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Preliminary Data Summary of Urban Storm Water Best Management Practices

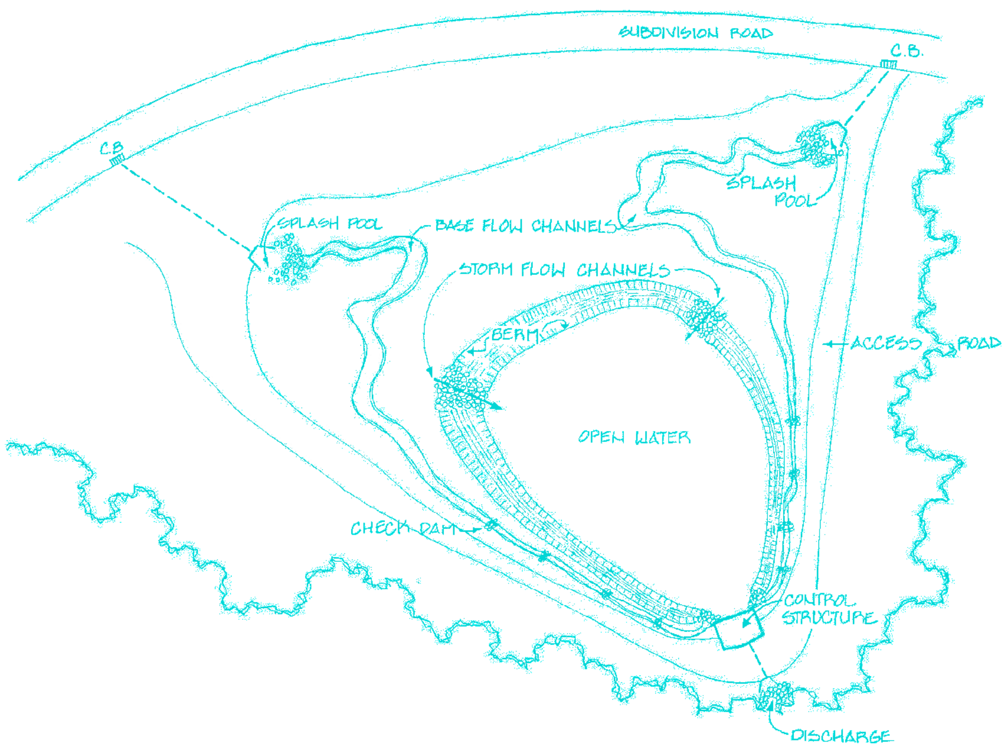

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Table of Contents

List of Tables

List of Figures

1.0 Summary

The significance of storm water runoff in affecting water quality in the United States has become an increasing concern in recent years, as further improvements are made in controlling other point sources such as municipal sewage and industrial waste. EPA conducted a broad analysis of storm water runoff characteristics in its *Nationwide Urban Runoff Program* between 1979 and 1983. During the 1980's the Agency made several attempts to promulgate regulatory controls for storm water runoff under the statutory framework of the 1972 Clean Water Act. Following enactment of the Water Quality Act of 1987, EPA began development of a more comprehensive regulatory program. During the course of these actions, the use of best management practices (BMPs) in addressing runoff problems was frequently identified, however it was known that additional research on the performance of BMPs was also needed.

EPA's Engineering and Analysis Division conducted a study on storm water best management practices during 1997 and 1998 as part of its series of preliminary studies in the effluent guidelines program. This report summarizes existing information and data regarding the effectiveness of BMPs to control and reduce pollutants in urban storm water. The report provides a synopsis of what is currently known about the expected costs and environmental benefits of BMPs, and identifies information gaps as well.

Detailed information about BMP design is beyond the scope of this report. Readers are encouraged to consult the wide range of storm water BMP design manuals available from states and localities and other organizations for detailed design guidelines. Information regarding BMP performance and selection is also provided in other EPA documents, such as *Guidance Specifying Management Measure for Sources of Nonpoint Source Pollution in Coastal Water* (US EPA, 1993a); *Urban Runoff Pollution Prevention and Control Planning* (US EPA, 1993c); and *Municipal Wastewater Management Fact Sheets: Storm Water Best Management Practices* (US EPA, 1996e). In addition, readers are encouraged to consult the ASCE/WEF Manuals of Practice, *Design and Construction of Urban Stormwater Management Systems* (ASCE/WEF, 1992) and *Urban Runoff Quality Management* (ASCE/WEF, 1998) for a more thorough discussion of storm water management design.

Summary of Findings

1. Waterways and receiving waters near urban and suburban areas are often adversely affected by urban storm water runoff. Impacts may be manifested in terms of:

- alterations in hydraulic characteristics of streams receiving runoff such as higher peak flow rates, increased frequency and duration of bankfull and sub-bankfull flows, increased occurrences of downstream flooding, and reduced baseflow levels

- changes in receiving stream morphology such as increased rates of sediment transport and deposition, increased shoreline erosion, stream channel widening, and increased stream bed scouring

- aquatic habitat impacts leading to changes in fish and macroinvertebrate populations and loss of sensitive species

- public health and recreation impacts such as increased risk of illness due to contact with contaminated water bodies, contamination of drinking water supplies, beach closures, restrictions on fishing, and shellfish bed closures.

2. A wide variety of BMPs, both structural and non-structural, are available to address urban storm water runoff and discharges.

- For various reasons (such as cost, suitability to site, etc.) some of these BMP types are widely used, some infrequently; some are relatively new designs that are not widely in use.

- Many BMPs are used primarily for water quantity control (i.e. to prevent flooding), although they may provide ancillary water quality benefits.

- Some BMP types have been analyzed for performance in terms of site-specific pollutant removal, although not extensively enough to allow for generalizations.

- The pollutant removal performance of some BMP types is essentially undocumented.

- Some BMP types, particularly non-structural and those that do not have discrete inflow or outflow points, are difficult to monitor.

- There is no widely-accepted definition of "efficiency" or "pollutant removal" for storm water BMPs.

- The role of chemical pollutant monitoring vs. receiving stream biological monitoring in evaluating BMP performance is not well documented.

3. Only a few cost studies have been conducted for storm water BMPs.

- Due to the limited cost data, a lack of clear definitions of performance, and limited "performance" data, it is difficult at this time to develop cost-effectiveness comparisons for various BMP types.

4. The benefits of individual BMPs are site-specific and depend on a number of factors including:

- the number, intensity and duration of wet weather events;
- the pollutant removal efficiency of the BMP;
- the water quality and physical conditions of the receiving waters;
- the current and potential use of the receiving waters; and
- the existence of nearby “substitute” sites of unimpaired waters.

Because these factors will vary substantially from site to site, data are not available with which to develop estimates of benefits for individual BMP types.

5. A number of researchers are continuing to work on BMP performance monitoring, and there are several attempts underway to develop comparison frameworks through the construction of comprehensive databases on BMP design characteristics and performance.

Organization of Report

This report is divided into six chapters. Chapter 1 presents a summary of the major findings of the report. Chapter 2 presents a general introduction of the purposes and goals of this evaluation. Chapter 3 summarizes existing regulations and permits developed by EPA to address urban storm water discharges, including regulations under the National Pollutant Discharge Elimination System (NPDES) and the Coastal Zone Act Reauthorization Amendments (CZARA). Chapter 4 presents an assessment of the environmental problems attributable to urban storm water discharges and Chapter 5 identifies the best management practices that can be used to control the quantity and improve the quality of storm water prior to discharge. Chapter 6 identifies the costs and benefits of storm water BMPs.

2.0 Introduction and Scope

2.1 Effluent Guidelines Program and Consent Decree Requirements

Effluent guidelines are national standards for categories of dischargers to surface waters. The program was established in 1972 under Title III of the Clean Water Act (CWA). Since that time EPA has developed effluent guideline regulations for over 50 categories, primarily industrial dischargers. In these regulations the Agency typically establishes numeric “end-of-pipe” effluent limitations for specific chemical pollutants and/or indicator parameters (e.g. BOD, oil and grease). For some categories, EPA has also issued narrative requirements for best management practices (BMPs) to address control of storm water runoff, plant maintenance schedules and training of plant personnel. The effluent limitations are generally based on the performance of available or demonstrated control and treatment technologies. Resulting effluent limitations are commonly referred to as "technology-based" standards. The regulations are implemented in National Pollutant Discharge Elimination System (NPDES) permits, which are issued by EPA and State agencies under the authority of CWA Section 402.

The Water Quality Act of 1987 added section 304(m) to the CWA. This provision requires EPA to publish a biennial Effluent Guidelines Plan and develop additional regulations. EPA’s effluent guidelines program is currently subject to a consent decree (“Decree”) in *Natural Resources Defense Council et al v. Browner* (D.D.C. 89-2980, January 31, 1992, as amended). The Decree requires the Agency to propose effluent guideline regulations and take final action for 20 point source categories, according to a specified schedule. Additionally, the Decree requires that the Agency conduct 11 preliminary studies to assist in selecting categories for regulation development.

The 1987 amendments also added section 402(p) to the CWA, which requires development of a national program for regulation of storm water discharges. This is discussed further in Chapter 3 of this report.

In 1996, the Natural Resources Defense Council (NRDC) recommended that EPA develop effluent guidelines for categories of storm water dischargers, to supplement the existing NPDES permit regulations covering storm water discharges. Because municipal storm water discharges present a range of complex phenomena that have not been extensively documented in the professional literature, and because there is a lack of generally accepted methods for evaluating storm water management practices, EPA determined that conducting a preliminary study would be appropriate to satisfy one of the study obligations under the Decree. This preliminary study is intended to assist decision making on initiating regulatory development projects.

2.2 Types of Discharges Addressed

This study is focused on BMPs designed to prevent, control or treat storm water discharges, and the nature and measurement of storm water discharges. Storm water discharges may flow directly into surface waters, into municipal separate storm sewer systems (“MS4s”), and/or infiltrate into groundwater. The emphasis on BMPs is intended to support the national NPDES storm water program. Some aspects of the BMPs described herein may also be relevant for other types of wet weather pollution problems, such as combined sewer overflows (CSOs).

Storm water BMPs may be organized into two major groups with multiple subgroups:

- *Structural* BMPs include:
    - infiltration systems such as infiltration basins and porous pavement
    - detention systems such as basins and underground vaults
    - retention systems such as wet ponds
    - constructed wetland systems
    - filtration systems such as media filters and bioretention systems
    - vegetated systems such as grass filter strips and vegetated swales
    - minimizing directly-connected impervious surfaces
    - miscellaneous and vendor-supplied systems such as oil/water separators and hydrodynamic devices

- *Non-Structural* BMPs include:
    - automotive product and household hazardous material disposal
    - commercial and retail space good housekeeping
    - industrial good housekeeping
    - modified use of fertilizers, pesticides and herbicides
    - lawn debris management
    - animal waste disposal
    - maintenance practices such as catch basin cleaning, street and parking lot sweeping, road and ditch maintenance
    - illicit discharge detection and elimination
    - educational and outreach programs
    - storm drain inlet stenciling
    - low-impact development and land use planning.

The impacts of storm water discharges are described in Chapter 4. Various BMP designs for addressing storm water discharges are described in Chapter 5, and the costs and economic impacts of BMP are described in Chapter 6.

2.3 Data Sources and Data Collection Techniques

ASCE National Stormwater BMP Database

Since 1995, EPA and the American Society of Civil Engineers (ASCE) have operated under a cooperative agreement to develop a database of storm water BMP design and performance. The initial version of this database provides pollutant removal data and other performance measures on approximately 75 BMPs based on published studies and reports. These studies and reports were carefully selected from a comprehensive screening of virtually all available published literature on BMP performance, amounting to about 800 bibliographic references.

A significant objective of the database is to provide a design tool for local storm water designers and planners. The database has the capacity to report extensive detail about the design of BMPs, along with descriptive information about the adjacent watershed, hydrology and other geographic data.

As of early 1999, the initial version of the database is being tested, and a public release will be available in mid-1999. EPA and ASCE are continuing to develop the database and are encouraging organizations that have conducted BMP monitoring to submit their findings to the ASCE Database Clearinghouse for entry into the database. As new data are gathered, periodic updates will be made available to the public through use of the Internet.

Center for Watershed Protection National Pollutant Removal Performance Database

In 1997, the Center for Watershed Protection developed a database for the Chesapeake Research Consortium titled, "National Pollutant Removal Performance Database for Stormwater BMPs" (Brown and Schueler, 1997a). This database focuses on the pollutant removal efficiency of commonly used and innovative urban BMPs for storm water control. The database is derived from 123 research studies developed between 1977 and 1996.

All of the studies in the database utilized data collected with automated sampling equipment and had documented methods to compute pollutant removal efficiencies. More than three-quarters of the studies were based on four or more storm samples, while the remaining studies were either based on fewer than four storms or the sample size was not stated.

Literature Cited

- EPA reports including the Nationwide Urban Runoff Program (NURP), National Water Quality Inventory, Coastal Nonpoint Pollution Program Guidance, NPDES Rules, guidance documents and fact sheets.

- Other Federal agency publications from U.S. Geological Survey and U.S. Department of Agriculture.
- Professional journals and manuals of practice such as those from ASCE and the Water Environment Federation
- Publications of research organizations such as the Center for Watershed Protection, Terrene Institute, Metropolitan Washington Council of Governments and the Watershed Management Institute
- State and local government BMP design manuals.

BMP Performance Data Developed for this Preliminary Study

EPA conducted field performance evaluations at three structural BMP sites during 1998. While these evaluations contribute to the literature on BMP performance, EPA also intended that the field testing would serve as an experimental framework for refining evaluation methodology. Three sites in the Washington, D.C. area were monitored: a constructed wetland, a peat-sand filter, and a regional wet pond. Data summaries for these monitoring activities appear in Chapter 5. Additional findings will be provided in a supplement to this report.

3.0 Existing Storm Water Regulations and Permits

Congress added Section 402(p) to the Clean Water Act in 1987 to require implementation of a comprehensive approach for addressing storm water discharges in two phases. Section 402(p)(4) required EPA to develop permit application regulations under the National Pollutant Discharge Elimination System (NPDES), submission of NPDES permit applications, issuance of NPDES permits, and compliance with NPDES permit conditions. Section 402(p)(6) requires EPA to designate storm water discharges to be regulated (within the statutory definitions provided in section 402(p)(2)) and establish a comprehensive regulatory program, which may include performance standards, guidelines, guidance, and management practices and treatment requirements.

3.1 Phase I NPDES

EPA promulgated the first phase of NPDES storm water permit application regulations ("Phase I") on November 16, 1990 (US EPA, 1990). The provisions addressing MS4s cover those systems serving a population of 100,000 or more. This includes 173 cities, 47 counties and additional systems designated by EPA or states based on such system's interrelationship with or proximity to the aforementioned systems, such as state highway departments. A total of 260 permits, covering approximately 880 operators (local governments, state highway departments, etc.) have been identified as subject to Phase I permit application requirements. As of late 1998, approximately 228 such permits have been issued in final form.

The CWA requires that MS4 permits effectively prohibit non-storm water discharges into the storm sewers as well as reduce the discharge of pollutants to the maximum extent practicable (including management practices, control techniques and system, design and engineering methods, and other provisions appropriate for the control of such pollutants).

Phase I MS4 permittees were required to submit an application that included source identification information, precipitation data, existing data on the volume and quality of storm water discharges, a list of receiving water bodies and existing information on impacts on receiving waters, a field screening analysis for illicit connections and illegal dumping, and other information.

Following this submission, MS4 permittees were to gather and provide additional information including:

- discharge characterization data based on quantitative data from 5 to 10 representative locations in approved sampling plans; estimates of the annual pollutant load and event mean concentration of system discharges for selected conventional pollutants and heavy metals; a proposed schedule to provide estimates of seasonal pollutant loads; and the mean concentration for certain detected constituents in a representative storm event;

- a proposed management program including descriptions of: structural and source control measures that are to be implemented to reduce pollutants in runoff from commercial and residential areas; a program to detect and remove illicit discharges; and a program to control pollutants in construction site runoff.

The Phase I rule also covers storm water discharges "associated with industrial activity." This includes facilities covered by effluent guidelines and other designated classes of industrial and commercial facilities, such as hazardous waste treatment, storage, or disposal; landfills; recycling; vehicle maintenance and equipment cleaning; sewage sludge handling; construction activity (sites with 5 or more acres of disturbed land); and facilities where materials are exposed to storm water. Permittees must prepare a storm water pollution prevention plan which describes pollution sources, measures and controls.

EPA and the states used several permit mechanisms for the many facilities receiving NPDES permits for the first time. EPA issued "baseline" general permits to cover a wide range of facilities with basic requirements, with the intent that more specific requirements would follow in subsequent permit cycles. Industry-specific or "group" permits were issued based on applications submitted by business associations, and other sites were issued individual permits.

The management and pollution prevention plans prepared by MS4s and industrial permittees vary in their level of detail and specificity regarding design and implementation of best management practices (BMPs). EPA and some states have issued guidance on preparation of these plans (US EPA, 1992d; US EPA, 1992e). The Agency has not conducted a nationwide review of these plans.

3.2 Phase II NPDES

EPA proposed the NPDES storm water regulations for the second phase of storm water discharge control ("Phase II") on January 9, 1998 (US EPA, 1998c). EPA is required to promulgate the Phase II rule in 1999 under a separate consent decree.

The proposal designates two classes of facilities for automatic coverage on a nationwide basis under the NPDES program, (1) small municipal separate storm sewer systems located in urbanized areas (about 3,500 municipalities would be included in the program); and (2) construction activities (pollutants include sediments and erosion from these sites) that disturb equal to or greater than one and less than five acres of land (about 110,000 sites per year will be included in the program). Those facilities designated above would need to apply for NPDES storm water permits by 2002. EPA is anticipating that most permittees would be covered under general permits.

EPA is also proposing to conditionally exclude from the NPDES storm water program Phase I facilities that have "no exposure" of industrial activities, such as industrial products, processes, or raw materials, to storm water, thereby reducing application of the program to many industrial activities currently covered by the program that have no industrial storm water discharges.

Some facilities that EPA is proposing to cover under the Phase II rule are currently subject to state and/or local storm water management requirements.

3.3 Coastal Zone Act Requirements

Section 6217 of the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 provides that States with approved coastal zone management programs must develop and submit coastal nonpoint pollution control programs to EPA and the National Oceanic and Atmospheric Administration (NOAA) for approval. Failure to submit an approvable program would result in a reduction of federal grants to such states under both the Coastal Zone Management Act and section 319 of the CWA.

State coastal nonpoint pollution control programs under CZARA are to include enforceable policies and mechanisms that ensure implementation of the management measures throughout the coastal management area. Section 6217(g)(5) defines management measures as "economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives." The amendments provide for a technology-based approach based on technical and economic achievability under the rationale that neither States nor EPA have the money, time, or other resources to create and expeditiously implement a program that depends on establishing cause and effect linkages between particular land use activities and specific water quality problems. If this technology-based approach fails to achieve and maintain applicable water quality standards and to protect designated uses, sec. 6217(b)(3) requires additional management measures.

EPA issued *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* under sec. 6217(g) in January 1993 (US EPA, 1993a). The guidance identifies management measures for five major categories of nonpoint source pollution: agriculture; forestry; urban; marinas and recreational boating; and hydromodification. The management measures reflect the greatest degree of pollutant reduction that is economically achievable for each of the listed sources. These management measures provide reference standards for the states to use in developing or refining their coastal nonpoint programs. In general, the management measures were written to describe systems designed to reduce the generation of pollutants. A few management measures, however, contain quantitative standards that specify pollutant loading reductions. For example, the new development management measure, which is applicable to storm water runoff associated with construction in urban areas, requires (1) that by design or performance the average annual total suspended solid loadings be reduced by 80 percent and (2) to the extent practicable, that the pre-development peak runoff rate and average volume be maintained. The management measures approach was adopted to provide state officials with flexibility in selecting strategies and management systems and practices that are appropriate for regional or local conditions, provided that equivalent or higher levels of pollutant control are achieved.

Storm water discharges regulated under the existing NPDES program, such as discharges from municipal separate storm sewers serving a population of 100,000 or more and from construction activities that disturb 5 or more acres, do not need to be addressed in Coastal Nonpoint Pollution Control programs. However, potential new sources, such as urban development adjacent to or surrounding municipal systems serving a population of 100,000 or more, smaller urbanized areas, and construction sites that disturb less than 5 acres, that are identified in management measures under section 6217 guidance need to be addressed in Coastal Nonpoint Pollution Control Programs until such discharges are issued an NPDES permit. EPA and NOAA have worked and continue to work together in their activities to ensure that authorities between NPDES and CZARA do not overlap.

EPA and NOAA published *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance* (US EPA, 1993d), which addresses such issues as the basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control programs, how EPA and NOAA expect state programs to implement management measures in conformity with EPA guidance, and procedures for reviewing and modifying state coastal boundaries to meet program requirements. The document clarifies that states generally must implement management measures for each source category identified in the EPA guidance developed under section 6217(g). The document also sets quantitative performance standards for some measures. Coastal Nonpoint Pollution Control programs are not required to address sources that are clearly regulated under the NPDES program as point source discharges. Specifically, such programs would not need to address small municipal separate storm sewer systems and construction sites covered under NPDES storm water permits (both general and individual). The guidance also clarifies that regulatory and non-regulatory mechanisms may be used to meet the requirement for enforceable policies and mechanisms, provided that non-regulatory approaches are backed by enforceable state authority ensuring that the management measures will be implemented. Backup authority may include sunset provisions for incentive programs. For example, a state may provide additional incentives if too few owners or operators participate in a tax incentive program or develop mandatory requirements to achieve the necessary implementation of management measures.

3.4 Regional, State and Local Programs

In addition to the existing Federal storm water management programs, there are a variety of State, local and regional storm water management programs in existence. Many of these programs pre-date the Federal programs and may include BMP design or performance standards, site plan review and inspection programs, and technical assistance. A review of these programs is outside the scope of this report.

4.0 Environmental Assessment

Waterways and receiving waters near urban and suburban areas are often adversely affected by urban storm water runoff. The degree and type of impact varies from location to location, but it is often significant relative to other sources of pollution and environmental degradation. Urban storm water runoff affects water quality, water quantity, habitat and biological resources, public health, and the aesthetic appearance of urban waterways. As reported in the National Water Quality Inventory 1996 Report to Congress (US EPA, 1998d), urban runoff was the leading source of pollutants causing water quality impairment related to human activities in ocean shoreline waters and the second leading cause in estuaries across the nation. Urban runoff was also a significant source of impairment in rivers and lakes. The percent of total impairment attributed to urban runoff is substantial. This impairment constitutes approximately 5,000 square miles of estuaries, 1.4 million acres of lakes, and 30,000 miles of rivers. Seven states also reported in the Inventory that urban runoff contributes to wetland degradation.

Adverse impacts on receiving waters associated with storm water discharges have been discussed by EPA (1995b) in terms of three general classes. These are:

- Short-term changes in water quality during and after storm events including temporary increases in the concentration of one or more pollutants, toxics or bacteria levels.

- Long-term water quality impacts caused by the cumulative effects associated with repeated storm water discharges from a number of sources.

- Physical impacts due to erosion, scour, and deposition associated with increased frequency and volume of runoff that alters aquatic habitat.

As described in the Terrene Institute's *Fundamentals of Urban Runoff Management* (Horner et al, 1994), pollutants associated with urban runoff potentially harmful to receiving waters fall into the categories listed below:

- Solids
- Oxygen-demanding substances
- Nitrogen and phosphorus
- Pathogens
- Petroleum hydrocarbons
- Metals
- Synthetic organics.

These pollutants degrade water quality in receiving waters near urban areas, and often contribute to the impairment of use and exceedences of criteria included in State water quality standards. The quantity of these pollutants per unit area delivered to receiving waters tends to increase with the degree of development in urban areas.

While water quality impacts are often unobserved by the general public, other storm water impacts are more visible. Stream channel erosion and channel bank scour provide direct evidence of water quantity impacts caused by urban storm water. Urban runoff increases directly with imperviousness and the degree of watershed development. As urban areas grow, urban streams are forced to accommodate larger volumes of storm water runoff that recur on a more frequent basis. This leads to stream channel instability. The change in watershed hydrology associated with urban development also causes channel widening and scour, and the introduction of larger amounts of sediment to urban streams. Visible impacts include eroded and exposed stream banks, fallen trees, sedimentation, and recognizably turbid conditions. The increased frequency of flooding in urban areas also poses a threat to public safety and property.

Both water quality and water quantity impacts associated with urban storm water combine to impact aquatic and riparian habitat in urban streams. Higher levels of pollutants, increased flow velocities and erosion, alteration of riparian corridors, and sedimentation associated with storm water runoff negatively impact the integrity of aquatic ecosystems. These impacts include the degradation and loss of aquatic habitat, and reduction in the numbers and diversity of fish and macroinvertebrates.

Public health impacts are for the most part related to bacteria and disease causing organisms carried by urban storm water runoff into waters used for water supplies, fishing and recreation. Water supplies can potentially be contaminated by urban runoff, posing a public health threat. Bathers and others coming in contact with contaminated water at beaches and other recreational sites can become seriously ill. Beach closures caused by urban runoff have a negative impact on the quality of life, and can impede economic development as well. Similarly, the bacterial contamination of shellfish beds poses a public health threat to consumers, and shellfish bed closures negatively impact the fishing industry and local economies.

Aesthetic impacts in the form of debris and litter floating in urban waterways and concentrated on stream banks and beaches are quite visible to the general public. Storm water is a major source of floatables that include paper and plastic bags and packaging materials, bottles, cans, and wood. The presence of floatables and other debris in receiving waters during and following storm events reduces visual attractiveness of the waters and detracts from their recreational value. Nuisance algal conditions including surface scum and odor problems can also be attributed to urban storm water in many instances.

Based on available information and data, the following general statements can be made about urban storm water impacts.

- Impacts to water quality in terms of water column chemistry tend to be transient and elusive, particularly in rivers.
- Impacts to habitat and aquatic life are generally more profound, and are easier to see and quantify than changes in water column chemistry.

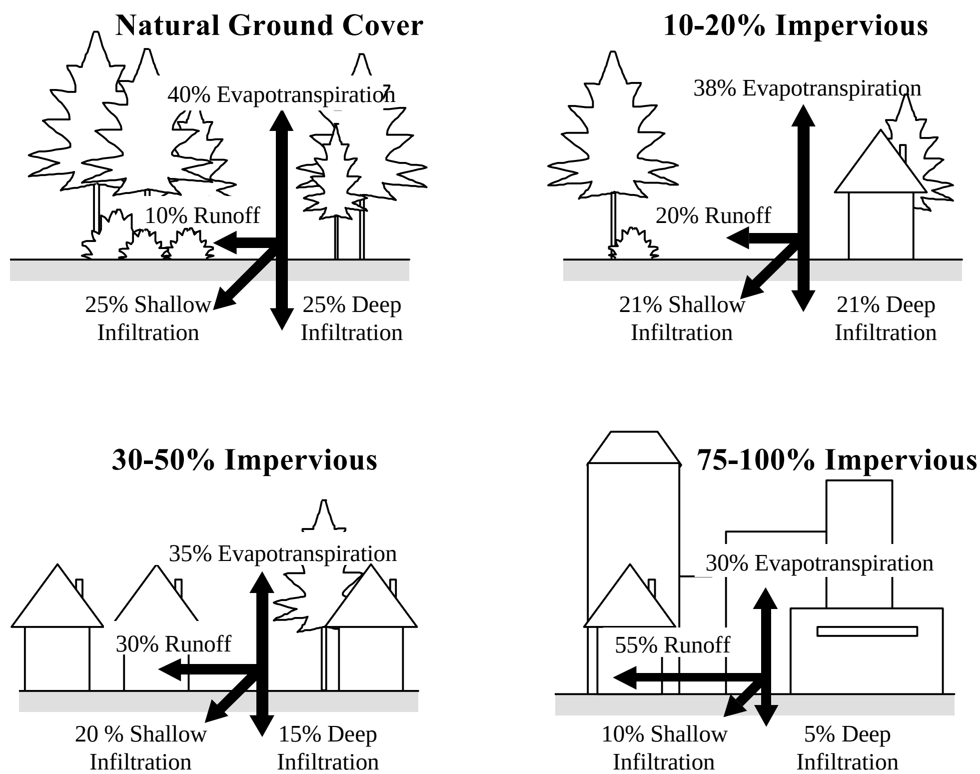
- Impacts are typically complex because urban storm water is often one of several sources including municipal discharges and diffuse runoff from agricultural and rural areas that affect urban waterways.
- Impacts are often interrelated and cumulative. For example, both degraded water quality and increased water quantity join to impact habitat and biological resources.

The following sections describe the sources of urban storm water runoff, the pollutants contained in urban runoff and the impacts attributable to urban storm water discharges. Examples supported by field observation and data have been used extensively to show storm water impacts. The impacts described include water quality impacts, water quantity impacts, public health impacts, habitat impacts, and aesthetic impacts.

4.1 Overview of Storm Water Discharges

Storm water runoff from urbanized areas is generated from a number of sources including residential areas, commercial and industrial areas, roads, highways and bridges. Essentially, any surface which does not have the capability to pond and infiltrate water will produce runoff during storm events. When a land area is altered from a natural forested ecosystem to an urbanized land use consisting of rooftops, streets and parking lots, the hydrology of the system is significantly altered. Water which was previously ponded on the forest floor, infiltrated into the soil and converted to groundwater, utilized by plants and evaporated or transpired into the atmosphere is now converted directly into surface runoff. An important measure of the degree of urbanization in a watershed is the level of impervious surfaces. As the level of imperviousness increases in a watershed, more rainfall is converted to runoff. Figure 4-1 illustrates this transformation.

Figure 4-1. Effects of Imperviousness on Runoff and Infiltration



Source: Adapted from Arnold and Gibbons, 1996

The traditional means of managing storm water runoff in urban areas has been to construct a vast curb-and-gutter, catch basin, and storm drain network to transport this runoff volume quickly and efficiently away from the urbanized area and discharge the water to receiving streams. Two types of sewer systems are used to convey storm water runoff: separate storm sewers and combined sewers.

- *Separate storm sewer systems* convey only storm water runoff. Water conveyed in separate storm sewers is frequently discharged directly to receiving streams without receiving any intentional form of treatment. (In a municipality with a separate storm sewer system, sanitary sewer flows are conveyed in a distinct sanitary sewer system to municipal wastewater treatment plants.)

- In a *combined sewer system*, storm water runoff is combined with sanitary sewer flows for conveyance. Flows from combined sewers are treated by municipal wastewater treatment plants prior to discharge to receiving streams. During large rainfall events however, the volume of water conveyed in combined sewers can exceed the storage and treatment capacity of the wastewater treatment system. As a result, discharges of untreated storm water and sanitary wastewater directly to receiving streams can frequently occur in these systems. These types of discharges are known as combined sewer overflows (CSOs).

Historically, as urbanization occurred and storm drainage infrastructure systems were developed in this country, the primary concern was to limit nuisance and potentially damaging flooding due to the large volumes of storm water runoff that are generated. Little, if any, thought was given to the environmental impacts of such practices. As a result, streams that receive storm water runoff frequently cannot convey the large volumes of water generated during runoff events without significant degradation of the receiving stream. In addition to the problems associated with excess water volume, the levels of toxic or otherwise harmful pollutants in storm water runoff and CSOs can cause significant water quality problems in receiving streams.

In addition to point sources such as municipal separate storm sewers and combined sewer overflows, storm water runoff can enter receiving streams as a non-point source. Storm water runoff from a variety of sources such as parking lots, highways, open land, rangeland, residential areas and commercial areas can enter waterways directly as sheet flow or as a series of diffuse, discrete flows. Due to the diffuse nature of many storm water discharges, it is difficult to quantify the range of pollutant loadings to receiving streams that are attributable to storm water discharges. It is much easier, however, to measure the increased stream flows during rainfall events that occur in urbanized areas and to document impacts to streams that receive storm water runoff.

Awareness of the damaging effects storm water runoff is causing to the water quality and aquatic life of receiving streams is a relatively recent development. Storm water management traditionally was, and still is in many cases, a flood control rather than a quality control program. Local governments intending to improve the quality of their runoff-impacted streams are incorporating best management practices (BMPs) into their drainage programs. BMPs which reduce the volume of runoff discharged to receiving streams, such as minimizing directly connected impervious surfaces, providing on-site storage and infiltration and implementing stream buffers and restoring riparian cover along urban streams can help to prevent further degradation and even result in improvements of streams which receive storm water discharges. However, in many existing urbanized areas, the cost of infrastructure changes necessary to retrofit existing storm water drainage systems with structural BMPs--to provide for storm water quality as well as quantity control--can be prohibitively expensive. In these cases, non-structural BMPs can be implemented to reduce pollutant sources and to reduce the transfer of urban pollutants to runoff, before more expensive, structural controls are instituted.

The climate of a region can have a significant impact on the quantity and quality of storm water runoff. Factors such as the length of the antecedent dry periods between storms, the average rainfall intensity, the storm duration and the amount of snowmelt present can have significant impacts on the characteristics of runoff from an area. In areas where there is a significant amount of atmospheric deposition of particulates, storm water runoff can contain high concentrations of suspended solids, metals and nutrients. Areas that have infrequent rainfall such as the southwest U.S. can have runoff with significant concentrations of pollutants, especially from “hot spots” such as roads, parking lots and industrial areas. These areas, which typically have high-intensity, short-duration rainfall events, can generate significant loadings of suspended solids in storm water runoff. Many specific geographic factors can influence the nature and constituents contained in storm water runoff. Factors such as the soil types, slopes, land use patterns and the amount of imperviousness of a watershed can greatly affect the quality and quantity of runoff that is produced from an area.

4.2 Pollutants in Urban Storm Water

Storm water runoff from urban areas can contain significant concentrations of harmful pollutants that can contribute to adverse water quality impacts in receiving streams. Effects can include such things as beach closures, shellfish bed closures, limits on fishing and limits on recreational contact in waters that receive storm water discharges. Contaminants enter storm water from a variety of sources in the urban landscape.

Urban storm water runoff has been the subject of intensive research since the inception of the Water Quality Act of 1965. There have been numerous studies conducted to characterize the nature of urban storm water runoff and the performance of storm water BMPs. Data sources include the "208 Studies," the area-wide waste treatment management plans conducted by states under section 208 of the 1972 CWA; EPA's Nationwide Urban Runoff Program (NURP); the U.S. Geological Survey (USGS) Urban Stormwater Database; and the Federal Highway Administration (FHWA) study of storm water runoff loadings from highways. In addition to these federal sources, there is a great deal of information in the technical literature, as well as data collected by states, counties and municipalities. A recent data source is storm water monitoring data collected by municipalities regulated by the Phase I NPDES storm water regulations. As part of the Phase I permit application, regulated municipalities were required to collect data from five representative sites during a minimum of three storm events.

The most comprehensive study of urban runoff was NURP, conducted by EPA between 1978 and 1983. NURP was conducted in order to examine the characteristics of urban runoff and similarities or differences between urban land uses, the extent to which urban runoff is a significant contributor to water quality problems nationwide, and the performance characteristics and effectiveness of management practices to control pollution loads from urban runoff (US EPA, 1983). Sampling was conducted for 28 NURP projects which included 81 specific sites and more than 2,300 separate storm events. NURP focused on the following ten constituents:

- Total Suspended Solids (TSS)

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Phosphorus (TP)
- Soluble Phosphorus (SP)
- Total Kjeldahl Nitrogen (TKN)
- Nitrate + Nitrite (N)
- Total Copper (Cu)
- Total Lead (Pb)
- Total Zinc (Zn).

NURP examined both the soluble and the particulate fraction of pollutants, since the water quality impacts can depend greatly on the form that the contaminant is present. NURP also examined coliform bacteria and priority pollutants at a subset of sites. Median event mean concentrations (EMCs) for the ten general NURP pollutants for various urban land use categories are presented in Table 4-1.

Table 4-1. Median Event Mean Concentrations for Urban Land Uses

Pollutant	Units	Residential		Mixed		Commercial		Open/ Non-Urban	
		Median	COV	Median	COV	Median	COV	Median	COV
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	--	--
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	µg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/l	33	0.99	27	1.32	29	0.81	--	--
Total Zinc	µg/l	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	µg/l	1900	0.73	1288	0.50	1179	0.43	965	1.00
Nitrate + Nitrite	µg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	µg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/l	143	0.46	56	0.75	80	0.71	26	2.11

COV: Coefficient of variation
Source: Nationwide Urban Runoff Program (US EPA 1983)

Results from NURP indicate that there is not a significant difference in pollutant concentrations in runoff from different urban land use categories. There is a significant difference, however, in pollutant concentrations in runoff from urban sources than that produced from non-urban areas.

The pollutants that are found in urban storm water runoff originate from a variety of sources. The major sources include contaminants from residential and commercial areas, industrial activities, construction, streets and parking lots, and atmospheric deposition. Contaminants commonly found in storm water runoff and their likely sources are summarized in Table 4-2.

Table 4-2. Sources of Contaminants in Urban Storm Water Runoff

Contaminant	Contaminant Sources
Sediment and Floatables	Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion
Pesticides and Herbicides	Residential lawns and gardens, roadsides, utility right-of-ways, commercial and industrial landscaped areas, soil wash-off
Organic Materials	Residential lawns and gardens, commercial landscaping, animal wastes
Metals	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes
Oil and Grease/ Hydrocarbons	Roads, driveways, parking lots, vehicle maintenance areas, gas stations, illicit dumping to storm drains
Bacteria and Viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems
Nitrogen and Phosphorus	Lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents

The concentrations of pollutants found in urban runoff are directly related to degree of development within the watershed. This trend is shown in Table 4-3, a compilation of typical pollutant loadings from different urban land uses.

Table 4-3. Typical Pollutant Loadings from Runoff by Urban Land Use (lbs/acre-yr)

Land Use	TSS	TP	TKN	NH_3-N	NO_2+NO_3-N	BOD	COD	Pb	Zn	Cu
Commercial	1000	1.5	6.7	1.9	3.1	62	420	2.7	2.1	0.4
Parking Lot	400	0.7	5.1	2	2.9	47	270	0.8	0.8	0.04
HDR	420	1	4.2	0.8	2	27	170	0.8	0.7	0.03
MDR	190	0.5	2.5	0.5	1.4	13	72	0.2	0.2	0.14
LDR	10	0.04	0.03	0.02	0.1	NA	NA	0.01	0.04	0.01
Freeway	880	0.9	7.9	1.5	4.2	NA	NA	4.5	2.1	0.37
Industrial	860	1.3	3.8	0.2	1.3	NA	NA	2.4	7.3	0.5
Park	3	0.03	1.5	NA	0.3	NA	2	0	NA	NA
Construction	6000	80	NA	NA	NA	NA	NA	NA	NA	NA

HDR: High Density Residential, MDR: Medium Density Residential, LDR: Low Density Residential
NA: Not available; insufficient data to characterize loadings
Source: Horner et al, 1994

As indicated in Table 4-3, urban storm water runoff can contain significant concentrations of solids, nutrients, organics and metals. A comparison of the concentration of water quality parameters in urban runoff with the concentrations in domestic wastewater is shown in Table 4-4.

Table 4-4. Comparison of Water Quality Parameters in Urban Runoff with Domestic Wastewater (mg/l)

Constituent	Urban Runoff		Domestic Wastewater		
	Separate Sewers		Before Treatment		After Secondary
	Range	Typical	Range	Typical	Typical
COD	200-275	75	250-1,000	500	80
TSS	20-2,890	150	100-350	200	20
Total P	0.02-4.30	0.36	4-15	8	2
Total N	0.4-20.0	2	20-85	40	30
Lead	0.01-1.20	0.18	0.02-0.94	0.10	0.05
Copper	0.01-0.40	0.05	0.03-1.19	0.22	0.03
Zinc	0.01-2.90	0.02	0.02-7.68	0.28	0.08
Fecal Coliform per 100 ml	400-50,000		10^6-10^8		200

Source: Bastian, 1997

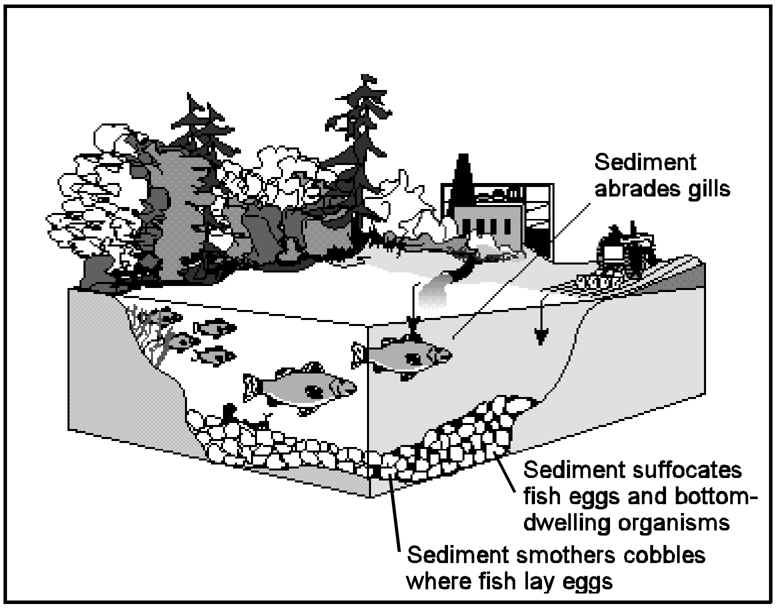
As indicated in Table 4-4, the concentrations of select water quality parameters in urban runoff is comparable to that found in untreated domestic wastewater. When untreated urban runoff is discharged directly to receiving streams, the loadings of pollutants can be much higher than the loadings attributable to treated domestic wastewater.

The following paragraphs summarize the major pollutants which are commonly found in urban storm water runoff.

4.2.1 Solids, Sediment and Floatables

Solids are one of the most common contaminants found in urban storm water. Solids originate from many sources including the erosion of pervious surfaces and dust, litter and other particles deposited on impervious surfaces from human activities and the atmosphere. Stream bank erosion and erosion at construction sites are also major sources of solids. Solids contribute to many water quality, habitat and aesthetic problems in urban waterways. Elevated levels of solids increase turbidity, reduce the penetration of light at depth within the water column, and limit the growth of desirable aquatic plants. Solids that settle out as bottom deposits contribute to sedimentation and can alter and eventually destroy habitat for fish and bottom-dwelling organisms (see Figure 4-2). Solids also provide a medium for the accumulation, transport and storage of other pollutants including nutrients and metals. Sediment bound pollutants often have a long history of interaction with the water column through cycles of deposition, re-suspension, and re-deposition. Impaired navigation due to sedimentation represents another impact affecting recreation and commerce. The relative contribution of TSS in urban storm water from different land uses is presented in Table 4-3. As shown in Table 4-4, the typical concentration of TSS in urban runoff is substantially higher than that in treated wastewater (Bastian, 1997). Construction produces the highest loading of TSS over other urban land use categories evaluated.

Figure 4-2. Effects of Siltation on Rivers and Streams



Source: US EPA, 1998d.

4.2.2 Oxygen-Demanding Substances and Dissolved Oxygen

The oxygen-demanding substances found in urban storm water can be measured by Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). Maintaining appropriate levels of dissolved oxygen in receiving waters is one of the most important considerations for the protection of fish and aquatic life. The amount of dissolved oxygen in urban runoff is typically 5.0 mg/l or greater, and it rarely poses a direct threat to in-stream conditions. As shown in Table 4-4, the level of COD associated with urban runoff is comparable to treated wastewater. The direct impact of urban storm water runoff on dissolved oxygen conditions in receiving waters is not thought to be substantial. However, the secondary impacts on the dissolved oxygen balance in receiving waters due to nutrient enrichment, eutrophication, and resulting sediment oxygen demand may be important.

4.2.3 Nitrogen and Phosphorus

Nitrogen and phosphorus are the principal nutrients of concern in urban storm water. The major sources of nutrients in urban storm water are urban landscape runoff (fertilizers, detergents, plant debris), atmospheric deposition, and improperly functioning septic systems (Terrene Institute, 1996). Animal waste can also be an important source. There are a number of parameters used to measure the various forms of nitrogen and phosphorus found in runoff. Ammonia (NH_3) nitrogen is the nitrogen form that is usually the most readily toxic to aquatic life. Nitrate (NO_3) and nitrite (NO_2) are the inorganic fractions of nitrogen. Very little nitrite is usually found in storm water. Total Kjeldahl nitrogen (TKN) measures the organic and ammonia nitrogen forms. By subtraction, the organic fraction can be determined. Total phosphorus measures the total amount of phosphorus in both the organic and inorganic forms. Ortho-phosphate measures phosphorus that is most immediately biologically available. Most of the soluble phosphorus in storm water is usually present in the ortho-phosphate form.

The degree to which nitrogen and phosphorus are present in a river, lake or estuary can determine the trophic status and amount of algal biomass produced. Excess nutrients tend to increase primary biological productivity. The major impact associated with nutrient over-enrichment is excessive growth of algae that leads to nuisance algal blooms and eutrophic conditions. A secondary impact is the residual negative effect of decomposing algae in the form of sediment oxygen demand that depletes dissolved oxygen concentrations, particularly in bottom waters. The NURP study reported that nutrient levels in urban runoff appear not to be high in comparison with other possible discharges. However, more recent studies and programs have recognized that the amount of nitrogen and phosphorus present in urban storm water can be substantial, and becomes increasingly important as other point sources of nutrients are brought under control. Walker (1987) reported that “cause-effect relationships linking urban development to lake and reservoir eutrophication are well established,” and that “urban watersheds typically export 5 to 20 times as much phosphorus per unit per year, as compared to undeveloped watersheds in a given region.” The nutrient loadings from different urban and suburban land uses are presented in Table 4-3. As shown in Table 4-4, the total phosphorus and total nitrogen concentrations in urban runoff are substantially less than treated wastewater concentrations, but storm water volumes can be greater during wet weather events.

4.2.4 Pathogens

Pathogens are disease-producing organisms that present a potential public health threat when they are present in contact waters. Since storm water runoff typically does not come into contact with domestic wastewaters, and direct exposure to runoff is usually limited, there is generally little threat of pathogens in storm water runoff causing a public health risk. However, where runoff is discharged to recreational waters such as beaches and lakes, or where runoff comes into contact with shellfish beds, there is a potential public health risk associated with pathogen contamination.

There are a number of indicator organisms that have been used to evaluate the presence of harmful pathogens in storm water runoff. Several strains of bacteria are present naturally in the soil and can be transported by runoff. In addition, BMPs with standing water can be breeding grounds for naturally occurring bacteria. Therefore, interpretation of bacteriological sampling results can be difficult. Nevertheless, indicator organisms can provide useful insight into the public health risk associated with runoff. Fecal coliform has been widely used as an indicator for the presence of harmful pathogens in domestic wastewaters, and therefore studies characterizing storm water runoff have frequently used this indicator as well. Other bacterial indicators that have been used to evaluate the presence of harmful pathogens in storm water runoff include *Escherichia coli, streptococci* and *enterococci*. The presence of enteric viruses has also been evaluated in storm water runoff, as well as protozoans such as *Giardia lamblia* and *cryptosporidium*.

Fecal coliform concentrations in urban runoff were evaluated by NURP at 17 sites for 156 storm events. NURP reported that coliform bacteria are present at high levels in urban runoff and can be expected to exceed EPA water quality criteria during and immediately after storm events in many surface waters, even those providing high degrees of dilution. Concentrations of fecal coliform found by NURP exhibited a large degree of variability, and did not indicate any distinctions based on land use. Data from different sites did show a dramatic seasonal effect on coliform concentrations. Coliform counts in urban runoff during warmer periods of the year were found to be approximately 20 times greater that those found during colder periods. Based on this data, NURP concluded that coliform sources unrelated to those traditionally associated with human health risk may be significant.

The Terrene Institute (1996) reported that the primary sources of pathogens in urban storm water drains are animal wastes (including pets and birds), failing septic systems, illicit sewage connections, and boats and marinas. Field et al (1993) reported pathogens levels from storm water runoff and urban streams as shown in Table 4-5. Pathogens enumerated included bacteria (total and fecal coliform, fecal streptococci, enterococci, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Salmonella*) and enteroviruses (poliovirus, Coxsackie virus, and Echovirus).

Table 4-5. Densities of Selected Pathogens and Indicator Microorganisms in Storm Water in Baltimore, Maryland Area

	Geometric Mean Densities							
Sampling Station	Entero-virus	*Salmon sp.*	*Pseudomon. aeruginosa*	*Staph. aureus*	Total Coliform	Fecal Coliform	Fecal Strep.	*Enterococci*
	PFU/ 10 L	MPN/ 10 L	MPN/ 10 L	MPN/ 100 mL	MPN/ 100 mL (10^4)	MPN/ 100 mL (10^3)	No./ 100 mL (10^4)	No./100 mL (10^4)
Bush St.	6.9	30	2000	120	38	83	56	12
Northwood	170	5.7	590	12	3.8	6.9	5	2.1

PFU: Plaque-forming units
MPN: Most Probable Number
Source: Field et al, 1993

As shown earlier in Table 4-4, typical fecal coliform concentrations for separate urban storm sewers varied widely, ranging between 400-50,000 mpn/100 ml. An example of fecal coliform concentrations measured in sheet flow associated with different impervious surfaces is presented in Table 4-6. The broad range in concentrations illustrates the highly variable nature of fecal coliform concentrations in storm water.

Table 4-6. Fecal Coliform Concentrations Collected in Sheetflow from Urban Land Uses

Land Use	**Median (MPN/100 ml)**	**Range (MPN/100 ml)**
Unpaved driveways and storage areas	26	0.02-300
Roof runoff	1.6	0.56-2.6
Sidewalks	55	19-90
Paved parking and driveways	2.8	0.03-66
Paved roads	19	1.8-430

MPN: Most Probable Number
Source: Field et al, 1993.

4.2.5 Petroleum Hydrocarbons

Petroleum hydrocarbons include oil and grease; the "BTEX" compounds: benzene, toluene, ethyl benzene, and xylene; and a variety of polynuclear aromatic hydrocarbons (PAHs). Sources of petroleum hydrocarbons include parking lots and roadways, leaking storage tanks, auto emissions, and improper disposal of waste oil. Petroleum hydrocarbons are typically concentrated along transportation corridors.

Petroleum hydrocarbons are known for their acute toxicity at low concentrations (Schueler, 1987). A study by Shepp (1996) measured the petroleum hydrocarbon concentrations in urban runoff from a variety of impervious areas in the District of Columbia and suburban Maryland. The amount of car traffic affects the concentration of hydrocarbons in runoff, with median concentrations ranging from 0.7 to 6.6 mg/l. Concentrations at these levels exceed the maximum concentrations recommended for the protection of drinking water supplies and fisheries protection. As pointed out by Shepp, the maximum concentration of petroleum hydrocarbons for protection of fisheries is 0.01 to 0.1 mg/l.

4.2.6 Metals

The primary sources of metals in urban storm water are industry and automobiles. Atmospheric deposition (both wet and dry) can make a substantial contribution in some parts of the country. A major finding of the NURP study is as follows:

> Heavy metals (especially copper, lead and zinc) are by far the most prevalent priority pollutant constituents found in urban runoff. End-of-pipe concentrations exceed EPA ambient water quality criteria and drinking water standards in many instances. Some of the metals are present often enough and in high enough concentrations to be potential threats to beneficial uses.

Metals in urban storm water have the potential to impact water supply and cause acute or chronic toxic impacts for aquatic life. Typical pollutant loading rates and urban runoff concentrations for lead, zinc and copper are presented in Tables 4-3 and 4-4. The frequency with which metals were detected as priority pollutants in the NURP study is presented in Table 4-7.

Table 4-7. Most Frequently Detected Priority Pollutants in Nationwide Urban Runoff Program Samples (1978-83)

Inorganics	Organics
Detected in 75% or more	
94% Lead 94% Zinc 91% Copper	None
Detected in 50-74%	
58% Chromium 52% Arsenic	None
Detected in 20-49%	
48% Cadmium 43% Nickel 23% Cyanides	22% Bis(2-ethylhexyl)phthalate 20% α-Hexachloro-cyclohexane
Detected in 10-19%	
13% Antimony 12% Beryllium 11% Selenium	19% α-Endosulfan 19% Pentachlorophenol* 17% Chlordane* 15% Lindane* 15% Pyrene** 14% Phenol 12% Phenanthrene** 11% Dichloromethane 10% 4-Nitrophenol 10% Chrysene** 10% Fluoranthene**

* Chlorinated hydrocarbon
** Polynuclear aromatic hydrocarbon
Source: US EPA, 1983

A major study of the quality of Wisconsin storm water (Bannerman et al, 1996) found that the probability of event mean concentrations for some metals (particularly copper and zinc) exceeding Wisconsin water quality criteria for cold water fish communities was high (Table 4-8). A study in Coyote Creek, California reported lead and zinc levels from urban runoff of 100 to 500 times the concentration in the ambient water column (Pitt, 1995).

Table 4-8. Probability of Event Mean Concentration of Constituents in Wisconsin Storm Water Exceeding Wisconsin Surface Water and Ground Water Quality Standards: Metals

Constituent	Probability of exceeding acute toxicity criteria for cold water fish communities (percent)	
	Storm Sewers	Streams
Cadmium, total recoverable	11	0
Copper, total recoverable	87	9
Lead, total recoverable	18	0
Silver, total recoverable	20	-
Zinc, total recoverable	91	7

Source: Bannerman et al, 1996.

4.2.7 Synthetic Organic Compounds

Synthetic organic compounds include a variety of manufactured compounds covering pesticides, solvents and household and industrial chemicals. The frequency that synthetic inorganics were detected as priority pollutants in the NURP study is presented in Table 4-7. In general, organic contaminants were found in less than 20 percent of samples. Nevertheless, synthetic organics do represent a threat. Even low concentrations of some synthetic organics over a long period of time have the potential to pose a severe health risks to humans and aquatic life though direct ingestion or bioaccumulation in the food chain. There is also some evidence that pesticides are found in higher concentrations in urban areas than agricultural areas (US EPA, 1995b). Further, Bannerman et al found that the probability for storm water and urban stream samples to exceed human cancer criteria for public water supply, and toxicity criteria for coldwater fish communities equaled or approached 100 percent for 10 compounds (Table 4-9).

Table 4-9. Probability of Event Mean Concentration of Constituents in Wisconsin Storm Water Exceeding Wisconsin Surface Water and Ground Water Quality Standards: Synthetic Organic Compounds

Constituent (Human cancer criteria for public water supply/ coldwater fish communities)	**Probability of exceedance (percent)**	
	Storm Sewers	**Streams**
Benzo[a]anthracene	98	100
Benzo[a]pyrene	99	100
Benzo[b]fluoranthene	100	100
Benzo[ghi]perylene	99	100
Benzo[k]fluoranthene	99	99
Chrysene	100	100
Indeno pyrene	100	99
Phenanthrene	100	99
Pyrene	100	100
DDT	98	100

Source: Bannerman et al, 1996

4.2.8 Temperature

Water temperature is an important measure of water quality. As described by Malina (1996), "the temperature of water affects some of the important physical properties and characteristics of water, such as… specific conductivity and conductance, salinity, and the solubility of dissolved gases (e.g., oxygen and carbon dioxide)." Specifically, water holds less oxygen as it becomes warmer, resulting in less oxygen being available for respiration by aquatic organisms. Furthermore, elevated temperatures increase the metabolism, respiration, and oxygen demand of fish and other aquatic life, approximately doubling the respiration for a 10°C (18°F) temperature rise; hence the demand for oxygen is increased under conditions where supply is lowered (California SWRCB, 1963).

Certain species of fish, such as salmon and trout, are particularly sensitive and require relatively low water temperatures. Even lower temperatures are required for spawning and egg hatching (US EPA, 1976). If the temperature of a stream reach is raised by 5 to 10°C (9 to 18°F), it is probable that such cold-water game fish will avoid this reach and that they will be replaced by “rougher,” more tolerant fish (California SWRCB, 1963). Thus, even without direct mortality, the character of the fish life will change. Sudden changes in temperature directly stress the aquatic ecosystem. The states have adopted varying criteria to protect fisheries from such stresses. Typically, states limit in-stream temperature rises above natural ambient temperatures to 2.8°C (5°F). Allowable temperature rises in streams that support cold water fisheries may be lower, with some states adopting values as low as 1°C (1.8°F) and 0.6°C (1°F) (US EPA, 1988).

The temperature of urban waters is often affected directly by urban runoff. Urban runoff can be heated as it flows over rooftops, parking lots and roadways. When it reaches urban waterways it can cause a temporary fluctuation in the in-stream water temperature. Other factors that tend to increase summer water temperature in urban waters include the removal of vegetation from stream banks, reduced ground water baseflow, and discharges from storm water facilities with elevated water temperature. Frequent fluctuations in stream temperature stress the aquatic ecosystem, and make it difficult for temperature-sensitive species to survive.

Galli (1990a) undertook a major study of thermal impacts associated with urbanization and storm water management in Maryland. Temperature observations were taken at stream stations representing different levels of development, with impervious cover ranging from 1 percent to 60 percent. Results were compared with Maryland Class III standards for natural trout waters (68 °F) and Class IV standards for recreational trout waters (75 °F). As shown in Figure 4-3, streams in developed watersheds (Lower Whiteoak and Tanglewood Stations) have significantly higher spring and summer temperatures than streams in less developed watersheds. Galli also found that “imperviousness together with local meteorological conditions had the largest influence on urban stream temperatures.” As shown in Figure 4-4, the rate of increase in baseflow water temperature in this study was determined to be 0.14 °F for each one percent increase in watershed imperviousness.

Figure 4-3. Relationship Between Increasing Imperviousness and Urban Stream Temperature

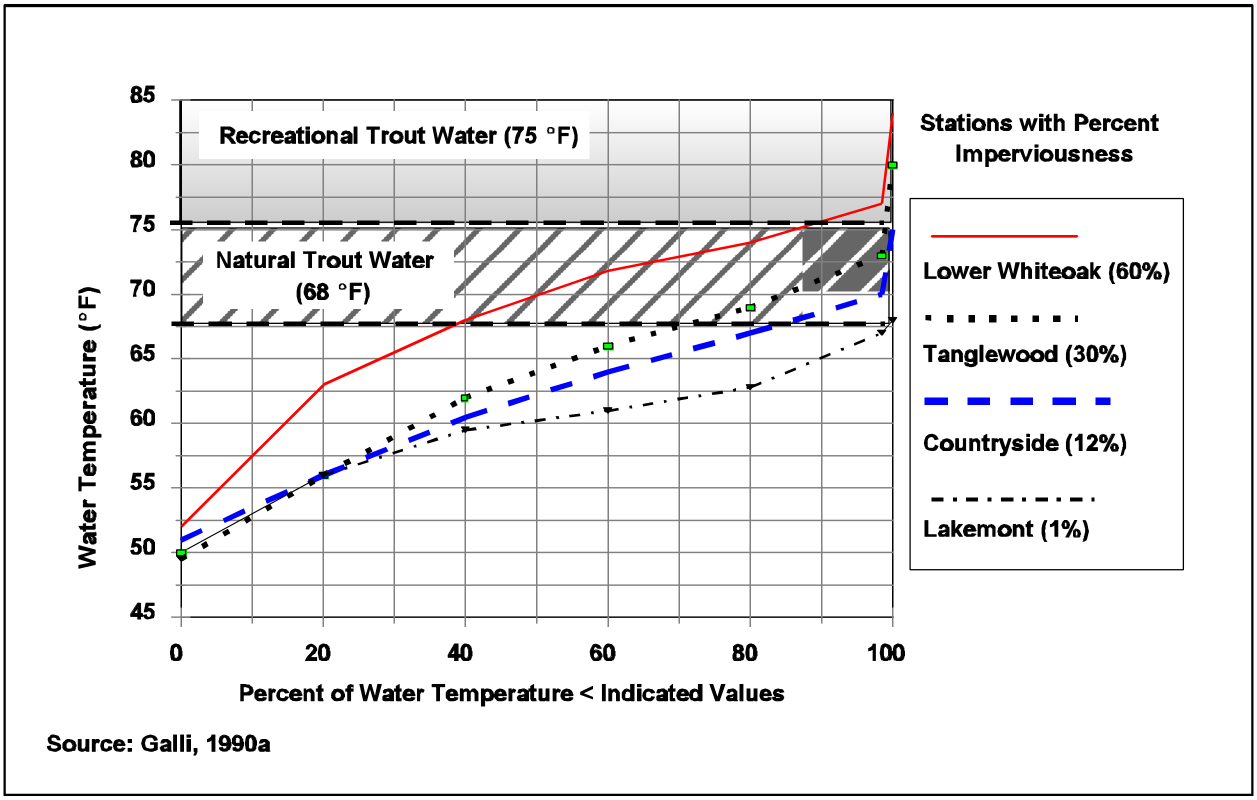
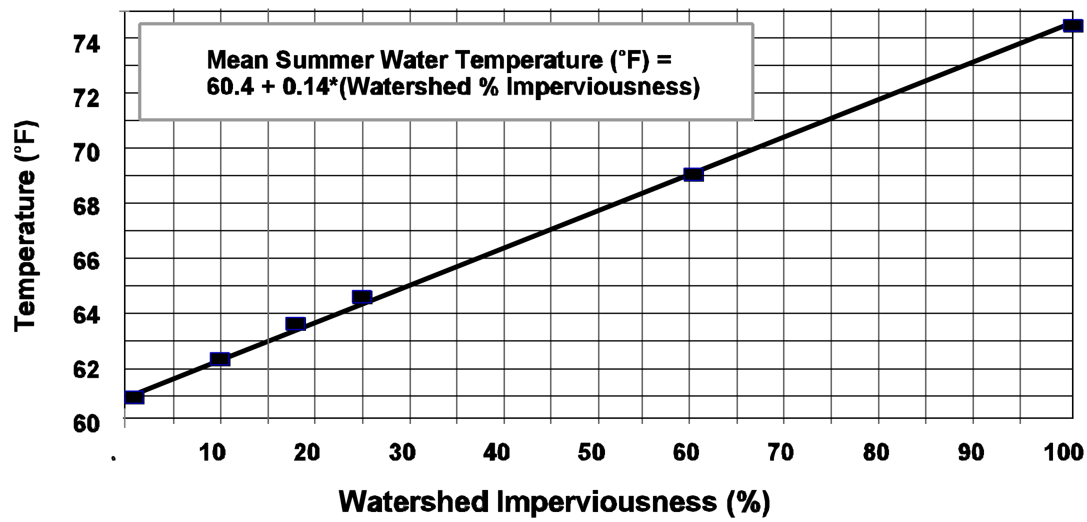


Figure 4-4. Relationship Between Watershed Imperviousness and Baseflow Water Temperature



Source: Galli, 1990a

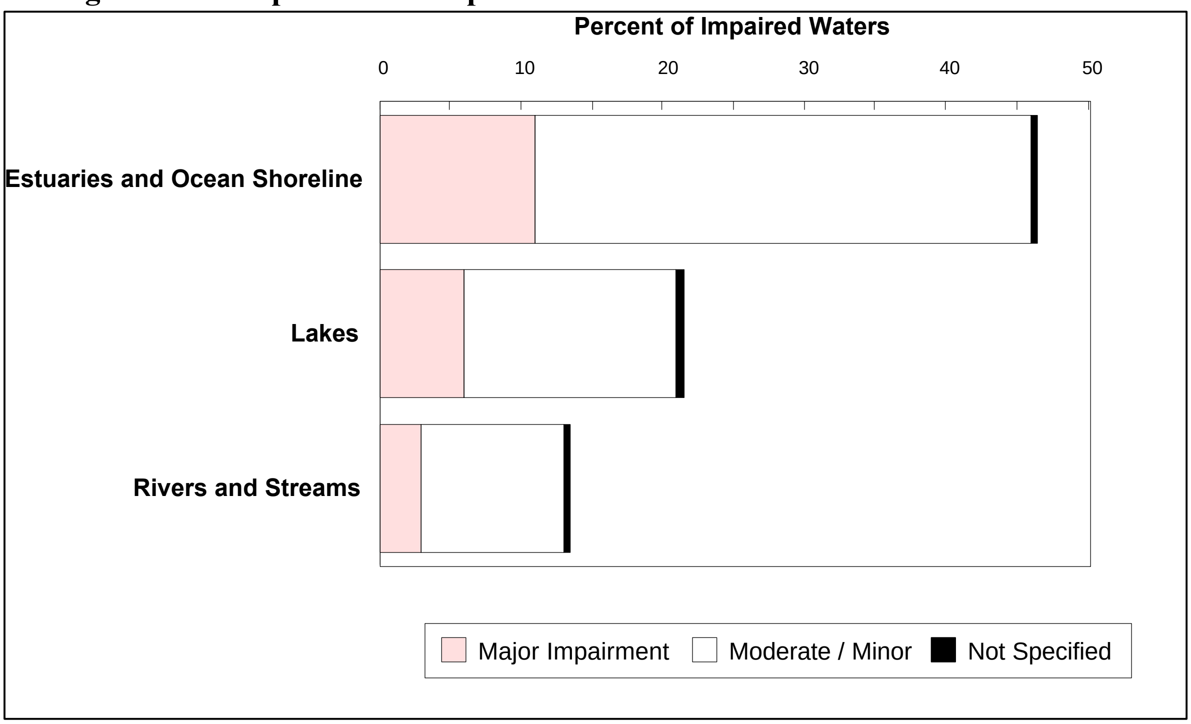
4.2.9 pH

As pointed out by Novotny and Olem (1994), "most aquatic biota are sensitive to pH variations," and "fish kills and reduction and change of other species result when the pH is altered outside their tolerance limits." Most pH impacts in urban waters are caused by runoff of rainwater with low pH levels (acid precipitation). In fact, urban areas tend to have more acidic rainfall than less developed areas. Some buffering of low pH rainwater occurs during contact with buildings, parking lots, roads and collection systems, and during overland flow. This is often very site specific. The alkalinity and thus the capacity of receiving waters to neutralize acidic storm water can also be important, and again is very site specific. Examples of pH impacts on fish populations are difficult to identify due to the cumulative, overlapping impacts from other factors. However, it is thought that the acidification problem in both the United States and Canada grows in magnitude when "episodic acidification" (brief periods of low pH levels from snow melt or heavy downpours) is taken into account (US EPA, 1992a). The spring snow melt can coincide with fish spawning periods.

4.3 Reported Impacts of Urban Storm Water

Urban runoff, which includes runoff from impervious surfaces such as streets, parking lots, buildings, lawns and other paved areas is one of the leading causes of water quality impairment in the United States. Based on the 1996 state Water Quality Inventory reports, siltation (sediment discharged from urban runoff, as well as construction sites, agriculture, mining and forests) is the leading cause of impaired water quality in rivers and streams. In the portion of the inventory identifying sources, urban runoff was listed as the leading source of pollutants causing water quality impairment related to human activities in ocean shoreline waters and the second leading cause in estuaries across the nation. Urban runoff was also a significant source of impairment in rivers and lakes. Urban runoff accounts for 47 percent of impaired miles of surveyed ocean shoreline, 46 percent of the impaired square miles of surveyed estuaries, 22 percent of the impaired acres of surveyed lakes and 14 percent of the impaired miles of surveyed rivers. Figure 4-5 illustrates the level of impairment attributable to urban storm water runoff based on states' Water Quality Inventory assessment reports.

Figure 4-5. Proportions of Impaired Water Bodies Attributed to Urban Runoff



Source: EPA, 1998d.

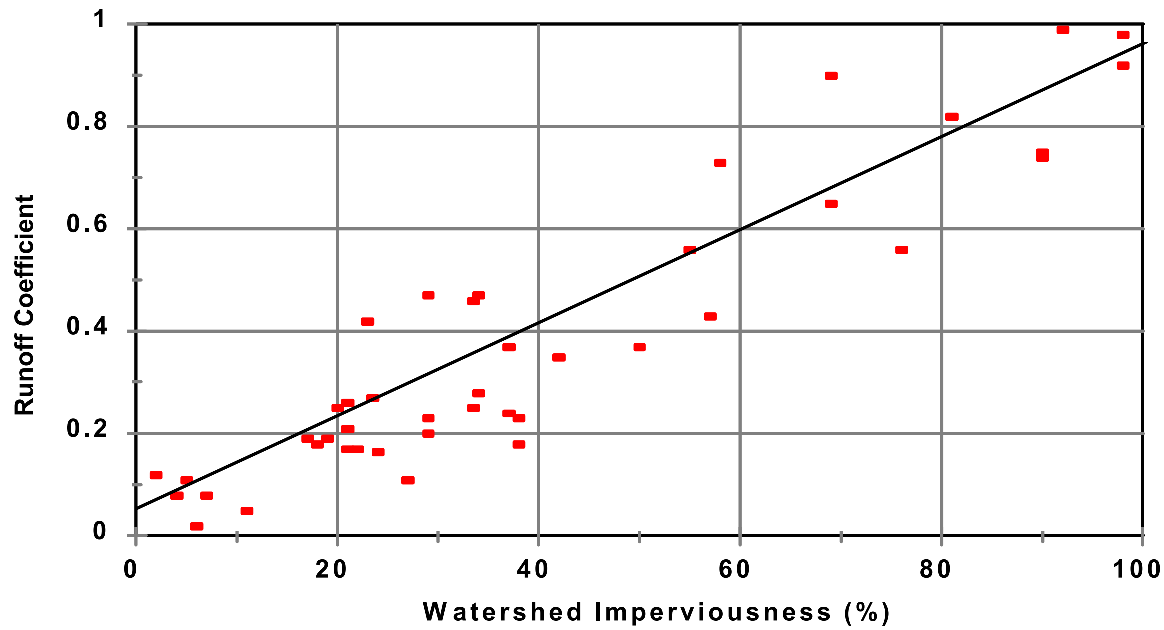
4.3.1 Flow Impacts

The volume and flow rate of storm water discharges can have significant impacts on receiving streams. In many cases, the impacts on receiving streams due to high storm water flow rates or volumes can be more significant than those attributable to the contaminants found in storm water discharges. While studies linking increased storm water flows due to urbanization to stream degradation are generally lacking in quantitative data, there are a number of studies that support this hypothesis. EPA summarized studies which contain documented evidence of impacts on steams due to urbanization (US EPA, 1997a). Impacts of urbanization and increased storm water discharges to receiving streams documented in this evaluation include:

- Increase in the number of bankfull events and increased peak flow rates
- Sedimentation and increased sediment transport
- Frequent flooding
- Stream bed scouring and habitat degradation
- Shoreline erosion and stream bank widening
- Decreased baseflow
- Loss of fish populations and loss of sensitive aquatic species
- Aesthetic degradation
- Changes in stream morphology
- Increased temperatures.

The amount of runoff generated within a watershed increases steadily with development. The presence of impervious areas such as roofs, parking lots and highways limits the volume of rain water infiltrated into the soil, and increases the amount of runoff generated. Urbanized areas also tend to have reduced storage capacities for runoff because of regrading, paving, and the removal of vegetative cover. Decreases in infiltration and evapotranspiration and an increase in runoff are the result of urbanization, with runoff volume linked to the percent of impervious area. The relationship between runoff coefficient and percent impervious area is illustrated in Figure 4-6.

Figure 4-6. Relationship of Watershed Imperviousness to Runoff Coefficient Levels



Source: Schueler, 1987

As shown in Table 4-10, the physical impacts to streams associated with increased imperviousness are substantial (US EPA, 1997a).

Table 4-10. Impacts from Increases in Impervious Surfaces

Increased Imperviousness Leads to:	Resulting Impacts				
	Flooding	Habitat loss	Erosion	Channel Widening	Stream bed Alteration
Increased Volume	✔	✔	✔	✔	✔
Increased Peak Flow	✔	✔	✔	✔	✔
Increased Peak Duration	✔	✔	✔	✔	✔
Increased Stream Temp.		✔			
Decreased Base Flow		✔			
Changes in Sediment Loading	✔	✔	✔	✔	✔

Source: EPA, 1997

The Delaware Department of Natural Resources and Environmental Control also identified a list of impacts on physical stream habitat attributed to urban storm water (DE DNREC, 1997). This list is as follows:

- Accelerated bank erosion
- Accelerated bank undercutting
- Increased siltation (burial of stable habitats)
- Elimination of meanders (channelization)
- Channel widening
- Reduced depth
- Reduced baseflow
- Loss of shade
- Increased temperature.

Specific impacts in the areas of flooding, stream bank erosion, and ground water recharge are described in the following subsections.

Flooding

Urbanization increases the frequency and severity of flooding due to increased runoff. Because of the decreased availability of pervious, permeable surfaces, and the related decrease in storage capacity, smaller more frequently occurring storms can create flooding problems. Hydrographs in urban streams peak higher and faster than streams in undeveloped areas. A comparison of estimated runoff volume and peak discharge for developed and undeveloped areas is presented in Table 4-11. As shown, both runoff volume and peak discharge are substantially increased under developed conditions.

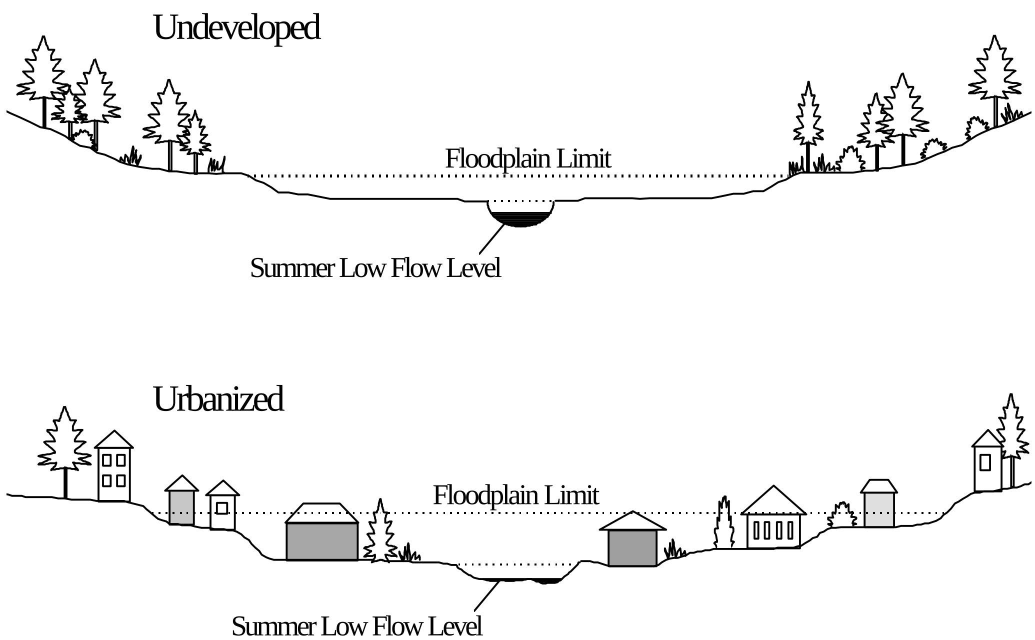
Table 4-11. Comparison of Estimated Runoff Volume and Peak Discharge for Developed and Undeveloped Areas

Storm Frequency (years)	Undeveloped Conditions (Woods in good condition)		Developed Conditions (Half-Acre Residential)	
	Estimated Runoff (in)	Estimated Peak Discharge (cfs)	Estimated Runoff (in)	Estimated Peak Discharge (cfs)
2	0.14	1.00	0.60	11.6
10	0.52	5.60	1.33	27.4
100	1.40	19.7	2.64	58.6

Source: Horner et al, 1994

The effects of urbanization on stream shape and the flood plain are illustrated in Figure 4-7. Increased peak discharge raises the flood plain level, flooding areas which were previously not at risk.

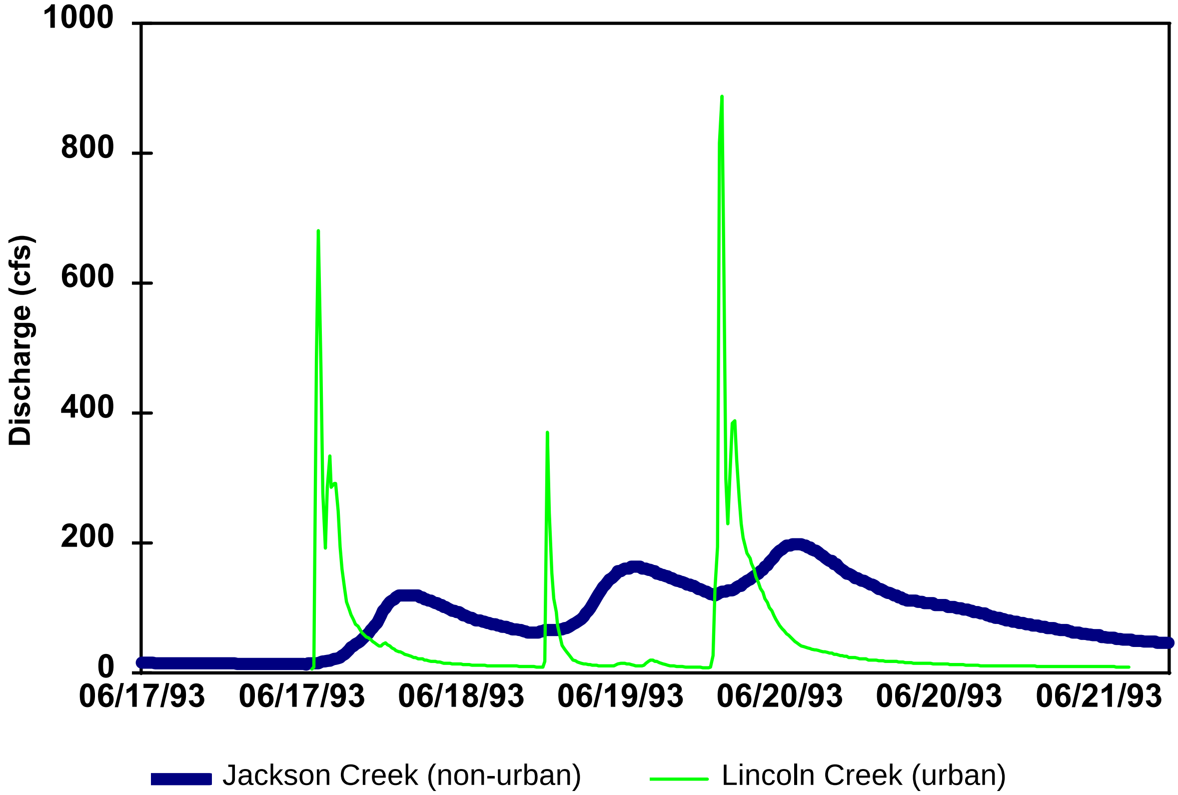
Figure 4-7. Effect of Urbanization on Stream Slope and Flooding



Source: Adapted from Schueler, 1987

A comparison of hydrographs from an urbanized stream (Lincoln Creek) and a non-urbanized stream (Jackson Creek) in Wisconsin are presented in Figure 4-8 (Masterson and Bannerman, 1994). As illustrated, the hydrograph for the urbanized stream exhibits a much higher peak flow rate that would correspond to a higher flood level.

Figure 4-8. Hydrographs for Urban and Non-Urban Streams



Source: Masterson and Bannerman, 1994

Stream Bank Erosion

Stream bank erosion is a natural phenomenon and source of both sediment and nutrients. However, urbanization can greatly accelerate the process of stream bank erosion. As the amount of impervious area increases, a greater volume of storm water is discharged directly to receiving waters, often at a much higher velocity. The increased volume and velocity of the runoff can overwhelm the natural carrying capacity of the stream network. In addition, streams in urbanized areas can experience an increase in bankfull flows. Since bankfull flows are highly erosive, substantial alterations in stream channel morphology can result.

Excessive bank erosion occurs as streams become wider and straighter to accommodate greater flows and an excess number of erosion-causing events. Signs of stream bank erosion attributable to increased storm water include undercut and fallen stream banks, felled bushes and trees along the banks, and exposed sewer and utility pipes. Sediments from eroding banks (and upland construction) are deposited in areas where the water slows, causing buildup, destruction of benthic habitat, and a decreased stream capacity for flood waters. This ultimately results in a greater potential for further erosion.

Krug and Goddard (1986) documented these phenomena in their study of Pheasant Branch, a developing watershed of 24.5 square miles near Middleton, Wisconsin. Local population grew markedly between 1970 to 1980, from 8,246 to 11,851, and is projected to reach 18,000 by the year 2000. Problems of stream channel erosion and suspended sediment developed in Pheasant Branch as a result of this growth. The increased erosion and sediment loadings have decreased the mean stream bed elevation by almost 2 feet, and increased the mean channel width by nearly 35 percent.

Table 4-12 shows the modeled percent increase at three sites for the volume of the 2-year flood, bankfull width, and bankfull depth under two development scenarios. These are the projected development levels in the year 2000 (projected urbanization), and complete urbanization of the watershed. The projected results are shown relative to pre-development conditions.

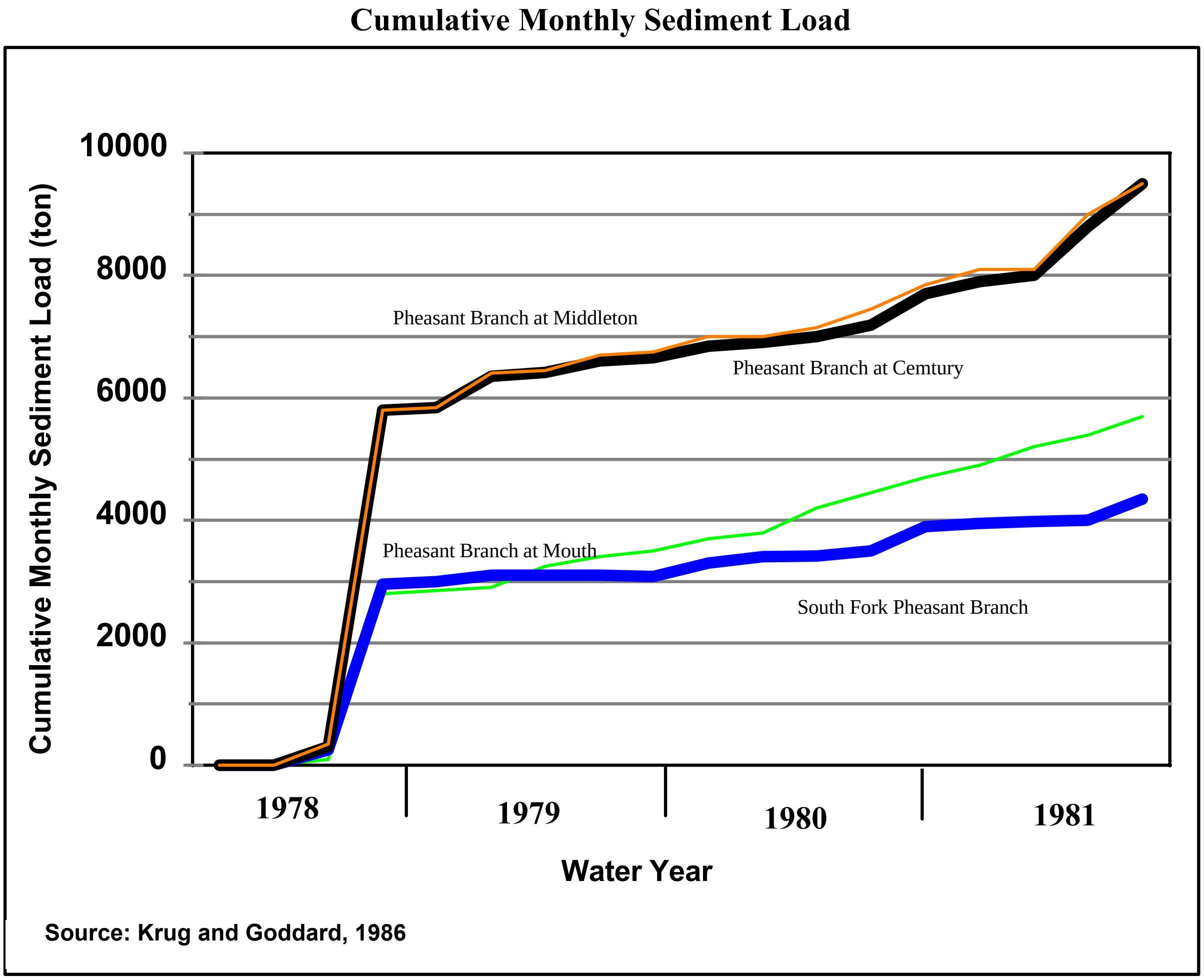
Table 4-12. Percent Increase of Two-Year Flood, Bankfull Width, and Bankfull Depth from Pre-Development Conditions to Urbanized Conditions (Based on Modeling Results)

Site	Projected Urbanization			Complete Urbanization		
	2-year	Width	Depth	2-year	Width	Depth
	(Percent Increase from Pre-urbanization)			(Percent Increase from Pre-urbanization)		
Site 1	99	40	30	140	60	40
Site 2	324	110	80	361	110	80
Site 3	32	10	10	224	80	60

Source: EPA, 1997a

An example of the impact of urbanization on increased sediment loadings in several small streams in Wisconsin before, during and after development is illustrated in Figure 4-9 (Krug and Goddard, 1986). Sediment loads are greatest during construction, but remain elevated after construction relative to pre-development conditions.

Figure 4-9. Sediment Loadings on Small Streams in Wisconsin



<u>Ground Water Recharge</u>

Urbanization can have a major impact on ground water recharge. As shown earlier in Figure 4-1, both shallow and deep infiltration decrease as watersheds undergo development and urbanization. Ground water recharge is reduced along with a lowering of the water table. This change in watershed hydrology alters the baseflow contribution to stream flow, and it is most pronounced during dry periods. Ferguson (1990) points out that “base flows are of critical environmental and economic concern for several reasons. Base flows must be capable of absorbing pollution from sewage treatment plants and non-point sources, supporting aquatic life dependent on stream flow, and replenishing water-supply reservoirs for municipal use in the seasons when [water] levels tend to be lowest and water demands highest.”

Base flows on Long Island, New York were substantially impacted by the construction of storm water conveyance systems during the period of rapid development between the 1940s and

1970s. As illustrated in Table 4-13, a steady decline in the average percent of baseflow was observed for streams in urbanized sewered areas relative to streams in un-sewered or rural areas (US EPA, 1997a).

Table 4-13. Average Percent Base Flow of Selected Streams on Long Island by Area

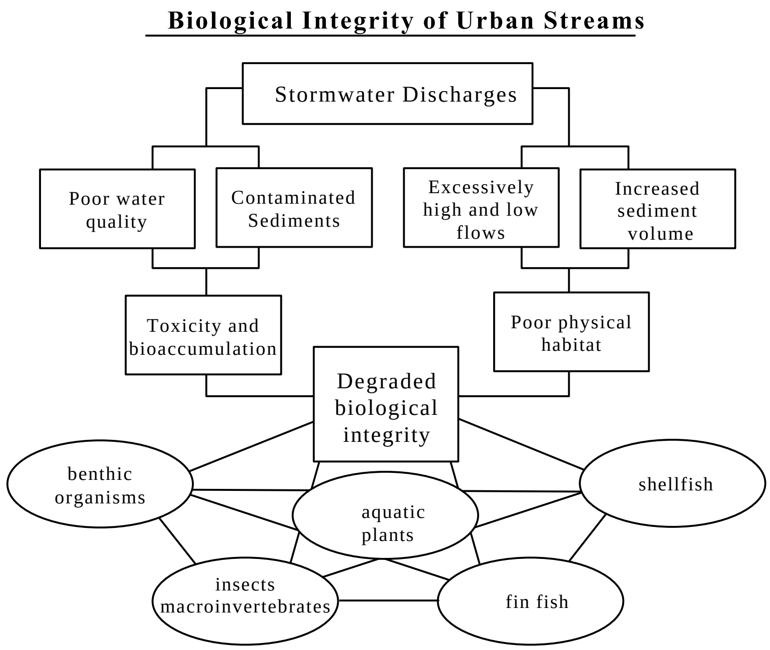
Years	Urbanized Sewered Area (% Flow from Base Flow)		Urbanized Un-sewered Area (% Flow from Base Flow)		Rural Un-sewered Area (% Flow from Base Flow)	
	Stream 1	Stream 2	Stream 1	Stream 2	Stream 1	Stream 2
1948-1953	(No data)	86	84	94	96	95
1953-1964	63	69	89	89	95	97
1964-1970	17	22	83	84	96	97

Source: US EPA, 1997a

4.3.2 Habitat Impacts

Natural ecosystems are a complex arrangement of interactions between the land, water, plants, and animals. The relationship between storm water discharge and the biological integrity of urban streams is illustrated in Figure 4-10 (Masterson and Bannerman, 1994). As shown, habitat is impacted by changes in both water quality and quantity, and the volume and quality of sediment. As reported by Schueler (1987), “no single factor is responsible for the progressive degradation of urban stream ecosystems. Rather, it is probably the cumulative impacts of many individual factors such as sedimentation, scouring, increased flooding, lower summer flows, higher water temperatures, and pollution.”

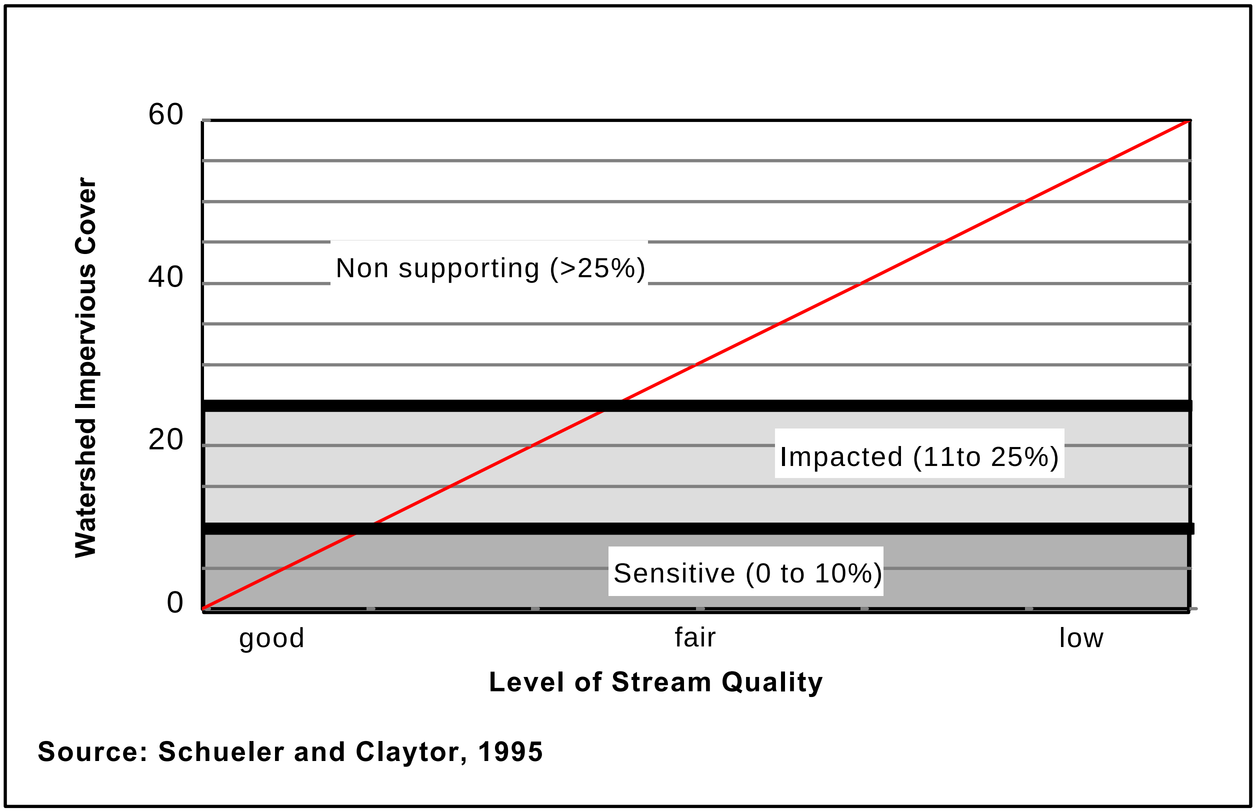
Figure 4-10. Relationship Between Urban Storm Water and Aquatic Ecosystems



Source: Adapted from Masterson and Bannerman, 1994

Schueler and Claytor (1995) also suggest a direct relationship between watershed imperviousness and stream health (Figure 4-11), and found that stream health impacts tend to begin in watersheds with only 10-20 percent imperviousness (the ten percent threshold). As shown, sensitive streams can exist relatively unaffected by urban storm water with good levels of stream quality where impervious cover is less than 10 percent although some sensitive streams have been observed to experience water quality impacts at as low as 5 percent imperviousness. Impacted streams are threatened and exhibit physical habitat changes (erosion and channel widening) and decreasing water quality where impervious cover is in the range of 10 to 25 percent. Streams in watersheds where the impervious cover exceeds 25 percent are typically degraded, have a low level of stream quality, and do not support a rich aquatic community.

Figure 4-11. Relationship Between Impervious Cover and Stream Quality



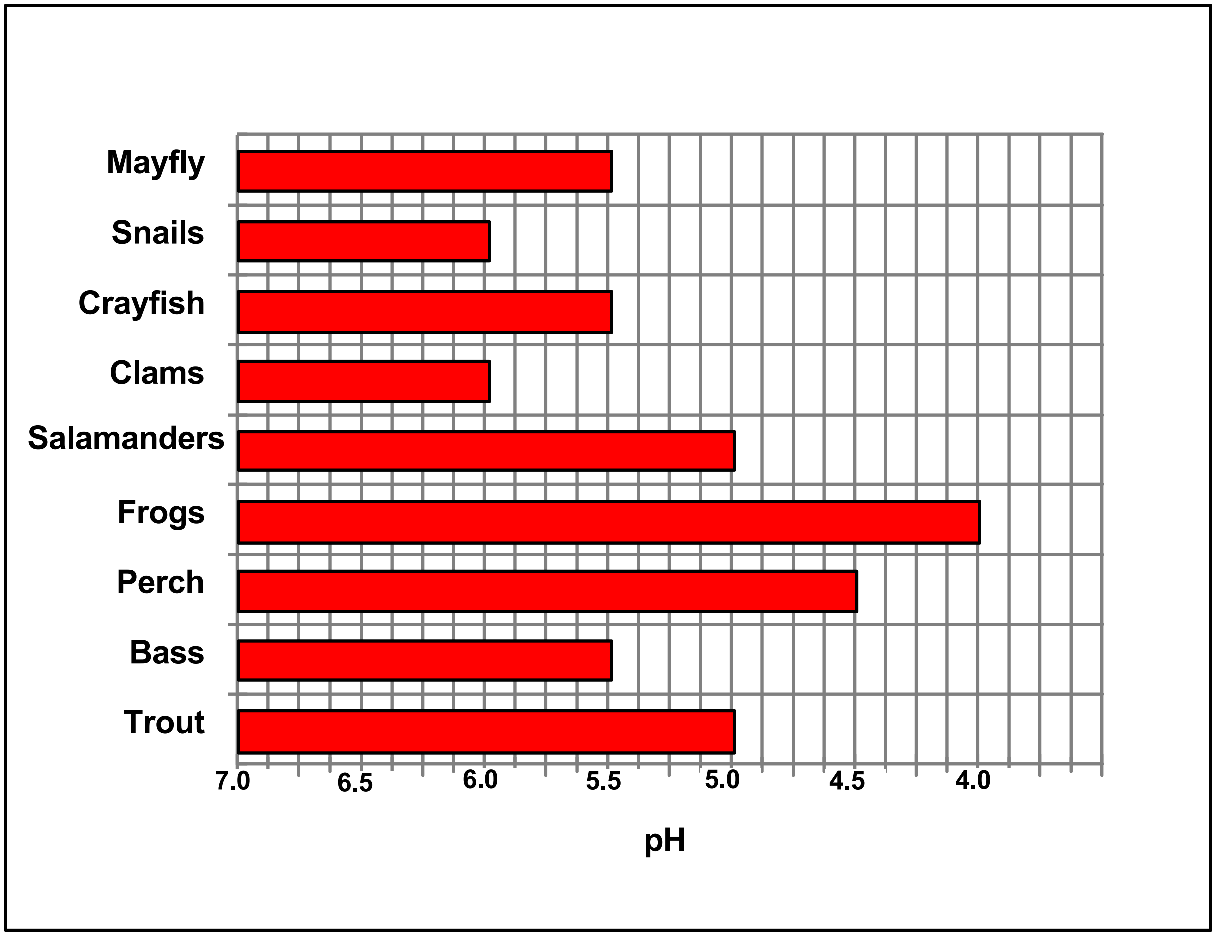
A summary of water quality impacts on habitat is presented in Table 4-14. The alteration of species distribution is the major impact, with pollutant tolerant and less sensitive species replacing native species in storm water impacted receiving waters.

Table 4-14. Water Quality Parameters Affecting Habitat

Water Quality Parameter	Habitat Effect
Bacteria	Contamination
Heavy metals	Alteration of species distribution
Toxic organics	Alteration of species distribution
Nutrients	Eutrophication, algal blooms
Sediment	Decreased spawning areas
BOD	Reduced dissolved oxygen levels
Temperature	Reduced dissolved oxygen levels
pH	Alteration of species distribution

Figure 4-12 illustrates that the pH tolerance of various forms of aquatic life varies substantially (US EPA, 1992b). The tolerance of aquatic life to changes in temperature, turbidity and toxic substances is also very important. Contaminants like heavy metals, pesticides, and hydrocarbons can alter the species distribution in receiving waters. Acute and chronic toxicity impacts may also occur. The relative toxicity of storm water samples from a variety of loading source areas is presented in Table 4-15. Some of the identified chronic toxicity effects are decreased growth and respiration rates (US EPA, 1996a). Toxic loads can reduce the hatching and survival rates of aquatic organisms, cause gross effects such as lesions or fin erosion in fish, and can eventually destroy the entire population of some sensitive species (Novotny and Olem, 1994). Hydrocarbons can be especially detrimental to benthic organisms because they can become bound to urban runoff sediments (Schueler, 1987).

Figure 4-12. Low pH Tolerance by Different Species



Source: EPA, 1992b

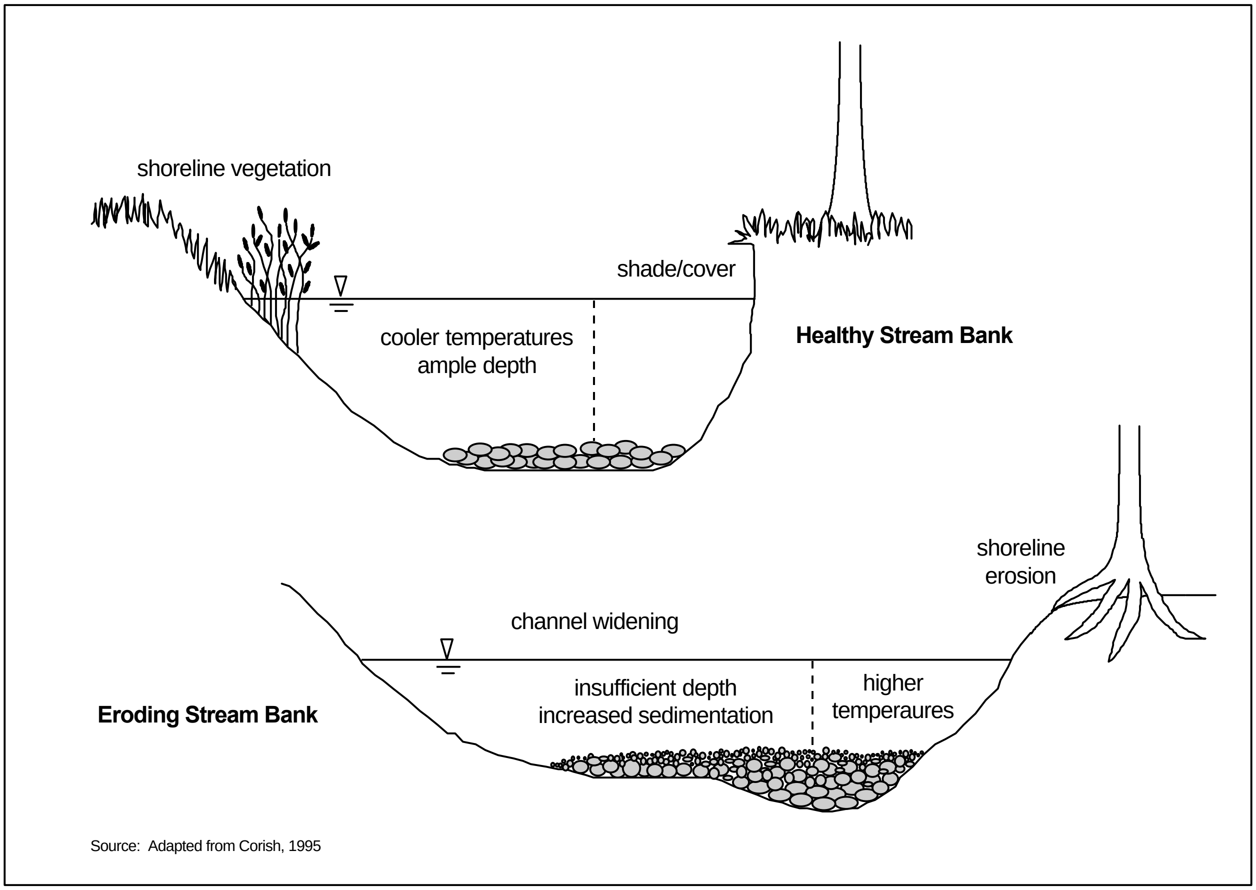
Table 4-15. Relative Toxicities of Samples Using Microtox® Measurement Method

Local Source Areas	Highly Toxic (%)	Moderately Toxic (%)	Not Toxic (%)
Roofs	8	58	33
Parking areas	19	31	50
Storage areas	25	50	25
Streets	0	67	33
Loading docks	0	67	33
Vehicle service areas	0	40	60
Landscaped areas	17	17	66
Urban creeks	0	11	89
Detention ponds	8	8	84
All source areas	9	32	59

Note: Microtox® results are primarily for comparison purposes.
Source: Pitt et al, 1995.

The physical impacts to streams due to urbanization and changes in watershed hydrology also cause many habitat changes. As illustrated in the comparison of healthy and eroding stream banks in Figure 4-13, loss of depth, sediment deposition, loss of shoreline vegetation, and higher temperatures combine to impact habitat.

Figure 4-13. Comparison of a Healthy Stream Bank and an Eroding Bank



Schueler (1987) states that sediment pollution in the form of increased suspended solids can cause the following harmful impacts to aquatic life:

- Increased turbidity
- Decreased light penetration
- Reduced prey capture for sight feeding predators
- Clogging of gills/filters of fish and aquatic invertebrates
- Reduced spawning and juvenile fish survival.

Sediment is also a carrier of metals and other pollutants, and a source of bioaccumulating pollutants for bottom feeding organisms. The rate of bioaccumulation is widely variable based upon site specific conditions including species, concentration, pH, temperature, and other factors. Barron (1995) reports that the bioaccumulation of organic contaminants results primarily from direct exposure to water and sediment rather than through the food chain.

Macroinvertebrate Impacts

The biological integrity of receiving waters impacted by urban storm water is typically reduced from more pristine, undeveloped circumstances. Impacts include a reduction in total numbers and diversity of macroinvertebrates, and the emergence of more pollutant-tolerant species. In a study in Delaware, it was found that approximately 70 percent of the macroinvertebrate community in streams in undeveloped, forested watersheds consisted of pollution sensitive mayflies, stoneflies and caddisflies, as compared with 20 percent in urbanized watersheds (Maxted and Shaver, 1997). As shown in Table 4-16, the relative abundance of pollution tolerant organisms increased with urbanization, including worms, midges and beetles.

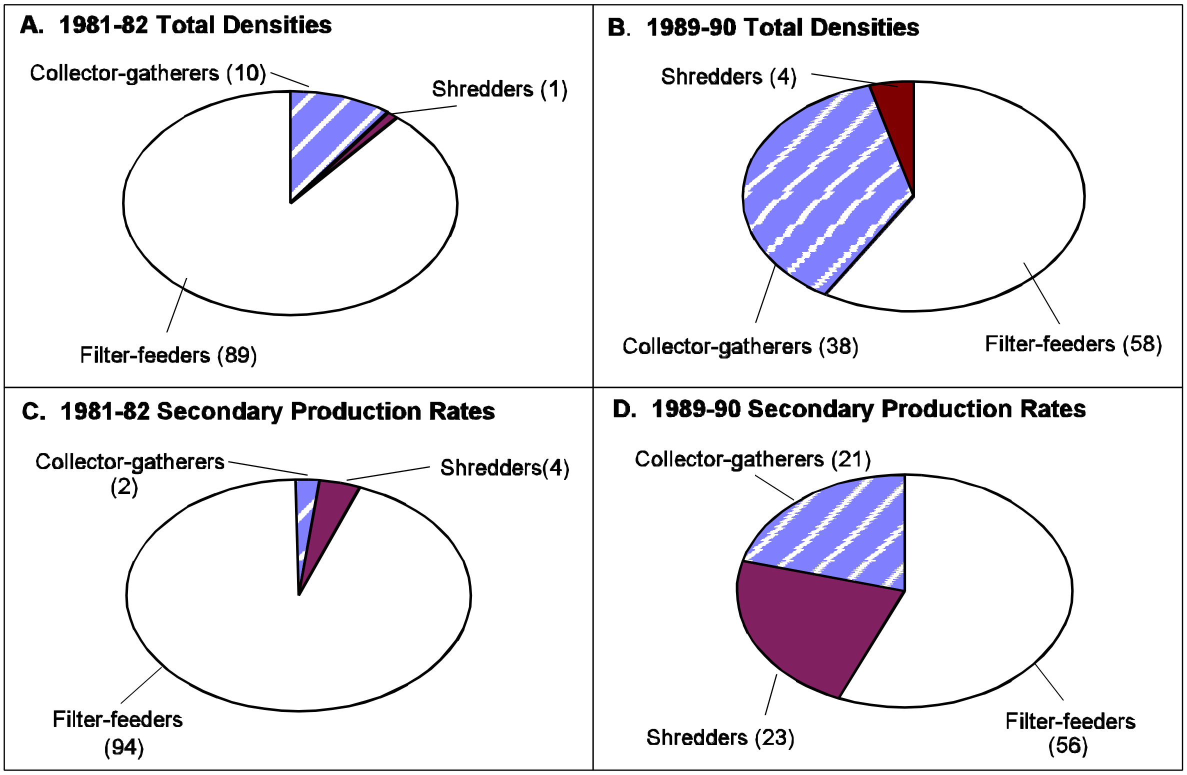
Table 4-16. Delaware Insect Population Abundance by Degree of Urbanization

Population Description				Relative Abundance by Degree of Urbanization (%)		
Class/ Order	**Genus species**	**Common Name**	**PT**	**None**	**Low**	**High**
Insecta/Trichoptera	Diplectrona modesta	caddisfly	0	14	2	1
Insecta/Ephemeroptera	Ephemerella spp.	mayfly	1	12	1	0
Insecta/Plecoptera	Allocapnia spp.	stonefly	3	10	18	3
Insecta/Ephemeroptera	Eurylophella spp.	mayfly	1	8	1	2
Insecta/Coleoptera	Anchytarsus bicolor	beetle	4	6	3	0
Insecta/Ephemeroptera	Stenonema spp.	mayfly	4	5	3	1
Insecta/Coleoptera	Optiservus spp.	beetle	4	4	2	8
Insecta/Coleoptera	Oulimnius latiusculus	beetle	2	4	3	5
Insecta/Trichoptera	Cheumatopsyche spp.	caddisfly	5	1	10	8
Insecta/Trichoptera	Hydropsyche betteni	caddisfly	6	1	4	5
Insecta/Diptera	Simulium vittatum	blackfly	7	0	8	1
Insecta/Diptera	Parametriocnemus spp.	midge	5	0	0	4
Oligochaeta	unidentified (Tubificidae)	worm	10	0	0	4

Note: rare organisms (fewer than 4 per 100 organisms) not included. Relative abundance (%) and pollution tolerance (PT) of macroinvertebrate species commonly found in Piedmont streams of Delaware for three levels of urbanization; none (0-2% impervious cover), low (6-13%), and high (15-50%); PT range from 0 (low tolerance) to 10 (high tolerance).
Source: Maxted and Shaver, 1997.

A study by Kohlepp and Hellenthal (1992) quantified the effects of sediment deposits on macroinvertebrates in Juday Creek, a tributary to the St. Joseph River in Indiana. The study included data before and after upstream channel maintenance operations introduced a large amount of sediment to the creek, similar to increased sediment yield from urban areas. A dramatic change in the species distribution of macroinvertebrates in the river was observed, and this was attributed to the changing sediment load and increased sedimentation. As shown in Figure 4-14, "the result was a shift from a community dominated by filter-feeders in both numbers and production rate in 1981-82, to a community in 1989-90 in which less desirable collector-gatherers and shredders increased in importance in terms of relative contribution to both numbers and production."

Figure 4-14. Effects of Sediment Deposits on Macroinvertebrates in Juday Creek, Indiana Proportion by Functional Feeding Group (percent)



Source: Kohlepp and Hellenthal, 1992

Fish Impacts

The health of an ecosystem is often measured by the abundance and variety of fish species present, and the presence of native species. A case study in California compared fish populations in urbanized and non-urbanized sections of Coyote Creek (Pitt, 1995). The relative abundance of different fish species in the different reaches is presented in Table 4-17. As shown, the native fish are generally replaced by introduced fish in the urbanized section.

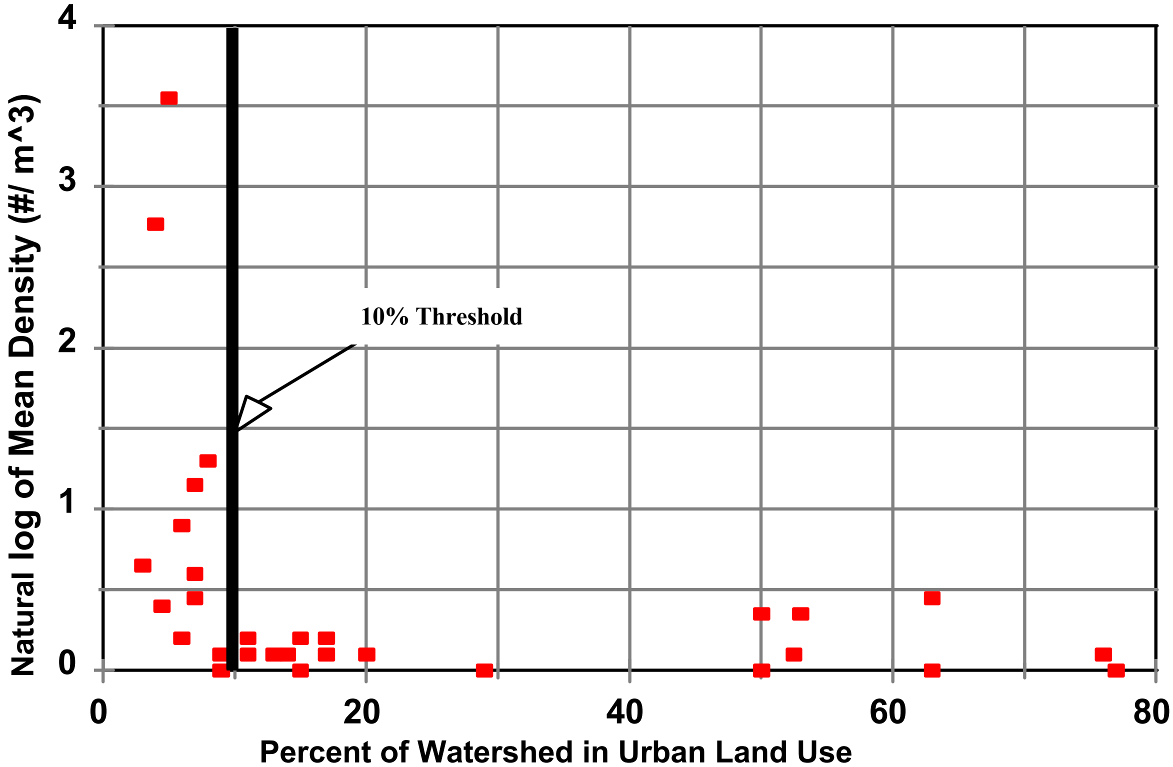
Table 4-17. Relative Abundance of Native and Introduced Fish in Urbanized and Non-Urbanized Areas in Coyote Creek, California

Species	Relative Abundance (%)	
	Non-urbanized Reach	**Urbanized Reach**
Native Fish		
Hitch	34.8	4.8
Threespine stickleback	27.3	0.8
Sacramento sucker	12.6	0.1
Introduced Fish		
Mosquitofish	5.6	66.9
Fathead Minnow	0.6	20.6
Threadfin shad	-	2.4

Source: Pitt, 1995

An illustration of the abundance of fish eggs and larvae associated with different levels of urban land use in New York is presented in Figure 4-15 (Limburg and Schmidt, 1990). This graph supports the “10 percent rule” reported by Schueler and Claytor (1995): stream impacts tend to begin in watersheds with only 10 to 20 percent imperviousness.

Figure 4-15. Average Densities of Fish Eggs and Larvae in New York



Source: Limburg and Schmidt, 1990

The change in the resident fish community due to urbanization in Tuckahoe Creek in Virginia was quantified by Weaver and Garman (1994). With urbanization increasing the percent of urban land from 7 percent to 28 percent between 1958 and 1990, a dramatic change in the fish assemblage was observed. As shown in Table 4-18, the total number of fish observed dropped sharply along with the total number of species present and the number of common species present.

Table 4-18. Effects of Urbanization on the Fish Community of Tuckahoe Creek, Virginia (Composite of 6 Sites)

Indicator	Fish Assemblage Year	
	1958	1990
% Urban (by land area)	7	28
total abundance	2,056	412
# species - total	31	23
# species - common*	21	6
% bluegill/shiner	28	67

* more than 10 individuals
Source: Weaver and Garman, 1994

4.3.3 Public Health Impacts

Public health impacts associated with urban storm water occur when humans ingest or come in contact with pathogens. While these impacts are not widely reported, they do occur, and some impacts have been documented. Examples related to swimming and contact recreation impacts and shellfish impacts are presented.

Contact Recreation Impacts

Beach closures are a common occurrence in many communities throughout the United States. Beach closures are primarily due to high levels of bacteria in water samples. The presence of medical waste and other dangerous floatable substances on beaches can also cause beach closures to occur. Storm water runoff can be responsible for both bacteria and floatables. Elevated levels of bacteria and viruses represent the most common threat to public health. Diarrhea and infection of the ear, eye, nose, or throat are possible.

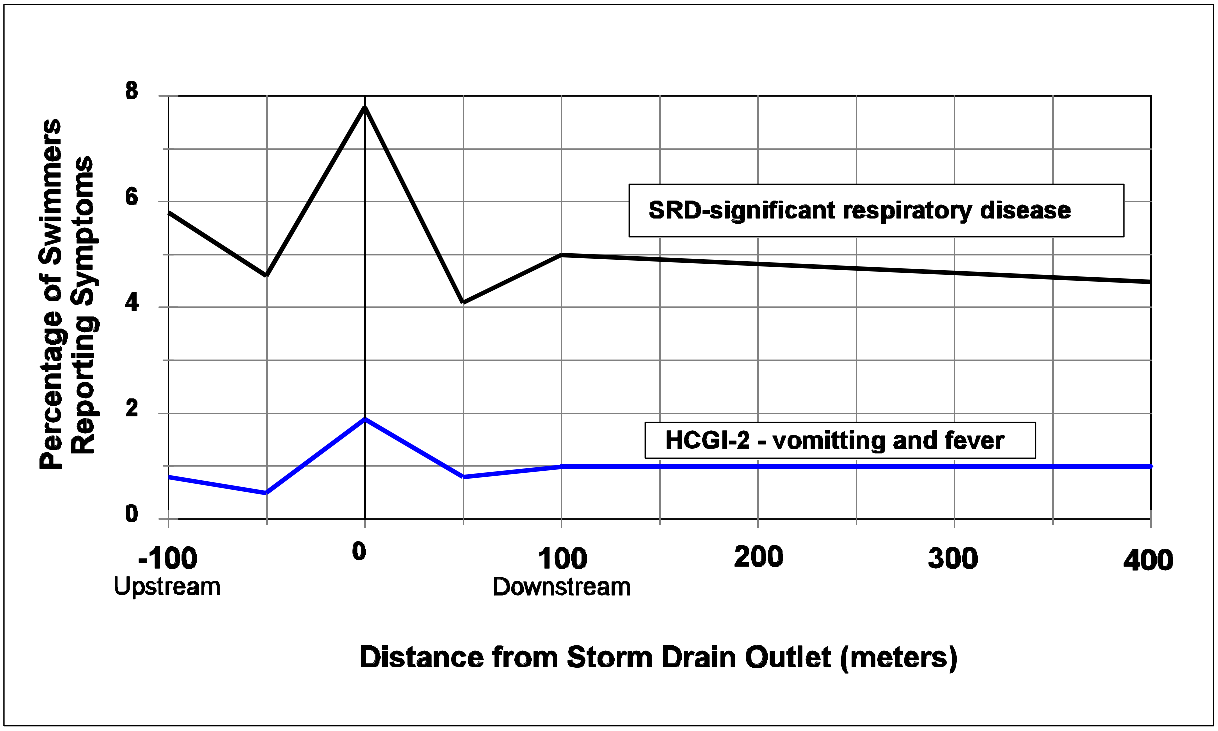
A study of epidemiological impacts associated with swimming in the vicinity of storm water outfalls in Santa Monica Bay in California was conducted in 1995 (SMBRP, 1996). The study focused on health effects, and not on possible sources of contamination to the storm drain system, such as illicit sewage connections and infiltration.[1] While the effects observed may be atypical of properly constructed and maintained storm drain outfalls, the findings indicate the potential health risks associated with pathogens. Major findings of this study are as follows:

- There is an increased risk of illness associated with swimming near flowing storm drain outlets in Santa Monica Bay.
- There is an increased risk of illness associated with swimming in areas with high densities of bacterial indicators.
- The total coliform to fecal coliform ratio was found to be one of the better indicators for predicting health risks.
- Illnesses were reported more often on days when the samples were positive for enteric viruses.
- High densities of bacterial indicators were measured on a significant number of survey days, particularly in front of drains.

People who swim in areas adjacent to flowing storm drains were found to be 50 percent more likely to get sick than people who swam in other areas. The sicknesses included fever, nausea, gastroenteritis, and flu-like symptoms such as nasal congestion, sore throat, fever, or coughing. As illustrated in Figure 4-16, swimmers who swam directly in front of storm drains were much more likely to become ill than those who swam away from the storm drains at distances of 100 to 400 meters. A comparative health outcome in terms of relative risk for swimming in front of the storm drain vs. swimming 400 meters away is presented in Table 4-19.

[1] Pilot studies conducted in the Bay prior to 1995 noted that some outfalls had regular dry weather discharges; this is a common indicator of storm drain contamination (SMBRP, 1990; SMBRP, 1992).

Figure 4-16. Health Effects Observed Relative to Distance from Santa Monica Bay Storm Drains



Source: Santa Monica Bay Restoration Project, 1996

Table 4-19. Comparative Health Outcomes for Swimming in Front of Drains in Santa Monica Bay

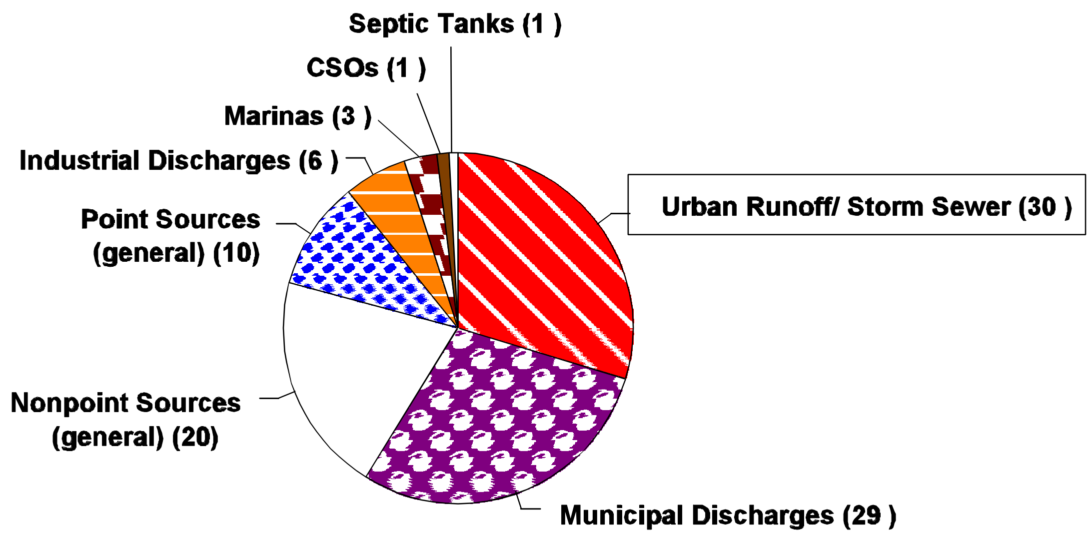
Health Outcome	Relative Risk for Swimming in Front of Drains*	Estimated No. Of Excess Cases per 10,000 Persons
Fever	57%	259
Chills	58%	138
Ear Discharge	127%	88
Vomiting	61%	115
Coughing with phlegm	59%	175
Any of the above symptoms	44%	373
HCGI-2	111%	95
SRD	66%	303
HCGI-2 or SRD	53%	314

* Compared to swimming 400 meters or more away from drains
Source: Santa Monica Bay Restoration Project, 1996

Seafood Hazard

The consumption of contaminated seafood, particularly shellfish, is a major public health problem. Shellfish are susceptible to bioaccumulating bacteria and viruses because they are filter feeders. In waters polluted by urban runoff, bacteria and viruses can be concentrated in the shellfish to much higher levels than those found in the surrounding waters. This becomes a public health concern because many potentially harmful bacteria and viruses can be ingested when people eat contaminated shellfish. As shown in Figure 4-17, the largest proportion of shellfish harvesting restrictions are caused by urban runoff (US EPA, 1995a).

Figure 4-17. Sources Associated with Shellfish Harvesting Restrictions, in Percent



Source: US EPA, 1995a

Fish can also be contaminated for a number of reasons. Recent fish sampling surveys in regions of the U.S. have shown widespread mercury contamination in streams, wetlands, reservoirs, and lakes. Based on 1997 data, 33 states have issued fish consumption advisories because of mercury contamination (US EPA, 1998a). Mercury is an urban/industrial pollutant that is released into the air and ends up in urban runoff by atmospheric deposition (Krabbenhoft and Rickert, 1995). The effects of fish contamination go beyond health issues, and hurt the recreational fishing industry as a whole.

4.3.4 Aesthetic Impacts

The aesthetic impacts associated with urban storm water are often difficult to quantify. However, aesthetic impacts are often very visible to the general public. EPA reports that "people have a strong emotional attachment to water, arising from its aesthetic qualities--tranquillity, coolness, and beauty" (US EPA, 1995c). The presence of floatables within urban waters and deposited along the banks of waterways represents a common aesthetic impact in most urban settings. Floatable wastes originate from street litter and improper solid waste disposal practices. The average total street debris loading rate in New York City was quantified at approximately 156 pounds per curb-mile per day, with a range from 3 to 2,700 pounds (HydroQual, 1995).

Aesthetic impacts from the eutrophication of urban waterways is caused in part by nutrients delivered in urban storm water. As reported by Schueler (1987), aesthetic impacts and nuisance conditions associated with eutrophication can include:

- Surface algal scum
- Water discoloration
- Strong odors
- Release of toxins.

The visual damage to urban streams from accelerated rates of storm water runoff also contribute to aesthetic impacts. These include eroded stream banks, fallen trees, and sedimentation. In summary, aesthetic impacts are often very visible in public areas where shoreline recreation occurs. Aesthetic impacts are therefore the storm water impacts most familiar to the general public.

5.0 Description and Performance of Storm Water Best Management Practices

A storm water best management practice (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. BMPs can be either engineered and constructed systems ("structural BMPs") that improve the quality and/or control the quantity of runoff such as detention ponds and constructed wetlands, or institutional, education or pollution prevention practices designed to limit the generation of storm water runoff or reduce the amounts of pollutants contained in the runoff ("non-structural BMPs"). No single BMP can address all storm water problems. Each type has certain limitations based on drainage area served, available land space, cost, pollutant removal efficiency, as well as a variety of site-specific factors such as soil types, slopes, depth of groundwater table, etc. Careful consideration of these factors is necessary in order to select the appropriate BMP or group of BMPs for a particular location.

5.1 Goals of Storm Water Best Management Practices

Storm water BMPs can be designed to meet a variety of goals, depending on the needs of the practitioner. In existing urbanized areas, BMPs can be implemented to address a range of water quantity and water quality considerations. For new urban development, BMPs should be designed and implemented so that the post-development peak discharge rate, volume and pollutant loadings to receiving waters are the same as pre-development values. In order to meet these goals, BMPs can be implemented to address three main factors: flow control, pollutant removal and pollutant source reductions.

5.1.1 Flow Control

Flow control involves managing both the volume and intensity of storm water discharges to receiving waters. Urbanization significantly alters the hydrology of a watershed. Increasing development leads to higher amounts of impervious surfaces. As a result, the response of an urbanized watershed to precipitation is significantly different from the response of a natural watershed. The most common effects are reduced infiltration and decreased travel time, which significantly increase peak discharges and runoff volumes. Factors that influence the amount of runoff produced include precipitation depth, infiltrative capacity of soils, soil moisture, antecedent rainfall, cover type, the amount of impervious surfaces and surface retention. Travel time is determined primarily by slope, length of flow path, depth of flow and roughness of flow surfaces. Peak discharges are based on the relationship of these parameters, and on the total drainage area of the watershed, the time distribution of rainfall, and the effects of any natural or manmade storage (USDA/NRCS, 1986).

High flow rates of storm water discharges can cause a number of impacts to receiving streams (see section 4.3), and may also increase the pollutant concentrations in storm water runoff. High velocity runoff can detach and transport significant amounts of suspended solids and associated pollutants such as nutrients and metals from the urban landscape. In addition, high flow rates in drainage channels and receiving waters can erode stream banks and channels, further increasing suspended solids concentrations in waters that receive storm water discharges. In order to reduce the pollutant concentrations in runoff and receiving water impacts associated with high storm water flow rates, BMPs that provide flow attenuation are frequently implemented.

In areas undergoing new development or redevelopment, the most effective method of controlling impacts from storm water discharges is to limit the amount of rainfall that is converted to runoff. By utilizing site design techniques that incorporate on-site storage and infiltration and reduce the amounts of directly connected impervious surfaces, the amount of runoff generated from a site can be significantly reduced. This can reduce the necessity for traditional structural BMPs to manage runoff from newly developed areas. There are a number of practices that can be used to promote on-site storage and infiltration and to limit the amount of impervious surfaces that are generated. However, the use of on-site infiltration can be limited in certain areas due to factors such as slope, depth to the water table, and geologic conditions.

- *Site design features* such as providing rain barrels, dry wells or infiltration trenches to capture rooftop and driveway runoff, maintaining open space, preserving stream buffers and riparian corridors, using porous pavement systems for parking lots and driveways, and using grassed filter strips and vegetated swales in place of traditional curb-and-gutter type drainage systems can greatly reduce the amount of storm water generated from a site and the associated impacts.

- *Street construction features* such as placing sidewalks on only one side of the street, limiting street widths, reducing frontage requirements and eliminating or reducing the radius of cul-de-sacs also have the potential to significantly reduce the amount of impervious surfaces and therefore the amount of rainfall that is converted to runoff.

- *Construction practices* such as minimizing disturbance of soils and avoiding compaction of lawns and greenways with construction equipment can help to maintain the infiltrative capacity of soils.

There are several guides that contain useful information regarding development practices that can limit the impacts associated with storm water runoff (Delaware DNREC, 1997; US EPA, 1996b; Center for Watershed Protection, 1998).

In areas that are already developed, flow control can be more complicated. Since a drainage infrastructure already exists, retrofitting these systems to provide flow control can be prohibitively expensive. Regional storm water management systems can be used to manage runoff in these areas, but space considerations and high capital costs can limit their usefulness. Depending on site-specific constraints, however, there are a number of practices that can be incorporated on-site to reduce runoff volumes from these areas. Down spouts can be disconnected from the storm drain system and this rainfall can instead be collected and stored on a property in rain barrels to be used for watering lawns and landscaping during inter-event periods. Infiltration and retention practices such as bioretention areas and infiltration trenches can be constructed to capture runoff from rooftops, lawns and driveways and reduce the volume of runoff discharged to storm sewers. Curb-and-gutter systems can be replaced with grassed swales or wetland channels to provide temporary ponding of runoff. Storm water from commercial areas and golf courses can be collected and stored in ponds and subsequently be used for irrigation. Storm water reuse can help to maintain a more natural, pre-development hydrologic balance in the watershed (Livingston et al, 1998). Parking lots can also be used as short-term storage areas for ponded storm water, and bioretention facilities placed around the perimeter of parking lots can be used to infiltrate this water volume.

Where the generation of runoff cannot be avoided, end-of-pipe structural BMPs may be implemented to decrease the impacts of storm water discharges to receiving streams. However, BMPs are limited in their ability to control impacts, and frequently cause secondary impacts such as increased temperatures of discharges to receiving streams. BMPs that can be designed to provide significant flow attenuation include grassed swales, vegetated filter strips, detention and retention basins, wetland basins, and wetland channels and swales. These BMPs can also provide the added benefit of removing pollutants such as suspended solids and associated nutrients and metals from storm water runoff.

The environmental aspects of storm water quantity control must be carefully balanced against the hazard and nuisance effects of flooding. Large or intense storm events or rapid snowmelt can produce significant quantities of runoff from urban areas with high levels of imperviousness. This runoff must be rapidly transported from urbanized areas in order to prevent loss of life and property due to flooding of streets, residences and businesses. This is frequently accomplished by replacing natural drainage paths in the watershed with paved gutters, storm sewers or other artificial means of drainage. These drainage systems can convey runoff at a faster rate than natural drainage paths, allowing rapid transport of runoff away from areas where flooding is likely to occur. However, as large quantities of runoff are conveyed rapidly from the urban landscape and discharged to receiving streams, downstream areas can flood. Following urbanization, large volumes of runoff can be produced from even small storm events due to the high amounts of impervious surfaces. As a result, flooding of streams that receive runoff can occur much more frequently following urbanization due to this excessive amount of runoff production. Therefore, design of storm water drainage systems must always balance flood protection with ecological concerns.

In highly urbanized and densely populated cities, little opportunity exists for retrofitting storm drainage systems with BMPs to provide water quantity control due to flooding considerations. The large area of impervious surfaces in heavily urbanized areas produce large quantities of runoff. Rapid conveyance by the storm drain system is frequently the only option that exists in order to prevent flooding of yards, streets and basements. In these areas, the most appropriate BMPs are those that limit the generation of pollutants or remove pollutants from the urban landscape. With this principle in mind, a unique opportunity exists in newly developing areas or in more sparsely populated suburban areas to use BMPs that control runoff at the point of generation, instead of trying to manage it at the point of discharge to the receiving stream. When rainfall is managed as a *resource* instead of as a waste stream requiring treatment, future problems with quantity control may be avoidable. When rainfall is managed at the site level by promoting the concepts of conservation design, and by providing on-site storage, infiltration and usage of rainfall for irrigation of the urban landscape, the need for traditional curb-and-gutter storm drainage system can be reduced. As a result, the need for constructing and maintaining capital-, land- and maintenance-intensive regional BMPs to manage large flows from developed watersheds may be reduced. Nuisance flooding of downstream areas can also be limited by reducing the overall volume of water draining from a watershed. Limiting the discharge of large volumes of storm water to urban streams can help to prevent the degradation of these streams to the point of being non-supporting of a designated use.

5.1.2 Pollutant Removal

Urbanized areas export large quantities of pollutants during storm events. The high population of pollutant sources in urbanized areas contribute large quantities of pollutants that accumulate on streets, rooftops and other surfaces. During rainfall or snowmelt, these pollutants are mobilized and transported from the streets and rooftops into the storm drain system, where they are conveyed and ultimately discharged to waterways. In order to reduce the impacts to receiving waters from the high concentrations of pollutants contained in the runoff, BMPs can be implemented to remove these pollutants.

Properly-designed, constructed and maintained structural BMPs can effectively remove a wide range of pollutants from urban runoff. Pollutant removal in storm water BMPs can be accomplished through a number of physical and biochemical processes. The efficiency of a given BMP in removing pollutants is dependent upon a number of site-specific variables, including the size, type and design of the BMP; the soil types and characteristics; the geology and topography of the site; the intensity and duration of the rainfall; the length of antecedent dry periods; climatological factors such as temperature, solar radiation, and wind; the size and characteristics of the contributing watershed; and the properties and characteristics of the various pollutants.

Pollutant removal in urban storm water BMPs can occur through the following mechanisms:

Sedimentation

Sedimentation is the removal of suspended particulates from the water column by gravitational settling. The settling of discrete particles is dependent upon the particle velocity, the fluid density, the fluid viscosity, and the particle diameter and shape. Sedimentation can be a major mechanism of pollutant removal in BMPs such as ponds and constructed wetlands. Sedimentation can remove a variety of pollutants from storm water runoff. Pollutants such as metals, hydrocarbons, nutrients and oxygen demanding substances can become adsorbed or attached to particulate matter, particularly clay soils. Removal of these particulates by sedimentation can therefore result in the removal of a large portion of these associated pollutants. The main factor governing the efficiency of a BMP at removing suspended matter by sedimentation is the time available for particles to undergo settling. Fine particulates such as clay and silt can require detention times of days or even weeks to settle out of suspension. Therefore, it is important to evaluate the settling characteristics of the particulates in runoff before BMP design in order to determine the detention time necessary for adequate settling to occur. The overall efficiency of a BMP in removing particulates by settling is also dependent upon the initial concentration of suspended solids in the runoff. In general, runoff with higher initial concentrations of suspended solids will have a greater removal efficiency. In addition, some particles, such as fine clays, will not settle out of suspension without the aid of a coagulant. As a result there is usually a minimum practical limit of approximately 10 mg/l of TSS, below which additional TSS removal can not be expected to occur (UDFCD, 1992).

Flotation

Flotation is the separation of particulates with a specific gravity less than that of water. Trash such as paper, styrofoam "peanuts" used for packaging, and other low-density materials can be removed from storm water by the mechanism of flotation. If the inlet area of the BMP is designed to allow for the accumulation of floatable materials, then these accumulated materials can periodically be manually removed from the BMP. Significant amounts of floatables can be removed from storm water in properly designed BMPs in this manner. In addition, oils and hydrocarbons will frequently rise to the surface in storm water BMPs. If the BMP is designed with an area for these materials to accumulate, then significant removals of these pollutants can occur. Many modular or drop-in filtration systems incorporate an oil and grease or hydrocarbon trap with a submerged outlet pipe that allows these contaminants to accumulate and to be periodically removed.

Filtration

Filtration is the removal of particulates from water by passing the water through a porous media. Media commonly used in storm water BMPs include soil, sand, gravel, peat, compost, and various combinations such as peat/sand, soil/sand and sand/gravel. Filtration is a complex process dependent on a number of variables. These include the particle shape and size, the size of the voids in the filter media, and the velocity at which the fluid moves through the media. Filtration can be used to remove solids and attached pollutants such as metals and nutrients. Organic filtration media such as peat or leaf compost can also be effective at removing soluble nutrients from urban runoff.

Infiltration

Infiltration is the most effective means of controlling storm water runoff since it reduces the volume of runoff that is discharged to receiving waters and the associated water quality and quantity impacts that runoff can cause. Infiltration is also an important mechanism for pollutant control. As runoff infiltrates into the ground, particulates and attached contaminants such as metals and nutrients are removed by filtration, and dissolved constituents can be removed by adsorption. However, infiltration is not appropriate in all areas.

Adsorption

Adsorption, while not a common mechanism used in storm water BMPs, can occur in infiltration systems where the underlying soils contain appreciable amounts of clay. Dissolved metals that are contained in storm water runoff can be bound to the clay particles as storm water runoff percolates through clay soils in infiltration systems.

Biological Uptake

Biological uptake of nutrients is an important mechanism of nutrient control in storm water BMPs. Urban runoff typically contains significant concentrations of nutrients. Ponds and wetlands can be useful for removing these nutrients through biological uptake. This occurs as aquatic plants, algae, microorganisms and phytoplankton utilize these nutrients for growth. Periodic harvesting of vegetation in BMPs allows for permanent removal of these nutrients. If plants are not harvested, however, nutrients can be re-released to the water column from plant tissue after the plants die.

Biological Conversion

Organic contaminants can be broken down by the action of aquatic microorganisms in storm water BMPs. Bacteria present in BMPs can degrade complex and/or toxic organic compounds into less harmful compounds that can reduce the toxicity of runoff to aquatic biota.

Degradation

BMPs such as ponds and wetlands can provide the conditions necessary for the degradation of certain organic compounds, including certain pesticides and herbicides. Open pool BMPs can provide the necessary conditions for volatilization, hydrolysis and photolysis of a variety of organic compounds to take place.

5.1.3 Pollutant Source Reductions

Source reduction is an effective non-structural way of controlling the amounts of pollutants entering storm water runoff. A wide range of pollutants are washed off of impervious surfaces during runoff events. Removing these contaminants from the urban landscape prior to precipitation can effectively limit the amounts of pollutants contained in the storm water runoff. Source reduction can be accomplished by a number of different processes including: limiting applications of fertilizers, pesticides and herbicides; periodic street sweeping to remove trash, litter and particulates from streets; collection and disposal of lawn debris; periodic cleaning of catch basins; elimination of improper dumping of used oil, antifreeze, household cleaners, paint, etc. into storm drains; and identification and elimination of illicit cross-connections between sanitary sewers and storm sewers.

5.2 Types of Storm Water Best Management Practices

There are a variety of storm water BMPs available for managing urban runoff. Regardless of the type, storm water BMPs are most effective when implemented as part of a comprehensive storm water management program that includes proper selection, design, construction, inspection and maintenance. Storm water BMPs can be grouped into two broad categories: structural and non-structural. *Structural* BMPs are used to treat the storm water at either the point of generation or the point of discharge to either the storm sewer system or to receiving waters. *Non-structural* BMPs include a range of pollution prevention, education, institutional, management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation. The descriptions in this section provide summary information on a variety of commonly used structural and nonstructural storm water BMPs. Information provided includes a general description of the technology or practice, important components and factors to incorporate into BMP design and planning, and the positive and negative aspects of the technology or practice. In addition, maintenance considerations for structural BMPs are discussed. Quantitative performance data for BMPs are not included in this section. These data are included in section 5.5, "Effectiveness of BMPs in Managing Urban Runoff."

<u>5.2.1 Structural BMPs</u>

There are a wide variety of structural BMPs in use for storm water management. Structural BMPs include engineered and constructed systems that are designed to provide for water quantity and/or water quality control of storm water runoff. Structural BMPs can be grouped into several general categories. However, the distinction between BMP types and the terminology used to group structural BMPs is an area that needs standardization. In particular, the terms "retention" and "detention" are sometimes used interchangeably, although they do have distinct meanings. Storm water detention is usually defined as providing temporary storage of a runoff volume for subsequent release (WEF/ASCE, 1992). Examples include detention basins, underground vaults, tanks or pipes, and deep tunnels, as well as temporary detention in parking lots, roof tops, depressed grassy areas, etc. Retention is generally defined as providing storage of storm water runoff without subsequent surface discharge (WEF/ASCE, 1992). With the strict interpretation of this definition, retention practices would be limited to those practices that either infiltrate or evaporate runoff, such as infiltration trenches, wells or basins. However, retention is also commonly used to describe practices that retain a runoff volume (and hence have a permanent pool) until it is displaced in part or in total by the runoff event from the next storm. Examples include retention ponds, tanks, tunnels, and underground vaults or pipes, and wetland basins. For purposes of this document, and in being consistent with the definitions and terminology used in the ASCE National Stormwater BMP Database, structural BMPs have been grouped and defined as follows:

- <u>Infiltration systems</u> capture a volume of runoff and infiltrates it into the ground.

- Detention systems capture a volume of runoff and temporarily retain that volume for subsequent release. Detention systems to not retain a significant permanent pool of water between runoff events.

- Retention systems capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems therefore maintain a significant permanent pool volume of water between runoff events.

- Constructed wetland systems are similar to retention and detention systems, except that a major portion of the BMP water surface area (in pond systems) or bottom (in meadow-type systems) contains wetland vegetation. This group also includes wetland channels.

- Filtration systems use some combination of a granular filtration media such as sand, soil, organic material, carbon or a membrane to remove constituents found in runoff.

- Vegetated systems (biofilters) such as swales and filter strips are designed to convey and treat either shallow flow (swales) or sheetflow (filter strips) runoff

- Minimizing directly connected impervious surfaces describes a variety of practices that can be used to reduce the amount of surface area directly connected to the storm drainage system by minimizing or eliminating traditional curb and gutter. This is considered by some to be a non-structural practice, but is has been included under the structural heading in this report due to the need to design and construct alternative conveyance and treatment options.

- Miscellaneous and vendor-supplied systems include a variety of proprietary and miscellaneous systems that do not fit under any of the above categories. These include catch basin inserts, hydrodynamic devices, and filtration devices.

5.2.1.1 Infiltration Systems

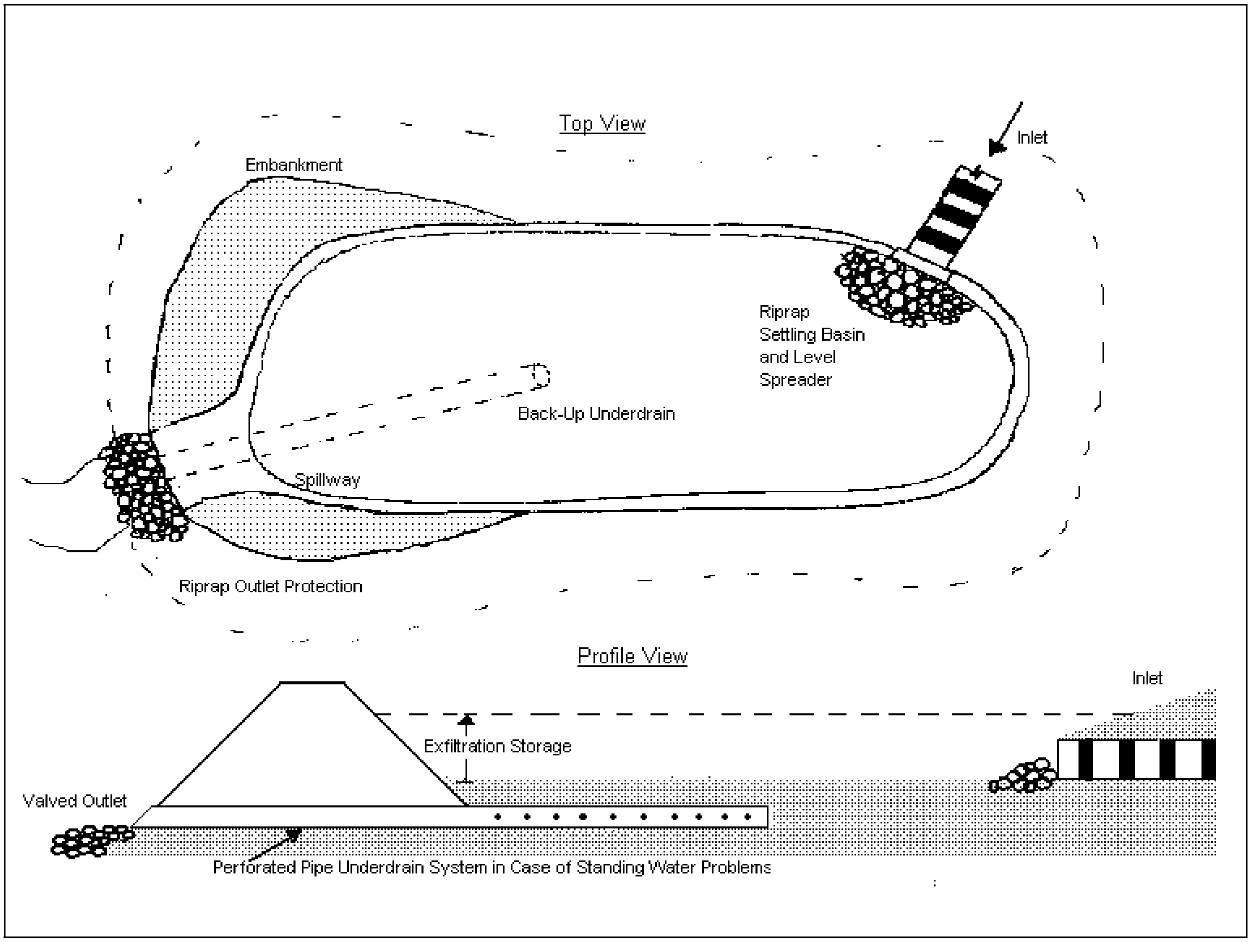
Infiltration systems include infiltration basins, porous pavement systems, and infiltration trenches or wells. An infiltration BMP is designed to capture a volume of storm water runoff, retain it and infiltrate that volume into the ground. Infiltration of storm water has a number of advantages and disadvantages. The advantages of infiltration include both water quantity control and water quality control. Water quantity control can occur by taking surface runoff and infiltrating this water into the underlying soil. This reduces the volume of water that is discharged to receiving streams, thereby reducing some of the potential impacts caused by an excess flow as well as increased pollutant concentrations in the receiving stream. Infiltration systems can be designed to capture a volume of storm water and infiltrate this water into the ground over a period of several hours or even days, thereby maximizing the infiltrative capacity of the BMP. Infiltration can have many secondary benefits such as increasing recharge of underlying aquifers and increasing baseflow levels of nearby streams. Infiltration BMPs can also provide water quality treatment. Pollutant removal can occur as water percolates through the various soil layers. As the water moves through the soil, particles can be filtered out. In addition, microorganisms in the soil can degrade organic pollutants that are contained in the infiltrated storm water.

Although infiltration of storm water has many benefits, it also has some drawbacks. First, infiltration may not be appropriate in areas where groundwater is a primary source of drinking water due to the potential for contaminant migration. This is especially true if the runoff is from a commercial or industrial area where the potential for contamination by organics or metals is present. Also, the performance of infiltration BMPs is limited in areas with poorly permeable soils. In addition, infiltration BMPs can experience reduced infiltrative capacity and even clogging due to excessive sediment accumulation. Frequent maintenance may be required to restore the infiltrative capacity of the system. Care must also be taken during construction to limit compaction of the soil layers underlying the BMP. Excessive compaction due to construction equipment may cause a reduced infiltrative capacity of the system. Plus, excessive sediment generation during construction and site grading/stabilization may cause premature clogging of the system. Infiltration systems should not be placed into service until disturbed areas in the drainage have been stabilized by dense vegetation or grasses.

Infiltration Basins

Infiltration basins are designed to capture a storm water runoff volume, hold this volume and infiltrate it into the ground over a period of days. Infiltration basins are almost always placed off-line, and are designed to only intercept a certain volume of runoff. Any excess volume will be bypassed. The basin may or may not be lined with plants. Vegetated infiltration systems help to prevent migration of pollutants and the roots of the vegetation can increase the permeability of the soils, thereby increasing the efficiency of the basin. Infiltration basins are typically not designed to retain a permanent pool volume. Their main purpose is to simply transform a surface water flow into a ground water flow and to remove pollutants through mechanisms such as filtration, adsorption and biological conversion as the water percolates through the underlying soil. Infiltration basins should be designed to drain within 72 hours in order to prevent mosquito breeding and potential odor problems due to standing water and to ensure that the basin is ready to receive runoff from the next storm (US EPA, 1993a). In addition to removing pollutants, infiltration basins are useful to help restore or maintain pre-development hydrology in a watershed. Infiltration can increase the water table, increase baseflow and reduce the frequency of bankfull flooding events. A diagram of a typical infiltration basin is shown below.

Figure 5-1. Infiltration Basin



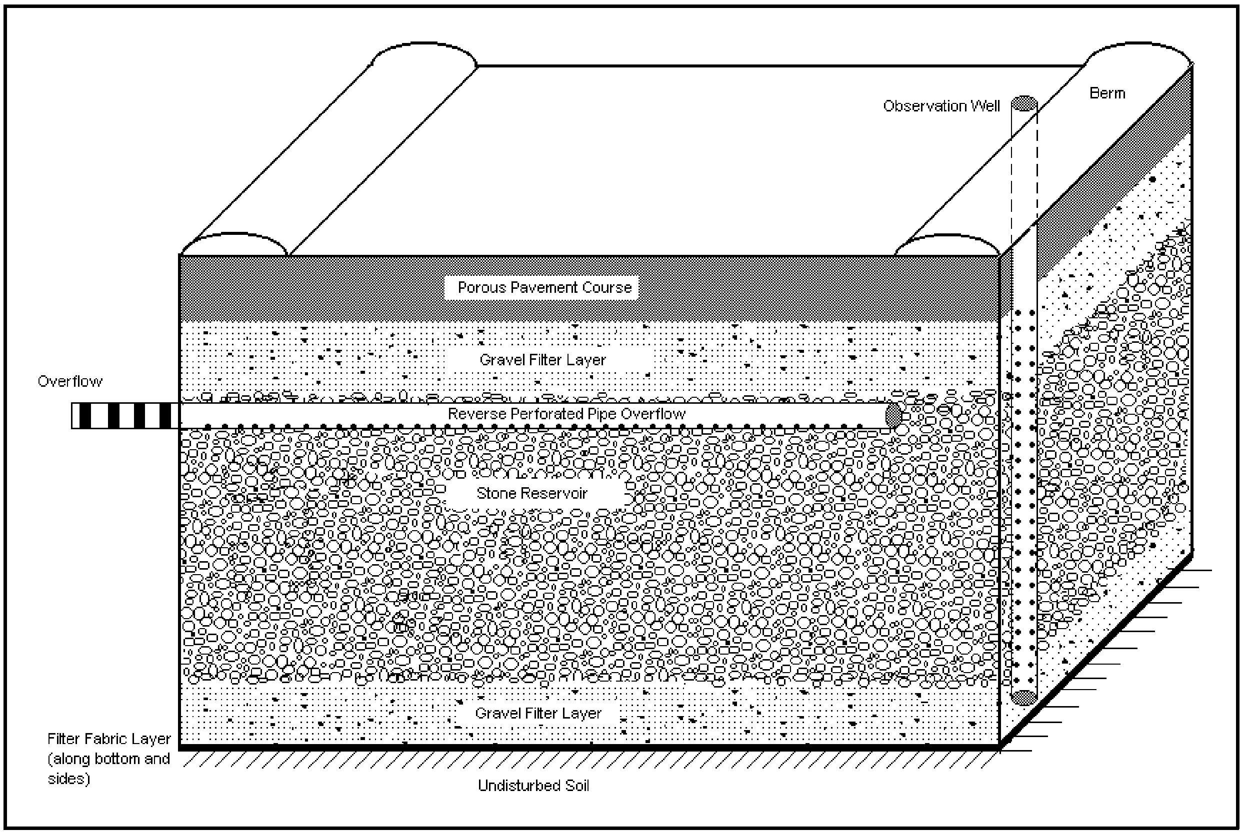
Source: Adapted from Schueler et al, 1992

Porous Pavement Systems

Porous pavement is an infiltration system where storm water runoff is infiltrated into the ground through a permeable layer of pavement or other stabilized permeable surface. These systems can include porous asphalt, porous concrete, modular perforated concrete block, cobble pavers with porous joints or gaps or reinforced/stabilized turf (Urbonas and Strecker, 1996). Permeable pavement can be used in parking lots, roads and other paved areas and can greatly reduce the amount of runoff and associated pollutants leaving the area. Porous pavement systems are suitable for a limited number of applications. Typically, porous pavement can only be used in areas that are not exposed to high volumes of traffic or heavy equipment. They are particularly useful for driveways and streets and in residential areas, and in parking areas in commercial areas. Porous pavement is not effective in areas that receive runoff with high amounts of sediment due to the tendency of the pores to clog. Porous pavements require maintenance including periodic vacuuming or jet-washing to remove sediment from the pores. Paved areas should be clearly marked to indicate that a porous pavement system is in use and to prevent frequent use by equipment, to prevent excess traffic volume, to limit the use of de-icing chemicals and sand, and to prevent resurfacing with non-porous pavement.

The performance of porous asphalt has been historically very poor in the mid-Atlantic region. However, many of these failures can be attributed to lack of proper erosion and sediment controls during construction or lack of contractor experience with installation of porous pavement systems. Porous concrete systems in use in Florida have performed very well (Florida Concrete and Products Assn., 1993). When properly designed and maintained, porous pavement systems can be an effective means of managing urban storm water runoff. Porous pavement systems are particularly useful for overflow parking areas that are not used on a daily basis. A diagram of a porous asphalt pavement system is shown below.

Figure 5-2. Porous Pavement System

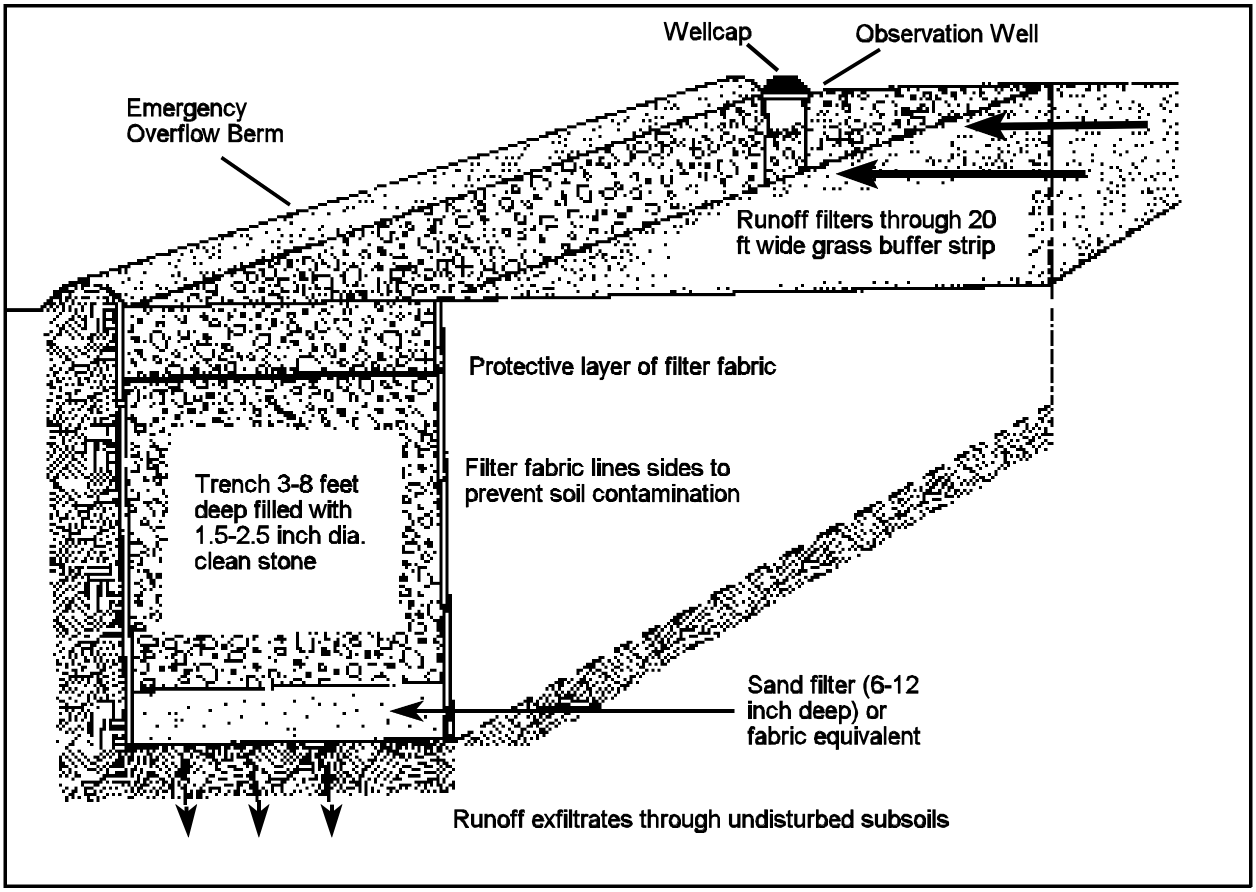


Source: Adapted from Schueler, 1987.

Infiltration Trenches and Wells

An infiltration trench or well is a gravel-filled trench or well designed to infiltrate storm water into the ground. A volume of storm water runoff is diverted into the trench or well where it infiltrates into the surrounding soil. Typically infiltration trenches and wells can only capture a small amount of runoff and therefore may be designed to capture the first flush of a runoff event. For this reason, they are frequently used in combination with another BMP such as a detention basin to control peak hydraulic flows. Infiltration trenches and wells can be used to remove suspended solids, particulates, bacteria, organics and soluble metals and nutrients through the mechanisms of filtration, absorption and microbial decomposition. They are also useful to provide groundwater recharge and to increase base flow levels in nearby streams. As with all infiltration practices, the possibility for groundwater contamination exists and must be considered where groundwater is a source of drinking water. A diagram of an infiltration trench is shown below.

Figure 5-3. Infiltration Trench



Source: Schueler et al, 1992.

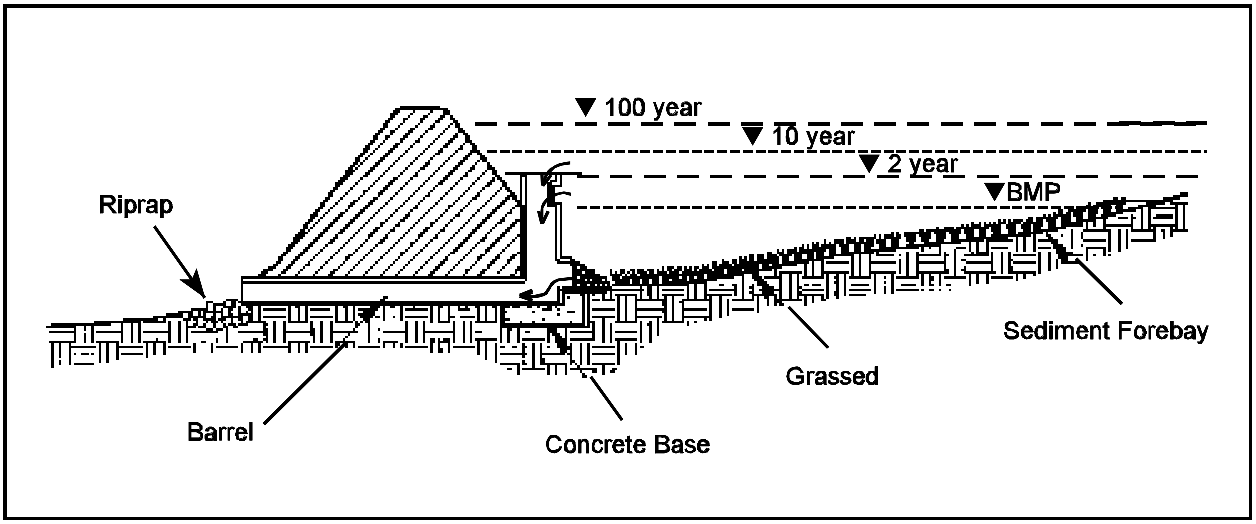
5.2.1.2 Detention Systems

Detention systems are BMPs that are designed to intercept a volume of storm water runoff and temporarily impound the water for gradual release to the receiving stream or storm sewer system. Detention systems are designed to completely empty out between runoff events, and therefore provide mainly water quantity control as opposed to water quality control. Detention basins can provide limited settling of particulate matter, but a large portion of this material can be re-suspended by subsequent runoff events. Detention facilities should be considered mainly as practices used to reduce the peak discharge of storm water to receiving streams to limit downstream flooding and to provide some degree of channel protection. There are several types of detention facilities used to manage storm water runoff, including detention basins and underground vaults, pipes and tanks.

Detention Basins

Detention basins are designed to intercept a volume of storm water, temporarily impound the water and release it shortly after the storm event. The main purpose of a detention basin is quantity control by reducing the peak flow rate of storm water discharges. They are designed to not retain a permanent pool volume between runoff events. and most basins are designed to empty in a time period of less than 24 hours. The treatment efficiency of detention basins is usually limited to removal of suspended solids and associated contaminants due to gravity settling. The efficiency can be increased by incorporating a forebay or pre-settling chamber for the accumulation of coarse sediment, facilitating periodic cleaning in order to prevent washout by subsequent runoff events. Detention basins can limit downstream scour and loss of aquatic habitat by reducing the peak flow rate and energy of storm water discharges to the receiving stream, but their removal of pollutant of potential water quality concern can be limited. A diagram of a typical detention basin is shown below.

Figure 5-4. Detention Basin



Source: NVPDC, 1992.

Underground Vaults, Pipes and Tanks

Underground detention facilities, such as vaults, pipes and tanks, are designed to provide temporary storage of storm water runoff. Significant water quality improvements should not be expected in underground detention facilities. They should mainly be used for providing storage to limit downstream effects due to high peak flow rates. Like detention basins, underground detention systems are designed to empty out between runoff events so that storage capacity is available for subsequent runoff events. In addition, studies are being conducted to evaluate the usefulness of in-system detention (storing runoff temporarily in the storm drainage system through the use of valves, gates, orifices, etc.), although these evaluations are in the preliminary stages and are only useful in certain cases (Lake Barcroft Watershed Improvement District, 1998). This is a potential alternative for retrofitting existing storm drains in the upper portions of the drainage system to delay the peak discharge rate and provide a limited amount of additional temporary storage volume. However, a careful analysis of the storm drainage system is necessary in order to prevent flooding in the upper reaches of the drainage area.

5.2.1.3 Retention Systems

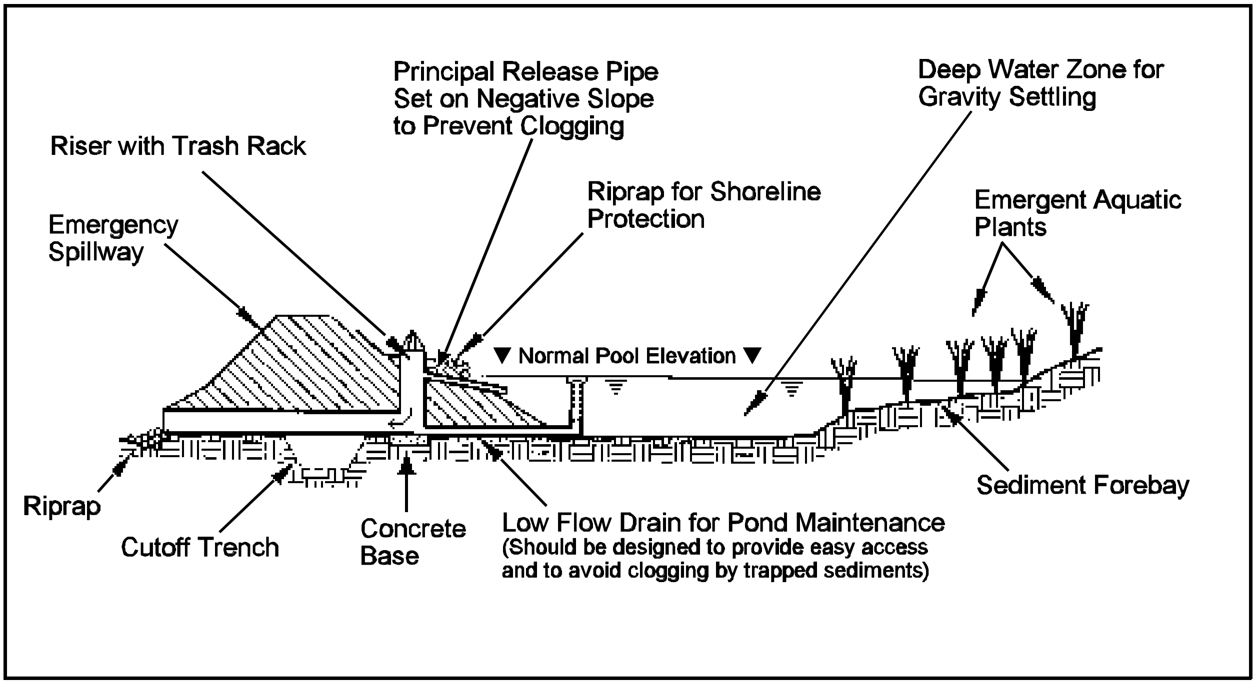
Retention systems include wet ponds and other retention systems such as underground pipes or tanks. Retention systems are designed to capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems can provide both water quantity and quality control. The volume available for storage, termed the water quality volume, is provided above the permanent pool level of the system. The main pollutant removal mechanisms in retention systems is sedimentation. By retaining a permanent pool of water, retention systems can benefit from the added biological and biochemical pollutant removal mechanisms provided by aquatic plants and microorganisms, mimicking a natural pond or lake ecosystem. Also, sediments that accumulate in the pond are less likely to be re-suspended and washed out due to the presence of a permanent pool of water. In addition to sedimentation, other pollutant removal mechanisms in retention systems include filtration of suspended solids by vegetation, infiltration, biological uptake of nutrients by aquatic plants and algae, volatilization of organic compounds, uptake of metals by plant tissue, and biological conversion of organic compounds.

<u>Retention Ponds</u>

Retention ponds (also known as wet ponds) are designed to intercept a volume of storm water runoff and to provide storage and treatment of this runoff volume. Water in the pond above the permanent pool level is displaced in part or completely by the runoff volume from subsequent runoff events. Retention ponds, when properly designed and maintained, can be extremely effective BMPs, providing both water quality improvements and quantity control, as well as providing aesthetic value and aquatic and terrestrial habitat for a variety of plants and animals.

Pollutant removal in retention ponds can occur through a number of mechanisms. The main mechanism is the removal of suspended solids and associated pollutants through gravity settling. Aquatic plants and microorganisms can also provide uptake of nutrients and degradation of organic contaminants. Retention basins that incorporate an aquatic bench around the perimeter of the basin that is lined with aquatic vegetation can have an added pollutant removal efficiency. This littoral zone can aid in pollutant removal efficiency by incorporating mechanisms found in wetland systems. These mechanisms include removal of sediment by filtration by aquatic plants, removal of metals and nutrients through biological uptake by aquatic vegetation and degradation of organic contaminants. If the bottom of the pond is not lined, then infiltration can occur aiding in the maintenance of local groundwater supplies. A diagram of a typical wet pond is shown below.

Figure 5-5. Retention Pond



Source: NVPDC, 1992.

<u>Retention Tanks, Tunnels, Vaults and Pipes</u>

Retention systems other than ponds include surface tanks and underground vaults, pipes and tunnels. These systems are not as prevalent as typical wet ponds, and therefore little information is contained in the literature about their design, applicability and usefulness.

5.2.1.4 Constructed Wetland Systems

Constructed wetland systems incorporate the natural functions of wetlands to aid in pollutant removal from storm water. Constructed wetlands can also provide for quantity control of storm water by providing a significant volume of ponded water above the permanent pool elevation. Constructed wetland systems have limits to their application. A water balance must be performed to determine the availability of water to sustain the aquatic vegetation between runoff events and during dry periods. In addition, a sediment forebay or some other pretreatment provision should be incorporated into the wetland system design to allow for the removal of coarse sediments that can degrade the performance of the system. Also, construction sediment should be prevented from entering constructed wetlands, as the resulting sediment loading can severely degrade the performance of the system. Constructed wetlands are particularly appropriate where groundwater levels are close to the surface because groundwater can supply the water necessary to sustain the wetland system.

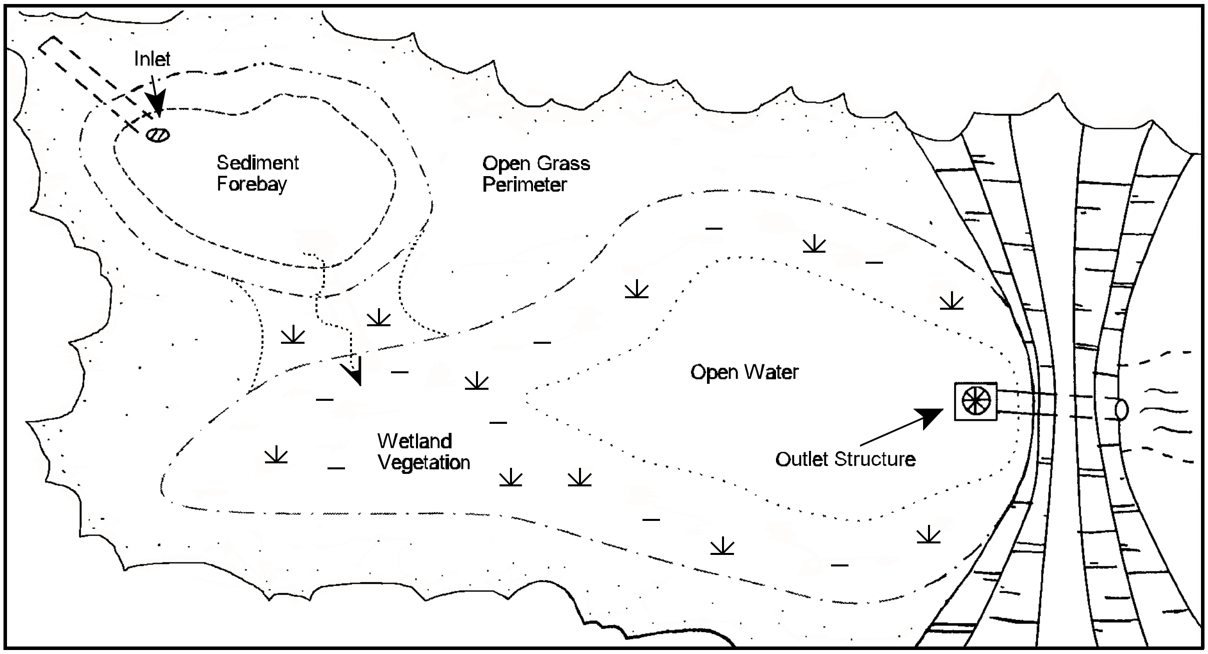
Storm water runoff should not be intentionally routed to natural wetlands without pretreatment due to the potentially damaging effects runoff can have on natural wetland systems. In addition, natural wetlands that receive storm water runoff should be evaluated to determine if the runoff is causing degradation of the wetland, and if so measures should be taken to protect the wetland from further degradation and to repair any damage that has been done. In addition, local permitting authorities should be consulted prior to designing and maintaining constructed wetland systems in order to determine if any local regulations apply to their use or maintenance.

Wetland Basins and Wetland Channels

Wetland basins and channels are any of a number of systems that incorporate mechanisms of natural wetland systems for water quality improvement and quantity control. A wetland channel is designed to develop dense wetland vegetation and to convey runoff very slowly (Urbonas and Strecker, 1996). Generally, this rate is less that 2 feet-per-second at the 2-year peak flow. Wetland basins may be designed with or without an open water (permanent pool) component. Wetland basins with open water are similar to retention ponds, except that a significant portion (usually 50 percent or more) of the permanent pool volume is covered by emergent wetland vegetation. Wetland basins without open water are inundated with water during runoff events, but do not maintain a significant permanent pool. Wetland basins of this type, also known as a wetland meadow, support a variety of wetland plants adapted to saturated soil conditions and tolerant of periodic inundation by runoff.

Pollutant removal in wetlands can occur through a number of mechanisms including sedimentation, filtration, volatilization, adsorption, absorption, microbial decomposition and plant uptake. In addition, wetlands can provide for significant water storage during runoff events, thus supplying water quantity control as well. A diagram of a typical storm water wetland system is included below.

Figure 5-6. Constructed Wetland System

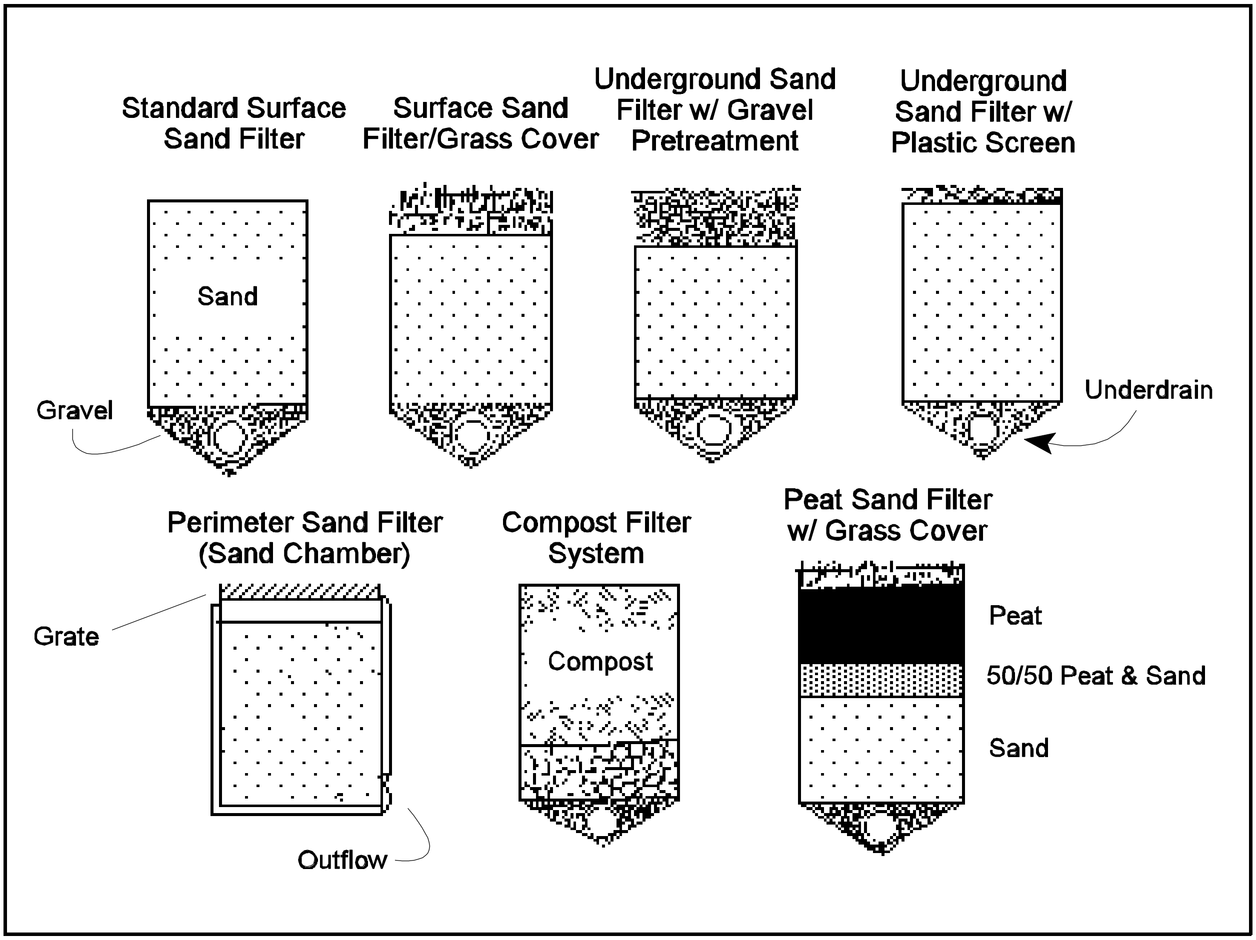


5.2.1.5 Filtration Systems

A filtration system is a device that uses a media such as sand, gravel, peat or compost to remove a fraction of the constituents found in storm water. There are a wide variety of filter types in use. There are also a variety of proprietary designs that use specialized filter media made from materials such as leaf compost. Filters are primarily a water quality control device designed to remove particulate pollutants. Quantity control can be included by providing additional storage volume in a pond or basin, by providing vertical storage volume above the filter bed, or by allowing water to temporarily pond in parking lots or other areas before being discharged to the filter. Media filters are commonly used to treat runoff from small sites such as parking lots and small developments, in areas with high pollution potential such as industrial areas, or in highly urbanized areas where land availability or costs preclude the use of other BMP types. Filters should be placed off-line (i.e., a portion of the runoff volume, called the water quality volume, is diverted to the BMP, while any flows in excess of this volume are bypassed) and are sometimes designed to intercept and treat only the first half inch or inch of runoff and bypass larger storm water flows. A benefit of using filters in highly urbanized areas is that the filter can be placed under parking lots or in building basements, limiting or eliminating costly land requirements. However, placing filters “out of sight” may have implications for continued maintenance and performance. Media filters should use a forebay or pre-settling chamber to remove a portion of the settleable solids prior to filtration. This helps to extend the life of the filter run and prevent clogging of the filter media by removing a portion of the coarse sediment. Also, care must be taken to prevent construction site sediments and debris such as fines washed off of newly paved areas from entering the filter, as these can cause premature clogging of the filter.

Filter types in common use include surface sand filters such as the “Austin” sand filter and underground vault filters such as the “D.C.” sand filter and the “Delaware” sand filter. There are a number of variations of these basic designs in common use. In addition, there are a number of proprietary filtering systems in use. There are also a number of variations in the types of filtration media that are in use in media filters. Designs may incorporate features such as a layer of filter cloth or a plastic screen, a gravel layer, a peat layer, a compost layer, a layer of peat or a peat/sand mixture. Typical variations in filtration media are shown below.

Figure 5-7. Filter Media

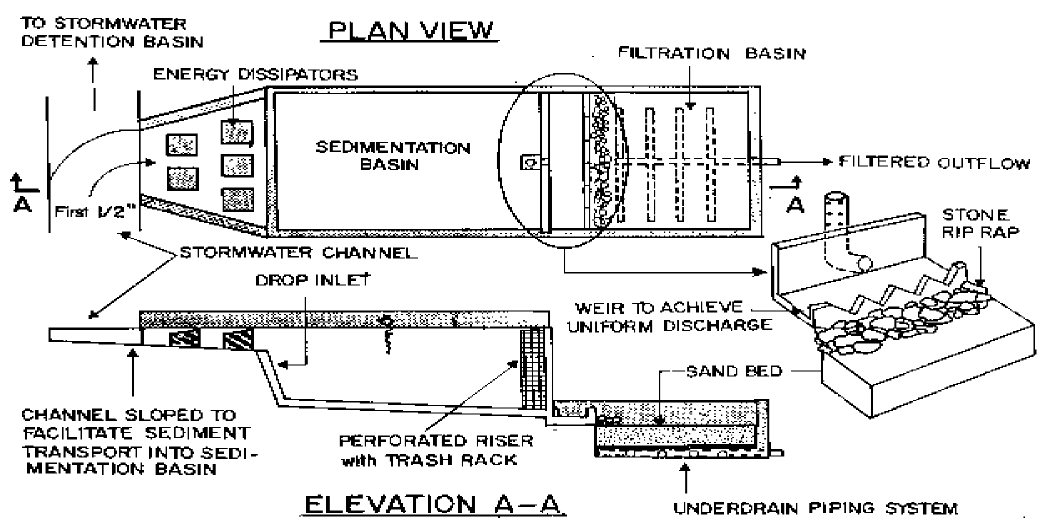


Source: Claytor and Schueler, 1996

<u>Surface Sand Filter</u>

The surface sand filter was developed in Florida in 1981 for sites that could not infiltrate runoff or were too small for effective use of detention systems. The city of Austin, Texas took the development of filter technology further in the mid-1980's. The surface sand filter system usually incorporates two basins. Runoff first enters a sedimentation basin where coarse particles are removed by gravity settling. This sedimentation basin can be either wet or dry. Water then flows over a weir or through a riser into the filter basin. The filter bed consists of sand with a gravel and perforated pipe under-drain system to capture the treated water. The surface of the filter bed may be planted with grass. Additional storage volume is provided above the filter bed to increase the volume of water that can be temporarily ponded in the system prior to filtration. This two-basin configuration can help to limit premature clogging of the filter bed due to excessive sediment loading. There are several design variations of the simple surface sand filter. Austin uses two variations, termed the partial and the full sedimentation-filtration systems. A diagram of the Austin surface sand filter is shown in Figure 5-8.

Figure 5-8. Austin Full Sedimentation-Filtration System

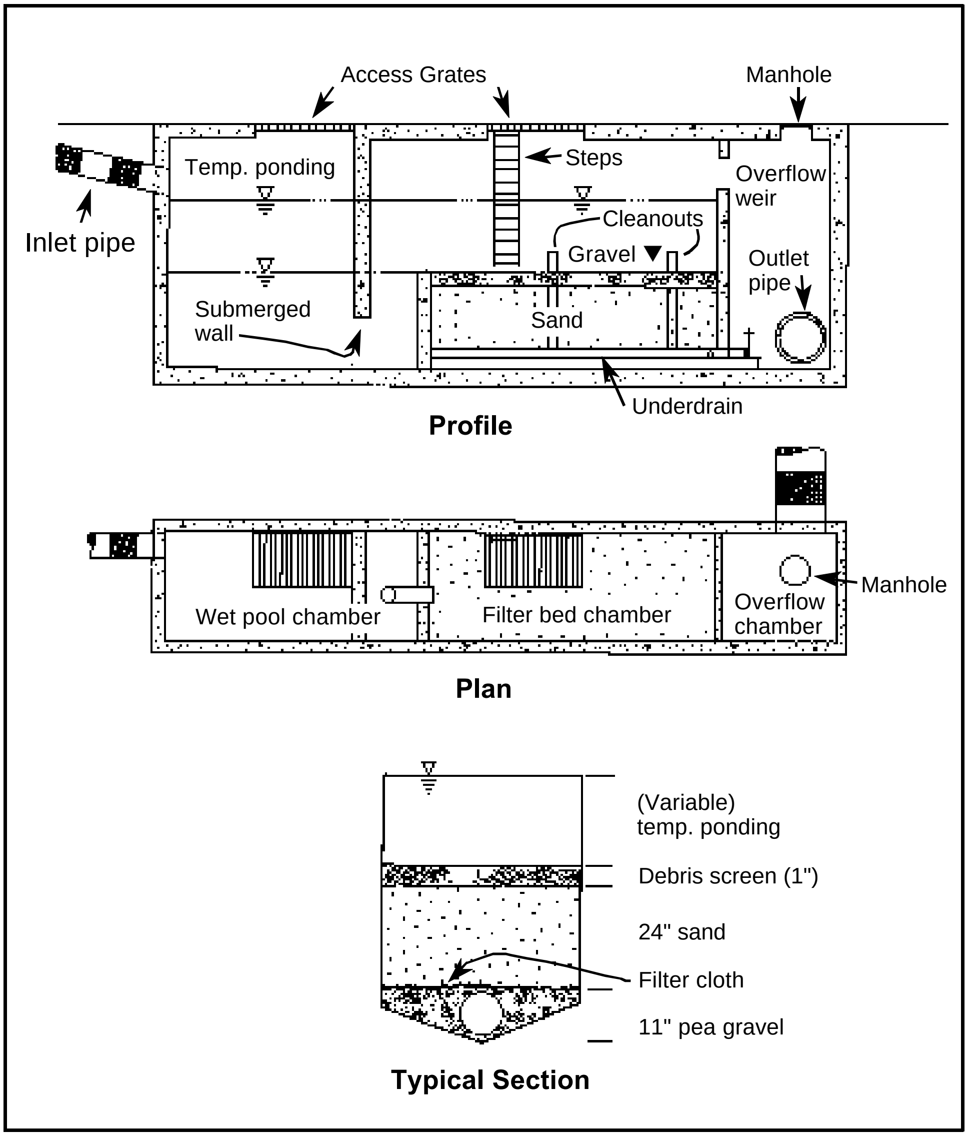


Source: Bell, 1998

Underground Vault Sand Filter

The underground vault sand filter was developed by the District of Columbia in the late 1980's. This filter design incorporates three chambers. The first chamber and the throat of the second chamber contain a permanent pool of water and functions as a sedimentation chamber and an oil and grease and floatables trap, as well as provides for temporary runoff storage. A submerged opening or inverted elbow near the bottom of the dividing wall connects the two chambers. This submerged opening provides a water seal that prevents the transfer of oil and floatables to the second chamber which contains the filter bed. During a storm event, water flows through the opening into the second chamber and onto the filter bed. Additional runoff storage volume is provided above the filter bed. Filtered water is collected by a gravel and perforated pipe under-drain system and flows into the third chamber, which contains a clearwell and a connection to the storm drain system. Overflow protection can be provided by placing the filter off-line, or by providing a weir at the top of the wall connecting the filter chamber with the clearwell chamber to serve as an overflow. A schematic of the "D.C. Sand Filter" is shown below.

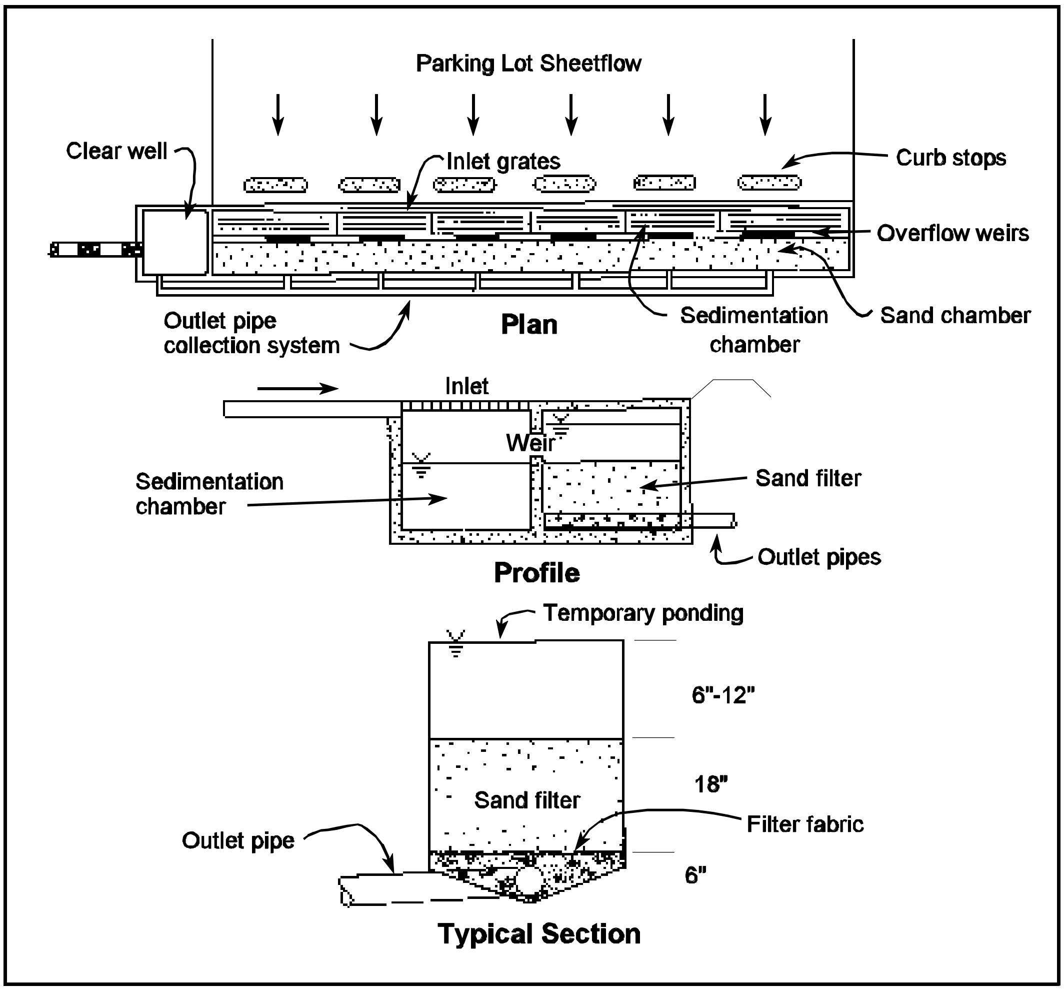
Figure 5-9. Underground Vault Sand Filter



Source: Claytor and Schueler, 1996.

Another underground vault sand filter, also termed a "perimeter" sand filter because it is particularly suited for use around the perimeter of parking lots, was developed in Delaware by Shaver and Baldwin and is known as the "Delaware Sand Filter." This system contains two chambers and a clearwell. Storm water runoff enters the first chamber, which serves as a sedimentation chamber. Water then flows over a series of weirs and into the second chamber which contains the filter media. Additional storage volume is provided by water temporarily ponding in both chambers. Filtered water is collected by a series of gravel and perforated pipe under-drains, and flows into a clearwell that contains a connection to the storm drain system. A schematic of the Delaware Sand Filter is shown below.

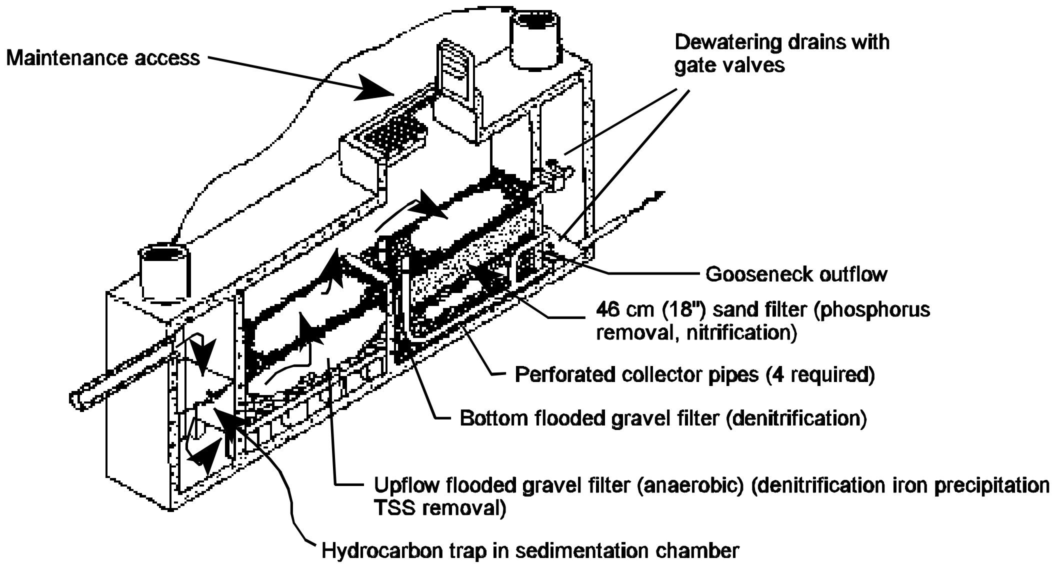
Figure 5-10. Delaware Sand Filter



Source: Shaver and Baldwin, 1991

In addition to the three basic filtering systems (D.C., Austin, and Delaware), there are a number of variations in use. The city of Alexandria, Virginia has developed a compound storm water filtering system (Bell, 1998). This design incorporates an anoxic filtration zone in a permanently flooded gravel layer in the filter. This anoxic zone aids in nitrogen removal by anoxic denitrification. Another configuration uses an upflow anaerobic filter upstream of the sand filter to enhance phosphorus removal by precipitating more iron on the sand filter. A diagram of the Alexandria Compound Filtration System is shown below.

Figure 5-11. Alexandria Compound Filter



Source: Bell, 1998.

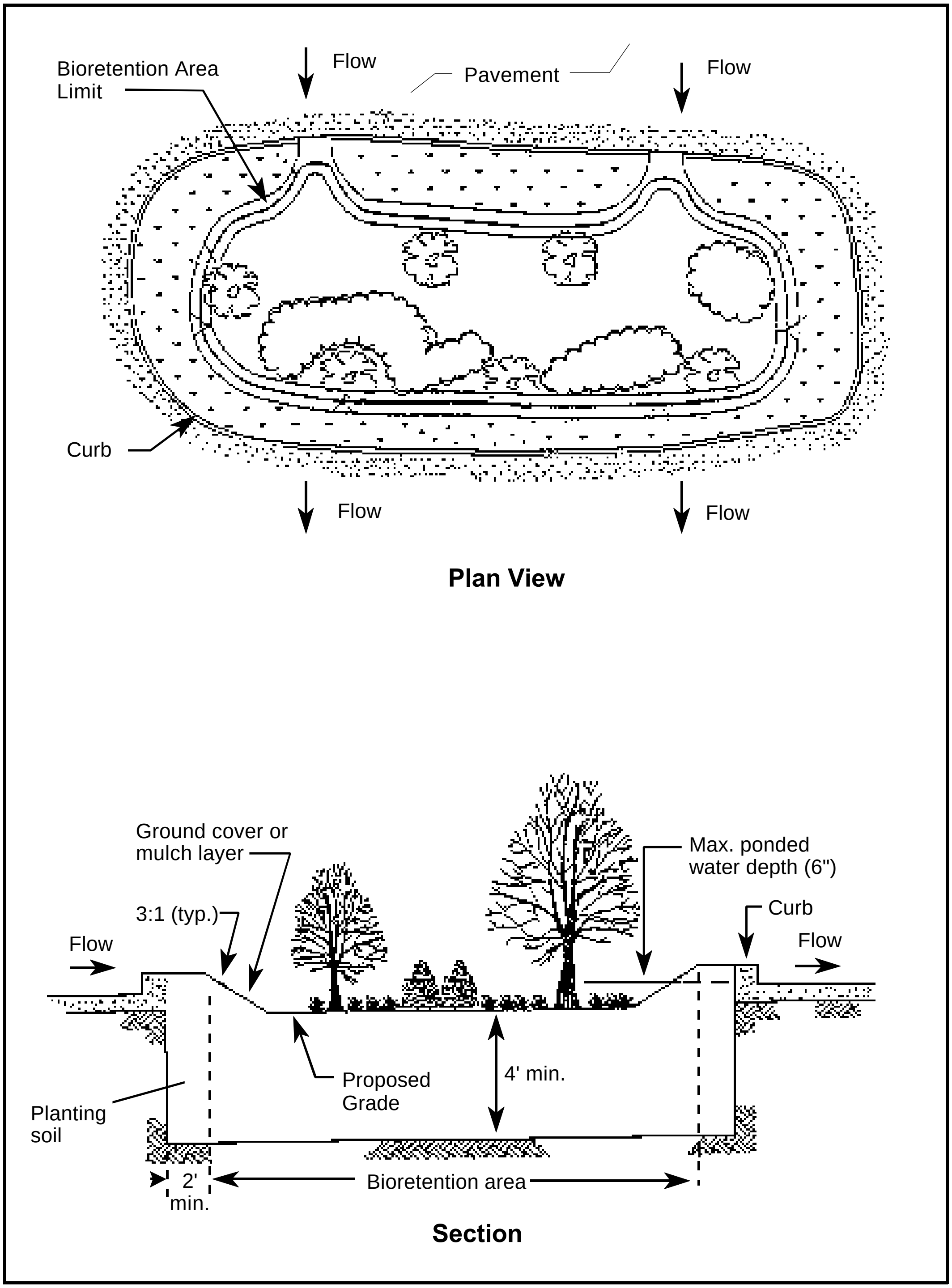
Filters that use an organic filtration media, such as peat or leaf compost, are useful in areas where additional nutrient or metal control is desirable due to the adsorptive capacity, its ion-exchange capability, and is ability to serve as a medium for the growth of a variety of microorganisms. However, peat must be carefully selected (fibric and/or hemic peat should be used, not sapric) and one must question the environmental consequences of destroying peat bogs to obtain filtration media when other technologies are available.

There are a number of references available that contain information on the design and selection of filtering systems for storm water treatment (Urbonas, 1999; Bell, 1998; Claytor and Schueler, 1996; Galli, 1990b; MDE, 1998; NVPDC, 1996a).

Biofiltration/Bioretention Systems

Bioretention systems are designed to mimic the functions of a natural forest ecosystem for treating storm water runoff. Bioretention systems are a variation of a surface sand filter, where the sand filtration media is replaced with a planted soil bed. Storm water flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition (Prince George's County, MD, 1993). Treated water is allowed to infiltrate into the surrounding soil, or is collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters. When water is allowed to infiltrate into the surrounding soil, bioretention systems can be an excellent source of groundwater recharge. A diagram of a typical bioretention area is shown below.

**Figure 5-12. Bioretention System
Traffic Island**



Source: Prince George's County, 1993.

The components of a bioretention system include:

- *Grass Buffer Strips* - runoff enters the bioretention area as sheet flow through the grass buffer strips. The buffers reduce the velocity of the runoff and filter particulates from the runoff.

- *Ponding Area* - The ponding area provides for surface storage of storm water runoff before it filters through the soil bed. The ponding area also allows for evaporation of ponded water as well as allows for settling of sediment in the runoff.

- *Organic Mulch Layer* - The organic mulch layer has several functions. It protects the soil bed from erosion, retains moisture in the plant root zone, provides a medium for biological growth and decomposition of organic matter, and provides some filtration of pollutants.

- *Planting Soil Bed* - The planting soil bed provides water and nutrients to support plant life in the bioretention system. Storm water filters though the planting soil bed where pollutants are removed by the mechanisms of filtration, plant uptake, adsorption and biological degradation.

- *Sand Bed* - the sand bed underlies the planting soil bed and allows water to drain from the planting soil bed through the sand bed and into the surrounding soil. The sand bed also provides additional filtration and allows for aeration of the planting soil bed.

- *Plants* - Plants are an important component of a bioretention system. Plants remove water though evapotranspiration and remove pollutants and nutrient through uptake. The plant species selected are designed to replicate a forested ecosystem and to survive stresses such as frequent periods of inundation during runoff events and drying during inter-event periods.

In addition to providing for treatment of storm water, bioretention facilities, when properly maintained, can be aesthetically pleasing. Bioretention facilities can be placed in areas such as parking lot islands, in landscaped areas around buildings, the perimeter of parking lots, and in other open spaces. Since local regulations frequently require site plans to incorporate a certain percentage of open landscaped area, additional land requirements for bioretention facilities are often not required. The layout of bioretention facilities can be very flexible, and the selection of plant species can provide for a wide variety of landscape designs. However, it is important that a landscape architect with proper experience in designing bioretention areas be consulted prior to construction to insure that the plants selected can tolerate the growing conditions present in bioretention facilities. Bioretention facilities can be adapted easily for use on individual residential lots. Prince George's County, MD has developed the concept of "rain gardens" which are small bioretention systems for use in single or multi-lot residential areas. They provide an easily maintainable, aesthetically pleasing, and effective means of controlling runoff from residential areas. By disconnecting down spouts and placing a series of bioretention areas throughout a residential area, the volume of storm water runoff produced and requiring subsequent management can be significantly reduced.

Additional design information on bioretention facilities can be found in *Design Manual for Use of Bioretention in Stormwater Management* (Prince George's County, 1993) and in *Design of Stormwater Filtering Systems* (Claytor and Schueler, 1996).

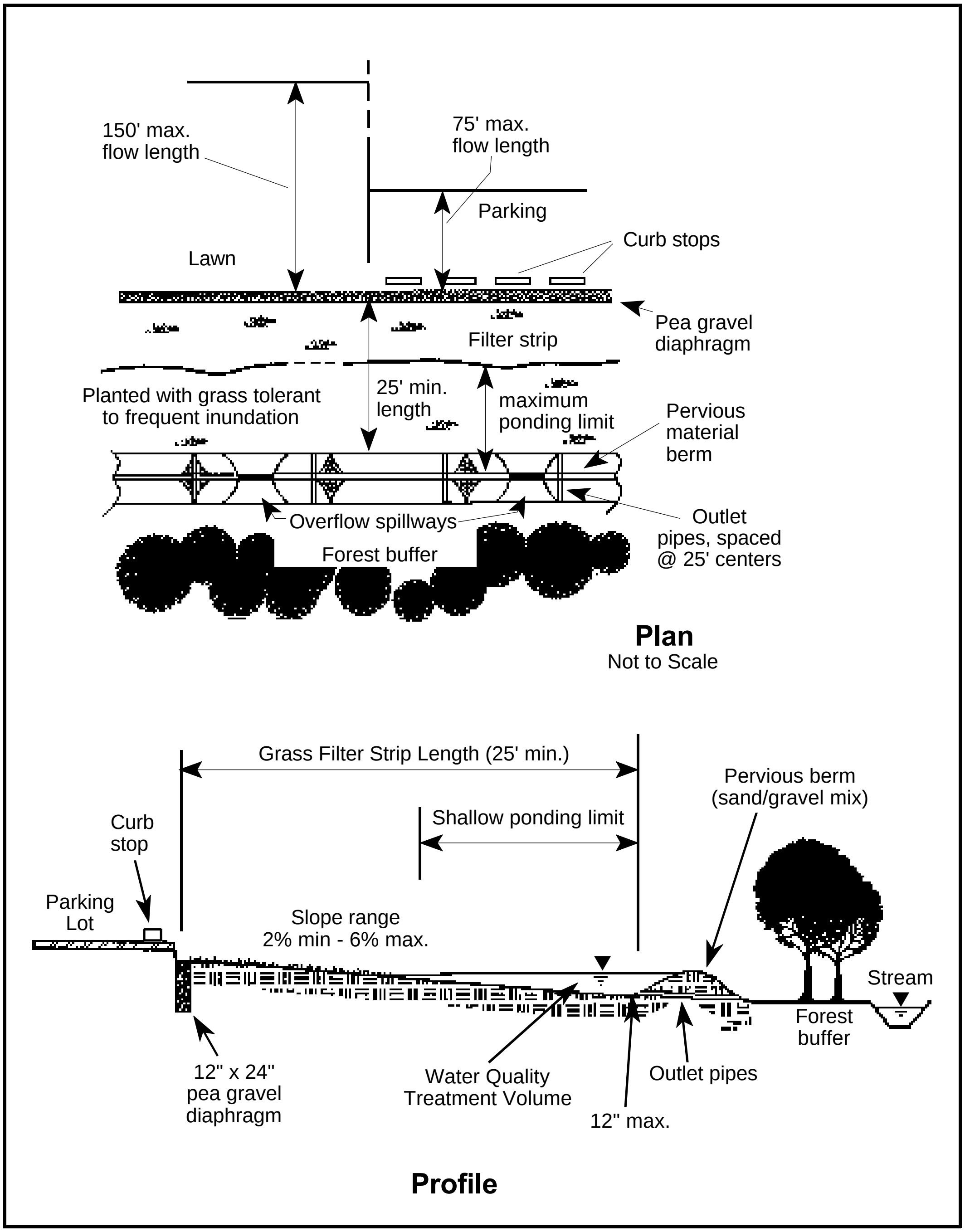
5.2.1.6 Vegetated Systems (Biofilters)

Vegetated systems such as grass filter strips and vegetated swales are used for conveying and treating storm water flows. These BMPs are commonly referred to as *biofilters*, since the grasses and vegetation "filter" the storm water as it flows. Open channel vegetated systems are alternatives to traditional curb-and-gutter and storm sewer conveyance systems. By conveying storm water runoff in vegetated systems, some degree of treatment, storage and infiltration can be provided prior to discharge to the storm sewer system. This can help to reduce the overall volume of storm water runoff that is generated from a particular drainage area.

<u>Grass Filter Strips</u>

Grass filter strips are densely vegetated, uniformly graded areas that intercept sheet runoff from impervious surfaces such as parking lots, highways and rooftops. Grass filter strips are frequently planted with turf grass, however alternatives that adopt any natural vegetated form such as meadows or small forest may be used. Grass filter strips can either accept sheet flow directly from impervious surfaces, or concentrated flow can be distributed along the width of the strip using a gravel trench or other level spreader. Grass filter strips are designed to trap sediments, to partially infiltrate this runoff and to reduce the velocity of the runoff. Grass filter strips are frequently used as a "pretreatment" system prior to storm water being treated by BMPs such as filters or bioretention systems. Grass filter strips can also be used in combination with riparian buffers in treating sheet flows and in stabilizing drainage channel banks and stream banks. In semi-arid climates, grass filter strips may need to be irrigated to maintain a dense stand of vegetation and to prevent export of unstabilized soil. A diagram of a grass filter strip is shown below.

Figure 5-13. Grass Filter Strip



Source: Claytor and Schueler, 1996.

Vegetated Swales

Vegetated swales are broad, shallow channels with a dense stand of vegetation covering the side slopes and channel bottom. Vegetated swales are designed to slowly convey storm water runoff, and in the process trap pollutants, promote infiltration and reduce flow velocities. Vegetated swales can be either wet or dry. Dry swales are used in areas where standing water is not desired, such as in residential areas. Wet swales can be used where standing water does not create a nuisance problem and where the groundwater level is close enough to the surface to maintain the permanent pool in inter-event periods. Wet swales provide the added benefit of being able to include a range of wetland vegetation to aid in pollutant removal.

5.2.1.7 Minimizing Directly-Connected Impervious Surfaces

Minimizing directly-connected impervious surface areas involves a variety of practices designed to limit the amount of storm water runoff that is directly connected to the storm drainage system. Runoff is instead directed to landscaped areas, grass buffer strips, and grassed swales to reduce the velocity of runoff, reduce runoff volumes, attenuate peak flows, and encourage filtration and infiltration of runoff (UDFCD, 1992). By incorporating these principles into site designs, the size and number of conventional BMPs such as ponds and constructed wetland systems can be significantly reduced.

Minimizing directly connected impervious surfaces incorporates both non-structural and structural control measures. Discussions in this section address the structural measures that can be incorporated into existing urbanized or newly developed areas to minimize the amount of runoff discharged to the storm drain system. Additional discussion on non-structural practices that can be used to minimize runoff generation in new developments is included in Section 5.2.3 "Low Impact Development Practices."

The Denver *Urban Storm Drainage Criteria Manual* (UDFCD, 1992) identifies the following three levels of minimizing directly connected impervious areas:

- *Level 1*: Runoff generated from impervious surfaces such as rooftops, driveways and parking lots is directed to flow over vegetated areas before flowing to a storm sewer system. This increases the travel time of runoff and promotes the removal of suspended solids by sedimentation and filtration.
- *Level 2*: Street curb-and-gutter systems are replaced by grassed swales and pervious street shoulders. Conveyance systems and storm sewer inlets are still used to collect runoff at downstream intersections and crossings.
- *Level 3*: In addition to incorporating Levels 1 and 2, swales are oversized and driveway and street crossing culverts are configured to use the grassed swales as detention basins having the capacity to capture runoff volume for a design storm (2-, 5-, 10- or 100-year runoff).

Practices that reduce the amount of directly connected impervious surfaces can easily be incorporated into site design plans during the planning stages of development projects. Using these practices can result in significant development cost savings due to the decreased need for drainage infrastructure and large end-of-pipe structural BMPs such as ponds and constructed wetlands. These practices can also limit secondary impacts from structural BMPs, such as temperature increases from retention ponds. Minimizing directly connected impervious areas can also be applied to existing urbanized areas through retrofit. Practices that can be used in retrofit instances include disconnecting rooftop downspouts from the storm drain system, use of on-site retention and infiltration to limit the amount of runoff leaving the site and replacing traditional curb-and-gutter systems with grassed swales and wetland channels. Additional discussion on practices that minimize runoff generation is included in Section 5.2.3.

5.2.1.8 Miscellaneous and Vendor-Supplied Systems

There are a wide variety of miscellaneous and proprietary devices that are used for urban storm water management. Many of these systems are "drop-in" systems, and incorporate some combination of filtration media, hydrodynamic sediment removal, oil and grease removal, or screening to remove pollutants from storm water. A few of the systems available include:

- BaySaver
- CDS Technologies
- Hydrasep®
- Storm*ceptor*®
- StormFilter™
- StormTreat™ System
- Vortechs™.

A thorough evaluation of vendor-supplied systems was not conducted in this report. Readers are encouraged to contact the product vendors to obtain information regarding these systems.

One of the main problems facing the use of proprietary devices is the lack of peer-reviewed performance data for these systems. Several vendor-supplied storm water treatment systems are being evaluated through EPA's Environmental Technology Verification (ETV) program. With financial assistance from the ETV program, the Civil Engineering Research Foundation (CERF) established the Environmental Technology Evaluation Center, commonly known as "EvTEC, " in 1998. EvTEC is a private sector program designed to utilize networks of experts, testing facilities and stakeholders to evaluate technologies dealing with a variety of environmental problems. One of the EvTEC projects is a collaborative effort with the Washington Department of Transportation (WSDOT) to verify the performance of innovative storm water BMPs under field operating conditions. These evaluations, which are scheduled to begin in 1999, are expected to provide comparable, peer-reviewed data on the performance of these systems (CERF, 1998).

5.2.2 Non-Structural BMPs

Non-structural BMPs include institutional and pollution-prevention type practices designed to prevent pollutants from entering storm water runoff or reduce the volume of storm water requiring management. Non-structural BMPs can be very effective in controlling pollution generation at the source, which in turn can reduce or eliminate the need for costly end-of-pipe treatment by structural BMPs. Non-structural BMPs discussed in this report include education and source controls, recycling and maintenance practices.

5.2.2.1 Education, Recycling and Source Controls

Public education can be an effective means of reducing the amounts of non-point source pollutants entering receiving streams. The public is often unaware that the combined effects of their actions can cause significant non-point source pollution problems. Proper education on day-to-day activities such as recycling of used automotive fluids, household chemical and fertilizer use, animal waste control and other activities can significantly reduce non-point source pollutant loadings to urban streams. The main components of a public education program include:

Automotive Product Disposal

Discharge of automotive fluids such as motor oil and antifreeze to the land or storm drains can cause significant water quality problems. "Do-it-yourself" automobile mechanics often incorrectly assume that materials that are dumped into storm drains will receive treatment at a wastewater treatment plant prior to discharge. Education on appropriate recycling and disposal techniques for these materials can help to reduce pollutant loadings to streams. Education programs should identify the location of community automotive products recycling centers. In addition to impacts associated with dumping used oil and antifreeze, potential runoff pollutant sources from home automobile maintenance activities include dirt, cleaners, oils and solvents from car washing, leaking fluids such as brake and transmission fluid and gasoline spills. To reduce impacts from these activities, the following practices should be used:

- all spills or leaks should be cleaned up using a dry absorbent such as cat litter or commercially available absorbents and disposed of appropriately;
- car washing should be done away from storm drains using biodegradable cleaners, or at a commercial carwash;
- all used fluids should be recycled or disposed of appropriately;
- all fluid leaks should be repaired as soon as possible to reduce loss to the environment.

Commercial and Retail Space Good Housekeeping

Commercial and retail areas can contribute significant pollutant loadings to runoff. The biggest contributor of pollutant is usually impervious surfaces used for vehicle parking, storage and maintenance areas, which can contribute sediment, metals and hydrocarbons. Other sources include raw material and finished product storage areas, pesticides and fertilizers from grounds maintenance, and rooftop runoff. Good housekeeping practices include using porous pavement or modular paving systems for vehicle parking lots; limiting exposure of materials and equipment to rainfall; spill cleanup, using dry cleanup techniques instead of wet techniques; and limiting direct runoff of rooftops to storm drains.

General Community Outreach

A main problem associated with identifying and controlling nonpoint source pollution is that the public is generally unaware of the sources and control measures for urban nonpoint source pollutants. Information dissemination is a critical need of most local storm water programs. Information that explains the sources of nonpoint source pollution, control measures available and the steps homeowners and commercial owners can do to reduce impacts of their activities can help to increase the public awareness of the need to control nonpoint source pollution. A few of the techniques available for providing educational materials to the public include television, radio and newspaper announcements, distribution of flyers, community newsletters, workshops and seminars, conducting teacher training programs at schools, and supporting citizen-based watershed stewardship groups and volunteer monitoring programs.

Industrial Good Housekeeping

Industrial areas can contribute significant loadings of toxic pollutants to storm water runoff. Therefore, educational programs that inform industrial site owners and operators about pollution prevention and source control programs to reduce nonpoint source pollutant can significantly reduce the amounts of pollutants discharged from industrial areas. Pollution prevention practices include minimizing or eliminating exposure of materials and products to rainfall by storing inside or under cover, spill cleanup, minimizing pesticide/herbicide and fertilizer use, and minimizing discharges of equipment wash water to storm drains.

Storm Drain Inlet Stenciling

Since storm drains frequently discharge runoff directly to water bodies without receiving any type of treatment, storm drain stenciling programs that educate residents not to dump materials into storm drains or onto sidewalks, streets, parking lots and gutters can be effective at reducing nonpoint source pollution associated with illegal dumping. Residents are frequently unaware that materials dumped down storm drains may be discharged to a local water body. Therefore, stenciling the inlets can be a simple yet effective means of alerting residents of this fact. The Northern Virginia *Nonstructural Urban BMP Handbook* (NVPDC, 1996b) contains a useful discussion on developing a storm drain stenciling program.

Pesticide/Herbicide Use

Due to their high aquatic toxicity, pesticides and herbicides can be a significant source of water quality impairment in urban streams. Pesticide usage in the United States was estimated at more than 1.2 billion pounds of active ingredients in 1995 (US EPA, 1997b). Of this total, agricultural usage constituted 939 million pounds (77 percent), commercial, industrial and government usage accounted for 150 million pounds (13 percent) and home and garden usage accounted for 133 million pounds (11 percent). A significant portion of these applications find their way into storm water runoff and ultimately into receiving streams through spray drift, transport by soils, solubilization by runoff, and by spillage, dumping and improper disposal of containers and residuals. Education on the proper methods of application, application rates and alternatives to pesticides can help to reduce the amount of pesticides that are carried by urban runoff. Alternatives to pesticides, such as in integrated pest management program and pesticide alternatives such as insecticidal soap or natural bacteria, can also reduce the need for pesticides.

Fertilizer Use

A significant amount of nutrients in urban runoff results from misapplication of fertilizer to the urban landscape. Residential lawn and garden maintenance and maintenance of landscape and turfgrass at golf courses, schools and commercial areas uses significant amounts of fertilizers containing nitrogen and phosphorus. Since most fertilizers are water soluble, over-application or application before rainfall events can allow significant quantities to be carried away by storm water runoff. Education on proper application of fertilizers can help to reduce the quantities of nutrients reaching receiving waters.

Household Hazardous Material Disposal

A variety of hazardous and potentially harmful chemicals and materials are improperly used and disposed of by residential homeowners. Materials such as paints and thinners, cleaning products, wood preservatives, driveway sealants and a variety of other miscellaneous household chemicals can find their way into storm water if improperly used, stored or disposed of. Education on usage and holding an annual or semi-annual community household hazardous waste collection program can help to reduce the amounts of these materials that enter storm water runoff.

Lawn Debris Management

Lawn debris such as grass trimmings and leaves require proper management in order to reduce impacts to urban streams. Grass trimmings and leaves can be carried away by runoff and can find their way into streams where they rapidly decompose and release nutrients. Grass trimmings and leaf litter can be controlled by composting or by community curbside collection programs. Composted yard debris can be an excellent source of mulch for residential landscape and gardens. Use of mulch can greatly reduce the need for inorganic fertilizers, which helps to keep nutrient loadings to streams to a minimum.

Pet Waste Disposal

Pet waste can cause significant loadings of bacteria, nutrients and oxygen demanding substances to urban runoff. Pet waste deposited on yards, sidewalks and streets can be carried by runoff into storm drains. As an example, it is estimated that 11,445 pounds of dog waste are generated in the Four Mile Run watershed in northern Virginia each day.[2] 378 pounds of BOD, 39 pounds of total phosphorus and 189 pounds of total nitrogen are washed off into Four Mile Run and its tributaries annually as a result of this pollution load (NVPDC, 1996b). In many areas,

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[2] This estimate was calculated based on the total waste load generated by the dog population in the area, not the waste load deposited on yards, sidewalks and streets.

regulations exist prohibiting the deposit of pet waste on public property. However, it is often very difficult to enforce these laws. Community education on the impacts associated with pet waste and alternative disposal methods such as flushing and disposal in the trash can help to reduce impacts associated with pest waste. A particularly useful method of controlling pet waste is for communities to provide pet waste receptacles in parks and other public areas for pet owners to deposit droppings from their pets.

Illicit Discharge Detection and Elimination

Illicit discharges to storm sewers can be a significant source of pollutants in urban storm water. A study conducted in Sacramento, California indicated that slightly less than one-half of the water discharged from a municipal separate storm sewer system was not directly attributable to precipitation runoff (US EPA, 1993b). A major source of illicit discharges to storm drain systems are direct connections of sanitary sewer piping to the storm drain system. In addition to direct connections, seepage and sewage from leaking sanitary sewer lines can find their way into storm drains, especially in areas where storm drains run parallel to the sanitary sewer lines. Spills can also be collected by storm drain inlets.

Detection and elimination of illicit connections and discharges can significantly reduce the concentrations of bacteria, nutrients and oxygen demanding substances contained in storm water discharges. Several methods exist for detection and elimination of illicit cross-connections. Useful indicators of the presence of cross connections include dry weather flows in storm sewer lines and biological indicators that indicate the presence of human fecal matter in storm drain outfalls. Once illicit connections are detected, excavation and correction of the illicit connections are necessary. In addition to detection and elimination of existing cross-connections, plans for new development should be carefully reviewed and inspections should be conducted during construction in order to prevent future cross-connections from being placed. Storm drain stenciling programs and a public spill reporting system can help to educate the public on proper procedures for managing spills to prevent discharge to the storm sewer system.

5.2.2.2 Maintenance Practices

Maintenance programs are necessary in order to reduce the pollutant contribution from the urban landscape and to ensure that storm water collection and treatment systems are operating as designed. Major maintenance practices that can be used include:

Catch Basin Cleaning

Catch basins naturally accumulate sediment and debris such as trash and leaf litter. In order to ensure their continued effectiveness, catch basins need to be periodically cleaned. This can be done by manual means, or by using a vacuum truck.

Street and Parking Lot Sweeping

Urban streets and parking lots can accumulate large amounts of pollutants that can be washed off during storm events. Streets and parking lots comprise a significant portion of the total impervious area within a developed watershed, and a large percentage, if not the entire area, of streets and parking lots are usually directly connected to the storm drain system. In an investigation conducted by Bannerman (Bannerman et al, 1993), data on runoff volumes from streets and parking lots collected during 4 years from two urbanized areas in Wisconsin indicated that 54 percent of the total runoff volume from residential areas was due to direct runoff from streets and parking lots, and that 80 percent of the total runoff volume from commercial areas was due to direct runoff from streets and parking lots. A breakdown of the runoff volumes based on source area is shown in Table 5-1.

Table 5-1. Percent Runoff Volumes Contributed by Source Area in Two Urbanized Areas of Wisconsin

Land Use	**Source Area Percent Runoff Contribution**					
	Feeder Streets	Collector Streets	Arterial Streets	Parking Lots	Total % due to roads and parking lots	Total Other %*
Residential	34	20	--	--	54	46
Commercial	--	10	21	49	80	20

* Other land uses include lawns, driveways, rooftops and sidewalks
Source: Adapted from Bannerman et al, 1993

Furthermore, Bannerman found that runoff from streets and parking lots contributed a significant portion of the total runoff pollutant loading. Table 5-2 summarizes the pollutant load contributions based on land uses, and indicates the total contaminant contribution in the urbanized area attributable to runoff from streets and parking lots.

Table 5-2. Contaminant Load Percentages in Two Urbanized Areas of Wisconsin

Contaminant	Percent Contribution by Source Area						Total Contaminant Contribution by Streets and Parking Lots
	Residential		*Commercial*		*Industrial*		
	Streets	**Parking Lots**	**Streets**	**Parking Lots**	**Streets**	**Parking Lots**	
Total Solids	76	--	57	31	20	60	**78**
Suspended Solids	80	--	68	27	25	55	**80**
Total Phosphorus	58	--	56	28	19	29	**54**
Dissolved Phosphorus	46	--	50	27	18	11	**39**
Dissolved Copper	73	--	50	39	16	73	**82**
Total Copper	78	--	60	32	22	67	**85**
Total Zinc	80	--	45	32	9	30	**49**
Fecal Coliform	78	--	82	10	10	19	**71**

Source: Adapted from Bannerman et al, 1993

Based on these data, streets and parking lots can contribute significant pollutant loadings to urban runoff. Therefore, sweeping programs that can remove a portion of these materials from streets and parking lots may significantly reduce the pollutant load contributions to urban runoff.

Road and Ditch Maintenance

Road and street surfaces undergo breakdown due to frictional action of traffic, freeze-thaw breakdown, frost heaving, and erosion of road subbase. Failure to correct deteriorating pavement can allow exposure of unstabilized subbase material to erosive forces of water and subsequent increases in suspended solids concentrations. The same process occurs in roadside ditches where high runoff rates cause channelization and erosion. Roadside ditches also accumulate sediment and debris from the road surface, which enters runoff during rainfall events. Maintenance of roads and cleaning and stabilization of ditches can help to reduce pollutant loadings from these sources. In roadside ditches, reducing the length and slope of ditch runs and reducing the velocity of runoff by using check dams can help to prevent excessive channelization and erosion.

Road Salting and Sanding

Road salting and sanding can contribute large quantities of sediment and salts to runoff. Highway maintenance programs in areas where road icing is a problem frequently apply large quantities of sand, salt, and coal ash to prevent icy road surfaces. Snowmelt can carry a large portion of these materials into the storm drainage system and ultimately to receiving streams. High salt concentrations can have significant impacts on receiving streams. In addition, road salt can contain cyanide, which may cause acute or chronic toxicity to aquatic organisms. Alternative deicing products such as acetates, formates and agricultural residues can be used if impacts due to traditional deicing products are significant.

Sediment and Floatables Removal from BMPs

Sediment and floatables removal is an important component of maintenance for BMPs that are designed for sediment capture. Removal of accumulated sediment is important so that the BMP continues to operate efficiently. Accumulation of excess sediment in pond and constructed wetland systems can lead to reduced storage capacity, short-circuiting and re-suspension of previously settled particles. All of these can lead to decreased efficiency of the BMP. Floatables in BMPs can accumulate and block outlet structures leading to changes in BMP hydraulics. Floatables can cause aesthetic impacts, and floating material such as algal scum and other debris can lead to odor problems. Sediment removal is also needed periodically in filtration systems. Sedimentation chambers require periodic cleanout of sediments and floatables (including accumulated oil) and filter beds will accumulate a sediment layer on the surface that will decrease the filtration rate of the system over time. Periodic removal of this sediment layer and a portion of the filtration media is necessary in order to restore the filtration capacity of the system. Sediments also accumulate in infiltration basins. The accumulation of sediments, particularly sediments from construction activities and improperly stabilized soil, will lead to a rapid reduction of the infiltrative capacity of infiltration basins, trenches and wells.

The frequency of sediment removal in BMP types can vary widely. Some BMPs require sediment removal every two or three years, while others may not need maintenance for more than 20 years. The frequency that sediment must be removed depends greatly on the land use and degree of soil stabilization in the contributing watershed. BMPs that receive runoff from a watershed that has significant construction activities will accumulate sediment at a rate much faster than a watershed with little or no construction activity. In addition, watersheds with dense, well established vegetation will contribute less sediment than sparsely vegetated watersheds. Also, watersheds in arid or semi-arid regions, which frequently are subject to high intensity rainfall and highly erosive storm water flows will produce large quantities of solids requiring frequent removal from BMPs. Table 5-3 summarizes maintenance requirements and frequency for different structural BMP types.

Vegetation Maintenance

Vegetative BMPs such as constructed wetlands, grassed filter strips, vegetated swales, and bioretention facilities require periodic vegetation maintenance to enhance performance. Grassed filter strips and vegetated swales require a dense stand of vegetation in order to function properly and to prevent export of sediment from unstabilized planting areas. Several seasons of planting and re-seeding of sparsely vegetated areas may be needed in order to reach optimum performance. Constructed wetland systems frequently require re-planting of wetland vegetation in areas where original plantings failed to become established. Once wetland systems are functioning, periodic vegetation harvesting is necessary to remove excess vegetation and stored nutrients. Invasive species also need to be periodically removed to promote growth of beneficial wetland vegetation. Grassed filter strips and vegetated swales require periodic mowing to remove excess vegetation and stored nutrients. Mowing of these systems should not be done too close to the ground, as dense vegetation is needed for optimum performance.

General BMP Maintenance

BMPs require a variety of periodic maintenance activities in order to enhance performance. In addition to sediment removal and vegetation maintenance, periodic maintenance and repair of outlet structures is needed, filtration media need to be periodically replaced, and eroded areas need to be repaired, to name a few. Table 5-3 summarizes general maintenance activities and frequency for a few BMP types. The actual maintenance schedule varies considerably based on site-specific conditions, and the values given should be used only as a general guideline for established residential or commercial areas without significant inputs of construction sediment or other sediment loadings.

Table 5-3. Recommended BMP Maintenance Schedules

BMP	Activity	Schedule
Retention Pond / Wetland[1]	• Cleaning and removal of debris after major storm events • Harvest excess vegetation • Repair of embankment and side slopes • Repair of control structure	Annual or as needed
	• Removal of accumulated sediment from forebays or sediment storage areas	5-year cycle, or as needed
	• Removal of accumulated sediment from main cells of pond once the original volume has been significantly reduced	20-year cycle (although can vary)
Detention Basin	• Removal of accumulated sediment • Repair of control structure • Repair of embankment and side slopes	Annual or as needed
Infiltration Trench[1]	• Cleaning and removal of debris after major storm events • Mowing[4] and maintenance of upland vegetated areas • Maintenance of inlets and outlets	Annual or as needed
Infiltration Basin[2]	• Cleaning and removal of debris after major storm events • Mowing[4] and maintenance of upland vegetated areas	Annual or as needed
	• Removal of accumulated sediment from forebays or sediment storage areas	3- to 5-year cycle
Sand Filters[3]	• Removal of trash and debris from control openings • Repair of leaks from the sedimentation chamber or deterioration of structural components • Removal of the top few inches of sand and cultivation of the surface when filter bed is clogged (only works for a few cycles) • Clean-out of accumulated sediment from filter bed chamber • Clean out of accumulated sediment from sedimentation chamber	Annual or as needed

1. Modified from Livingston et al (1997)
2. Modified from Livingston et al (1997), based on infiltration trench requirements
3. Modified from Claytor and Schueler (1996)
4. Mowing may be required several times a year, depending on local conditions

Table 5-3. Recommended BMP Maintenance Schedules (continued)

BMP	Activity	Schedule
Bioretention[1]	• Repair of eroded areas • Mulching of void areas • Removal and replacement of all dead and diseased vegetation • Watering of plant material	Bi-Annual or as needed
	• Removal of mulch and application of a new layer	Annual
Grass Swale[2]	• Mowing[4] and litter and debris removal • Stabilization of eroded side slopes and bottom • Nutrient and pesticide use management • De-thatching swale bottom and removal of thatching • Discing or aeration of swale bottom	Annual or as needed
	• Scraping swale bottom, and removal of sediment to restore original cross section and infiltration rate • Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle
Filter Strip[3]	• Mowing[4] and litter and debris removal • Nutrient and pesticide use management • Aeration of soil in the filter strip • Repair of eroded or sparse grass areas	Annual or as needed

1. Modified from Prince George's County (1993)
2. Modified from Livingston et al (1997)
3. Modified from Livingston et al (1997) based on grass swale recommendations
4. Mowing may be required several times a year, depending on local conditions

5.2.3 Low-Impact Development Practices

There are a number of low-impact development practices that can be used at the site level. While these practices often do not produce direct removal of pollutants from runoff, they can significantly reduce runoff volumes that are generated, reduce the impacts associated with runoff and reduce the need for conventional structural BMPs. There are a number of practices that are in use, and therefore an exhaustive summary has not been included in this document. However, a few of the more common practices in use are presented briefly in the following sections.

Minimizing Impervious Areas

Minimizing the amount of impervious surfaces that are created in a new development can greatly reduce the volume of storm water runoff that is generated. There are many opportunities that exist for reducing impervious surfaces, including:

- limiting the number, length and radius of cul-de-sacs;

- using porous pavement or modular block pavers in parking areas and low-traffic areas;
- reducing the width of streets;
- placing sidewalks on only one side of the street;
- reducing frontage requirements to lessen paved surface areas.

Although the above practices can reduce the amounts of impervious surfaces that are created, there will still be a great deal of impervious surfaces that must be included into a site plan such as rooftops, streets, driveways and lawns. To limit the impacts associated with runoff from these surfaces, it is important to limit the amount of areas that are directly connected to the storm drainage system. This can be accomplished by providing on-site retention and infiltration to collect rooftop and driveway runoff, and through the use of BMPs such as grassed swales, vegetated filter strips and wetland channels in place of traditional curb-and-gutter systems.

Directed Growth

Directed growth involves placing controls on land use through mechanisms such as master planning and zoning ordinances. Local governments may utilize these mechanisms in order to protect sensitive areas from development and to target growth to areas that are more suitable for development where it is easier to control the impacts associated with runoff. Directed growth can be a complex process, and must balance a number of factors such as economic considerations, local laws and ordinances, secondary impacts such as increased traffic and population in certain areas, as well as the availability of public utilities such as sewage treatment and drinking water service, and schools, hospitals and fire stations. Nevertheless, with careful planning and consideration, directed growth can help to reduce impacts associated with development of an area.

Sensitive Area Protection

Sensitive area protection is an important component of conservation design. Sensitive areas include the areas adjacent to streams, wetlands and natural drainage channels, cold water fisheries, shellfish beds, swimming beaches, recharge areas, and drinking water supplies. These areas are particularly susceptible to degradation by storm water runoff. Preservation of these areas and incorporation of stream and wetland buffers into site plans can help to preserve the integrity of these areas.

Open Space Preservation

Preservation of open space such as forested areas and meadows can help to reduce the impacts associated with development of an area. Open space preservation helps to reduce the generation of runoff, and can reduce the overall impact that results from development of an area by limiting the amount of impervious areas that are created. Open space allows the preservation of buffers and natural drainage corridors, and retains the natural storm water filtering, retention and infiltration effects of these areas. Open space can also increase the aesthetics of a development, and make the area more desirable to potential home buyers.

Minimizing Soil and Vegetation Disturbance

Soil and vegetation disturbance can significantly increase the amount of runoff that is generated from a site and the concentrations of pollutants that are transported by the runoff. Disturbed soil areas are particularly susceptible to erosion during storm events. Vegetation helps to stabilize soil and prevent detachment and transport by flowing water. By minimizing the area that is disturbed to only areas undergoing active construction (often termed "fingerprinting"), erosion of soil can be minimized. In addition, disturbance of soil and vegetation should be limited to only those areas that are necessary. Disturbing soil by excavation, grading and compaction reduces the infiltrative capacity of the soil, creating additional runoff that must be managed. Maintaining naturally vegetated areas minimizes the amount of increased runoff that is produced.

5.3 BMP Selection

BMP selection is a complex process. There are a number of competing factors that need to be addressed when selecting the appropriate BMP or suite of BMPs for an area. It should be stressed that BMPs should be incorporated into a comprehensive stormwater management program. Without proper BMP selection, design, construction and maintenance, BMPs will not be effective in managing urban runoff. BMP selection can be tailored to address the various sources of runoff produced from urbanized areas. For example, a particular suite of BMPs may be developed for use on construction sites and new land development, where opportunities exist for incorporating BMPs that are focused on runoff prevention, reducing impervious surfaces and maintaining natural drainage patterns. In established urban communities, a different suite of BMPs may be more appropriate due to space constraints. In these areas, BMPs may be selected to focus on pollution prevention practices along with retrofit of the established storm drain system with regional BMPs. *Site suitability* for selecting a particular BMP strategy is key to successful performance. Most BMPs have limitations for their applicability, and therefore cannot be applied nationwide. A few considerations to incorporate into BMP selection are:

- drainage area;
- land uses;
- average rainfall frequency, duration and intensity;
- runoff volumes and flow rates;
- soil types;
- site slopes;
- geology/topography;
- availability of land;
- future development/land use in watershed;
- depth to groundwater table;
- availability of supplemental water to support vegetative BMPs;
- susceptibility to freezing;
- safety and community acceptance;
- maintenance accessability;
- periodic and long-term maintenance/rehabilitation needs.

In addition to site-specific applicability requirements, factors such as BMP cost, local regulations or requirements, aesthetics, the experience of a developer or contractor with a particular design, and competing receiving water considerations such as temperature and nutrient levels should be addressed. The combination of these factors make selection of appropriate BMPs a difficult task, and one that should be done only by an experienced storm water practitioner. This is especially true in established urban areas, where knowledge of local factors that affect design and performance is needed. BMP use in arid and semi-arid climates also presents unique challenges. The availability of water to support vegetative and open pool BMPs such as retention ponds and wetland systems is of primary concern in these areas. Without adequate water sources, these systems may not function properly and may become public nuisances. A designer with adequate experience in designing BMPs for arid climates should be consulted in these instances. In addition to arid climates, BMP use in areas where freezing conditions can be encountered presents design problems. In cold climates, design modifications may be needed to adjust for freezing and spring snowmelt (Caraco and Claytor, 1997). Given the variety of local considerations that exist, developing a matrix of BMP applicability is outside of the scope of this report. There are several references that readers should consult to obtain additional information on BMP selection, including *Fundamentals of Urban Runoff Management* (Horner et al, 1994), *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs* (Schueler, 1987), *A Watershed Approach to Urban Runoff: Handbook for Decisionmakers* (Terrene Institute, 1996), *Urban Targeting and BMP Selection* (Terrene Institute, 1990), *Guidance Specifying Management Measures for Sources on Nonpoint Source Pollution in Coastal Waters* (US EPA, 1993a), *Handbook Urban Runoff Pollution Prevention and Control Planning* (US EPA, 1993c), *Municipal Wastewater Management Fact Sheets: Storm Water Best Management Practices* (US EPA, 1996e), *Design and Construction of Urban Stormwater Management Systems* (WEF and ASCE, 1992), and *Urban Runoff Quality Management* (WEF and ASCE, 1998).

5.4 Monitoring BMP Effectiveness

Monitoring the effectiveness of BMPs can be done in a number of ways. Since urban runoff frequently contains pollutants that can contribute to water quality impacts to receiving streams, the ability of a BMP to remove pollutants from runoff is often of concern. The typical method for measurement of the pollutant removal efficiency of a BMP system is to collect and analyze *water quality samples*. This can be accomplished by measuring the concentration of a target parameter or group of parameters in an inflow sample or set of samples and comparing these values to samples collected from the outflow of the BMP. The reduction in concentrations or loading across the BMP can be termed the pollutant removal efficiency.

In addition to monitoring the pollutant removal efficiency of BMPs, it is important to *monitor the hydraulic performance* of the BMP. A major problem associated with urban runoff is the total volume and flow rate of water that is discharged to the storm sewer system or the receiving stream. To evaluate the effectiveness of BMPs in reducing these impacts, hydraulic parameters such as the reduction in peak discharge rate, reduction in total volume discharged, and the time effects of discharges are frequently measured. To do this, measurement of flow rates and water volumes into and out of the system are conducted by using flow monitoring equipment.

Since the ultimate goal of BMPs is to protect or improve the quality of receiving streams, another method of evaluating the effectiveness of BMPs is to *evaluate the quality of waters receiving runoff*. Measures of water quality such as pollutant levels, pH, dissolved oxygen and other parameters can give an indication as to the effectiveness of a given BMP or group of BMPs. Evaluation of the contaminant levels present in sediments of receiving waters is also an important measure of BMP effectiveness. In addition, measures of aquatic habitat and stream channel morphology can give an indication as to the effectiveness of BMPs in controlling impacts or improving channel or habitat quality. Another measure to evaluate the effectiveness of BMPs is to measure the organisms that live in the receiving stream. Biological indicators such as macroinvertebrate counts, fish counts, and aquatic plant surveys can indicate the overall health of the receiving stream and indicate, over time, the effectiveness of BMPs. A potential problem with in-stream indicators is that it is sometimes difficult to isolate the impacts or improvements attributable to one particular variable. Since there are potentially a number of different factors that can influence a stream such as the amount of riparian cover, the existence of point source discharges, seepage from on-site disposal systems, as well as urban runoff, in can be very difficult to isolate impacts or improvements attributable to one particular stressor. Therefore, many years of data, collected both before and after a BMP implementation, may be needed to indicate a change. In spite of these shortcomings, in-stream monitoring and evaluation of the cumulative effects in a watershed as a result of BMP implementation is a very important measure of BMP effectiveness.

5.4.1 Water Quality Monitoring of BMPs

BMP monitoring can be conducted for a number of reasons, and the type of monitoring conducted and the instrumentation or equipment used can vary greatly depending upon the parameters of interest. BMP monitoring and data analysis is a complex process, and therefore a thorough explanation of all of the available monitoring practices and procedures is not included here. An important point to emphasize with respect to BMP monitoring is that consistent data reporting is needed in order to compare data between studies. Consistent reporting of BMP design parameters and watershed parameters as well as consistent monitoring methods and data analysis protocols is key to conducting data comparisons. It is recommended that individuals conducting BMP monitoring use the data reporting protocols developed by the American Society of Civil Engineers (ASCE) for the National Stormwater BMP Database (Urbonas and Strecker, 1996). These protocols are included with the database software, and are also available from the ASCE website.[3]

The following discussion includes a description of the most common methods used to evaluate BMP performance. Readers are encouraged to consult various monitoring manuals that

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[3] The website address is http://www.asce.org/peta/tech/nsbd01.html

are available and papers that are contained in the literature for more detailed information on BMP monitoring and data analysis. Recommended references include *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (US EPA, 1997c), *NPDES Storm Water Sampling Guidance Document* (US EPA, 1992c), and *Stormwater NPDES Related Monitoring Needs* (Torno, 1995).

BMPs are frequently evaluated by collecting inflow and outflow samples and comparing concentrations of pollutants. Samples can be collected in a number of different ways. The most common way is by collecting flow- or time-weighted composite samples from inflow and outflow points and measuring the concentrations of a targeted group of parameters in these samples. Composite samples can be collected by using automatic samplers, or by collecting a series of discrete samples and manually compositing. Composite samples are useful for determining an overall average or “event mean” concentration for a particular sampling point, and are commonly used to evaluate BMP performance. However, composite samples cannot be used to evaluate any trends in pollutant concentrations over time or varying flow rates. In order to conduct these types of evaluations, it is necessary to collect a series of discrete grab samples either by an automatic sampler or by collecting grabs manually. By collecting a series of discrete time-weighted or flow-weighted samples, a “pollutograph” of concentration versus time or flow rate can be prepared, which can give insight into the performance of the BMP under various hydraulic loadings. Sample results can then be combined mathematically to determine representative event mean concentrations. Manual grab samples are also used for collecting samples that are not amenable to collection by automated equipment, such as microbiological samples, samples for oil and grease evaluation, and samples for volatile organic compounds analysis.

BMP monitoring frequently incorporates measurements of water flow rates and volumes into and out of the system. Flow rates are frequently determined by using a combination of a primary control device (weir, flume or orifice) that is calibrated to discharge water according to a known relationship based on the depth of the water flowing over or through the device, along with a secondary control device (bubbler, pressure transducer, float, etc.) that is used to measure the depth of water flowing through or over the primary control device. A digital recorder is frequently used to record the depth of water measured by the secondary control device and to calculate the flow rate through the primary control device based on a pre-determined relationship between water depth and flow rate. The digital recorder can be used to log this flow data for subsequent retrieval and analysis, and can activate automated sampling equipment to collect samples at pre-determined flow rates or times. By using a configuration such as this, flow-weighted samples or discrete samples can be collected automatically, reducing or eliminating the need for personnel to be on-site during an event.

In addition to measuring surface runoff contributions to BMPs, measurement of the contribution of groundwater and subsurface flow may be necessary for BMPs that have a significant groundwater contribution. Constructed wetland systems that are close to or at groundwater level are a good example of BMPs where measurement of groundwater flows may be necessary.

BMP monitoring programs also frequently incorporate measurements of rainfall depths, intensities and duration by using a rain gauge. Additional meteorological monitoring equipment can measure parameters such as air temperature, solar radiation, humidity, atmospheric pressure and wind speed and direction, which can aid in interpreting BMP performance data. Other instruments such as continuous pH, dissolved oxygen, and conductivity meters are also frequently incorporated into BMP monitoring programs in order to measure parameters of interest.

BMP monitoring programs can also include measurements of the atmospheric deposition rates of pollutants by using wet deposition and dry deposition sampling equipment. Atmospheric deposition can contribute significant loadings of pollutants to storm water BMPs, especially to BMPs that have a large surface area such as ponds or constructed wetlands.

Analysis of data collected from BMP monitoring programs can be conducted in a number of ways. Some of the most common methods used to measure effectiveness are measures of pollutant removal efficiency based on event mean concentrations (EMC). An event mean concentration can be determined directly from a flow-weighted composite sample. Estimations of pollutant removal efficiency in use include the efficiency ratio, the summation of loads, and the regression of loads. These methods are defined as follows (from Martin and Smoot, 1986 and reported by Strecker, 1995):

- The efficiency ratio (ER) is defined in terms of the average event mean concentration of pollutants from inflows and outflows:

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

- The summation of loads method is based on the loads of pollutants removed during monitored storms:

$$SOL = 1 - \frac{\sum\ of\ outlet\ loads}{\sum\ of\ inlet\ loads}$$

- The regression of loads method defines the efficiency ratio as the slope of a simple linear regression of inlet loads and outlet loads of pollutants. The equation is:

$$Loads\ in = \$ \cdot Loads\ out$$

where β equals the slope of the regression line, with the intercept constrained at zero.

The above are only a few of the methods available for computing BMP pollutant removal efficiency. The selection of method can have a large impact on the reported removal efficiency. As a result, reported removal efficiency is not always comparable between studies due to differences in the way that pollutant removal was calculated. Additional work is needed in this area in order to standardize BMP data analysis and reporting.

5.4.2 Receiving Stream Assessments

Receiving stream assessments are an important means of determining the effectiveness of BMPs. The health of the biological community and the quality of the habitat present in the stream can be strong indicators of the effectiveness of BMPs. There are a number of biological indicators that can be used to evaluate streams, and a discussion of these methods is not within the scope of this document. Readers are encouraged to consult available documents for additional information on this subject, and for recommendations on developing biological criteria programs. Recommended readings include *Biological Criteria Technical Guidance for Streams and Small Rivers* (US EPA, 1996c) and *Restoring Life in Running Waters: Better Biological Monitoring* (Karr and Chu, 1998).

Physical habitat and fish and macroinvertebrate diversity indices have been identified as suitable indicators to assess the effectiveness of storm water controls (Center for Watershed Protection, 1996). EPA's *Rapid Bioassessment Protocols for Use in Streams and Rivers* (US EPA, 1997f) can be used to survey biological communities. In addition, many local and state environmental protection agencies have developed monitoring protocols for streams within their geographic area. Readers are encouraged to contact county and state environmental agencies to obtain more information regarding stream assessments. In addition to surveys of biological communities, measures of stream habitat are also useful for determining the effectiveness of BMPs. Some available methods for assessing habitat include:

- Physical habitat assessment component of EPA's Rapid Bioassessment Protocols;
- The Rapid Stream Assessment Technique (RSAT);
- The Ohio EPA's Qualitative Habitat Evaluation Index (QHEI);
- The Rosgen Stream Classification.

EPA used several receiving stream assessment methods in its 1998 field work at one BMP site. Findings from these assessments will appear in a supplement to this report.

5.5 Effectiveness of BMPs in Managing Urban Runoff

There has been a great deal of storm water and BMP monitoring data collected by a number of organizations. However, most of these data have focused on characterization of pollutants in runoff, and not on the effectiveness of various control measures. Several nation-wide monitoring programs have been conducted to characterize pollutants in urban storm water runoff and to evaluate the performance of storm water BMPs. The major federal monitoring programs that have been conducted are listed in Table 5-4.

Table 5-4. Sources of Storm Water Runoff and BMP Monitoring Data

Data Source	Year	Type of Monitoring Conducted
"208 Studies" under FWPCA Amendments of 1972	late 1970's	Limited storm water quality data
Nationwide Urban Runoff Program (NURP)	1978-83	Storm water quality data collected at 81 outfalls at 28 cities for a total of 2,300 storm events as well as some BMP data
Federal Highway Administration (FHWA)	1970's - 80's	Storm water runoff loadings from highways at 31 sites in 11 states
USGS Urban Storm Studies*	1970's - 90's	Rainfall, runoff and water-quality data for areas throughout the United States
Phase I NPDES Municipalities (260 permittees)	1990's	Storm water and BMP monitoring data for 5 representative sites during a minimum of 3 storm events

* USGS prepared a database that includes rainfall, runoff and water-quality data for 717 storms from 99 stations in 22 metropolitan areas throughout the United States, including much of the data collected during the NURP program, in the mid-1980's (Driver et al, 1985)

The USGS has been collecting urban rainfall and runoff data for several decades. In the 1970's and early 1980's, monitoring programs were conducted to collect water quality data in addition to rainfall and runoff data in order to characterize the pollutants present in storm water runoff and to evaluate the impacts attributable to wet weather discharges. The major programs included the Nationwide Urban Runoff Program (NURP) conducted by EPA and USGS and the FHWA evaluation of runoff from highways. Data from these evaluations indicated that urban storm water runoff was contributing significant levels of pollutants to the nations waters, and that control of urban runoff was warranted. However, these investigations also indicated that there was insufficient data available to quantify the degree of impacts attributable to urban runoff and to evaluate the effectiveness of various runoff control practices.

In addition to the major federal investigations, some data has been published in the professional literature. A number of bibliographies have been prepared that include storm water BMP-related literature. These include the ASCE Urban BMP Effectiveness Bibliography, and the National Highway Runoff Water-Quality Data and Methodology Synthesis Bibliography compiled by USGS and FHWA. The Center for Watershed Protection (CWP) has prepared a database containing BMP performance data for 123 structural BMPs (Brown and Schueler, 1997a). The

FHWA and ASCE are currently developing databases of published highway and urban BMP effectiveness data. In addition to data in the published literature, a large amount of data has been collected by various cities and municipalities as part of the storm water permitting program under the Phase I NPDES program for storm water discharges. To date, EPA has not undertaken a concerted effort to collect and evaluate this data. In addition to published data sources, a number of states, counties and cities have collected a significant amount of monitoring data for their own use. The extent of this data is not currently known, but several county and city storm water programs have collected a great deal of potentially useful BMP monitoring data. An effort to collect and evaluate these data may provide more useful information on the effectiveness of various control measures.

The effectiveness of BMPs can be measured in various ways. Non-structural BMPs deal mainly with pollution prevention and limiting the amounts of pollutants that are carried away by runoff. Their effectiveness is best measured in terms of the degree of change in people's habits following implementation of the management program or by the degree of reduction of various pollutant sources. It is oftentimes very difficult to measure the success of non-structural BMPs in terms of pollution reduction and receiving stream improvements. Structural BMPs can be measured in terms in the reductions of pollutants discharged from the system and by the degree of attenuation of storm water flow rates and volumes discharged to the environment. Various physical, chemical and biological evaluation methods exist for determining the pollutant removal efficiency of structural BMPs. The following sections summarize existing data on the pollutant removal efficiency of a variety of BMPs.

5.5.1 Controlling Pollution Generation

The literature on the effectiveness of BMPs in controlling the generation of pollutants is not very extensive. Pollution prevention type BMPs such as street sweeping, public education and outreach, collection of lawn debris, etc., are conceptually very effective means of controlling the generation of pollutants that can enter storm water runoff. However, it is often very difficult to develop a representative means of monitoring or evaluating their effectiveness. Additional work in this area is needed in order to measure the effectiveness of these controls. Effectiveness data and information for pollution prevention BMPs that has been identified is presented in the following sections.

Education and Outreach

Evaluating the performance of education and outreach programs is difficult. There is little quantitative data in the literature that measures the effectiveness of these programs in improving water quality. Information exists on how educational programs have been implemented and what their success rate has been as far as changing the habits of a select group of people, but data linking implementation with improvements in water quality are scarce. Nevertheless, educational programs are a valuable component of a comprehensive storm water management program. Surrogate measures of the effectiveness of education and outreach programs include:

- numbers of flyers distributed per given time period;
- number of radio or television broadcasts;
- number of public workshops held per year;
- the percentage of storm drains that have been stenciled;
- the number of volunteer monitoring and stewardship groups that have been formed.

A literature review by ASCE (Strecker and Quigley, 1998) did not identify any published studies that contained quantitative information evaluating the effectiveness of Education and Outreach BMPs in improving water quality.

Recycling and Source Controls

Evaluating the effectiveness of recycling and source control programs can be measured in terms of the quantities of materials that are being recycled, but it is often difficult to determine water quality improvements as a result of these programs. Measures of effectiveness include:

- surveys that evaluate how many residents have changed habits such as picking up pet waste and composting lawn debris;
- volumes of materials such as used oil and antifreeze that are recycled;
- the volume and types of materials collected during community household hazardous waste collection days;
- the number of illicit cross connections that have been detected and eliminated;
- the total curb miles of streets that are swept annually and the quantity of materials removed; and
- reductions in pesticide and fertilizer usage.

Monitoring of storm water quality to evaluate the effectiveness of source control programs is possible, however very few studies have been conducted. The difficulty stems from isolating the impacts of a particular source control program on the overall water quality draining from the watershed. The ASCE bibliography identified one study that potentially contains quantitative information about the effectiveness of recycling automotive products as a BMP (Horner et al, 1985). Additional data are needed in this area in order to evaluate the effectiveness of recycling and source controls.

Maintenance Practices

Maintenance practices are a necessary part of any municipal storm water program. In addition to maintenance of storm water management infrastructure and BMP maintenance, a range of municipal maintenance activities impact the quality of storm water runoff. As with other non-structural control practices, data evaluating the effectiveness of maintenance practices at reducing the impacts associated with storm water discharges are scarce.

Studies conducted during the NURP project indicated that street sweeping was generally not an effective BMP. This is mainly due to the fact that street sweepers remove only the coarse particles on streets, and are not generally effective at removing the fine particles. It is the "fines" that frequently contain the highest fractions of pollutants, especially metals. In fact, the NURP study report from Winston-Salem reported that street sweeping could actually increase the concentrations of select pollutants by removing the surface "armoring" of coarse particles, which during normal runoff events inhibit the removal of fine surface loads (Noel et al, 1987). Likewise, NURP studies conducted in Long Island, New York, Champaign, Illinois and Bellevue, Washington found little or no benefit of street sweeping programs. A study in Durham, New Hampshire, which evaluated the effectiveness of pavement vacuum cleaning, indicated that this technology was effective at removing BOD and fecal streptococci bacteria. It was thought that these contaminants were mainly associated with the coarser sediments, which this technology was able to effectively remove. Although the NURP data indicated that street sweeping was not an effective BMP for improving water quality, the usefulness of street sweeping programs cannot be discounted. Improvements in sweeper technology have occurred since the NURP studies were conducted, and today's sweepers may be more efficient at removing fine particulates. Regardless, sweeping programs can remove a significant amount of dirt and debris from streets and parking lots. However, obtaining data linking sweeping programs to water quality improvements may be difficult due to the variety of pollutant sources present in urban areas.

Data on other maintenance practices are likewise scarce. Practices such as catch basin cleaning, street pavement repair, and ditch maintenance are all necessary components of a storm water management program. However, data that indicate their effectiveness may be difficult to obtain due to the lack of appropriate evaluation methodologies and the difficulty associated with isolating water quality improvements attributable to these practices. The ASCE bibliography identified two NURP studies that included evaluating the effectiveness of catch basin cleaning as a storm water BMP (Lake Hills and Surrey Downs, Bellevue, Washington).

5.5.2 Controlling Pollution Discharges

There has been a great deal of published data documenting the efficiency of BMPs in removing pollutants from storm water. Much of this data provides useful insights into the performance of various types of storm water BMPs. For the purposes of this study, *efficiency* has been used to describe the ability of the management practice to remove pollutants from runoff. *Effectiveness* refers to the actual improvements in water quality, habitat or other parameters as a result of implementing the management practice. Most of the data contained in the literature reports efficiency of a BMP. Little of the available data can be used to evaluate actual effectiveness.

Brown and Schueler (1997a) documented the pollutant removal efficiency of commonly used and innovative urban storm water BMPs. The number of monitoring reports of various BMP categories included in this study are summarized in Table 5-5.

Table 5-5. Monitoring Studies for BMP Categories

BMP Type	Number of Studies
Detention Basins	8
Retention Basins	35
Wetland Systems	36
Filtration Systems	15
Swales and Filter Strips	20
Other	4

Evaluation of the existing BMP monitoring data gives an indication of the information gaps that exist in BMP monitoring studies that have been performed to date. Commonly used BMPs that are seldom monitored include infiltration trenches, infiltration basins, bioretention practices and filter strips. The reason for the limited number of monitoring studies for these practices is due to the difficulty involved in collecting inflow and outflow samples to calculate pollutant removals. Bioretention practices and filter strips frequently accept runoff as sheet flow, which must be concentrated in order to collect a representative sample. Infiltration practices and bioretention practices can discharge water through a large surface area into surrounding soil layers, and therefore collection of a representative "outflow" sample is problematic. There are also a number of innovative and infrequently used BMPs that are seldom monitored. These include sand filters, vegetated filter strips, filters with organic media, wetland channels and swales.

In addition to a general lack of monitoring data for certain types of BMPs, there is also a lack of performance data for all BMP types for certain parameters. While BMP monitoring studies typically monitor for parameters such as total phosphorus, total lead, and total suspended solids, there is little monitoring data available for parameters such as bacteria, dissolved metals and hydrocarbons. Table 5-6 summarizes the frequency with which selected parameters have been monitored in BMP performance studies (Brown and Schueler, 1997a).

Table 5-6. Extent of Monitoring for Selected Pollutants in BMP Performance Studies

Parameter	Percent Monitored
Total Phosphorus	94
Total Lead	94
Total Suspended Solids	92
Total Nitrogen	70
Soluble Nitrogen	70
Total Zinc	67
Soluble Phosphorus	60
Organic Carbon	55
Total Copper	42
Bacteria	19
Total Cadmium	15
Total Dissolved Solids	13
Dissolved Metals	10
Hydrocarbons	9

Review of the existing BMP monitoring data gives an indication of the pollutant removal efficiency of various BMPs. Several efforts have been conducted to attempt to evaluate the range of pollutant removals that can be expected to occur in various BMP designs. Evaluation of these data can give an indication of the range of pollutant removals expected, however arriving at a fixed numerical “percent removal” for each BMP type or category is a difficult task. The main problem associated with comparing BMP performance data is the variety of techniques that are used to compute performance, as well as the variation in the ways that samples are collected and in the parameters that are measured in the samples. Performance calculations are further complicated by the errors that result from measuring flow rates and volumes of storm water that pass through the BMP. A study conducted by USGS evaluated 23 flow measurement techniques in order to determine potential differences in reported flows. Average percent differences between reported total storm volumes were in many cases greater than 25 percent over a range of storms (Strecker, 1998). With errors of this magnitude, calculation of pollutant loadings and loadings reductions can be complicated significantly.

Efficiency of a BMP can be related to the removal of individual pollutants on both an event basis and on a long-term basis. Frequently, the statistical rigor with which BMP sampling data are analyzed is poor or even nonexistent. Most BMP performance data are reported as event mean concentrations (EMCs). An EMC can either be determined directly from a flow-weighted composite sample, or calculated based on a series of discrete samples. While an EMC may be an appropriate method for determining the reduction in pollutant concentrations for an individual event, an EMC may not give an indication of the long-term performance of the BMP or the performance for runoff events of varying intensity and volume. A more appropriate means of determining the long-term performance of a BMP may be to do a statistical evaluation of inflow and outflow loadings over a range of storm event sizes and durations. Samples must also account for the seasonality of performance that results with certain BMP types such as ponds and constructed wetlands. The selection of the method used can have a significant impact on the reported performance. Additional work to standardize BMP monitoring protocols and to standardize calculations for performance is needed in order to make BMP monitoring data comparable from site to site.

BMP performance can vary considerably based on differences in the design criteria and performance standards for which the BMP was designed. Comparing pollutant removal efficiency for similar BMP types with very different performance goals may result in widely disparate efficiency estimations. In addition to differences in performance goals, variations in watershed parameters can cause significant differences in performance among otherwise similar BMPs. In most cases, parameters such as the size of the drainage area, the level of watershed imperviousness, the duration and volume of runoff entering the BMP, and the land use of contributing drainage areas are not easily comparable from study to study. In addition, differences in BMP design parameters such as the ratio of the BMP volume to the contributing drainage area, the retention time in the BMP, the physical dimensions and the construction of the BMP further complicate direct comparisons between BMP monitoring data. Also, a great deal of variability exists in the performance of each BMP due to event and seasonal variations.

Despite these shortcomings, some general ranges of expected BMP efficiency have been compiled from the literature. Documents that summarize BMP efficiency information include the CWP's National Pollutant Removal Performance Database (Brown and Schueler, 1997a), the Terrene Institute's report *The Use of Wetlands for Controlling Stormwater Pollution* (Strecker et al, 1992), as well as a variety of articles and documents contained in the professional and scientific literature. In addition, the ASCE National Storm Water BMP Database is expected to provide BMP monitoring studies in a format that will facilitate evaluation and comparison of BMP performance data. Readers are encouraged to consult the variety of referenced information resources for more detailed BMP performance data than is presented in this report. Table 5-7 presents expected pollutant removal efficiencies for various BMP types (US EPA, 1993c). The values found in this table give an indication of the expected overall pollutant removal efficiency for a properly sited, designed, sized, constructed and maintained BMP. The sections that follow Table 5-7 summarize the actual performance data contained in the literature on pollutant removal efficiencies for selected BMP types.

Table 5-7. Structural BMP Expected Pollutant Removal Efficiency

BMP Type	Typical Pollutant Removal (percent)				
	Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals
Dry Detention Basins	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Retention Basins	50 - 80	30 - 65	30 - 65	< 30	50 - 80
Constructed Wetlands	50 - 80	< 30	15 - 45	< 30	50 - 80
Infiltration Basins	50 - 80	50 - 80	50 - 80	65 - 100	50 - 80
Infiltration Trenches/ Dry Wells	50 - 80	50 - 80	15 - 45	65 - 100	50 - 80
Porous Pavement	65 - 100	65 - 100	30 - 65	65 - 100	65 - 100
Grassed Swales	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Vegetated Filter Strips	50 - 80	50 - 80	50 - 80	< 30	30 - 65
Surface Sand Filters	50 - 80	< 30	50 - 80	< 30	50 - 80
Other Media Filters	65 - 100	15 - 45	< 30	< 30	50 - 80

Source: Adapted from US EPA, 1993c.

Infiltration Systems

Infiltration systems can be considered 100 percent effective at removing pollutants in the fraction of water that is infiltrated, since the pollutants found in this volume are not discharged directly to surface waters. Quantifying the removal efficiency of infiltration systems, therefore, can perhaps best be determined by calculating the percent of the average annual runoff volume that is infiltrated, and assuming 100 percent removal of the pollutants found in that runoff volume. Since collecting samples of runoff once it has been infiltrated can be very difficult, little field data exist on the efficiency of infiltration for treatment of storm water. Since infiltrated water does not leave the BMP as a discrete flow, there is no representative way of collecting a true outflow sample. Infiltration systems can be monitored by installing a series of wells around the perimeter of the BMP for collecting samples. However, this can add significant costs to any monitoring effort. Table 5-8 summarizes the available field data on the efficiency of infiltration practices in treating storm water. Reported removal efficiencies are based on the results of three studies that evaluated the performance of infiltration trenches and two studies that evaluated the efficiency of porous pavement systems.

Table 5-8. Pollutant Removal Efficiency of Infiltration Practices

Parameter	Median or Average Removal Efficiency (percent)	Number of Observations
Total Phosphorus	65	5
Ammonia-Nitrogen	83	3
Nitrate	82	3
Total Nitrogen	83	2
Suspended Solids	89	2
Organic Carbon	82	1
Lead	98	1
Zinc	99	1

Source: Brown and Schueler, 1997a

Conceptually, infiltration should provide significant pollutant removal for a wide variety of storm water pollutants. As water moves through the underlying soil layers, suspended particulates and associated pollutants should be filtered out. In addition, pollutants can be adsorbed by soil particles and microorganisms in the soil can degrade organic pollutants. There is little data available, however, regarding the potential mobility of metals and hydrocarbons that enter groundwater due to infiltration of storm water. This may be a particular problem in areas with extremely high soil permeabilities (such as coastal areas), where pollutants can rapidly enter underlying aquifers with insufficient contact time for breakdown or adsorption of contaminants. Consequently, additional data gathering to target the behavior of these pollutants is warranted.

The success of infiltration systems has been mixed. In same areas, infiltration has been applied successfully, while in others infiltration systems have clogged in a very short time. Many failures can be attributed to contractor inexperience, to compaction of soil by construction equipment and to excess sediment loading during construction activities, and to improper design and siting. In order to apply infiltration successfully, the following guidelines should be applied:

- Permeability of soils must be verified. A percolation rate of 0.5 inches per hour or more, and an soil layer of 4 feet or more is essential (Cahill, 1994).
- Construction site runoff must be kept from entering the recharge bed, and the infiltration system should not be placed into service until all disturbed land that drains to the system has been stabilized by vegetation. Strict erosion and sediment controls during any construction or re-landscaping is a must to prevent clogging of the system.

- A sedimentation basin or chamber placed before the infiltration system to remove a portion of the sediment can help to extend the life of the infiltration system.
- Use of filter fabric between the recharge bed and soil interface (in porous pavement and infiltration trench systems) can prevent the migration of soil into the recharge bed.
- Construction traffic should be directed away from the infiltration bed before and during construction to prevent compaction of underlying soil layers and loss of infiltrative capacity.
- Porous pavement systems should be clearly marked to prevent use by heavy vehicles and resurfacing with non-porous pavement.
- A basin drain should be provided so that the basin can be drained and maintenance performed if the basin becomes clogged.

Readers are encouraged to consult the ASCE/WEF manual of practice (WEF and ASCE, 1992) for additional guidelines on using infiltration systems.

Retention Basins (wet ponds)

Retention basins can be very effective systems for removing pollutants from storm water. Retention basins provide quiescent conditions with long retention times that allow a large fraction of suspended solids and associated pollutants such as metals, nutrients and organics to be removed by sedimentation. In addition, degradation of organic compounds by microorganisms and uptake of nutrients by aquatic vegetation can provide additional water quality benefits. Retention basins have been one of the most widely-monitored storm water BMP types, mainly due to their prevalence and relative ease of monitoring in comparison to other BMP types. In arid regions, artificial or decorative lakes can function as retention basins. However, as with all other BMP types, the available monitoring data are not always comparable from study to study due to variations in procedures, protocols and methods. Although the mechanisms taking place in retention basins are fairly well known, additional data are needed in order to determine what the important design parameters are and to determine what event, seasonal and long-term performance variances exist. Table 5-9 summarizes the pollutant removal efficiency of retention basins systems. Reported removal efficiencies are based on data contained in 35 studies evaluating retention basins.

Table 5-9. Pollutant Removal Efficiency of Retention Basins

Parameter	Median or Average Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	34	-12	90	20
Total Phosphorus	46	0	91	44
Ammonia-Nitrogen	23	-107	83	14
Nitrate	23	-85	97	27
Organic Nitrogen	23	2	34	6
Total Nitrogen	30	-12	85	24
Suspended Solids	70	-33	99	43
Bacteria	74	-6	99	10
Organic Carbon	35	-30	90	29
Cadmium	47	-25	54	5
Chromium	49	25	62	5
Copper	55	10	90	18
Lead	67	-97	95	34
Zinc	51	-38	96	32

Source: Brown and Schueler, 1997a

The wide range of variability in reported removal efficiencies of retention systems is due to a number of factors. Watershed variables such as the area draining to the pond, the percent imperviousness and land use of the watershed, the design features of the basin such as surface area and depth of permanent pool, and hydraulic and hydrologic parameters such as rainfall intensity, rainfall volume, length of antecedent dry periods, time of concentration and peak inflow rate can have a large impact on the efficiency of a particular retention system. Studies that contain data on the efficiency of retention systems sometimes report only pollutant removal statistics, but fail to report the relationship to the hydraulics of the system. A thorough evaluation of the hydraulics of the system is needed in order to properly evaluate the efficiency of ponds. This evaluation should also include a measure of the expected suspended solids settling characteristics of the pond influent through a settling velocity column test or particle size distribution analysis, which can shed light on the observed efficiency of the pond in removing sediments and associated pollutants. Greb and Bannerman (1997) reported that the influent particle size distribution plays a significant role in the overall solids removal efficiency. Perhaps the greatest parameter influencing pond efficiency is retention time. Studies indicate that residence times on the order of 14 days may be necessary to allow for sufficient removal of sediment and associated pollutants and to meet receiving water standards (Rushton and Dye, 1993). In fact, Florida requires that the permanent pool volume of ponds treating runoff from new land use activities must provide a minimum residence time of 14 days.

While retention systems can be very effective at removing pollutants from storm water, there are some potential problems associated with these systems. During periods of intense runoff, the retention time in the pond can decrease, resulting in decreased efficiency. In addition, previously removed sediments can be re-suspended, resulting in a net export of pollutants from the pond. This is one of the reasons that negative removals are frequently reported for pond systems for parameters such as suspended solids and associated contaminants such as nutrients and metals. Also, changes in water chemistry such as increased or decreased pH, alkalinity and hardness can occur in the pond, which can effect the solubility of metals that are present in pond sediments and the behavior of various nutrient species. This can also affect the chemistry of the receiving waters, since the aquatic toxicity of certain metal species is dependant on hardness. There is also evidence that anaerobic bottom sediments promote more soluble forms of phosphorus and some metals, which can increase their release to the water column (Rushton and Dye, 1993).

Perhaps the greatest problem is the increased temperature of discharges that occur from storm water retention systems. Retention ponds can have a significant surface area, and during summer months elevation of the temperature of water in the pond can occur. When this warm water is displaced during the next runoff event, the elevated temperature can cause detrimental impacts to the receiving waters, including loss of sensitive species and downstream shift of trophic status (Galli, 1988). Ponds can also fail to function properly in the winter time when the surface of the pond freezes. Water entering the pond can flow over the ice surface directly to the outlet structure. This short circuiting can limit the retention time of storm water entering the ponds and reduce the sedimentation efficiency. Outlet structures are also prone to freezing in the winter time, which can cause serious flooding problems. In order to prevent cold-weather problems with wet ponds, several design features can be incorporated in ponds that are used in cold climates. Readers are encouraged to consult the *Stormwater BMP Design Supplement for Cold Climates* published by CWP (Caraco and Claytor, 1997) for additional information regarding BMP designs for cold climates.

Retention systems also present a potential hazard to nearby residents and children, can often become populated with large number of waterfowl, and can be breeding grounds for mosquitoes and odor producers if not designed and maintained properly. Large ponds also can present a danger of downstream flooding and risk of catastrophic loss of life and property in the event of an embankment or outlet structure failure. Several pond failures have occurred that are attributable to piping around outlet structures and eventual failure of embankments due to poor installation. Careful adherence to design and construction standards is necessary and inspections during construction should be conducted to ensure that ponds are installed correctly.

In addition to relating performance to measures of pollutant reduction across the BMP, evaluations that measure effluent from BMPs and compares these values to receiving water criteria can provide useful data. One such study was conducted in Florida, and it was determined that effluent from 22 wet detention facilities was in most cases in compliance with class III Florida state water quality standards. The ponds evaluated in this study were permitted by Florida and met the required state design criteria. Parameters analyzed in samples included eight metal species, six nutrient species, turbidity, TSS, temperature, dissolved oxygen, pH and conductivity. The constituents that were in compliance 100 percent of the time included un-ionized ammonia, iron, manganese (class II standard) and nickel. All other analyzed parameters, with the exception of dissolved oxygen, were in compliance greater than 65 percent of the time, with most in compliance greater than 79 percent of the time. Dissolved oxygen was in noncompliance 64 percent of the time (Carr and Kehoe, 1997). The results of this study indicate that evaluation of constituents in BMP effluent and comparison with water quality standards may be an effective measure of BMP effectiveness. In many cases, data of this nature may be more useful than data that indicates percent removal of a targeted group of constituents across the BMP. It is also important to note that the Florida study found that concentrations of constituents (with the exception of dissolved oxygen) in samples collected at these systems did not vary significantly between samples collected immediately before the outflow weir and after the outflow weir. Therefore, sampling before the weir, where more convenient, does not significantly alter sample results. This may be useful where the BMP discharges through an outflow structure where samples are not easily collected (such as in a manhole or other confined space).

In addition to treating runoff, retention systems can be adapted for storm water reuse. Florida is actively seeking reuse of storm water runoff for reuse as irrigation water. Reuse of storm water reduces the volume of water and the amount of pollutants discharged to receiving streams. In addition, reuse of storm water as irrigation water can help to recharge aquifers and restore pre-development hydrologic conditions. Also, significant financial incentives exist for reuse as irrigation in areas where water rates are high. However, the health risks of storm water reuse have not been thoroughly investigated. Additional research in this area is warranted to determine if a risk of exposure to potentially harmful microorganisms or other health risks exist. Livingston et al (1998) presented a discussion of storm water reuse opportunities and discussed design considerations for sizing ponds for reuse. Readers are encouraged to consult this reference for additional information on storm water reuse.

There are a number of design features that can be included in retention system designs to increase their effectiveness, reduce maintenance burdens and reduce impacts to receiving waters. These include:

- A broad, flat aquatic bench around the perimeter of the pond planted with emergent wetland vegetation;

- A permanent pool volume that provides a long residence time to promote maximum removal of suspended solids;
- An irregular pool shape that increases sinuosity of flow paths;
- A sediment forebay for removal of coarse sediments and ease of maintenance;
- A submerged reversed-slope pipe or other non-clogging low-flow orifice;
- Concrete, rather than corrugated metal risers and outlet structures;
- Preservation of riparian cover along drainage channels to limit temperature increases;
- Maintenance access to forebays and inlet and outlet structures for removal of sediments and repairs.

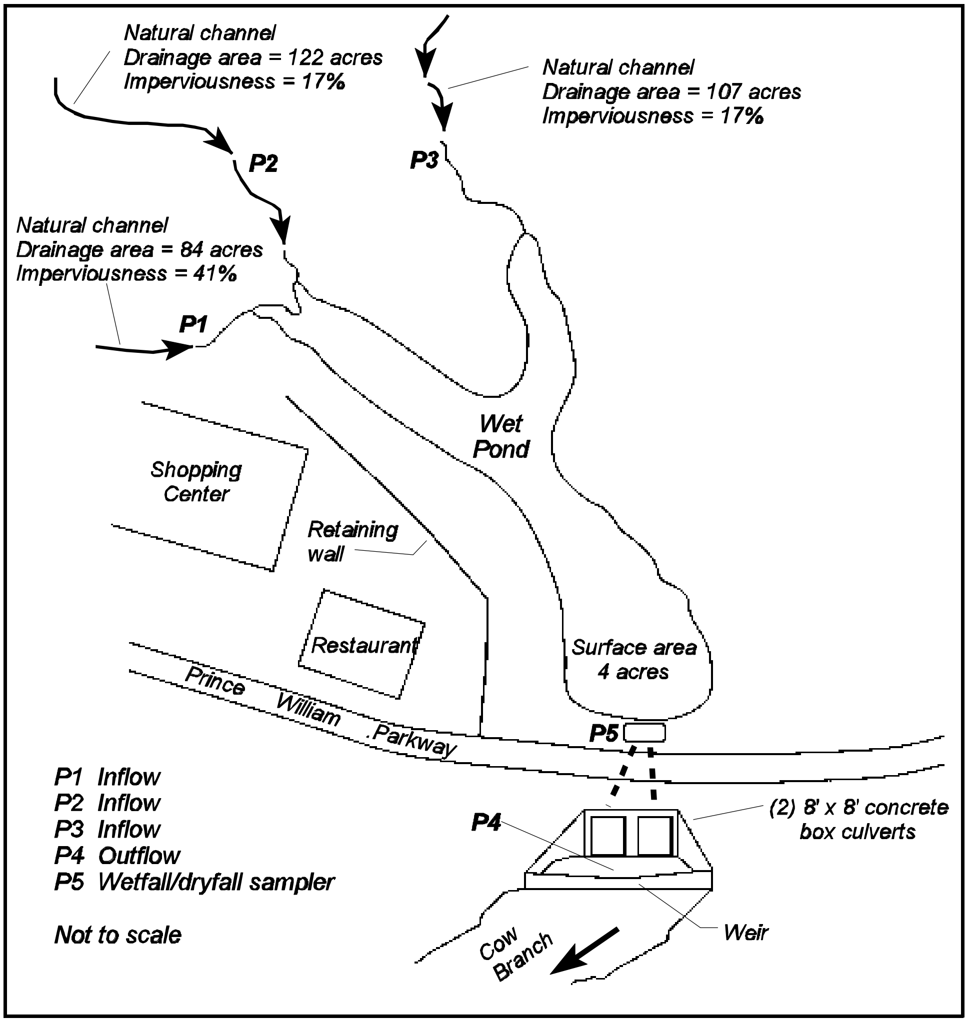
<u>Prince William Parkway Regional Wet Pond</u>

In 1998 EPA conducted sampling activities at a retention system in Prince William County, Virginia. The Prince William Parkway Wet Pond is a regional wet pond located adjacent to a major county road in Dale City. The pond has a surface area of 4 acres, and has a total volume of approximately 25 acre-feet at the permanent pool level. The pond is approximately 1,000 feet in length, 260 feet wide at its widest point, and was constructed by placing an earthen dam in what appears to previously have been a natural drainage channel. The discharge is to Cow Branch, a tributary of Neabsco Creek. The contributing drainage area to the pond is approximately 310 acres. The land use of the watershed is approximately 20 percent commercial, 30 percent forested, 40 percent open land, 5 percent residential (mostly lots less than 1 acre) and 5 percent from other sources. The pond is designed to control up to the 100-year storm event for the fully developed watershed conditions. There are a total of 5 discrete inflow points to the wet pond. Three of these points were natural drainage channels (identified as P1, P2 and P3), while the 4th and 5th points were concrete channels. Points P1, P2 and P3, which represent a majority of the contributing drainage area, were monitored during the course of the study period. The contributing drainage area and percent imperviousness of these sub-basins are:

Sub-Basin	Area (acres)	Imperviousness (%)
P1	84	41
P2	122	17
P3	107	17

The other two inflow points, which conveyed runoff from a small segment of Prince William Parkway, were not monitored and their contributions of both storm flow and pollutant loadings were considered negligible due to the small drainage area in comparison to the overall watershed area. The outflow of the pond occurs through a pair of 8 by 8-foot concrete box culverts. A concrete V-notch weir is installed at the outflow of the pond. See Figure 5-14.

Figure 5-14. Prince William Parkway Regional Wet Pond



During May through October 1998, rainfall and hydrologic data were collected for 14 storm events and water quality samples were collected during 10 storm events at the pond. In addition, samples of atmospheric deposition (dryfall) and precipitation (wetfall) were collected for a number of storms. The following tables summarize a portion of the analytical data collected during the study period and the corresponding flow volume at each of the sampling points. Wetfall volumes were determined by multiplying the total storm rainfall depth by the surface area of the pond. A detailed presentation of the sampling results and an analysis of the sampling data will be included in a supplement to this report.

Table 5-10. Summary of Prince William Parkway Regional Wet Pond Sampling Data

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/01/98										
Total Kjeldahl Nitrogen (mg/l as N)	---	---	---	0.95	---	---	---	1.1	0.67	ND (0.1)
Ammonia (mg/l as N)	---	---	0.97	0.39	---	---	0.39	0.37	0.61	ND (0.1)
Nitrate/Nitrite (mg/l as N)	---	---	0.45	0.52	---	---	0.13	0.18	0.18	ND (0.01)
Biochemical Oxygen Demand (mg/l)	---	---	4	7	---	---	4	3	---	---
Chemical Oxygen Demand (mg/l)	---	---	ND (20)	ND (10)	---	---	ND (10)	ND (10)	---	---
Total Organic Carbon (mg/l)	---	---	7	9.1	---	---	5.4	6.5	2.2	ND (1)
Phosphorus (mg/l)	---	---	0.02	ND (0.01)	---	---	0.02	0.03	ND (0.01)	ND (0.01)
Total Orthophosphate (mg/l)	---	---	ND (0.01)	---	---	---	ND (0.01)	---	---	ND (0.01)
Total Suspended Solids (mg/l)	---	---	266	---	---	---	48	---	---	---
Total Dissolved Solids (mg/l)	---	---	46	---	---	---	65	---	---	---
Volatile Suspended Solids (mg/l)	---	---	26	---	---	---	14	---	---	---
Chloride (mg/l)	---	---	4	---	---	---	13	---	---	---
Alkalinity (mg/L)	---	---	5	---	---	---	26	---	---	---
Hardness (mg/l as CaCO3)	---	---	35	---	---	---	35	---	---	---
Runoff Volume (gallons)	201,800		619,700		152,500		1,071,000		61,000	
6/11/98										
Total Kjeldahl Nitrogen (mg/l as N)	---	---	5.6	1.12	---	---	9.52	9.52	2.24	8.96
Ammonia (mg/l as N)	---	---	ND (1)	ND (1)	---	---	ND (1)	ND (1)	ND (1)	ND (1)
Nitrate/Nitrite (mg/l as N)	---	---	0.53	0.59	---	---	0.13	0.16	0.18	0.42
Biochemical Oxygen Demand (mg/l)	---	---	---	3.65	---	---	6.9	2.8	---	---
Chemical Oxygen Demand (mg/l)	---	---	45.6	26	---	---	27.6	27.2	---	---
Total Organic Carbon (mg/l)	---	---	9.35	7.91	---	---	9.35	6.47	3.58	3.58
Phosphorus (mg/l)	---	---	0.25	0.051	---	---	0.25	0.017	0.044	0.038
Total Orthophosphate (mg/l)	---	---	0.094	---	---	---	0.062	---	ND (0.01)	---
Total Suspended Solids (mg/l)	---	---	14	---	---	---	8	---	---	---
Total Dissolved Solids (mg/l)	---	---	49	---	---	---	62	---	---	---
Volatile Suspended Solids (mg/l)	---	---	3	---	---	---	3	---	---	---
Alkalinity (mg/L)	---	---	13.2	---	---	---	24	---	---	---
Hardness (mg/l as CaCO3)	---	---	18	---	---	---	26	---	---	---
Runoff Volume (gallons)	244,500		849,400		242,200		1,434,000		81,500	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/12/98										
Total Kjeldahl Nitrogen (mg/l as N)	8.96	11.8	8.96	2.8	---	---	1.68	8.4	5.04	---
Ammonia (mg/l as N)	1.12	ND (1)	ND (1)	ND (1)	---	---	ND (1)	ND (1)	1.12	---
Nitrate/Nitrite (mg/l as N)	1	0.88	0.57	0.61	---	---	0.15	0.12	0.66	---
Biochemical Oxygen Demand (mg/l)	4.3		2.5	2	---	---	3.7	40.8	---	---
Chemical Oxygen Demand (mg/l)	36.4	47.2	106	14	---	---	27.2	20.4	---	---
Total Organic Carbon (mg/l)	5.83	10.2	5.83	5.83	---	---	10.2	10.2	4.37	---
Phosphorus (mg/l)	0.1	0.049	0.82	0.08	---	---	0.18	0.04	0.046	---
Total Orthophosphate (mg/l)	0.038	---	0.099	---	---	---	0.099	---	---	---
Total Suspended Solids (mg/l)	18	---	53	---	---	---	9	---	---	---
Total Dissolved Solids (mg/l)	90	---	37	---	---	---	65	---	---	---
Volatile Suspended Solids (mg/l)	6	---	6	---	---	---	6	---	---	---
Alkalinity (mg/L)	13.9	---	9.7	---	---	---	24	---	---	---
Hardness (mg/l as CaCO3)	28	---	20	---	---	---	28	---	---	---
Runoff Volume (gallons)	162,400		237,600		191,700		631,000		36,000	
6/13/98										
Total Kjeldahl Nitrogen (mg/l as N)	---	---	ND (1)	7.84	---	---	1.68	17.4	---	---
Ammonia (mg/l as N)	---	---	ND (1)	1.12	---	---	ND (1)	ND (1)	---	---
Nitrate/Nitrite (mg/l as N)	---	---	0.2	0.25	---	---	0.28	0.29	---	---
Biochemical Oxygen Demand (mg/l)	---	---	5.9	2.5	---	---	3.9	ND (2)	---	---
Chemical Oxygen Demand (mg/l)	---	---	32.8	25.2	---	---	22.8	20.8	---	---
Total Organic Carbon (mg/l)	---	---	4.37	4.37	---	---	5.83	5.83	---	---
Phosphorus (mg/l)	---	---	0.35	---	---	---	0.091	0.17	---	---
Total Orthophosphate (mg/l)	---	---	0.097	---	---	---	ND (0.1)	---	---	---
Total Suspended Solids (mg/l)	---	---	31	---	---	---	8	---	---	---
Total Dissolved Solids (mg/l)	---	---	245	---	---	---	54	---	---	---
Volatile Suspended Solids (mg/l)	---	---	6	---	---	---	4	---	---	---
Alkalinity (mg/L)	---	---	5.2	---	---	---	22	---	---	---
Hardness (mg/l as CaCO3)	---	---	10		---	---	24	---	---	---
Runoff Volume (gallons)	166,700		411,600		136,000		765,000		43,500	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/15/98										
Total Kjeldahl Nitrogen (mg/l as N)	3.92	2.24	8.4	13.4	---	---	21.3	5.6	---	---
Ammonia (mg/l as N)	---	2.8	1.12	9.52	---	---	16.8	6.16	---	---
Nitrate/Nitrite (mg/l as N)	0.23	0.21	0.2	0.35	---	---	0.29	0.31	---	---
Biochemical Oxygen Demand (mg/l)	4.25	3.8	4.05	2.7	---	---	1.8	4	---	---
Chemical Oxygen Demand (mg/l)	18.4	24	22	66.4	---	---	21.6	17.2	---	---
Total Organic Carbon (mg/l)	7.11	19	4.47	9.75	---	---	5.79	20.3	---	---
Phosphorus (mg/l)	0.072	---	0.2	---	---	---	0.069	---	---	---
Total Orthophosphate (mg/l)	0.017	---	ND (0.01)	---	---	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	ND (4)	---	21	---	---	---	ND (4)	---	---	---
Total Dissolved Solids (mg/l)	61	---	58	---	---	---	19	---	---	---
Volatile Suspended Solids (mg/l)	ND (4)	---	5	---	---	---	ND (4)	---	---	---
Alkalinity (mg/L)	10	---	4.2	---	---	---	ND (20)	---	---	---
Hardness (mg/l as CaCO3)	18	---	10	---	---	---	24		---	---
Runoff Volume (gallons)	841,600		1,260,900		719,600		3,097,500		176,000	
6/17/98										
Total Kjeldahl Nitrogen (mg/l as N)	1.05	1.06	---	---	0.55	---	0.75	0.97	---	---
Ammonia (mg/l as N)	0.32	0.26	---	---	ND (0.1)	---	ND (0.1)	ND (0.1)	---	---
Nitrate/Nitrite (mg/l as N)	0.33	0.33	---	---	0.12	---	0.19	0.2	---	---
Biochemical Oxygen Demand (mg/l)	4	4	---	---	---	---	6	4	---	---
Chemical Oxygen Demand (mg/l)	ND (10)	ND (10)	---	---	ND (10)	---	ND (10)	26	---	---
Total Organic Carbon (mg/l)	8.8	9	---	---	7.5	---	8	7.9	---	---
Phosphorus (mg/l)	0.12	---	---	---	0.11	---	0.13	---	---	---
Total Orthophosphate (mg/l)	ND (0.01)	---	---	---	ND (0.01)	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	ND (4)	---	---	---	19	---	8	---	---	---
Total Dissolved Solids (mg/l)	142	---	---	---	121	---	79	---	---	---
Volatile Suspended Solids (mg/l)	ND (4)	---	---	---	ND (4)	---	ND (4)	---	---	---
Alkalinity (mg/L)	26	---	---	---	13	---	10	---	---	---
Hardness (mg/l as $CaCO_3$)	24	---	---	---	---	---	12	---	---	---
Runoff Volume (gallons)	129,400		215,200		162,500		554,500		31,500	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
6/23/98										
Total Kjeldahl Nitrogen (mg/l as N)	0.22	---	1.44	6.1	1.15	0.3	0.76	0.51	---	---
Ammonia (mg/l as N)	0.12	---	0.2	0.5	0.14	0.13	0.31	ND (0.1)	---	---
Nitrate/Nitrite (mg/l as N)	0.23	---	0.4	0.42	0.15	0.14	0.21	0.17	---	---
Biochemical Oxygen Demand (mg/l)	ND (2)	---	ND (2)	6	ND (2)	23	ND (2)	52	---	---
Chemical Oxygen Demand (mg/l)	ND (10)	---	31	15	34	ND (10)	ND (10)	ND (10)	---	---
Total Organic Carbon (mg/l)	3.1	---	4.4	7.7	4.7	7.4	3.2	3.8	---	---
Phosphorus (mg/l)	0.06	---	0.02	---	ND (0.01)	---	0.04	---	---	---
Total Orthophosphate (mg/l)	0.03	---	ND (0.01)	---	ND (0.01)	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	19	---	33	---	29	---	10	---	---	---
Total Dissolved Solids (mg/l)	47	---	79	---	64	---	69	---	---	---
Volatile Suspended Solids (mg/l)	9	---	16	---	13	---	11	---	---	---
Alkalinity (mg/L)	6	---	13	---	7	---	14	---	---	---
Hardness (mg/l as $CaCO_3$)	8	---	20	---	10	---	19	---	---	---
Runoff Volume (gallons)	1,207,300		1,064,200		756,800		3,499,000		199,000	
6/24/98										
Total Kjeldahl Nitrogen (mg/l as N)	0.73	---	0.71	---	0.7	---	0.53	---	---	---
Ammonia (mg/l as N)	0.22	---	0.22	---	0.16	---	0.55	---	---	---
Nitrate/Nitrite (mg/l as N)	0.4	---	0.61	---	0.27	---	0.32	---	---	---
Biochemical Oxygen Demand (mg/l)	3	---	4	---	3	---	2	---	---	---
Chemical Oxygen Demand (mg/l)	ND (10)	---	ND (10)	---	14	---	ND (10)	---	---	---
Total Organic Carbon (mg/l)	3.8	---	4	---	5.6	---	3.1	---	---	---
Phosphorus (mg/l)	0.05	---	0.1	---	0.05	---	0.12	---	---	---
Total Orthophosphate (mg/l)	ND (0.01)	---	ND (0.01)	---	ND (0.01)	---	ND (0.01)	---	---	---
Total Suspended Solids (mg/l)	ND (4)	---	57	---	54	---	8	---	---	---
Total Dissolved Solids (mg/l)	45	---	48	---	69	---	51	---	---	---
Volatile Suspended Solids (mg/l)	4	---	5	---	6	---	3	---	---	---
Alkalinity (mg/L)	6	---	6	---	12	---	8	---	---	---
Hardness (mg/l as $CaCO_3$)	8	---	11	---	17	---	15	---	---	---
Runoff Volume (gallons)	293,200		682,400		290,400		1,415,000		80,000	

Sample Location ➤ Sample Dates and Analytes	P1	P1 (dissolved)	P2	P2 (dissolved)	P3	P3 (dissolved)	P4	P4 (dissolved)	Wetfall	Dryfall
7/31/98										
Total Kjeldahl Nitrogen (mg/l as N)	1.3	1	2.7	---	---	---	1.2	---	---	---
Ammonia (mg/l as N)	1	1.1	0.74	---	---	---	0.96	---	1.5	---
Nitrate/Nitrite (mg/l as N)	1.51	1.51	1.81	---	---	---	0.13	---	---	---
Biochemical Oxygen Demand (mg/l)	6	26	27	6	---	---	5	---	---	---
Chemical Oxygen Demand (mg/l)	16	ND (10)	106	---	---	---	ND (10)	---	---	---
Total Organic Carbon (mg/l)	11	11	20	---	---	---	8.1	---	---	---
Phosphorus (mg/l)	0.05	---	0.36	---	---	---	0.09	---	---	---
Total Orthophosphate (mg/l)	0.03	---	ND (0.1)	---	---	---	ND (0.01)	---	ND (0.01)	---
Total Suspended Solids (mg/l)	9	---	51	---	---	---	11	---	---	---
Total Dissolved Solids (mg/l)	92	---	115	---	---	---	90	---	---	---
Volatile Suspended Solids (mg/l)	9	---	16	---	---	---	7	---	---	---
Alkalinity (mg/L)	17	---	15	---	---	---	25	---	---	---
Hardness (mg/l as $CaCO_3$	40	---	52	---	---	---	36	---	---	---
Runoff Volume (gallons)	79,400		436,900		32,000		593,000		33,500	

Constructed Wetland Systems

Constructed wetlands can be effective BMPs for removing pollutants from urban storm water. The main mechanism of pollutant removal in wetland systems is sedimentation (Strecker et al, 1992). Other pollutant removal mechanisms include filtration by aquatic vegetation and by underlying soil and gravel in systems where subsurface flow is present, biological conversion of organic compounds by microorganisms, uptake of nutrients by aquatic plants and algae, uptake of metals by plant tissue, adsorption of metals by clay soils, and volatilization of hydrocarbons and volatile organics. While the literature contains hundreds of references to constructed wetlands systems, very few quantitative studies have been conducted with sufficient rigor to provide good estimates of performance. Strecker's evaluation of the literature on wetland treatment systems identified only 17 reports that discussed the results of research on a functioning wetland system (of 140 reviewed reports). This indicates that there is a general lack of thorough, scientifically-defensible evaluations on the performance of wetland treatment systems. As a result, there is a wide range of variability in reported efficiency data. Table 5-11 summarizes the pollutant removal efficiency of constructed wetland systems based on Strecker's evaluation of published studies.

Table 5-11. Pollutant Removal Efficiency of Constructed Wetland Systems

Parameter	Median Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	23	-30	78	12
Ortho-Phosphate	28	-109	93	7
Total Phosphorus	46	-120	97	37
Ammonia-Nitrogen	33	-86	62	15
Nitrate	46	4	95	18
Organic Nitrogen	7	-36	39	7
Total Nitrogen	24	-20	83	11
Suspended Solids	76	-300	98	26
Bacteria	78	55	97	3
Organic Carbon	28	-31	93	15
Cadmium	69	-80	80	6
Chromium	73	38	98	3
Copper	39	2	84	10
Lead	63	23	94	17
Zinc	54	-74	90	16

Sources: Strecker at al (1992); Organic Carbon, Bacteria and Metals from Brown and Schueler, 1997a

Evaluation of wetland performance is problematic because the basic mechanisms taking place in wetland systems are not well understood. Wetlands are complex ecosystems, and variations in design and watershed factors can have a significant impact on performance. As a result, data collected from various sites are not always comparable.

Due to the limited amount of comparable data that is available on the performance of storm water wetland systems, it is difficult to arrive at any meaningful relationships indicating the important factors in wetland system design. Strecker indicated that perhaps the greatest factor influencing performance of constructed wetlands is the hydrology of the watershed and the inflow hydraulics. Other factors having a major influence on performance are wetland size and volume, the design of the inlet and outlet structures, flow patterns through the system, vegetational community structure, seasonal productivity and decay of wetland plants, and changes in evapotranspiration rates. In addition, the presence of subsurface flows can complicate wetland performance evaluations.

Strecker recommends that an important evaluation step in determining wetland performance is to compare runoff volumes with storage volumes and contact surface area of the wetland. However, he was unable to conduct this evaluation due to the lack of consistent reporting of rainfall statistics, watershed imperviousness, land uses, flow volumes, capacity and surface areas for contact. In order to ensure the comparability of future data reporting for wetland systems, it is recommended that a standardized set of monitoring protocols be adopted for all future monitoring efforts.

An important factor in the variation of reported efficiency is the wide range of designs that are used in constructed wetland systems. A few design variations include:

- ponds with an emergent wetland area on the pond perimeter;
- shallow wetlands with subsurface flow;
- wetland channels;
- pond-wetland systems;
- extended detention wetlands.

Although the design of a particular systems is dependent upon a number of site-specific variables, there are some important design factors that should be incorporated in wetland system designs including:

- a pre-settling chamber for removal of heavy sediments and to limit disturbance of the wetland to remove accumulated sediments;
- adjustable level control at the outlet by means of an adjustable weir or orifice;
- design the flow path to limit short circuiting and dead space and to maximize detention time;
- a broad, densely planted aquatic bench;
- selection of planting species to produce a dense stand of vegetation for filtration and nutrient uptake;
- periodic harvesting of excess vegetation to prevent nutrient release and to remove undesirable species.

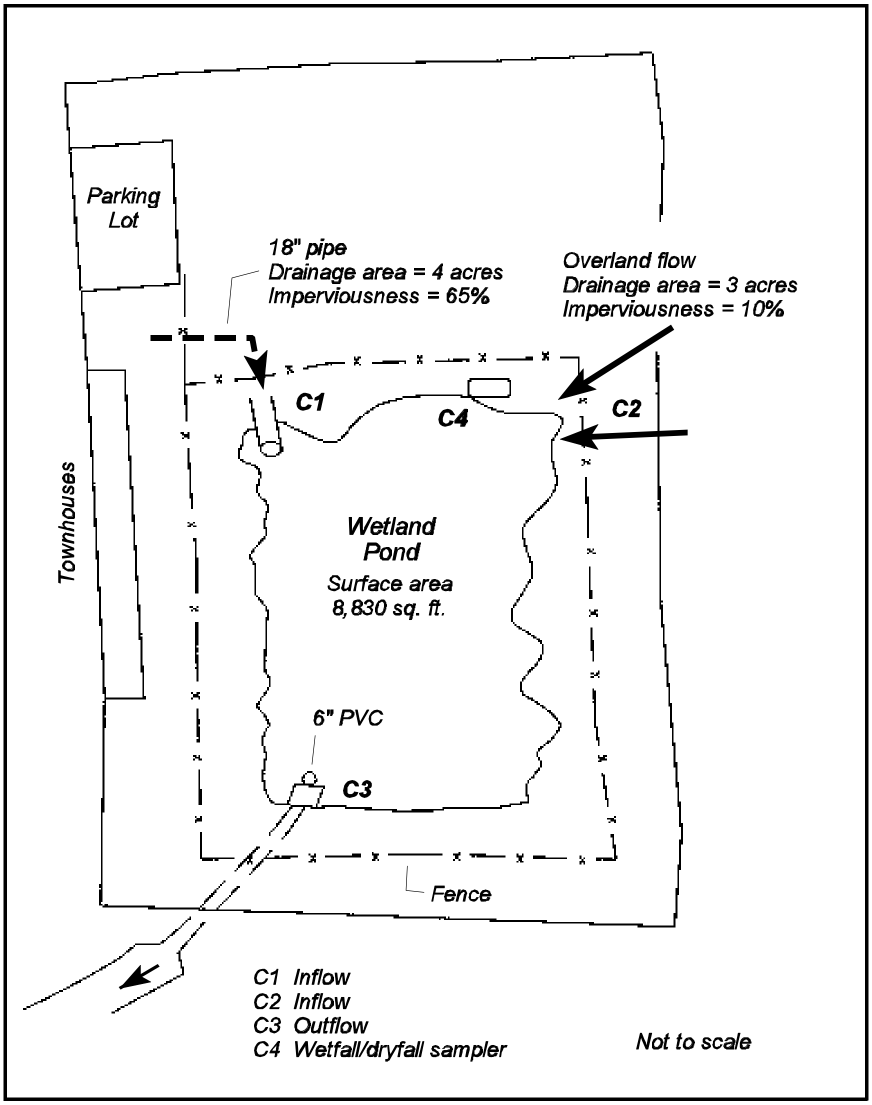
<u>Crestwood Marsh Constructed Wetland</u>

In 1998 EPA conducted sampling activities at a constructed wetland in Manassas, Virginia. The Crestwood Marsh is located in a residential area and was originally constructed as a dry detention basin, but conditions at the site were such that a wetland system formed on its own. The outlet structure was modified in 1995 to provide an extended detention time of 24 hours within the wetland. As a result of this modification, the system has developed into a shallow emergent marsh and contains a variety of wetland species. The wetland has a surface area of

8,830 ft^2. The water quality detention volume of the wetland is 2,524 ft^3, and the flood control volume above the water quality volume is 3,523 ft^3. The area draining to the wetland is a 7-acre townhouse community, with the land area consisting of approximately 60 percent townhouses, 30 percent forested and 10 percent open space. The drainage area is estimated to be approximately 40 percent impervious. The constructed wetland is located at the headwaters of a small unnamed stream that drains to Bull Run, within the Occoquan River Watershed.

Flow enters the wetland at the eastern corner through an 18-inch concrete pipe situated flush with the bottom grade (point C1). From this point, water gradually spreads throughout the wetland and drains to the northern corner of the pond and is discharged through a 6-inch PVC outlet pipe (point C3). There is an additional inlet point located at the southwest corner of the wetland, which consists of overland flow from an adjacent area of forested parkland. EPA concentrated the flow at this point in order to allow estimation of flow rates and volumes, and to allow for collection of water quality samples (point C2). See Figure 5-15.

Figure 5-15. Crestwood Marsh Constructed Wetland



During the spring and summer of 1998, storm event sampling was conducted during nine events. Sampling consisted of collecting flow-weighted composite samples as well as recording rainfall depth, and runoff flow rates and volumes into and out of the wetland. In addition to water quality monitoring, atmospheric deposition and wetfall deposition samples were collected during the study period. The water quality sampling data collected during the study period are summarized in the tables below. Additional data, as well as a detailed description of the sampling program, wetland design, and an evaluation of the performance of the wetland will be included in a supplement to this report.

Table 5-12. Summary of Crestwood Marsh Constructed Wetland Sampling Data

Analytes — Sample Date ➤ / Location ➤	06/01/98 C1	06/01/98 C2	06/01/98 C3	06/11/98 C1	06/11/98 C2	06/11/98 C3	06/12/98 C1	06/12/98 C2	06/12/98 C3
Runoff Volume (gal)	7,625	No Flow	1,376	9,439	No Flow	3,237	11,621	No Flow	3,903
Total Suspended Solids (mg/l)	41	--	--	18	--	--	70	--	4
Chemical Oxygen Demand (mg/l)	75	--	--	28.4	--	--	37.2	--	--
Total Organic Carbon (mg/l)	13	--	--	5.02	--	--	5.83	--	--
Total Kjeldahl Nitrogen (mg/l as N)	2	--	--	12.3	--	--	5.04	--	--
Total Inorganic Nitrogen (mg/l as N)	0.67	--	--	0.33	--	--	0.47	--	--
Ammonia (mg/l as N)	0.75	--	--	<1	--	--	1.12	--	--
Total Phosphorus (mg/l)	0.12	--	--	0.084	--	--	0.22	--	--
Ortho-Phosphate (mg/l)	<0.01	--	--	0.032	--	--	0.18	--	0.021
Alkalinity (mg/l as $CaCO_3$)	31	--	--	6.8	--	--	4.8	--	4.3
Hardness (mg/l as $CaCO_3$)	--	--	--	--	--	--	14	--	--
Lead	--	--	--	--	--	--	6.9	--	--
Copper	--	--	--	--	--	--	10.1	--	--
Zinc	--	--	--	--	--	--	64.9	--	--
Nickel	--	--	--	--	--	--	6.6	--	--
Aluminum	--	--	--	--	--	--	2690	--	--
Chromium	--	--	--	--	--	--	4.4	--	--

Analytes — Sample Date ➤ / Location ➤	06/14/98 C1	06/14/98 C2	06/14/98 C3	06/16/98 C1	06/16/98 C2	06/16/98 C3	06/23/98 C1	06/23/98 C2	06/23/98 C3
Runoff Volume (gal)	7,624	No Flow	No Flow	53,457	6,985	57,216	81,327	6,334	139,390
Total Suspended Solids (mg/l)	44	--	--	<4	19	<4	5	34	6
Chemical Oxygen Demand (mg/l)	64	--	--	12.8	45.6	15.2	<10	24	<10
Total Organic Carbon (mg/l)	14.3	--	--	4.47	9.75	5.79	4.1	7.4	3.1
Total Kjeldahl Nitrogen (mg/l as N)	3.36	--	--	2.8	7.28	17.4	0.57	0.44	0.8
Total Inorganic Nitrogen (mg/l as N)	0.4	--	--	0.2	0.15	0.16	0.81	0.27	0.53
Ammonia (mg/l as N)	1.12	--	--	<1	<1	<1	0.37	0.27	0.32
Total Phosphorus (mg/l)	0.17	--	--	0.078	0.2	0.11	0.2	0.24	0.05
Ortho-Phosphate (mg/l)	0.058	--	--	0.05	0.032	0.026	0.12	0.05	0.05
Alkalinity (mg/l as $CaCO_3$)	6.5	--	--	5.2	20	6.7	11	8	<1
Hardness (mg/l as $CaCO_3$)	--	--	--	--	24	44	20	10	<1
Lead	6.6	--	--	<2	<2	<2	--	--	--
Copper	10.3	--	--	<1	<1	<1	--	--	--
Zinc	68.5	--	--	<2	<2	<2	--	--	--

Analytes — Sample Date ➤ / Location ➤	06/14/98			06/16/98			06/23/98		
	C1	C2	C3	C1	C2	C3	C1	C2	C3
Nickel	<1	--	--	2.3	<1	<1	--	--	--
Aluminum	3450	--	--	<54	3420	<54	--	--	--
Chromium	<1	--	--	2	4.7	<1	--	--	--

Analytes — Sample Date ➤ / Location ➤	06/24/98			07/24/98			07/31/98		
	C1	C2	C3	C1	C2	C3	C1	C2	C3
Runoff Volume (gal)	11,766	7,604	38,353	20,820	9,645	4,579	11,929	761	No Flow
Total Suspended Solids (mg/l)	37	45	<4	68	--	5	30	--	--
Chemical Oxygen Demand (mg/l)	<10	67	18	32	--	<10	27	--	--
Total Organic Carbon (mg/l)	3.6	17	9.2	7.9	--	10.4	12	--	--
Total Kjeldahl Nitrogen (mg/l as N)	0.52	1.28	0.48	1.14	--	0.9	1	--	--
Total Inorganic Nitrogen (mg/l as N)	0.52	0.11	0.15	0.48	--	0.33	0.67	--	--
Ammonia (mg/l as N)	0.18	0.13	0.15	0.46	--	0.22	0.97	--	--
Total Phosphorus (mg/l)	0.11	0.12	0.02	0.15	--	0.83	0.1	--	--
Ortho-Phosphate (mg/l)	0.03	<0.01	<0.01	0.09	--	0.28	0.03	--	--
Alkalinity (mg/l as $CaCO_3$)	7	17	15	2	--	8	4	--	--
Hardness (mg/l as $CaCO_3$)	6	28	17	15	--	--	21	--	--
Lead	--	--	--	18.2	--	--	16.2	--	--
Copper	--	--	--	10.4	--	--	8	--	--
Zinc	--	--	--	75.2	--	--	86.3	--	--
Nickel	--	--	--	10	--	--	11.1	--	--
Aluminum	--	--	--	2430	--	--	1370	--	--
Chromium	--	--	--	7.7	--	--	4.8	--	--

Filtration and Bioretention Systems

Filtration systems are seeing increased usage, especially in ultra-urban environments where space constraints prohibit the use of detention, retention and constructed wetland systems. Filtration systems can provide significant water quality improvements, but only a small amount, if any, water quantity control. It should also be stressed that filters must be placed off-line in order to assure continued functioning, and therefore only provide treatment of a volume of water based on a design storm. Any volume in excess of the design storm is bypassed without treatment.

Limited monitoring data are available on the efficiency of storm water filtering systems. This is mainly due to storm water filters being a relatively new technology, as opposed to more conventional BMPs such as wet ponds and constructed wetland systems. As a result, only a few published monitoring studies are available to evaluate the efficiency of various filter designs. The following Table 5-13 summarizes the pollutant removal efficiencies for storm water filtration systems. Removal efficiencies are based on data collected from 13 monitoring studies.

Table 5-13. Pollutant Removal Efficiency of Storm Water Filtration Systems

Parameter	Median or Average Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	-31	-37	-25	2
Total Phosphorus	45	-25	80	15
Ammonia-Nitrogen	68	43	94	4
Nitrate	-13	-100	27	13
Organic Nitrogen	28	0	56	2
Total Nitrogen	32	13	71	9
Suspended Solids	81	8	98	15
Bacteria	37	36	83	5
Organic Carbon	57	10	99	11
Cadmium	26	N/A	N/A	1
Chromium	54	47	61	2
Copper	34	22	84	9
Lead	71	-16	89	11
Zinc	69	33	91	15

Source: Brown and Schueler, 1997a

Storm water filtration systems can be highly effective at removing pollutants from storm water runoff. They are particularly effective at removing TSS and total phosphorus, although many filters export inorganic nitrogen due to nitrification of ammonia and organic nitrogen in the filter (Bell, 1998). Bell's study reported that significant phosphorus removals can be attributed to reaction and precipitation with sand that contains iron, calcium and aluminum. Although the limited data that are available on storm water filters indicates that their overall performance is good, additional data are needed to evaluate their efficiency, especially data that can be used to evaluate their long-term hydraulic performance and maintenance requirements. For example, Urbonas et al (1997) found that the hydraulic flow-through rate of a sand filter decreased from 3 feet-per-hour per square foot of filter area to less than 0.05 feet-per-hour after only several storms. This rapid decrease in flow-through rate causes a marked decrease in efficiency, since more of the storm flow will be bypassed unless adequate detention storage volume is provided up-stream of the filter. Therefore, overall TSS removal rates are significantly lower when this bypass flow is accounted for (for example, Urbonas' evaluation of storms over the 1995 season resulted in only a 15 percent overall TSS removal when bypass flows were taken into account). Due to the potential decrease in efficiency of sand filtration systems, careful consideration of design parameters is needed. Urbonas (1999) presents a thorough discussion of sand filtration design. Readers are urged to consult this reference for information on sand filtration system design.

In order to provide adequate filter functioning, the following basic design and operation guidelines should be followed:

- The filter should be placed off-line;
- A sedimentation chamber or basin should be provided upstream of the filter bed in order to allow for the removal of sediments to extend the length of the filter run between maintenance activities;
- The filter should be sized adequately or else adequate detention facilities should be provided upstream of the filter in order to capture expected storm water flows and to minimize bypasses;
- Care should be taken to limit excessive sediment loadings to the filter during construction or landscaping activities;
- Periodic maintenance to remove accumulated sediments and restore the filter flow-through rate may be necessary in areas with high solids loadings.

As with filtration systems, the available data on the performance of bioretention facilities are limited. Since bioretention facilities incorporate many of the same mechanisms as filtration systems, their performance for removal of parameters such as TSS are expected to be similar. Due to their biological nature, however, bioretention facilities are expected to also provide conditions necessary for uptake of nutrients by vegetation, degradation of organic contaminants by soil microorganisms, and biochemical reactions within the soil matrix and around the root zone of plants. Available data on the efficiency of bioretention facilities (based on laboratory data and one field study) indicates that bioretention can obtain removals on the order of 95-97 percent for metals, 75 percent for total phosphorus, 69 percent for TKN, 79 percent for ammonia, 21 percent for nitrate and 56 percent for total nitrogen (adapted from Bell (1998), average of all reported values).

The following general guidelines should be followed when designing bioretention facilities:

- Water should not be allowed to pond for more than four days in order to prevent mosquito breeding and to prevent adverse effects on plants;
- Plants selected for bioretention should be tolerant to stresses found in urban areas such as pollutants, variable soil moisture, periodic inundation, and high temperatures;

- Native plant species should be used whenever possible (Prince George's County, 1993), and species diversity should be maintained in order to prevent loss of all plants in the event of disease or infestation.
- Plants should be placed with regard to the elevation and moisture level of the planting bed (i.e., more water-tolerant species should be placed in lower areas where water is likely to pond longer);
- A mulch layer should be installed and maintained in order to prevent erosion of soils and to retain soil moisture;
- Where concentrated runoff enters the bioretention system, reinforcement (such as stone stabilization or synthetic erosion protection materials) may be needed to reduce erosion of the mulch layer and disturbance of the planting bed (Claytor and Schueler, 1996).
- The clay content of soils used in bioretention facilities may need to be limited to prevent clogging of the soil bed (Bell, 1998).

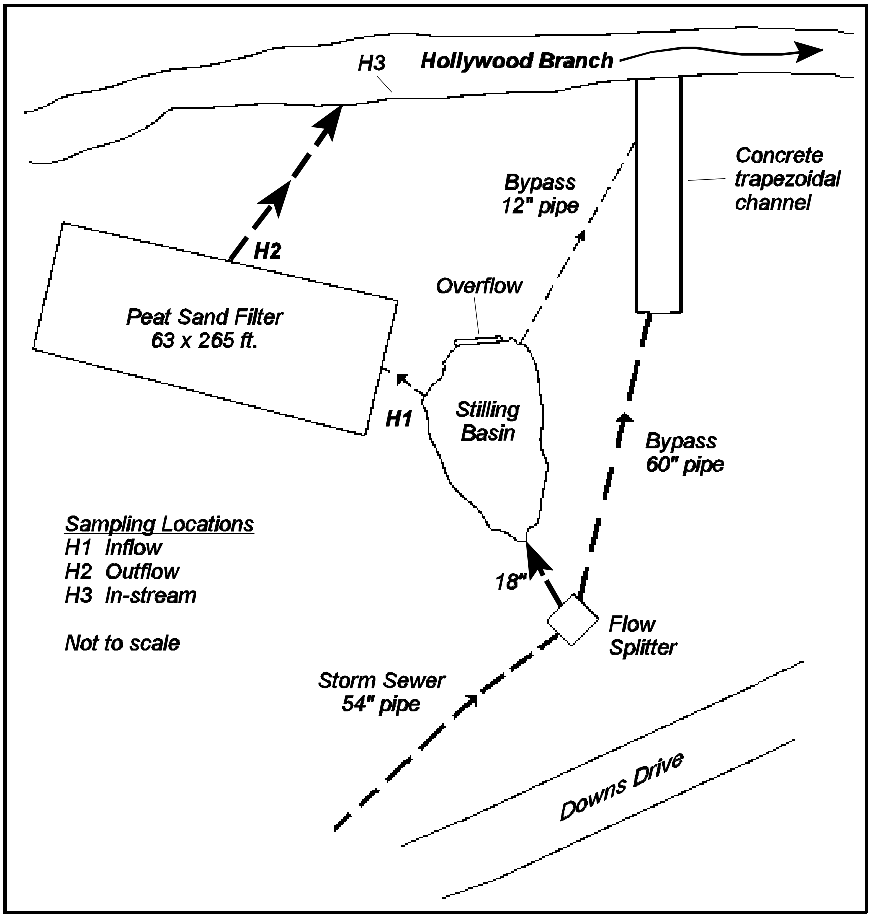
Readers are encouraged to consult *Design Manual for Use of Bioretention in Stormwater Management* (Prince George's County, 1993) and *Design of Stormwater Filtering Systems* (Claytor and Schueler, 1996) for additional information on the bioretention concept.

Hollywood Branch Peat/Sand Filter

In 1998 EPA conducted sampling activities at a peat/sand filter in Montgomery County, Maryland. The Hollywood Branch filter is a surface sand filter with a peat/sand filtration media that was designed based on the Galli paper (1990b). The filter is located in a county park in the Colesville area of Montgomery County and discharges to Hollywood Branch, a first-order stream that discharges into Paint Branch approximately 3,000 feet downstream of the filter. The drainage area covers approximately 140 acres and consists of 73 percent residential, 13 percent industrial and 14 percent other sources. The filter was one of several retrofit projects installed by Montgomery County as part of a watershed restoration effort in the Paint Branch watershed.

The filter is located off-line of the storm drainage system, and is designed to capture the first 0.1 watershed inches of runoff via a flow-splitter located in the storm sewer. This corresponds to a runoff volume of approximately 50,280 ft^3. Any runoff in excess of this amount bypasses the filter and is discharged directly to Hollywood Branch. Runoff from the flow splitter first enters a small stilling basin before being discharged to the filter. The stilling basin functions as a pre-settling chamber to remove coarse sediments in order to prolong the life of the filter. The stilling basin has a volume of 16,940 ft^3 at the permanent pool level, a depth of 3 feet, and length-to-width ratio of approximately 3:1. The edge of the stilling basin is planted with emergent wetland vegetation. Water is discharged from the stilling basin and into the filter through a submerged 18 inch pipe. The filter has dimensions of 265 feet by 63 feet. The filter is designed to pond water to a maximum depth of 2 feet, which corresponds to a volume of 33,880 ft^3. The filter bed is designed to have a minimum infiltration rate of 1.0 inch/hour. The filter bed consists of a 12-inch peat top layer, underlain by a 4-inch sand/peat mix, which is underlain by a 20-inch layer of sand. Water entering the filter is distributed by a series of interconnected 6 inch PVC half-pipes placed along the surface of the filter bed. The filter contains an under-drain system consisting of 6 inch perforated PVC pipes encased in a crushed gravel layer. Filtered water collected in the under-drain system is discharged to Hollywood Branch through a 12-inch concrete pipe. See Figure 5-16.

Figure 5-16. Hollywood Branch Peat/Sand Filter



The monitoring program consisted of recording runoff flow rates and volumes and collecting flow-weighted composite samples from the inflow and outflow of the filter using automatic sampling equipment. A tipping bucket rain gauge was used to record precipitation levels. Flow monitoring and water quality sampling was conducted for five events during the spring and summer of 1998. Baseflow samples were collected from the filter on three occasions. In addition, in-stream sediment samples were collected on one occasion, and bioassessment and physical habitat measurements were also conducted.

The following tables summarize the chemical sampling data collected during this evaluation. Additional information describing the sampling program, additional sampling and assessment data (including sediment, bioassessment and physical habitat assessment) and an analysis of the performance of the filter will be included as a supplement to this report.

Table 5-14. Summary of Hollywood Branch Peat/Sand Filter Storm Event Sampling Data

Analytes / Sample Dates ➤	06/01/98		06/12/98		06/14/98		06/24/98		07/31/98	
	Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
Event Volume (gal)	7,597	No flow	68,436	28,470	308,705	149,184	131,744	75,003	151,395	72,537
Total Suspended Solids (mg/l)	--	--	10	< 4	7	17	12	8	38	31
Chemical Oxygen Demand (mg/l)	16	--	25.2	17.6	24	14.4	< 10	11	30	34
Total Organic Carbon (mg/l)	10.4	--	7.29	4.37	4.37	4.37	5.5	6	14	10.4
Total Kjeldahl Nitrogen (mg/l as N)	2	--	7.28	5.6	2.24	11.2	0.91	0.78	1.8	0.68
Total Inorganic Nitrogen (mg/l as N)	1.11	--	0.77	2.14	0.66	2.07	1	1.86	1.13	2.21
Ammonia (mg/l as N)	0.56	--	< 1	< 1	1.68	14.6	0.28	0.16	0.32	< 0.1
Total Phosphorus (mg/l)	0.14	--	0.094	0.16	0.19	0.14	0.19	0.2	0.18	0.15
Ortho-Phosphate (mg/l)	--	--	0.047	0.27	0.23	0.049	< 0.01	< 0.01	0.1	< 0.01
Lead (µg/l)	2.1	--	13.6	2.4	2.3	3.7	2.7	5.6	3.8	8.9
Copper (µg/l)	6.8	--	8.3	2	4.7	1.3	7	4	6.5	11.3
Zinc (µg/l)	17.1	--	40.1	< 2	< 2	< 2	26.8	22.6	43	41.8
Nickel (µg/l)	2.4	--	2.4	22.3	<1	< 1	1.5	4.7	3.2	7.4
Aluminum (µg/l)	< 54	--	488	1360	899	2010	956	2810	497	3450
Chromium (µg/l)	< 1	--	1.4	6.3	< 1	< 1	< 1	4.8	< 1	7.7

Table 5-15. Summary of Hollywood Branch Peat/Sand Filter Baseflow Sampling Data

Sample Dates ➤ Analytes	05/19/98		06/23/98		08/14/98	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Total Suspended Solids (mg/l)	< 4	< 4	---	< 4	---	< 4
Chemical Oxygen Demand (mg/l)	< 10	< 10	---	< 10	---	< 20
Total Organic Carbon (mg/l)	< 10	< 10	---	3.5	---	6.6
Total Kjeldahl Nitrogen (mg/l as N)	1.66	19.8	---	0.55	---	1.28
Total Inorganic Nitrogen (mg/l as N)	1.79	0.64	---	0.74	---	0.23
Ammonia (mg/l as N)	0.49	< 0.1	---	< 0.1	---	< 1
Total Phosphorus (mg/l)	0.02	< 0.01	---	0.14	---	0.054
Ortho-Phosphate (mg/l)	0.02	0.02	---	< 0.01	---	0.069
Lead (µg/l)	< 2	< 2	---	---	---	< 2
Copper (µg/l)	< 1	< 1	---	---	---	1.2
Zinc (µg/l)	< 2	< 2	---	---	---	30.5
Nickel (µg/l)	2.3	3.1	---	---	---	2.7
Aluminum (µg/l)	59.8	< 54	---	---	---	1590
Chromium (µg/l)	< 1	--	---	---	---	2.3

Open Channel Vegetated Systems

Open channel vegetated systems are used widely for storm water quality control. However, these systems can be difficult to monitor, especially systems that intercept runoff as sheet flow such as grass filter strips. As a result, data on these types of systems are not as prevalent as other more readily monitored BMP types such as ponds and constructed wetlands. Table 5-16 summarizes the pollutant removal efficiency of open channel vegetated systems. Removal efficiencies are based on data collected from 20 monitoring studies.

Table 5-16. Pollutant Removal Efficiency of Open Channel Vegetated Systems

Parameter	Average or Median Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	11	-45	72	8
Total Phosphorus	15	-100	99	18
Ammonia-Nitrogen	3	-19	78	4
Nitrate	11	-100	99	13
Organic Nitrogen	39	11	86	3
Total Nitrogen	11	-100	99	10
Suspended Solids	66	-100	99	18
Bacteria	-25	-100	0	5
Organic Carbon	23	-100	99	11
Cadmium	49	20	80	6
Chromium	47	14	88	5
Copper	41	-35	89	15
Lead	50	-100	99	19
Zinc	49	-100	99	19

Source: Brown and Schueler, 1997a

Evaluation of available data does not provide a good indication as to the actual performance of these systems. The above data indicate that a wide range in pollutant removal efficiency is reported in the literature for open channel vegetated systems. Since there are a variety of system designs lumped into the above summary, arriving at efficiency estimates for a particular system type given available data is difficult. In general, these types of BMPs should be effective at removing suspended solids and associated pollutants from runoff by sedimentation and by filtration by vegetation, and are certainly effective at slowing the velocity of storm water runoff and for providing detention of runoff if check dams or other structures are incorporated to provide ponding of runoff. However, dense vegetation must be maintained in order to assure proper functioning. In addition, negative removals are frequently reported for sediment and nutrients. If open channel vegetated systems are not properly maintained, significant export of sediments and associated pollutants such as metals and nutrients can occur from eroded soil. In addition, standing water in these systems can be a significant source of bacteria and can provide the conditions necessary for mosquito breeding. Additional data gathering is needed in order to support these assumptions and to quantify the efficiency of these systems.

Open channel vegetated systems can be used as pretreatment devices for other BMPs, or can be used in a "treatment train" approach. For example, grass filter strips are commonly used to accept sheet flow from parking lots in order to pre-treat runoff prior to being treated by a bioretention facility or a filter. Vegetated swales can be used to convey runoff to BMPs such as ponds or constructed wetlands, providing pretreatment of the runoff volume. When used in combination with other BMPs, the overall quality of the treated runoff can be improved and the total runoff volume can be reduced due to infiltration that occurs in the open channel vegetated systems.

Miscellaneous and Vendor-Supplied Systems

Little data exist in the published literature on the efficiency of vendor-supplied systems. Data is frequently available from the vendors, and as more of these systems are installed it is expected that more data will become available. An evaluation of the efficiency of these systems has not been included in this report. The EvTEC program (see section 5.2.1.8) and other evaluation programs should provide useful information that indicates the efficiency of these systems in removing pollutants from runoff.

5.5.3 Controlling Flow Impacts

The removal of pollutants from storm water runoff is an important function of storm water BMPs. However, in many cases receiving water problems are not due to the pollutants contained in storm water, but rather can be attributed to the large flow rates that result in receiving streams that receive storm water discharges. Therefore, in some cases, controlling the volume and flow rate of storm water discharges is as important, if not more important, than removing pollutants prior to discharge. Site-specific parameters will dictate the importance of flow control in preventing degradation of receiving waters.

Evaluating the effectiveness of BMPs in controlling flow impacts is not an easy task. Site-specific variations such as slope, soil types, ground cover, and watershed-imperviousness can greatly impact the hydraulic response of a watershed to rainfall. In addition, receiving water parameters greatly influence the degree of flow control that is necessary in order to prevent degradation. As a result, little information is contained in the literature describing the performance of BMPs at controlling impacts in receiving streams due to excessive storm water flows. The literature that does exist, however, indicates a direct correlation between urbanization and receiving stream degradation. It is not difficult to infer, therefore, that storm water flow is a major contributor to receiving stream degradation, and that control of storm water flow rates and volumes is warranted in order to restore degraded receiving waters and to prevent degradation of receiving waters in newly developing areas. Additional information on the hydrological benefits of BMPs is presented in section 6.3.2 of this report.

Important measures of the effectiveness of BMPs at controlling storm water flows include:

- reductions in peak flow rate across the BMP;
- total storage volume provided in the BMP;
- infiltrative capacity of the BMP;
- retention time in the BMP;
- relationship of post-development hydrologic conditions to pre-development hydrology;
- retention volume necessary for receiving stream channel protection.

Local conditions will dictate the BMP design parameters that are necessary to reduce impacts due to flow. For example, the state of Maryland has developed unified BMP sizing criteria that is designed to provide adequate control of pollutants, limit degradation of streams, provide adequate groundwater recharge, and protect downstream areas from flooding. Additional work is needed in other areas of the country to evaluate the effectiveness criteria necessary to limit flow impacts and to provide adequate BMP sizing standards.

Flow control can be accomplished by using both structural and non-structural practices. Structural BMPs that can provide flow control include retention basins, detention basins, constructed wetlands, infiltration practices, grassed swales and minimizing directly connected impervious surface areas. Filters and bioretention facilities can also be adapted to provide some degree of quantity control if they are used in conjunction with detention basins or other means of providing detention of storm water prior to treatment, such as providing temporary ponding in overflow parking areas. Non-structural BMPs and land-use practices that can help to reduce the volume of storm water runoff discharged to receiving streams should also be considered a vital component of storm water management. Practices that can reduce the impact of storm water runoff due to excessive flows include land use regulations such as zoning, natural area and stream buffer preservation, limits on impervious surfaces, and cluster development. Practices that limit the generation of storm water can be very effective in preventing degradation of streams, and can limit the need for structural storm water controls. Information on development practices aimed at reducing impacts due to site development practices can be found in *Conservation Design for Stormwater Management* (Delaware DNREC, 1997) and in *Green Development* (US EPA, 1996b).

5.6 Conclusions

There are a wide variety of BMPs available to manage storm water runoff. The efficiency of various BMP types has been documented to some degree, but there is still a great need for focused research in certain areas, particularly for newer and innovative structural BMP types, as well as non-structural BMPs. However, due to the complexity involved in isolating the reaction of a complex and highly variable system such as a watershed to one isolated input, evaluations of non-structural BMPs are ambitious tasks. Still, where storm water management is largely driven by the availability of scarce funding, data that indicate the cost-effectiveness of various control strategies are badly needed.

Ultimately, receiving stream morphology, habitat and biological communities may turn out the be the driving factors indicating the success of BMPs at controlling impacts due to storm water flows and the pollutants that they contain. In order for such measures to work, however, it is necessary to isolate the response of a receiving stream system to the implementation of BMPs. Frequently, there are too many variables in a watershed and too many other potential sources of degradation to isolate the improvements (or even to indicate potential negative impacts) of a particular BMP or group of BMPs. For example, Maxted and Shaver (1997) did not observe a significant difference in macroinvertebrate communities between 8 sites with storm water retention ponds and 33 sites with no storm water controls. In addition, the BMPs did not prevent the almost complete loss of sensitive aquatic species. Whether or not these impacts were caused by storm water flows, pollutants or other non-storm water sources was not indicated, and the data to be able to answer these questions may not be forthcoming in the foreseeable future. Therefore, until data are available to indicate that specific BMPs can prevent impacts and prevent degradation of receiving streams in urbanized areas, one should not assume that structural, "end-of-pipe" BMPs are the only answer to the storm water problem.

Available data seem to indicate that urbanization and traditional urban development at almost any level can cause degradation of streams, and that BMPs may be able to mitigate these impacts to a certain level. Accordingly, storm water management should start at the point of runoff generation, and incorporate site planning principles that prevent or minimize the generation of runoff, prevent development in floodplains, preserve natural drainage systems, and avoid disturbing sensitive areas such as wetlands and riparian areas. Where runoff generation cannot be avoided, then properly sited, designed, constructed and operated BMPs can be implemented to attempt to reduce the impacts associated with this runoff. There are data available on the effectiveness of BMPs in reducing pollutant loads, but these data are not comprehensive enough to either characterize the performance of all BMPs in use or to determine if they are actually controlling impacts to receiving waters. Additional data gathering is necessary, but the monitoring and data analysis protocols necessary to do so have not been fully developed. Standardization of monitoring protocols for data transferability is a vital component of successful data evaluation, and is an area that should be actively pursued in the near future.

6.0 Costs and Benefits of Storm Water BMPs

Storm water best management practices (BMPs) are the primary tool to improve the quality of urban streams and meet the requirements of NPDES permits. They include both the structural and non-structural options reviewed in Section 5.2 of this report. Some BMPs can represent a significant cost to communities, but these costs should be weighed against the various benefits they provide. This chapter will focus on reviewing available data on the costs and potential benefits of both structural and non-structural BMPs designed to improve the quality of urban and urbanizing streams, and the larger water bodies to which they drain.

As described in previous chapters, storm water runoff can contribute loadings of nutrients, metals, oil and grease, and litter that result in impairment of local water bodies. The extent to which these impairments are eliminated by BMPs will depend on a number of factors, including the number, intensity, and duration of wet weather events; BMP construction and maintenance activities; and the site-specific water quality and physical conditions. Because these factors will vary substantially from site to site, data and information are not available with which to develop dollar estimates of costs and benefits for individual types of BMPs. However, EPA's national estimates of costs and benefits associated with implementation of the NPDES Phase II rule are discussed in Section 6.4.

6.1 Structural BMP Costs

The term structural BMPs, often referred to as "Treatment BMPs," refers to physical structures designed to remove pollutants from storm water runoff, reduce downstream erosion, provide flood control and promote groundwater recharge. In contrast with non-structural BMPs, structural measures include some engineering design and construction.

Structural BMPs evaluated in this report include:

- Retention Basins
- Detention Basins
- Constructed Wetlands
- Infiltration Practices
- Filters
- Bioretention
- Biofilters (swales and filter strips).

The two infiltration systems focused on in this report are infiltration trenches and infiltration basins. Although bioretention can serve as a filtering system or infiltration practice, it is discussed separately because it has separate cost data and design criteria. In this report, wet swales are assumed to have the same cost as biofilters, because there are little cost data available on this practice. Additional information about these structural BMPs, including descriptions, applicability and performance data can be found in Chapter 5 of this report. Other BMPs include experimental and proprietary products, as well as some conventional structures such as water quality inlets. They are not included in this analysis because sufficient data are not available to support either the performance or the cost of these practices.

6.1.1 Base Capital Costs

The base capital costs refer primarily to the cost of constructing the BMP. This may include the cost of erosion and sediment control during construction. The costs of design, geotechnical testing, legal fees, land costs, and other unexpected or additional costs are not included in this estimate. The cost of constructing any BMP is variable and depends largely on site conditions and drainage area. For example, if a BMP is constructed in very rocky soils, the increased excavation costs may substantially increase the cost of construction. Also, land acquisition costs vary greatly from site to site.[4] In addition, designs vary slightly among BMP types. A wet pond may be designed with or without various levels of landscaping, for example. The data in Table 6-1 represent typical unit costs (dollars per cubic foot of treated water volume) from various studies, and should be considered planning level. In the case of retention and detention basins, ranges are used to reflect the economies of scale involved in designing these BMPs.

[4] Land cost is the largest variable influencing overall BMP cost.

Table 6-1. Typical Base Capital Construction Costs for BMPs

BMP Type	Typical Cost* ($/cf)	Notes	Source
Retention and Detention Basins	0.50-1.00	Cost range reflects economies of scale in designing this BMP. The lowest unit cost represents approx. 150,000 cubic feet of storage, while the highest is approx. 15,000 cubic feet. Typically, dry detention basins are the least expensive design options among retention and detention practices.	Adapted from Brown and Schueler (1997b)
Constructed Wetland	0.60-1.25	Although little data are available to assess the cost of wetlands, it is assumed that they are approx. 25% more expensive (because of plant selection and sediment forebay requirements) than retention basins..	Adapted from Brown and Schueler (1997b)
Infiltration Trench	4.00	Represents typical costs for a 100-foot long trench.	Adapted from SWRPC (1991)
Infiltration Basin	1.30	Represents typical costs for a 0.25-acre infiltration basin.	Adapted from SWRPC (1991)
Sand Filter	3.00-6.00	The range in costs for sand filter construction is largely due to the different sand filter designs. Of the three most common options available, perimeter sand filters are moderate cost whereas surface sand filters and underground sand filters are the most expensive.	Adapted from Brown and Schueler (1997b)
Bioretention	5.30	Bioretention is relatively constant in cost, because it is usually designed as a constant fraction of the total drainage area.	Adapted from Brown and Schueler (1997b)
Grass Swale	0.50	Based on cost per square foot, and assuming 6 inches of storage in the filter.	Adapted from SWRPC (1991)
Filter Strip	0.00-1.30	Based on cost per square foot, and assuming 6 inches of storage in the filter strip. The lowest cost assumes that the buffer uses existing vegetation, and the highest cost assumes that sod was used to establish the filter strip.	Adapted from SWRPC (1991)

* Base year for all cost data: 1997

In some ways there is no such value as the “average” construction cost for some BMPs, because many BMPs can be designed for widely varying drainage areas. However, there is some value in assessing the cost of a typical application of each BMP. The data in Table 6-2 reflect base capital costs for typical applications of each category of BMP. It is important to note that, since many BMPs have economies of scale, it is not practical to extrapolate these values to larger or smaller drainage areas in many cases.

Table 6-2. Base Costs of Typical Applications of Storm Water BMPs[1]

BMP Type	Typical Cost ($/BMP)	Application	Data Source
Retention Basin	$100,000	50-Acre Residential Site (Impervious Cover = 35%)	Adapted from Brown and Schueler (1997b)
Wetland	$125,000	50-Acre Residential Site (Impervious Cover = 35%)	Adapted from Brown and Schueler (1997b)
Infiltration Trench	$45,000	5-Acre Commercial Site (Impervious Cover = 65%)	Adapted from SWRPC (1991)
Infiltration Basin	$15,000	5-Acre Commercial Site (Impervious Cover = 65%)	Adapted from SWRPC (1991)
Sand Filter	$35,000-$70,000[2,3]	5-Acre Commercial Site (Impervious Cover = 65%)	Adapted from Brown and Schueler (1997b)
Bioretention	$60,000	5-Acre Commercial Site (Impervious Cover = 65%)	Adapted from Brown and Schueler (1997b)
Grass Swale	$3,500	5-Acre Residential Site (Impervious Cover = 35%)	Adapted from SWRPC (1991)
Filter Strip	$0-$9,000[3]	5-Acre Residential Site (Impervious Cover = 35%)	Adapted from SWRPC (1991)

1. Base costs do not include land costs.
2. Total capital costs can typically be determined by increasing these costs by approximately 30%.
3. A range is given to account for design variations.

Although various manuals report construction cost estimates for storm water ponds, EPA has identified only three studies that have systematically evaluated the construction costs associated with structural BMPs since 1985. The three studies used slightly different estimation procedures. Two of these studies were conducted in the Washington, DC region and used a similar methodology (Wiegand et al, 1986; Brown and Schueler, 1997b). In both studies, the costs were determined based on engineering estimates of construction costs from actual BMPs throughout the region. In the third study, conducted in Southeastern Wisconsin, costs were determined using standardized cost data for different elements of the BMP, and assumptions of BMP design (SWRPC, 1991).

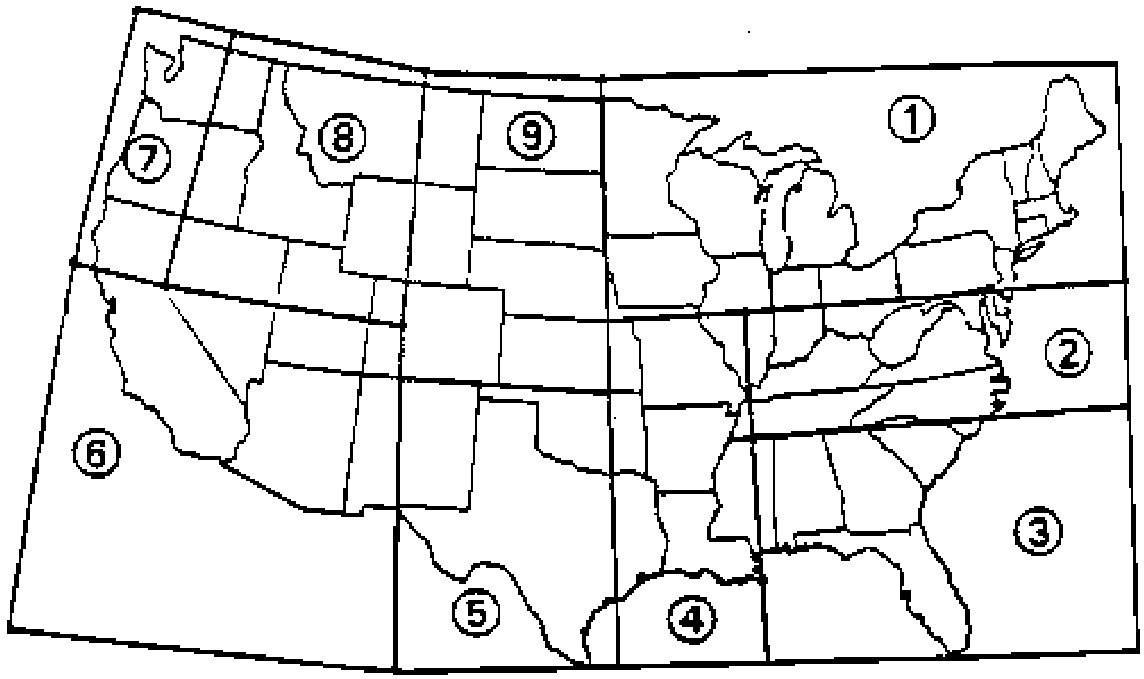
Any costs reported in the literature need to be adjusted for inflation and regional differences. All costs reported in this report assume a 3 percent annual inflation rate. In addition, studies are adjusted to the "twenty cities average" construction cost index, to adjust for regional biases, based on a methodology followed by the American Public Works Association (APWA, 1992). Using EPA's rainfall zones (see Figure 6-1), a cost adjustment factor is assigned to each zone (Table 6-3). For example, rainfall region 1 has a factor of 1.12. Thus, all studies in the Northeastern United States are divided by 1.12 in order to adjust for this bias.

Table 6-3. Regional Cost Adjustment Factors

Rainfall Zone	1	2	3	4	5	6	7	8	9
Adjustment Factor	1.12	0.90	0.67	0.92	0.67	1.24	1.04	1.04	0.76

Source: Modified from APWA, 1992

Figure 6-1. Rainfall Zones of the United States



Not shown: Alaska (Zone 7); Hawaii (Zone 7); Northern Mariana Islands (Zone 7); Guam (Zone 7); American Samoa (Zone 7); Trust Territory of the Pacific Islands (Zone 7); Puerto Rico (Zone 3) Virgin Islands (Zone 3).
Source: NPDES Phase I regulations, 40 CFR Part 122, Appendix E (US EPA, 1990)

6.1.1.1 Retention/Detention Basins and Constructed Wetlands

The total volume of the basin is generally a strong predictor of cost (Table 6-4). There are some economies of scale associated with constructing these systems, as evidenced by the slope of the volume equations derived. This is largely because of the costs of inlet and outlet design, and mobilization of heavy equipment that are relatively similar regardless of basin size.

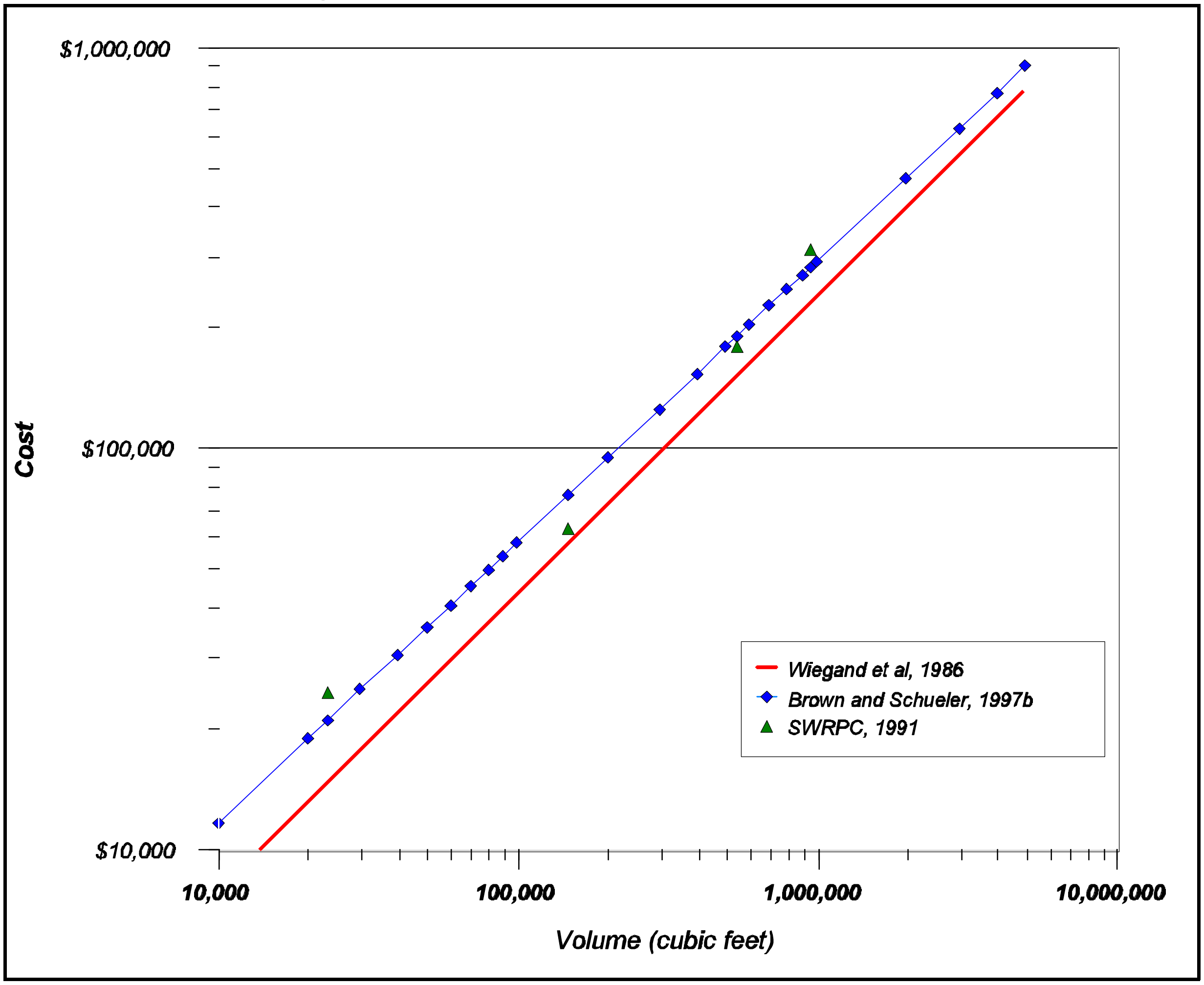
Erosion and sediment control represents only about 5 percent of the construction cost of basins and wetlands (Brown and Schueler, 1997b). Thus, the construction cost estimates presented in Table 6-2 are comparable. The cost of building storm water retention and detention systems has increased since 1986 (Figure 6-2), even after adjusting for inflation. Part of the reason for this increase is thought to be attributable to the improved design of these systems to enhance water quality driven by a more complex regulatory and review environment (Brown and Schueler, 1997b). The cost estimations made by SWRPC (1991) were generally a mid-range between the earlier and more recent studies.

Table 6-4. Base Capital Costs for Storm Water Ponds and Wetlands

<table>
<tr><th rowspan="2">BMP Type</th><th rowspan="2">Cost Equation or Estimate</th><th colspan="2">Costs Included</th><th rowspan="2">Source</th></tr>
<tr><th>Construction</th><th>E&S Control</th></tr>
<tr><td rowspan="2">Retention Basins and Wetlands</td><td>$7.75V^{0.75}$</td><td>✔</td><td>✔</td><td>Wiegand et al, 1986</td></tr>
<tr><td>$18.5V^{0.70}$</td><td>✔</td><td></td><td>Brown and Schueler, 1997b</td></tr>
<tr><td>Detention Basins</td><td>$7.47V^{0.78}$</td><td>✔</td><td>✔</td><td>Brown and Schueler, 1997b</td></tr>
<tr><td rowspan="4">Retention Basins</td><td>1.06V: 0.25 acre retention basin (23,300 cubic feet)</td><td rowspan="4">✔</td><td rowspan="4"></td><td rowspan="4">SWRPC, 1991</td></tr>
<tr><td>0.43V: 1.0 acre retention basin (148,000 cubic feet)</td></tr>
<tr><td>0.33V: 3.0 acre retention basin (547,000 cubic feet)</td></tr>
<tr><td>0.31V: 5.0 acre retention basin (952,000 cubic feet)</td></tr>
</table>

Notes
V refers to the total basin volume in cubic feet
Costs presented from SWRPC (1991) are “moderate” costs reported in that study.

Figure 6-2. Retention Basin Construction Cost



6.1.1.2 Infiltration Practices

Costs for infiltration BMPs are highly variable from site to site, depending on soils and other geotechnical information. Perhaps because of this variability, cost estimates for infiltration trenches have been widely different (Table 6-5; Figure 6-3). Brown and Schueler (1997b) concluded that the Wiegand (1986) equation underestimated cost, partially because of the lack of pretreatment in earlier designs, although they were unable to develop a consistent equation due to a small sample size.

It is difficult to estimate the cost of infiltration basins, mainly due to a lack of recent cost data. The costs estimates for SWRPC are dramatically higher than those estimated by Schueler, 1987 (Figure 6-4). This is largely because the SWRPC document assumes that 50 percent additional volume is excavated for the spillway, while Schueler uses a retention basin cost equation.

Table 6-5. Base Capital Costs for Infiltration Practices

BMP Type	Cost Equation or Estimate[4]	Costs Included		Source
		Construction	E&S Control	
Infiltration Trenches[1]	$33.7V^{0.63}$	✔		Wiegand et al, 1986
	2V to 4V; average of 2.5V	✔		Brown and Schueler, 1997b
	\$4,400: 3-foot deep, 4-foot wide, 100-foot long trench	✔		SWRPC, 1991
	\$10,400: 6-foot deep, 10-foot wide, 100-foot long trench			
	3.9V+2,900: 3-foot deep, 100-foot long trench	✔		Modified from SWRPC, 1991
Infiltration Basins[2]	$13.2V^{0.69}$	✔	✔	Schueler, 1987; Modified from Wiegand et al, 1986
	1.3V: 0.25-acre infiltration basin (15,000 cubic feet)	✔		SWRPC, 1991
	0.8V: 1.0-acre infiltration basin (76,300 cubic feet)			
Porous Pavement[3]	50,000A	✔		SWRPC, 1991
	80,000A	✔		Schueler, 1987

1. V for infiltration trenches refers to the treatment volume (cubic feet) within the trench, assuming a porosity of 32%.
2. V for infiltration basins refers to the total basin volume (cubic feet).
3. A is the surface area in acres of porous pavement.
4. Costs presented from SWRPC (1991) are “moderate” costs reported in that study.

Figure 6-3. Infiltration Trench Cost

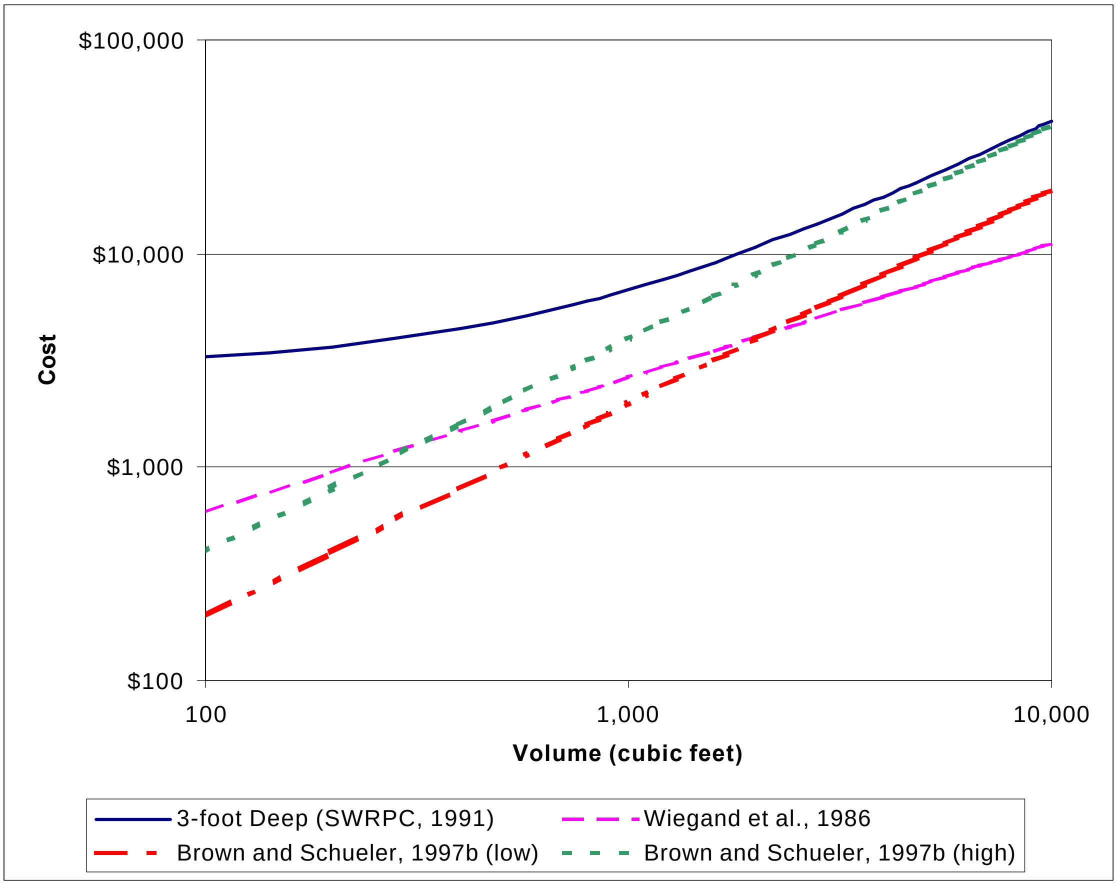
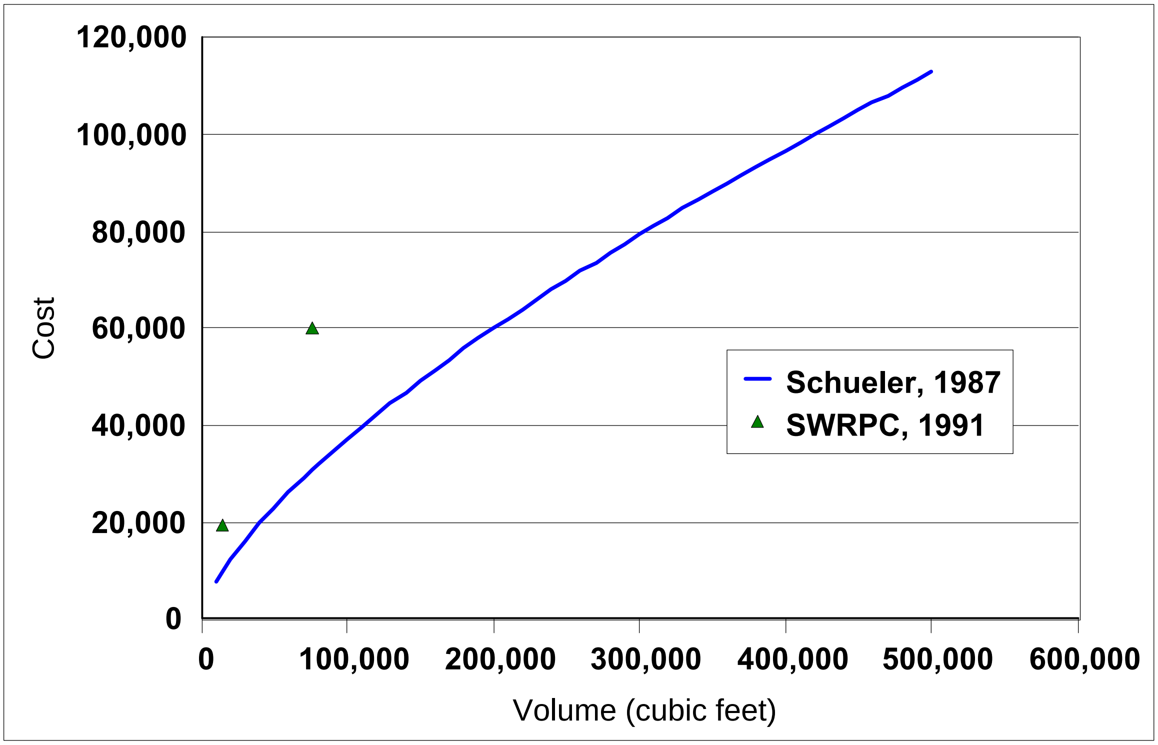


Figure 6-4. Infiltration Basin Construction Cost



6.1.1.3 Sand Filters

Since sand filters have not been used as long as other BMPs, less information is available on their cost than on most BMPs. In addition, the costs of sand filters vary significantly due to the wide range of design criteria for sand filters (Table 6-6). Brown and Schueler (1997b) were unable to derive a valid relationship between sand filter cost and water quality volume, with costs ranging between $2 and $6 per cubic foot of water quality volume, with a mean cost of $2.50 per cubic foot. The water quality volume includes the pore space in the sand filter, plus additional storage in the pretreatment basin.

Because of the lack of cost data, no equation referencing the economies of scale has been developed. However, it appears that economies of scale do exist. For example, data from Austin indicates that the cost per acre decreased by over 80 percent for a design of a 20-acre drainage area, when compared with a 1-acre drainage area. (Schueler, 1994a).

Table 6-6. Construction Costs for Various Sand Filters

Region (Design)	Cost/Impervious Acre
Delaware	$10,000
Alexandria, VA (Delaware)	$23,500
Austin, TX (< 2 acres)	$16,000
Austin, TX (> 5 acres)	$3,400
Washington, DC (underground)	$14,000
Denver, CO	$30,000-$50,000

Source: Schueler, 1994a

6.1.1.4 Bioretention

Little information is available on the costs of bioretention because it is a relatively new practice. Brown and Schueler (1997b) found consistent construction costs of approximately $5.30 per cubic foot of water quality volume for the construction cost. The water quality volume includes 9 inches above the surface area of the bioretention structure.

6.1.1.5 Vegetative BMPs

The two major types of vegetative BMPs include filter strips and grassed swales (also called “biofilters”). The costs for these BMPs vary, and largely depend on the method used to establish vegetation (Table 6-7).

Table 6-7. Base Capital Costs of Vegetative BMPs

BMP Type	Cost Equation or Estimate[1]	Costs Included		Source
		Construction	E&S Control	
Filter Strips	Existing Vegetation: 0 Seed: $13,800/acre Sod: $29,000/acre	✔		SWRPC, 1991
Grassed Channels	25¢ per square foot	✔		SWRPC, 1991

1. Costs presented from SWRPC (1991) are "moderate" costs reported in that study.

6.1.2 Design, Contingency and Permitting Costs

Most BMP cost studies assess only part of the cost of constructing a BMP, usually excluding permitting fees, engineering design and contingency or unexpected costs. In general, these costs are expressed as a fraction of the construction cost (Table 6-8). These costs are generally only estimates, based on the experience of designers.

Table 6-8. Design, Contingency and Permitting Costs

Additional Costs Estimate (Fraction of base construction costs)	Source	Comments
25%	Wiegand et al, 1986	Includes design, contingencies and permitting fees
32%	Brown and Schueler, 1997b	Includes design, contingencies, permitting process and erosion and sediment control

6.1.3 Land Costs

The cost of land is extremely variable both regionally and by surrounding land use. For example, many suburban jurisdictions require open space allocations within the developed site, reducing the effective cost of land for BMPs to zero (Schueler, 1987). On the other hand, the cost of land may far outweigh construction and design costs in ultra-urban settings. For this reason, some underground BMPs that are relatively expensive to construct may be attractive in this "ultra-urban" setting if sub-surface conditions are suitable (Lundgren, 1996). The land consumed per treatment volume depends largely on how much of the BMP's treatment is underground, and varies considerably (Table 6-9).

Table 6-9. Relative Land Consumption of Storm Water BMPs

BMP Type	**Land consumption (% of Impervious Area)**
Retention Basin	2-3%
Constructed Wetland	3-5%
Infiltration Trench	2-3%
Infiltration Basin	2-3%
Porous Pavement	0%
Sand Filters	0%-3%
Bioretention	5%
Swales	10%-20%
Filter Strips	100%

Note: Represents the amount of land needed as a percent of the impervious area that drains to the practice to achieve effective treatment.
Source: Claytor and Schueler, 1996

6.1.4 Operation and Maintenance Costs

Maintenance can be broken down into two primary categories: aesthetic/nuisance maintenance and functional maintenance. Functional maintenance is important for performance and safety reasons, while aesthetic maintenance is important primarily for public acceptance of BMPs, and because it may also reduce needed functional maintenance. Aesthetic maintenance is obviously more important for BMPs that are very visible, such as ponds and biofiltration facilities.

In most studies, operation and maintenance (O&M) costs have been estimated as a percentage of base construction costs (Table 6-10). While some BMPs require infrequent, costly maintenance, others need more frequent but less costly maintenance.[5] Accordingly, selection of appropriate structural BMPs must factor in maintenance cost (and a responsible party to carry out maintenance) to ensure the necessary long-term performance. Typical maintenance activities are included in Table 5-3.

Table 6-10. Annual Maintenance Costs

BMP	Annual Maintenance Cost (% of Construction Cost)	Source(s)
Retention Basins and Constructed Wetlands	3%-6%	Wiegand et al, 1986 Schueler, 1987 SWRPC, 1991
Detention Basins[1]	<1%	Livingston et al, 1997; Brown and Schueler, 1997b
Constructed Wetlands[1]	2%	Livingston et al, 1997; Brown and Schueler, 1997b
Infiltration Trench	5%-20%	Schueler, 1987 SWRPC, 1991
Infiltration Basin[1]	1%-3%	Livingston et al, 1997; SWRPC, 1991
	5%-10%	Wiegand et al, 1986; Schueler, 1987; SWRPC, 1991
Sand Filters[1]	11%-13%	Livingston et al, 1997; Brown and Schueler, 1997b
Swales	5%-7%	SWRPC, 1991
Bioretention	5%-7%	(Assumes the same as swales)
Filter strips	$320/acre (maintained)	SWRPC, 1991

1. Livingston et al (1997) reported maintenance costs from the maintenance budgets of several cities, and percentages were derived from costs in other studies

[5] Maintenance costs can also vary significantly based on a variety of site- and region-specific parameters, therefore the maintenance costs presented in Table 6-10 should be considered only as general guidelines.

6.1.5 Long-Term BMP Costs: Two Scenarios

In order to compare various BMP options, costs were calculated for a 5-acre commercial site and a 38-acre residential site.[6] Construction costs were evaluated using the following steps:

1. *Calculate the water quality volume* (WQ_v).[7]
Using a water quality volume based on a 1-inch storm, the volume is equal to:

$$WQ_v = (.05 + .9I)\, A/12$$

where:
WQ_v = Water Quality Volume (Acre-Feet)
I = Impervious Fraction in the Watershed
A = Watershed Area (Acres)

2. *Calculate the detention storage volume.*
Total detention storage was determined using standard peak flow methods (USDA/NRCS, 1986). Detention storage was calculated for a 5-inch storm.

3. *Calculate total volume.*
Many BMPs do not require any detention storage, but for BMPs that do provide flood storage, the total volume is the sum of the water quality and detention volumes calculated in steps 1 and 2.

4. *Determine the construction cost.*
The construction cost for each BMP is determined based on equations described in Section 6.1.1.

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[6] Although these evaluations are useful for comparing potential costs of various structural BMPs, they should not be applied for use in all areas of the country. In addition, the BMPs, selected in these examples and the sizing criteria that the costs were based on should not be considered as recommendations for actual BMP selection and design. They are presented solely for illustrative purposes.

[7] "Water quality volume" refers to the volume of water that the BMP is designed to treat. For example, a BMP may be designed to capture the first inch of runoff from the drainage area. Any volume of rainfall over the first inch would bypass the BMP. Therefore water quality volume for this BMP would be one watershed inch.

6.1.5.1 5-Acre Commercial Development

The following data were used as the basis for the 5-acre commercial development.

Table 6-11. Data for the Commercial Site Scenario

Area (A)	5 acres
Impervious Cover (I)	65%
<u>Water Quality Volume</u> P · Rv · A/12 P = 1" of rainfall Rv = 0.5 + 0.9 (I) A = Drainage Area	0.26 ac-ft
Total Detention Storage (using TR-55 model)	0.74 ac-ft
Total Storage	1.00 ac-ft

These data were then used to compare various BMP options (Table 6-12). Grassed swales and filter strips were not included in this analysis because, although they do improve water quality, they are typically used only in combination with other BMPs in a new development area. Again, it is important to note that the cost of land is not included in this calculation. Although retention basins are the least expensive option on an annual basis, the cost of land may drive designs to less space-consumptive BMPs, such as sand filters or bioretention systems.

Table 6-12. BMP Costs for a Five Acre Commercial Development

BMP Type	Construction Cost Equation	Construction Cost	Typical Design, Contingency & Other Capital Costs (30% of Construction Costs)	Annual Maintenance Costs (% of Construction, $)	Notes	Sources
Retention Basin	$18.5V_t^{0.70}$	$32,700	$9,810	5%; $1,640	Much of the cost associated with this BMP is the extra storage to provide flood control and channel protection. Ponds are very reliable.	a, b, c, d, e
Infiltration Trench	$3.9WQ_v$ +2,900	$47,100	$14,100	12%; $5,650	Although infiltration trenches are designed to last a long time, they need to be inspected and rebuilt if they become clogged.	c, d, e
Infiltration Basin	$1.3WQ_v$	$14,700	$4,410	8%; $1,180	Infiltration basins require careful siting and design to perform effectively..	b, c, d, e
Sand Filter	$4WQ_v$	$45,200	$13,600	12%; $5,420	Sand filters require frequent maintenance in order to function long-term.	a, e, f
Bioretention	$5.30WQ_v$	$60,000	$18,000	6%; $3,600	Bioretention is a relatively new BMP. Little is known about its long-term performance.	a, d

1. WQv = Water Quality Volume, cu. ft. 2. V_t = Total Volume, cu. ft.
3. Sand filter volume was estimated at 4WQv, which is slightly high, to account for the relatively small drainage area.

a. Brown and Schueler, 1997b b. Wiegand et al, 1986 c. Schueler, 1987 d. SWRPC, 1991 e. US EPA, 1993a f. Livingston et al, 1997

6.1.5.2 38-Acre Residential Development

The following data were used as the basis for the 38-acre residential development.

Table 6-13. Data for the Residential Site Scenario

Area (A)	38 acres
Impervious Cover (I)	36%
Water Quality Volume	1.1 ac-ft
Total Detention Storage (using TR-55 model)	2.8 ac-ft
Total Storage	3.9 ac-ft

The same analysis conducted for the commercial site was repeated for the larger site (Table 6-14). Bioretention and infiltration systems were not included in this analysis, because these BMPs are best applied on smaller sites. The costs of swales and filter strips were also not included, although they could be effectively used in combination with retention systems to provide pretreatment.

6.1.6 Adjusting Costs Regionally

The cost data in these examples can be adjusted to specific zones of the country using the regional cost adjustment factors in Table 6-3. For example, if costs for Rainfall Zone 1 were needed, the data in Tables 6-12 or 6-14 would be multiplied by 1.12.

In addition, design variations in different regions of the country may cause prices to be changed. For example, wetland and wet ponds may be restricted in arid regions of the country. Furthermore, while retention basins are used in semi-arid regions, they usually incorporate design variations to improve their performance (Saunders and Gilroy, 1997). In cold regions, BMPs may need to be adapted to account for snowmelt treatment, deep freezes and road salt application (Oberts, 1994; Caraco and Claytor, 1997), which will cause additional changes in BMP costs.

Table 6-14. BMP Costs for a Thirty-Eight Acre Residential Development

BMP Type	Construction Cost Equation	Construction Cost	Design, Contingency and other Capital Costs (30% of Construction)	Annual Maintenance Costs (% of Construction; $)	Notes	Sources
Retention Basin	$18.5V_t^{0.70}$	$84,800	$25,400	5%; $4,240	Pond systems are relatively easy to apply to large sites.	a, b, c, d, e
Sand Filter	$2WQ_v$	$95,800	$28,700	12%; $11,500	Although the sand filter is used in this example, some evidence suggests that sand filters may be subject to clogging if used on a site that drains a relatively pervious drainage area such as this one.	a, e, f
1. WQv = Water Quality Volume, cu. ft. 2. Vt = Total Volume, cu. ft. 3. Sand filter volume was estimated at 2V, which is slightly low, to account for the relatively large drainage area						
a. Brown and Schueler, 1997b b. Wiegand et al, 1986 c. Schueler, 1987 d. SWRPC, 1991 e. US EPA, 1993a f. Livingston et al, 1997						

6.2 Non-Structural BMP Costs

Non-structural BMPs are management measures that prevent degradation of water resources by preventing pollution at the source, rather than treating polluted runoff. Non-structural practices include a variety of site-specific and regional practices, including: street sweeping, illicit connection identification and elimination, public education and outreach, land use modifications to minimize the amount of impervious surface area, waste collection and proper materials storage. While non-structural practices play an invaluable role in protecting surface waters, their costs are generally not as easily quantified as for structural BMPs. This is primarily because there are no "design standards" for these practices. For example, the cost of a public education program may vary due to staff size. However, it is possible to identify costs associated with specific components of these programs based on past experience.

6.2.1 Street Sweeping

The costs of street sweeping include the capital costs of purchasing the equipment, plus the maintenance and operational costs to operate the sweepers, as well as costs of disposing the materials that are removed. Both equipment and operating costs vary depending on the type of sweeper selected. There are several different options for sweepers, but the two basic choices are mechanical sweepers versus vacuum-assisted sweepers. Mechanical sweepers use brushes to remove particles from streets. Vacuum-assisted dry sweepers, on the other hand, use a specialized brush and vacuum system in order to remove finer particles. While the equipment costs of mechanical sweepers are significantly higher, the total operation and maintenance costs of vacuum sweepers can be lower (Table 6-15).

Table 6-15. Street Sweeper Cost Data

Sweeper Type	Life (Years)	Purchase Price ($)	Operation and Maintenance Costs ($/curb mile)	Sources
Mechanical	5	75,000	30	Finley, 1996; SWRPC, 1991
Vacuum-assisted	8	150,000	15	Satterfield, 1996; SWRPC, 1991

Using these data, the cost of operating street sweepers per curb mile were developed, assuming various sweeping frequencies (Table 6-16). The following assumptions were made to conduct this analysis:

- One sweeper serves 8,160 curb miles during a year (SWRPC, 1991).

- The annual interest rate is 8 percent.

Table 6-16. Annualized Sweeper Costs ($/curb mile/year)

Sweeper Type	Sweeping Frequency					
	Weekly	Bi-weekly	Monthly	Four times per year	Twice per year	Annual
Mechanical	1,680	840	388	129	65	32
Vacuum-Assisted	946	473	218	73	36	18

Modified from Finley, 1996; SWRPC, 1991; and Satterfield, 1996

6.2.2 Illicit Connection Identification and Elimination

One source of pollutants is direct connections or infiltration to the storm drain system of wastewaters other than storm water, such as industrial wastes. These pollutants are then discharged through the storm drain system directly to streams without receiving treatment. These illicit connections can be identified using visual inspection during dry weather or through the use of smoke or dye tests. Using visual inspection techniques, illicit connections can be identified for between $1,250 and $1,750 per square mile (Center for Watershed Protection, 1996).

6.2.3 Public Education and Outreach

Public education programs encompass many other more specific programs, such as fertilizer and pesticide management, public involvement in stream restoration and monitoring projects, storm drain stenciling, and overall awareness of aquatic resources. All public education programs seek to reduce pollutant loads by changing people’s behavior. They also make the public aware of and gain support for programs in place to protect water resources. Most municipalities have at least some educational component as a part of their program. A recent survey found that 30 of the 32 municipal storm water programs surveyed (94 percent) incorporate an education element and 11 programs (34 percent) mandated this element in law or regulation (Livingston et al, 1997).

The City of Seattle, with a population of approximately 535,000, has a relatively aggressive education program, including classroom and field involvement programs. The 1997 budget for some aspects of the program is included in Table 6-17. Although this does not necessarily reflect typical effort or expenditures, it does provide information on some educational expenditures. These data represent only a portion of the entire annual budget.

Table 6-17. Public Education Costs in Seattle, Washington

Item	Description	1997 Budget
Supplies for Volunteers	Covers supplies for the Stewardship Through Environmental Partnership Program	$17,500
Communications	Communications strategy highlighting a newly formed program within the city	$18,000
Environmental Education	Transportation costs from schools to field visits (105 schools with four trips each)	$46,500
Education Services / Field Trips	Fees for student visits to various sites	$55,000
Teacher Training	Covers the cost of training classroom teachers for the environmental education program	$3,400
Equipment	Equipment for classroom education, including displays, handouts, etc.	$38,800
Water Interpretive Specialist: Staff	Staff to provide public information at two creeks	$79,300
Water Interpretive Specialist: Equipment	Materials and equipment to support interpretive specialist program	$12,100
Youth Conservation Corps	Supports clean-up activities in creeks	$210,900

Source: Washington DOE, 1997

Some unit costs for educational program components (based on two different programs) are included in Table 6-18.

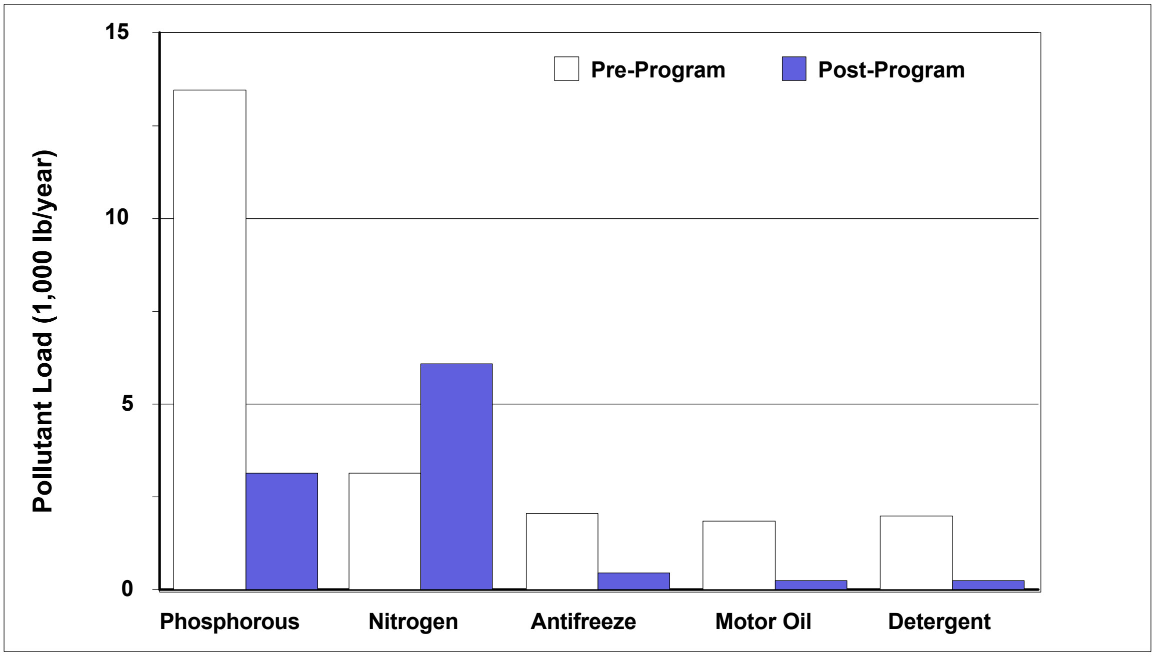
Table 6-18. Unit Program Costs for Public Education Programs

Item	Cost	Source
Public Attitude Survey	$1,250-$1,750 per 1,000 households	Center for Watershed Protection, 1996
Flyers	10-25¢/ flyer	Ferguson et al, 1997
Soil Test Kit*	$10	Ferguson et al, 1997
Paint	25-30¢/SD Stencil	Ferguson et al, 1997
Safety Vests for Volunteers	$2	Ferguson et al, 1997

* Includes cost of testing, but not sampling.

Although public education has the intended benefit of raising public awareness, and therefore creating support of environmental programs, it is difficult to quantify actual pollutant reductions associated with education efforts. Public attitudes can be used as a gauge of how these programs perform, however. In Prince George's County, Maryland a public survey was used in combination with modeling to estimate pollutant load reductions associated with public education (Smith et al, 1994; Claytor, 1996; Figure 6-5). An initial study was conducted to estimate pollution from field application of fertilizers, and use of detergents, oil and antifreeze. Pollutant reductions were then completed assuming that 70 percent of the population complied with recommendations of the public education program. A follow-up survey was used to assess the effectiveness of the program. Although insufficient data were available to support a second model run, a follow-up survey indicated that educational programs influenced many citizen behaviors, such as recycling. They were unsuccessful, however, at changing the rate at which citizens apply lawn fertilizers.

Figure 6-5. Changes in Pollutant Load Associated with a Public Education Program Based on a Public Survey



Source: Claytor, 1996

<u>6.2.4 Land Use Modifications</u>

One of the most effective tools to reduce the impacts of urbanization on water resources is to modify the way growth and development occurs across the landscape. At the jurisdictional or regional level, growth can be managed to minimize the outward extension of development. Jurisdictions can direct growth away from environmentally sensitive areas using such techniques as open space preservation, re-zoning or the transfer of development rights. At the site level, the nature of development can be modified to reduce the impacts of impervious cover at individual development projects through techniques such as reduced street widths, clustered housing, smaller parking lots, and incorporation of vegetative BMPs into site design. While there are legal fees associated with changing both local and regional zoning codes, data suggest that concentrating development and minimizing impervious cover at the site level can actually reduce construction costs to both developers and local governments.

By concentrating development near urban areas, the capital costs of development can be lowered substantially due to existing infrastructure and other public services. With conventional development patterns, the cost of servicing residential developments exceeds the tax revenues from these developments by approximately 15 percent (Pelley, 1997). By encouraging growth to occur in a compact region, rather than over a large area, these capital costs can be reduced substantially (Table 6-19).

Table 6-19. Comparison of Capital Costs of Municipal Infrastructure for a Single Dwelling Unit

Development Pattern	Capital Costs[1] (1987 Dollars)
Compact Growth[2]	$18,000
Low-Density Growth (3 units/acre)	$35,000
Low-Density Growth, 10 Miles from Existing Development[3]	$48,000

<u>Notes</u>
1. Costs include streets (full curb and gutter), central sewers and water supply, storm drainage and school construction.
2. Assumes housing mix of 30% single family units and townhouses; 70% apartments.
3. Assumes housing is located 10 miles from major concentration of employment, drinking water plant and sewage treatment plant.

Source: Frank, 1989

Savings can also be realized at the site level by reducing the costs of clearing and grading, paving and drainage infrastructure. A recent study compared conventional development plans with alternative options designed to reduce the impacts of development on the quality of water resources. The cost savings realized through these alternative options are summarized in Table 6-20. In all site designs, the road width was reduced from 28 feet to 20 feet, lot sizes were reduced or reconfigured to consume less open space, and on-site storm water treatment was provided.

Table 6-20. Impervious Cover Reduction and Cost Savings of Conservation Development

Location	Techniques Used	Impervious Cover Reduction	Cost Savings
Sussex County, DE	1. Reduced street widths 2. Smaller lots 3. Cluster development	38%	52%
New Castle County, DE	4.Houses clustered into attached units around courtyards	6%	63%
Kent County, DE	5. Reduced road and driveway widths 6. Minimum disturbance boundary	24%	39%

Source: Delaware DNREC, 1997

6.2.5 Oil and Hazardous Waste Collection

Providing a central location for the disposal of oil or hazardous wastes protects water quality by offering citizens an alternative to disposing of these materials in the storm drain. Disposal costs vary considerably depending on the size of the program, and what types of wastes are collected. One study estimated the capital costs at approximately $30,000, with about $12,000 maintenance for a used oil collection recycling program in a typical MS4 (US EPA, 1998b). This estimate was based on data from the Galveston Bay National Estuary Program. Data from the City of Livonia, Michigan indicates that the cost of hazardous waste disposal averages about $12 per gallon (Ferguson et al, 1997).

6.2.6 Proper Storage of Materials

Proper storage of materials can prevent accidental spills or runoff into the storm drain. The design of storage structures varies depending on the needs of the facility. There are also training costs associated with the proper storage of materials. Typical cost estimates, based on standard construction data, are $6 to $11 per square foot for pre-engineered buildings and $3.40 to $5 per square foot for a 6-inch thick concrete slab (Ferguson et al, 1997).

6.3 Benefits of Storm Water BMPs

Although it is possible to estimate the economic benefits of water quality improvement (US EPA, 1983a), it is difficult to create a "balance sheet" of economic costs and benefits for individual BMPs. Ideally, benefits analysis would specify and quantify a chain of events: pollutant loading reductions achieved by the BMP; the physical-chemical properties of receiving streams and consequent linkages to biologic/ecologic responses in the aquatic environment; and human responses and values associated with these changes. However, the necessary data to conduct such an analysis does not currently exist. Instead, the benefits can be outlined in terms of: 1) effectiveness at reducing pollutant loads; 2) direct water quality impacts; and 3) economic benefits or costs.

6.3.1 Storm Water Pollutant Reduction

A primary function of storm water BMPs is to prevent pollutants from reaching streams and rivers. While all BMPs achieve this function to some extent, there is considerable variability between different types of BMPs. The extent of benefits from non-structural BMPs may be more speculative, partly because their ability to influence human behavior is difficult to predict.

A detailed discussion of pollution removal efficiencies for individual structural BMPs is provided in Section 5.5 of this report, so only non-structural BMPs will be reviewed in this section. Unlike structural BMPs, it is generally not possible to associate specific pollutant removal rates with non-structural BMPs, with the exception of street sweeping (Satterfield, 1996). However, some non-structural BMPs are targeted at specific pollutants. Table 6-21 outlines non-structural BMPs believed by designers to be the most effective for removing specific types of pollutants.

Table 6-21. Non-Structural BMPs Suited to Controlling Various Pollutants

Pollutant	Appropriate BMPs	
Solids	Street Sweeping	Land Use Modifications
Oxygen-Demanding Substances	Street Sweeping Education: Storm Drain Stenciling Land Use Modifications	Education: Pet Scoop Ordinance Illicit Connections Eliminated
Nitrogen and Phosphorus	Street Sweeping Education: Pet Scoop Ordinance Land Use Modifications Proper Materials Handling	Illicit Connections Eliminated Education: Lawn Care Materials Storage and Recycling
Pathogens	Illicit Connections Eliminated Land Use Modifications	Education: Pet Scoop Ordinance
Petroleum Hydrocarbons	Street Sweeping Education: Storm Drain Stenciling Proper Materials Handling	Illicit Connections Eliminated Materials Storage and Recycling Land Use Modifications
Metals	Street Sweeping Education: Storm Drain Stenciling Proper Materials Handling	Illicit Connections Eliminated Materials Storage and Recycling Land Use Modifications
Synthetic Organics	Illicit Connections Eliminated Education: Storm Drain Stenciling Proper Materials Handling	Education: Lawn Care Materials Storage and Recycling Land Use Modifications
Temperature	Land Use Modifications	
pH	Illicit Connections Eliminated Proper Materials Handling	Materials Storage and Recycling Land Use Modifications

6.3.1.1 Solids

Both highway runoff and soil erosion can be sources of solids in urban runoff. Street sweeping can reduce solids in urban runoff by removing solids from roadways and parking lots before they can be detached and transported by runoff. The benefits associated with street sweeping depend largely on the climate. In arid regions, airborne pollutants are a serious concern, and there is a long time between storms for pollutants to accumulate[8]. In humid regions, on the other hand, frequent rainfall makes the use of sweepers between storms less practical. In colder

[8] Therefore, regular sweeping programs in these areas can potentially remove large amounts of solids from roadways.

regions, sweeping is recommended twice per year: once in the fall after leaves fall and once in the spring in anticipation of the spring snowmelt (MPCA, 1989).

Modifying land use to preserve open space and to limit the impervious cover can also reduce solids loads. By preserving open space and maintaining vegetative cover, the amount of land cleared is limited, thus reducing the erosion potential during construction. Natural vegetated cover has less than one percent of the erosion potential of bare soil (Wischmeier and Smith, 1978).

6.3.1.2 Oxygen-Demanding Substances

Since the primary oxygen-demanding substances are organic materials (such as leaves and yard waste), BMPs that target these substances are best suited to reducing the oxygen demand in storm water. BMPs that reduce sediment loads often also reduce the loads of the organic material associated with that sediment. Pet waste is also a significant source of organic pollutants, and its control can reduce the loads of oxygen demanding substances in urban runoff. Finally, programs geared at reducing illegal dumping and eliminating illicit connections and accidental spills of materials can reduce the oxygen demand associated with these sources.

6.3.1.3 Nitrogen and Phosphorus

Nitrogen and phosphorus are prevalent in urban and suburban storm water. Nitrogen and phosphorus are natural components of soil, and can enter runoff from storm-induced erosion. Additional sources include the use of fertilizer on urban lawns and airborne deposition. Street sweeping can reduce nutrient loads by removing deposited nutrients from the street surface. Programs that focus on lawn chemical handling or replacing turf with natural vegetation also act to reduce nutrient loading. Finally, programs that educate the public or industry about illegal dumping to storm drains can result in reducing the nutrient loads associated with dumping chemicals that have high nutrient content. Energy conservation and reduced automobile use can reduce airborne nitrogen deposition.

6.3.1.4 Pathogens

Pathogens, including protozoa, viruses and bacteria, are prevalent in urban runoff. Bacteria can be found naturally in soil, and the urban landscape can produce large loads of bacteria that can be carried by runoff. Dogs in particular can be a significant source of pathogens. Thus, pet scoop ordinances and associated education are effective tools at reducing bacteria in urban runoff. Illicit connections of sewage may also be a source of pathogens, therefore eliminating these sources can effectively reduce pathogens in runoff.

6.3.1.5 Petroleum Hydrocarbons

Petroleum hydrocarbons are present in many chemicals used in the urban environment, from gasoline to cleaning solvents. Since roadways are a major source of petroleum pollution, scheduled street sweeping can be used to remove hydrocarbon build-up prior to storm water runoff. Programs geared at preventing spills of chemicals to the storm drain, either through deliberate or accidental dumping, are effective at reducing hydrocarbon loads. Modifying the way land is developed can reduce hydrocarbon loads on both a site and a regional level by reducing the use of the automobile and replacing impervious surfaces with natural vegetation.

6.3.1.6 Metals

Metals sources in urban runoff include automobiles and household chemicals, which can contain trace metals. Street sweeping can reduce metals loads deposited on the road surface. In addition, programs that focus on reducing dumping and proper material storage can reduce accidental or purposeful spills of chemicals with trace metals to the storm drain system. Finally, modifying land use can reduce metals loads by reducing impervious cover, thus reducing total runoff containing metals, and reducing the roadway length, which is often a source of runoff containing metals.

6.3.1.7 Synthetic Organics

Much of the source of synthetic organics in the urban landscape is household cleaners and pesticides. Thus, education programs geared at reducing chemical and pesticide use, and proper storage and handling of these chemicals, can reduce their concentrations in urban runoff. In addition, land use modifications that replace turf with natural vegetation will reduce pesticide use.

6.3.1.8 Temperature

Most non-structural BMPs are not able to prevent the increase in temperature associated with urban development. One exception is the use of site designs that more closely mimic the natural hydrograph by reducing impervious cover and encouraging infiltration.

6.3.1.9 pH

The primary source of low pH in urban runoff is acid rain, and most non-structural BMPs are not used to treat this problem. BMPs that focus on proper materials handling and disposal can prevent dumping of chemicals with extremely high or low pH, but this is generally not a major problem in urban watersheds.

6.3.2 Hydrological and Habitat Benefits

As reviewed in Chapter 4, one major impact of urbanization is induced through the conversion of farmland, forests, wetlands, and meadows to rooftops, roads, and lawns. This process of urbanization has a profound influence on surface water hydrology, morphology, water quality, and ecology (Horner et al, 1994). In this section, the hydrologic and related habitat impacts are briefly discussed as well as the potential benefits that can be achieved by managing storm water runoff using structural and non-structural BMPs.

Many of these impacts can be directly or indirectly related to the change in the hydrologic cycle from a natural system to the urban system. Figure 4-1 illustrates the fundamental effects that occur along with the development process. In the natural setting, very little annual rainfall is converted to runoff and about half is infiltrated into the underlying soils and water table. This water is filtered by the soils, supplies deep water aquifers, and helps support adjacent surface waters with clean water during dry periods. In the urbanizing conditions, less and less annual rainfall is infiltrated and more and more volume is converted to runoff. Not only is this runoff volume greater, it also occurs more frequently and at higher magnitudes. The result is that less water is available to streams and waterways during dry periods and more flow is occurring during storms. A recent study in the Pacific Northwest found that the ratio of the two-year storm to the baseflow discharge increased more than 20 percent in developed sub-watersheds (impervious cover approximately 50 percent) versus undeveloped sub-watersheds (May et al, 1997).

As a result of urbanization, runoff from storm events increases and accelerates flows, increases stream channel erosion, and causes accelerated channel widening and down cutting (Booth, 1990). This accelerated erosion is a significant source of sediment delivery to receiving waters and also can have a smothering effect on stream channel substrates, thereby eliminating aquatic species habitat. As a result, aquatic habitat is often degraded or eliminated in many urban streams. The results are that aquatic biological communities are among the first to be impacted and/or simplified by land conversion and resulting stream channel modifications. Subsurface drainage systems which frequently serve urbanized areas also contribute to the problem, by bypassing any attenuation achieved through surface flows over vegetated areas.

A unifying theme in stream degradation is this direct link with impervious cover. Impervious cover, or imperviousness, is defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces in the urban landscape. This unifying theme can be used to guide the efforts of the many participants in watershed protection. Figure 6-6 visually illustrates this trend in degradation for a series of small headwater streams in the Mid-Atlantic Piedmont. Here, four stream segments, each with approximately the same drainage area, and subjected to the same physiographic conditions, respond to the effects of increased impervious cover. Similar results have been observed in the Southern United States with studies in Virginia, North Carolina and Georgia evidencing this same decline in fish and macroinvertebrate populations with increasing impervious cover (Crawford and Lenant, 1989; Weaver and Garman, 1994; Couch et al, 1996)

Figure 6-6. Effects of Impervious Cover on Stream Quality

Sensitive Stream ➜
(Impervious Cover ≤10%)
- *Stable Channel*
- *Excellent Biodiversity*
- *Excellent Water Quality*

🡐 Impacted Stream
(Impervious Cover 10-20%)
- *Channel Becoming Unstable*
- *Fair to Good Biodiversity*
- *Fair to Good Water Quality*

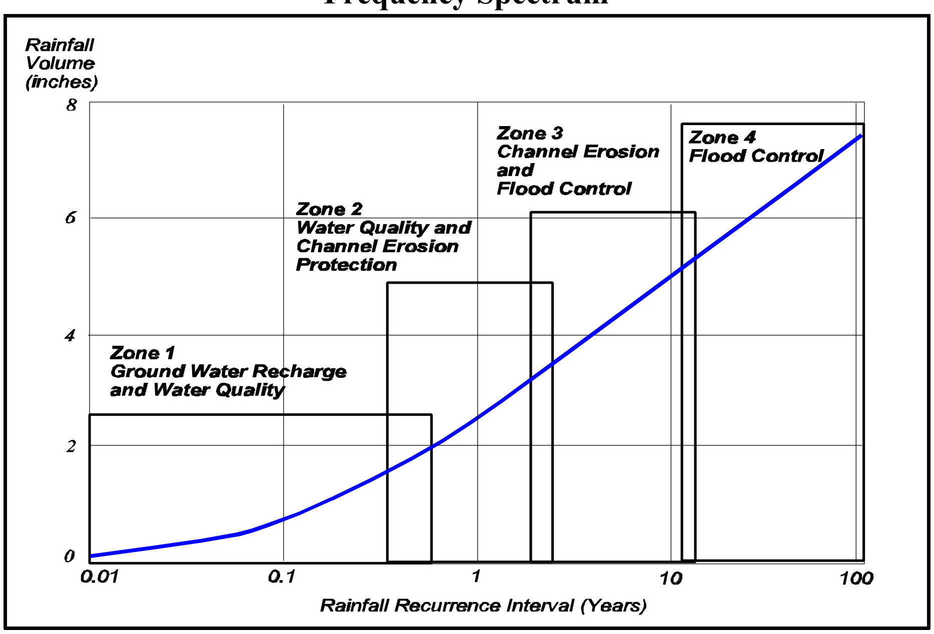
Restorable Stream ➜
(Impervious Cover ≈40%)
- *Highly Unstable Channel*
- *Poor Biodiversity*
- *Poor to Fair Water Quality*

Non-Supporting Stream ➜
(Impervious Cover ≈65%)
- *Poor to No Biodiversity*
- *Poor Water Quality*

To mitigate this impact, many local and state governments have required the installation of storm water management detention basins to attenuate this increased runoff volume. It is important to recognize that the change in hydrology caused by urbanization affects more than just a single storm return interval (e.g., the two-year event). Urbanization shifts the entire "rainfall frequency spectrum" (RFS) to a higher magnitude. As illustrated in Figure 6-7, the most significant change is to the smallest, most frequent storms that occur several times per year. In the undeveloped condition, most of the rainfall from these events is infiltrated into the underlying soil. In the developed condition, much of this rainfall is runoff. As the storm return interval increases, the difference between the undeveloped and developed condition narrows. Many jurisdictions only require management of specific storms, usually the two, ten and sometimes, the one hundred year events. The two-year storm is probably the most frequently used control point along this frequency spectrum. Hence, while BMPs may do a fairly good job of managing these specific control points, there have been very few locations across the country that have specific criteria in place to manage storm water over a wide range of runoff events. Claytor and Schueler (1996) describe the RFS as:

> ...classes of frequencies often broken down by return interval, such as the two year storm return interval. Four principal classes are typically targeted for control by stormwater management practices. The two smallest, most frequent classes [Zones 1 and 2] are often referred to as water quality storms, where the control objectives are groundwater recharge, pollutant load reduction, and to some extent control of channel erosion producing events. The two larger classes [Zones 3 and 4] are typically referred to as quantity storms, where the control objectives are channel erosion control, overbank control, and flood control.

Figure 6-7. Stormwater Control Points Along the Rainfall Frequency Spectrum



Source: Claytor and Schueler, 1996

One recent study by MacRae (1997) concluded that stream channels below storm water detention basins designed to manage the two year storm experienced accelerated erosion at three times the pre-developed rate. His findings went on to suggest that the streams were eroding at much the same rate as if no storm water controls existed.

Other jurisdictions have employed an additional level of detention storage above and beyond that required for the two year storm. This concept is often called "extended detention" (ED). McCuen and Moglen (1988) conducted a theoretical analysis of this design criteria based on sediment transport capacity of the pre-developed channel versus that with ED control. This study found ED could produce an 85 percent reduction in the pre-developed peak flow of the two-year storm. What it did not analyze, however, was the erosion potential over a wide range of storms. MacRae (1993) suggested a different storm water control criterion called "distributed runoff control" (DRC). Here, channel erosion is minimized if the erosion potential along a channel's perimeter is maintained constant with pre-developed levels. This is accomplished by providing a non-uniform distribution of the storage-discharge relationship within a BMP, where multiple control points are provided along the runoff frequency spectrum.

6.3.2.1   Benefits of BMPs to Control Hydrologic Impacts

Numerous prior studies have documented the degradation of aquatic ecosystems of urban and suburban headwater streams. As stated above, in general, the studies point to a decrease in stream quality with increasing urbanization. Unfortunately, the benefits of BMPs to protect streams from hydrologic impacts have only recently been investigated and only for a few studies.

Maxted and Shaver (1997), Jones et al (1997), and Horner et al (1997) attempted to isolate the potential beneficial influence of local storm water best management practices on the impervious cover/stream quality relationship. Horner examined the possible influence of stream-side management on stream quality as a function of urbanization. Coffman et al (1998) recently presented data on the potential hydrologic benefits of alternative land development techniques. Called the "Low Impact Development Approach," this methodology attempts to mimic pre-developed hydrology by infiltrating more rainfall at the source, increasing the flow path and time of concentration of the remaining runoff, and providing more detention storage throughout the drainage network, as opposed to a one location at the end of the pipe.

The preliminary findings of Maxted and Shaver, and Jones et al, suggest that, for the BMPs examined, stream quality (as measured by a limited group of environmental indicators) cannot be sustained when compared to reference stream conditions. Jones assessed several BMPs by conducting biomonitoring (fish and macroinvertebrate sampling) above and below BMPs and comparing them to a reference watershed. He found that the biological community tended to be degraded immediately below BMPs as compared to the reference watersheds. One major flaw in the study was the lack of analysis in developed watersheds without BMPs. This would have compared the influence of BMPs on the aquatic community as compared to no BMPs.

Maxted and Shaver examined eight sub-watersheds with and without BMPs. Their study also concluded that BMPs did not adequately mitigate the impacts of urbanization once watershed impervious reached 20 percent cover. While this study was useful in defining the cumulative impacts of BMPs on watersheds, several critical questions remain. First, since no sub-watersheds with less than 22 percent impervious cover were analyzed, little is known about BMP ability to protect the most sensitive species seen in less developed watersheds. Data for sub-watersheds with BMPs was collected approximately three years after data for the sub-watersheds without BMPs, so climatic/seasonal constraints may have affected the outcome as much, or more than the BMPs themselves.

Horner et al (1997) evaluated several sub-watersheds, with varying levels of impervious cover, but only tangentially related the effectiveness of BMPs to protecting stream quality. Horner found that at relatively low levels of urbanization (approximately 4 percent impervious area) the most sensitive aquatic biological communities (e.g., salmonids) were adversely affected, and stream quality degradation (as measured by a several indicators) continued at a relatively continuous rate with increasing impervious area. Horner's study demonstrates a link between urbanization and stream quality in the Puget Sound region, but since the effects of BMPs were not directly assessed, the question of whether BMPs could "raise" these thresholds could not be answered.

Horner did find a positive relationship between stream quality and riparian buffer width and quality. Here, the otherwise direct relationship of degrading stream quality with increasing impervious cover was positively altered where good riparian cover existed. In other words, increasing the buffer width and condition tended to keep the stream systems healthier.

Coffman demonstrated techniques for maintaining pre-developed hydrologic parameters by replicating the curve number and time of concentration. The analysis indicated the amount of storage required on-site to accommodate the change in site imperviousness. The benefits of this type of development, while not yet fully monitored in a field study, are likely to include increased groundwater recharge, reduced channel erosion potential, and decreased flood potential.

One major hydrologic benefit of storm water management structures is the ability to mitigate for the potential flooding associated with medium to larger storms. Storm water detention and retention facilities have been applied in many parts of the country since about 1970 (Ferguson and Debo, 1990). These facilities include wet and dry basins, as well as rooftop and parking lot detention and underground storage vaults. These *storage facilities* attempt to reduce flooding downstream from developments by reducing the rate of flow out of the particular structure being used. Although the rate of flow is reduced, the volume of flow is generally not reduced. Instead, this volume is delivered downstream at a slower rate, and stretched out over a longer time. With the exception of properly design wet ponds, these structures do not provide any water quality benefit beyond the hydrologic modifications. This technique has proved to be a successful method of suppressing flood peaks when properly applied on a watershed-wide basis.

6.3.3 Human Health Benefits

Storm water can impact human health through direct contact from swimming or through contamination of seafood. Most human health problems are caused by pathogens, but metals and synthetic organics may cause increased cancer risks if contaminated seafood are consumed. Mercury, PCBs, and some pesticides have been linked to human birth defects, cancer, neurological disorders and kidney ailments. The risks may be greater to sensitive populations such as children or the elderly. BMPs that reduce pathogens, metals and synthetic organics will help to limit these health risks.

Economic benefits of avoiding human health problems can include swimming and recreation costs, as well as saved medical costs. One study in Saginaw, Michigan estimated that the swimming and beach recreation benefits associated with a CSO retention project exceeded seven million dollars (US EPA, 1998c). As another example, EPA initially estimated that proposed Phase II storm water controls would reduce the cost of shellfish-related illnesses by between $73,000 and $300,000 per year (US EPA, 1997d).

6.3.4 Additional and Aesthetic Benefits

Storm water BMPs can be perceived as assets or detriments to a community, depending on their design. Some examples of benefits include: increased wildlife habitat, increased property values, recreational opportunities, and supplemental uses. Detriments include: mosquito breeding, reduced property values, less developable land and safety concerns. These detriments can be mitigated through careful design.

6.3.4.1 Property Values and Public Perception

The impacts of BMPs on property values are site-specific. The presence of a structural BMP can affect property values in one of three ways: increase the value, decrease the value, or have no impact. BMPs that are visually aesthetic and safe for children can lead to increased property values. A practice becoming more prevalent is to situate developments around man-made ponds, lakes, or wetlands created to control flooding and reduce the impacts of urban runoff. Buffer zones and open areas that control runoff also provide land for outdoor recreation such as walking or hiking and for wildlife habitat. In many cases, developers are able to realize additional profits and quicker sales from units that are adjacent to such areas. A survey of residents in an Illinois subdivision indicates that residents are willing to pay between 5 percent and 25 percent more to be located next to a wet pond, but that being located next to a poorly-designed dry detention basin can reduce home values (Emmerling-Dinovo, 1995).

Safety is also a concern among the public. A childless adult may perceive a wet pond as an amenity, but a family might view it as a potential hazard to children. These concerns can be alleviated using such design features as gently sloping edges, a safety “bench” (a flat area surrounding a pond) and the use of dense vegetation surrounding ponds and infiltration basins to act as a barrier.

Aesthetic maintenance is also important when considering long term impacts on property values. Poorly-maintained wet ponds or constructed wetlands may be unsightly due to excess algal growth or public littering. Wet ponds and constructed wetlands can also become mosquito breeding grounds. However, mosquito problems can usually be reduced or eliminated through proper design and/or organic controls such as mosquito-eating fish. Successful designs avoid shallow or stagnant water, and reduce large areas of periodic drying, as occur in a dry detention basin (McLean, 1995). All BMPs need to have trash and debris removed periodically to prevent odor and preserve aesthetic values.

6.3.4.2 Dual-Use Systems

Since BMPs can consume a large amount of space, communities may opt to use these facilities for other purposes in addition to storm water management. Two examples are "water reuse" ponds and dual use infiltration or detention basins. In one study, a storm water pond was used to irrigate a golf course in Florida, decreasing the cost of irrigation by approximately 85 percent (Schueler, 1994b). In the southwestern United States, BMPs are often completely dry in between rain events. In these regions, it is very common to design infiltration basins or detention basins as parks that are maintained as a public open space (Livingston et al, 1997).

6.4 Review of Economic Analysis of the NPDES Phase II Storm Water Rule

The proposed storm water Phase II rule specifies that Phase II municipalities and operators of construction sites disturbing between one and five acres of land must apply for and receive a storm water permit. To meet this requirement, municipalities must develop a storm water pollution prevention plan that addresses six minimum measures[9]. Operators of construction sites are required to incorporate soil and erosion controls into their construction sites and implement a water pollution prevention plan. The analysis presented here is a summary of the most recent benefit-cost analysis prepared for the proposed Phase II storm water rule (Preliminary draft number 3). In order to address the issues raised in the public comments and during internal review, EPA gathered additional data and information to refine the analysis of potential benefits and costs conducted for the proposed Phase II rule. These data, analyses, and results are described in detail in the Preliminary Draft of the Economic Analysis of the Final Phase II Storm

[9] The six minimum measures are:

- Public Education and Outreach on Storm Water Impacts
- Public Involvement/Participation
- Illicit Discharge Detection and Elimination
- Construction Site Storm Water Runoff Control
- Post-Construction Storm Water Management in New Development and Redevelopment
- Pollution Prevention/Good Housekeeping for Municipal Operations (US EPA, 1998c).

Water Rule ("EA"), and are summarized in the sections that follow. All cost and benefit estimates are presented in 1998 dollars.

The reader should note that the Agency continues to revise the analysis based on internal review and new data and information. EPA envisions completing the economic analysis in conjunction with the Storm Water Phase II Final Rule. Hence, all estimates are subject to future refinement.

6.4.1 Analyses of Potential Costs

This section provides an overview of the methodology used to estimate costs and pollutant loading reductions for both municipalities and construction sites subject to the final Phase II rulemaking. The specific components of the analysis are discussed in detail in the Draft Final EA. Current Agency estimates of national compliance costs, which are subject to change, are also provided.

6.4.1.1 Municipal Costs

EPA estimated annual per household program cost for automatically designated municipalities (MS4s) using actual expenditures reported by 35 Phase I municipalities. Based on census data, EPA estimated the Phase II municipal universe to be 5,040 MS4s with a total population of 85 million people and 32.5 million households. An average annual per household administrative cost was estimated to address application, record keeping, and reporting requirements, which was added to the program per household cost to derive a total average per household cost. To obtain the national estimate of compliance costs, the Agency multiplied the estimated total per household compliance cost ($9.09) by the expected number of households in Phase II communities. EPA estimates the national Phase II municipal compliance costs to be approximately $295 million (see Section 4.2.1.3 in the draft EA)[10].

6.4.1.2 Construction Costs

In estimating incremental costs attributable to the final Phase II rule, EPA estimated a per site cost for construction sites of one, three, and five acres and multiplied the cost by the total number of Phase II construction starts in these size categories to obtain a national estimate of compliance costs. The Agency used construction start data from eleven municipalities that record construction start information to estimate the number of construction starts disturbing between one and five acres of land (see Section 4.2.2.1 in the Draft Final EA).

[10] Estimated annual per household cost of compliance ranged from $0.63 to $60.44. See Section 4.2.1.2 in the Draft Final EA for a discussion of how EPA chose the mean value of $9.09 per household. Note that the estimated per household cost does not include municipal expenditures for post-construction storm water controls.

In estimating construction BMP costs, EPA used standard cost estimates from R.S. Means (R.S. Means, 1997a and 1997b) and created 27 model sites of typical site conditions in the United States. The model sites considered three different site sizes (1, 3, and 5 acres), three slope variations (3, 7, and 12 percent), and three soil erosivity conditions (low, medium, and high). The Agency used a database compiled by the Water Environment Federation (1992) to develop and apply BMP combinations appropriate to the model site conditions. For example, sites with shallow slopes and a low erosivity require few BMPs, while larger, steeper, and more erosive sites required more BMPs. Detailed site plans, assumptions, and BMPs that could be used are found in Appendix B-3 of the Draft Final EA. Based on the assumption that any combination of site factors are equally likely to occur on a given site, EPA averaged the matrix of estimated costs to develop an average cost for one, three, and five acre starts for all soil erodibilities and slopes. The average BMP cost was estimated to be $1,206 for a one-acre site, $4,598 for a three-acre site, and $8,709 for a five-acre site.

Administrative costs for the following elements were estimated per construction site and added to each BMP cost: submittal of a notice of intent (NOI) for permit coverage ($74); notification to municipalities ($17); development of a storm water pollution prevention plan ($1,219); record retention ($2); and submittal of a notice of termination ($17) for a total cost of $1,329 per site. From this analysis, EPA estimated total average compliance costs (BMP plus administrative) for a Phase II construction site of $2,535 for sites disturbing between one and two acres of land, $5,927 for sites disturbing between two and four acres, and $10,038 for sites disturbing between four and five acres of land.

The total per site costs were then multiplied by the total number of Phase II construction sites within each of those size categories to obtain the national compliance cost estimate. EPA estimated construction costs for 15 climatic zones to reflect regional variations in rainfall intensity and amount. Once the Phase II storm water rule is fully implemented, the total annual compliance cost is expected to be approximately $512 million (assuming 109,652 construction starts in 1998).

6.4.1.3 Pollutant Loading Reductions

To estimate municipal pollutant loading reductions for the final Phase II rulemaking, EPA used the results from a 1997 EPA draft report that calculated national municipal loading reductions for TSS based on the NURP study (US EPA, 1997d). To estimate pollutant loading reductions from Phase II construction starts, the U.S. Army Corps of Engineers developed a model based on EPA’s 27 models sites to estimate sediment loads from construction starts with and without Phase II controls (US ACE, 1998). Estimating the pollutant loading reduction for TSS does not capture the full extent of potential loading reductions that result from implementing storm water controls, but provides a minimum estimate of the reductions that may result from the

Phase II rule[11]. EPA also anticipates that the rule will result in reductions in oil and grease, nitrogen, phosphorus, pathogens, lead, copper, zinc and other metals. Estimated annual TSS loading reductions range from 639,115 to approximately 4 million tons for municipalities and 2 million to 8 million tons for construction sites assuming BMP effectiveness of 20 to 80 percent.

6.4.2 Assessment of Potential Benefits

A number of potential problems are associated with assessing the benefits from the Phase II rule, including identifying the regulated municipalities as sources of current impairment to waters and determining the likely effectiveness of various measures; difficulties in water quality modeling; difficulties in modeling construction site BMP effectiveness; and most importantly, the inability to monetize some categories of benefits with currently available data.

The national benefits of Phase II controls will depend on a number of factors, including the number, intensity, and duration of wet weather events; the success of municipal programs; the effectiveness of the selected construction site BMPs; the site-specific water quality and physical conditions of receiving waters; the current and potential use of receiving waters; and the existence of nearby "substitute" sites of unimpaired waters. Because these factors will vary substantially from site to site, data are not available with which to develop estimates of benefits for each site and aggregate to obtain a national estimate. As a result, the Agency developed national level estimates of benefits based largely on a benefits transfer approach. This approach allows estimates of value developed for one site and level of environmental change to be applied in the analysis of similar sites and environmental changes.

6.4.2.1 Anticipated Benefits of Municipal Measures

As part of an effort to quantify the value of the United States' waters impaired by storm water discharges, EPA applied adjusted Carson and Mitchell (1993) estimates of willingness to pay (WTP) for incremental water quality improvements to estimates of waters impaired by storm water discharges as reported by states in their biennial Water Quality Inventory reports[12]. Potential Phase II benefits are assumed to equal the WTP for the different water quality levels multiplied by the water quality impairment associated with Phase II municipalities multiplied by the relevant number of households (WTP x percent impaired x number of households).

The Carson and Mitchell estimates apply to all fresh water, however it is not clear how these values would be apportioned among rivers, lakes and the Great Lakes. Lakes are the water

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[11] To date, there are no national studies that estimate pollutant loading reductions due to the implementation of municipal storm water controls for the other pollutants found in storm water runoff and discharges.

[12] EPA adjusted the WTP amounts to account for inflation growth in real per capita income, inflation, and a 30 percent increase in attitudes towards pollution control.

bodies most impaired by urban runoff and discharges, followed closely by the Great Lakes and then rivers. Hence, EPA applied the WTP values to the categories separately and assumed that the higher resulting value for lakes represents the high end of the range and the lower resulting value for rivers represents the low end of a value range for all fresh waters (i.e. high end assumes that lake impairment is more indicative of national fresh water impairment while low end assumes that river impairment is more indicative).

The extent to which impairment will be eliminated by the municipal measures is uncertain; hence, estimates are adjusted for a range of potential effectiveness of municipal measures. EPA expects that municipal programs will achieve at least 80% effectiveness, resulting in estimated annual benefits from fresh water use and passive use in the range of $67.2 to $241.2 million. The potential value of improvements in marine waters and human health benefits have not been quantified at this time.

6.4.2.2 Anticipated Benefits of Construction Site Controls

EPA estimates the benefits of construction site controls using a benefits transfer approach applying WTP estimates for an erosion and sediment control plan from Paterson et al (1993) contingent valuation (CV) survey of North Carolina residents. The adjusted WTP estimates are intended to reflect potential benefits of erosion and sediment control programs that protect all lakes, rivers, and streams. In order to transfer adjusted WTP results to estimate the potential benefits of the Phase II rule, EPA calculated the percentage of Phase II construction starts that are not covered by a state program or CZARA for each state. This percentage is multiplied by the number of households in the state and the adjusted mean WTP of $25. The results were then summed across all states and indicate that WTP for the erosion and sediment controls of the Phase II rule may be as high as $624.2 million per year.

6.4.3 Comparison of Benefits and Costs

EPA estimates the total compliance costs of the rule to be $807.2 million. The largest portion of the total cost, $512 million, is associated with erosion and sediment controls at construction sites. EPA was able to develop a partial monetary estimate of expected benefits of both the six minimum municipal measures and the construction components of the rule. The sum of these benefits ranges from $700 to $865 million annually [assuming 80 percent effectiveness of municipal programs and using the mean WTP ($25) from Paterson]. The largest portion of benefits, $624 million, are associated with erosion and sediment controls for construction sites.

6.5 Financial Issues

Effective storm water programs require both the existence of well-performing, cost-effective BMPs and sufficient funding. Financing issues are discussed extensively in other Agency reports and only briefly reviewed below.[13] Section 6.5.1 focuses on financing options for municipal storm water programs but does not discuss regulatory impacts on municipalities.

6.5.1 Municipal Financing of Storm Water Programs

Around the nation, local government general tax funds are the most commonly used source of funding for storm water programs. However, this may be the least suitable source of storm water program or maintenance funding. General tax revenues originate at a number of sources and are used to finance an equally diverse number of public programs, including education, police and fire protection, civil and criminal courts, and social and economic support programs. Storm water programs and maintenance must compete against a large number of other vital public programs for a very limited number of tax dollars. This problem has been compounded in recent years by tax caps and the public's general opposition to new or higher taxes.

The unreliability of general tax funds has led many communities around the country to develop storm water utilities. Storm water utilities rely on dedicated user charges related to the level of service provided. Charges are typically paid by property owners and managed in a separate enterprise fund. A variety of methods are used to determine charges, but are usually based on some estimate of the amount of storm water runoff contributed by the property, such as the total impervious surface or a ratio of impervious surface to total property area. Generally a flat rate is charged for residential properties.

There are several advantages of using utility fees to finance storm water programs. Unlike general tax revenues, utility charges are a dedicated, stable, and predictable source of funds and are not subject to state "tax cap" limitations. Also, because charges are based on the user's contribution to storm water runoff, it is often seen as more equitable or fair. Finally, utility fees provide a mechanism to incorporate economic incentives for implementation of on-site storm water management through reduced charges. For example, credits or discounts are often provided for on-site retention of storm water by nonresidential property owners. Providing such incentives creates greater flexibility by allowing each user to choose the cheaper option - paying the utility charge or implementing on-site controls. Storm water utilities are now well established as an effective financing option. As of 1991, over 100 communities across the country had instituted storm water utilities (US EPA, 1994a).

Similar to utility fees, the use of inspection or permit fees to help publicly finance storm water programs represents a relatively new application of an established component of government revenues. Often, these fees are associated with the issuance of a permit, such as a

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[13] EPA has prepared publications to assist local governments in planning for program funding (US EPA, 1994b). More recently the Agency has established an internet site with current information, the "Environmental Finance Information Network." The website address is http://www.epa.gov/efinpage/efin.htm .

building permit, clearing permit, storm water permit, or sewer connection permit. A permit program based upon fees for annual inspections, such as a storm water discharge or storm water operating permit, can provide a continuing source of funds. However, many permit or inspection fees are a one time charge, typically when the facility is first constructed. These are generally not a good funding source for continuing storm water system maintenance.

Finally, the use of dedicated contributions from land developers may be used to finance public maintenance of storm water systems. Under this program, the local government assumes the operation and maintenance of a storm water system constructed as part of a private development. All or a portion of the estimated required funding for the O&M is obtained through a one-time contribution by the land developer to a dedicated account which is controlled by the local government. Often the developer is responsible for O&M during a "warranty period," frequently the first two years. Dedicated contributions provide a secure, dedicated funding source that is not subject to state tax cap limits. A disadvantage is that dedicated contributions are only applicable to new storm water systems.

6.6 Summary

The use of BMPs to control storm water runoff and discharges where none previously existed will ultimately result in a change in pollutant loadings, and there are indications that in the aggregate BMPs will improve water quality. The actual manner in which the loadings reductions are achieved will depend on the BMPs selected, which will determine the associated costs. The physical-chemical properties of receiving streams and consequent linkages to biologic/ecologic responses in the aquatic environment, and human responses and values associated with these changes will determine the benefits.

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Index