should include spring-loaded or lightweight access hatches that can be opened easily. Covers should seal completely.

  3. All-weather road access (with provisions for turning a full-size work vehicle) should be provided along at least one side of large aboveground BMPs that are less than 7 m wide. BMPs that have shoreline-to-shoreline distances in excess of 7 m should have a perimeter road for access to both sides. (Mosquito larvicides are applied with handheld equipment at small sites and with backpack or truck-mounted high-pressure sprayers at large sites. The effective swath width of most backpack or truck-mounted larvicide sprayers is approximately 7 m on a windless day.)

  4. Access roads should be built as close to the shoreline as possible. It is important to not have vegetation or other obstacles between the access road and the BMP that might obstruct the path of larvicides to the water.

  5. Vegetation should be controlled (removal, thinning, or mowing) periodically to prevent access barriers.

REFERENCES

Chapter 1

None.

Chapter 2

None.

Chapter 3

Adams, T.R. undated. *Designing Stormwater Quality Facilities to Comply with Volume-Based Treatment Requirements.* Available at: http://www.vortechnics.com/techbulletins/ (Last accessed 9/12/04)

Claytor R.A. and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. The Center for Watershed Protection. Silver Spring, Maryland.

Federal Highway Administration (FHWA). undated. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*. Available at: http://www.fhwa.dot.gov/environment/ultraurb/ (Last accessed 9/12/04)

Lenhart, J. H., and J. Battiata. 1999. *Development of a Methodology for Sizing Flow-Based Stormwater Quality Treatment Facilities for the Commonwealth of Virginia*. Presented at StormCon™ The North American Surface Water Quality Conference and Exposition August, 2002.

Leopold, L.B., Wolman, M.G. and J.P. Miller. 1964. *Fluvial Processes in Geomorphology*. San Francisco: W. H. Freeman and Company.

Pfankuch, D.J. 1975. *Stream Reach Inventory and Channel Stability Evaluation – A Watershed Procedure*. R1-75-002. USDA Forest Service, Northern Region. Missoula, MT.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Inc., Fort Collins, CO.

Schueler, T. R. 1987. *Controlling Urban Runoff – A Practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments, Washington, DC.

Chapter 4

Center for Watershed Protection, 2000. *National Pollutant Removal Performance Database for Stormwater Treatment Practices*. 2nd Edition. Ellicott City, Maryland.

City of Austin (1995). *Characterization of Stormwater Pollution for the Austin (draft)*. Texas Area. Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin, Austin, TX.

Federal Highway Administration (FHWA). No date. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*. Available at: http://www.fhwa.dot.gov/environment/ultraurb/index.htm

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

Khan, Z., C. Thrush, P. Cohen, L. Kulyer, R. Franklin, D. Field, J. Koon, and R. Homer. 1992. Biofiltration Swale Performance, Recommendations, and Design Considerations. Municipality of Metropolitan Seattle, Water Pollution Control Department, Seattle, WA.

Marsh, S.L. 1996. *Stormwater Control with Grassy Swales*. Master's Thesis. Department of Civil Engineering, University of Virginia. Charlottesville, Virginia.

Maryland Department of the Environment (MDE). 2000. *2000 Maryland Stormwater Design Manual. Volume I*. Baltimore, MD.

Schueler, T.R. 1992a. *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetland Systems in the Mid-Atlantic Region*. Washington, D.C.: Metropolitan Washington Council of Governments

----------------- 1992b. *A Current Assessment of Urban Best Management Practices*. Metropolitan Washington Council of Governments.

----------------- 1987. *Controlling Urban Runoff – A Practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999. *Storm WaterTechnology Fact Sheet - Infiltration Trench.*. EPA 832-F-99-019 Office of Water. Washington, D.C.

Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook. First Edition.* Richmond, VA. Available at: http://www.dcr.state.va.us/sw/stormwat.htm (Last accessed on 9/12/04)

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for: US EPA Office of Water. Washington, DC.

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

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.

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

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.

Chapter 5

Berg, V.H, 1991. *Water Quality Inlets (Oil/Grit Separators)*. Maryland Department of the Environment, Sediment and Stormwater Administration.

Brisbane, T.E., M.L. Heintz, and S.R. Abt. 2000. *Hydraulic Testing of the Jensen Precast Storm Water Detention Vault.* Prepared for Jensen Precast. Colorado State University, Fort Collins, Colorado.

Claytor, R.A., and T.R. Schueler, 1996. *Design of Stormwater Filtering Systems*. The Center for Watershed Protection. Silver Spring, Maryland.

Coffman, L.S., 2001. *Low Impact Development creating a storm of controversy*. Water Resources Impact, 3 (6), 7-9. Available at: http://www.awra.org, and http://www.lid-stormwater.net/intro/background.htm (Last accessed on 9/12/04).

Corcoran, E., and D. Rich. 1995. Report to Sorbant Environmental Group. Rio Palenque Research Corporation.

Davis, A., M. Shokouhian, H. Sharma, and C. Minami. 1998. *Optimization of Bioretention Design for Water Quality and Hydrologic Characteristics – Final Report.* Environmental Engineering Program, Department of Civil Engineering, University of Maryland.

Fassman, L. 2002. Methods for Evaluation of Ultra-Urban BMPs. Ph.D. Dissertation. University of Virginia Department of Civil Engineering.

Federal Highway Administration (FHWA). 2004. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring.* 3.6 Water Quality Inlets. Available at: http://www.fhwa.dot.gov/environment/ultraurb/uubmp3p5.htm. Last accessed 9/12/04.

Hager, M.C. 2003. *Low-Impact Development*. Stormwater. Forester Communications, Inc., Santa Barbara, CA. pp. 12-25.

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

Northern Virginia Planning District Commission and Engineers and Surveyors Institute, 1992.

Othmer, E.F., G. Friedman, J.S. Borroum, and B. Currier. 2001. *Performance Evaluation of Structural BMPs: Drain Inlet Inserts (Fossil Filter ™ and StreamGuard ™) and Oil/Water Separator.* Proceedings of the EWRI World Water and Environmental Resources Congress. Orlando, Florida.

Prince George's County, Maryland. 2002. *Bioretention Manual*. Available at: http://www.co.pg.md.us/Government/AgencyIndex/DER/PPD/LID/bioretention.asp?h=20&s=&n=50&n1=160. (Last accessed 9/12/04)

Prince George's County, Maryland. 1999. *Low-Impact Development Design Manual*, Department of Environmental Resources, Prince George's County, Maryland

Stephenuck, K.F, R.L. Crunkilton, and L. Wang. 2002. *Impacts of Urban Landuse on Macroinvertebrate Communities in Southeastern Wisconsin Streams*. J. AWWA. 38(4):1041-1051.

Schueler, T.R. 1994. *Hydrocarbon Hotspots in the Urban Landscape*. Watershed Protection Techniques. The Center for Watershed Protection. 1(1):3-5.

--------------. 1992. *A Current Assessment of Urban Best Management Practices*. Metropolitan Washington Council of Governments.

--------------. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Land Planning Series. Metropolitan Washington Council of Governments, Center for Watershed Protection, Washington, D.C.

U.S. Environmental Protection Agency, 1999a. *Preliminary Data Summary of Urban Stormwater Best Management Practices*. EPA-821-R-99-012. Office of Water. Washington, D.C.

-- 1999b. *Storm WaterTechnology Fact Sheet - Infiltration Trench.*. EPA 832-F-99-019 Office of Water. Washington, D.C.

-- 1999c. *Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)*. EPA/600/R-99/017. Office of Research and Development. Washington, D.C.

--- 1999d. *Preliminary Data Summary of Urban Storm Water Best Management Practices.* EPA-821-R-99-012. Washington, D.C.

--- 1999e. *Storm Water Technology Fact Sheet: Hydrodynamic Separators*. EPA 832-F-99-017. Office of Water. Washington, D.C.

Chapter 6

None.

Chapter 7

Metzger, M.E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer., 2002. *The Dark Side of Stormwater Runoff Management: Disease Vectors Associated with Structural BMPs.* Stormwater. March/April, 2002. Forester Communications, Inc. Santa Barbara, CA.

Rosgen, D.L., 1996. *Applied River Morphology*. Wildland Hydrology Books, Ft. Collins, Colo.

Rosgen, D.L., 1998. *The Reference Reach - a Blueprint for Natural Channel Design*. Proceedings for ASCE Wetlands Engineering and River Restoration Conference in Denver Colorado. March 1998. ASCE. Reston, VA.