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Considerations in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality

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Notice

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Foreword

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The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

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Abstract

For the past three decades, municipalities in the United States have successfully addressed pollution in the watershed by collecting and treating their wastewater. Currently, all municipalities provide secondary level treatment, and in some cases tertiary treatment, and industries provide best available/best practicable treatment. This has had great benefits. More rivers are meeting water quality standards, and the public health is being protected from waterborne disease. The challenge now facing us is to address pollution associated with storm water runoff, since this is now the last major threat to water quality.

It is less costly to prevent the generation of polluted runoff than to treat it. Today, many municipalities are implementing low-cost best management practices (BMPs) that prevent runoff. The lowest cost BMPs, termed non-structural or source control BMPs, include practices such as limiting pesticide use in agricultural areas or retaining rainwater on residential lots (currently termed “low impact development”). There are a set of higher cost BMPs, which involve building a structure of some kind to store stormwater until it can be discharged into a nearby receiving water. These can be more costly, especially in areas where land costs are high. The three most commonly used structural treatment BMPs that will be discussed in the document are ponds (detention/retention), vegetated biofilters (swales and filter/buffer strips) and constructed wetlands. Two categories of treatment considered in this document are ponds and vegetated biofilters. Ponds are probably the most frequently used BMP in the United States. There are three types of pond BMPs: wet ponds (retention ponds); dry ponds (notably extended detention ponds); and infiltration basins. Three different types of vegetative biofilter BMP types are discussed: grass swales, vegetated filter strips, and bioretention cells. Grass swales include three variations: traditional grass swales, grass swales with media filters and wet swales.

This document presents factors that should be considered in the design of treatment BMPs to improve water quality. The state-of-the-practice is such that existing design guides vary and the performance of treatment BMPs shows a wide range of pollutant removal effectiveness.

Contents

Notice . . . ii
Foreword . . . iii
Abstract . . . iv
Table of Contents . . . v-vi
List of Figures . . . vii
List of Tables . . . viii
Acronyms and Abbreviations . . . x-xi
Acknowledgments . . . xii

Chapter One
Role of Best Management Practices (BMPs) in Improving Water Quality
1.1 Introduction . . . 1 - 1
1.2 Impacts of Nonpoint Sources on Receiving Waters . . . 1 - 2
1.3 Impacts of Urbanization on Receiving Waters - Physical and Chemical . . . 1 - 8
1.4 Impacts of Urbanization on Receiving Waters - Biological Communities . . . 1 - 10
1.5 Pollutant Loadings Associated with Urban Stormwater . . . 1 - 13
1.6 Stormwater Management - EPA Regulatory Requirements . . . 1 - 21
1.7 Role of BMPs in Developing an Urban Stormwater Management Plan . . . 1 - 22
1.8 Current Peak Discharge Control Strategies . . . 1 - 23
1.9 Design of Treatment BMPs to Improve Water Quality . . . 1 - 25
1.10 Concerns with BMP Performances . . . 1 - 25

Chapter Two
Watershed Hydrology Pertinent to BMP Design
2.1 Introduction . . . 2 - 1
2.2 Amount and Distribution of Rainfall Intensity and Volume . . . 2 - 1
2.3 Hydrologic Concepts for BMP Design . . . 2 - 4
2.4 Peak Discharge Control Strategies . . . 2 - 5
2.5 Water Quality Control Strategies . . . 2 - 13

Chapter Three
Types of BMPs and Factors Affecting their Selection
3.1 Introduction . . . 3 - 1
3.2 Types of BMPs . . . 3 - 1
3.3 BMP Selection Criterion - Meeting Stormwater Management Goals . . . 3 - 3
3.4 BMP Selection Criterion - On-Site vs Regional Controls . . . 3 - 7
3.5 BMP Selection Criterion - Watershed Factors . . . 3 - 11
3.6 BMP Selection Criterion - Terrain Factors . . . 3 - 13
3.7 BMP Selection Criterion - Physical Suitability Factors . . . 3 - 14

3.8 BMP Selection Criterion - Community and Environmental Factors . . . . 3 - 16
3.9 BMP Selection Criterion - Location and Permitting Factors . . . . 3 - 17
3.10 Federal Regulations That Impact Stormwater BMP Design . . . . 3 - 19
3.11 State and Municipal Requirements That Impact Stormwater BMP Design . 3 - 25

Chapter Four
BMP Effectiveness in Removing Pollutants
4.1 Introduction . . . . 4 - 1
4.2 Current Flow Control Watershed Management Strategies . . . . 4 - 1
4.3 Pollutant Loading Estimates . . . . 4 - 2
4.4 Effectiveness of Treatment BMPs using Current Design Approaches . . . . . . 4 - 5
4.5 Importance of Particle Size Distribution . . . . 4 - 8
4.6 Approaches to Implementing BMPs for Improved Water Quality in the Urban Watershed . . . . 4 - 9
4.7 Removal Processes Occurring in Treatment BMPs . . . . 4 - 12
4.8 Treatment-Train Approach to Improve Water Quality . . . . 4 - 17

Chapter Five
Types of Pond BMPs and Their Ability to Remove Pollutants
5.1 Introduction . . . . 5 - 1
5.2 Design of Wet Ponds to Maximize Sedimentation . . . . 5 - 5
5.3 Design of Extended Detention Basins for Water Quality Improvements . . . 5 - 14
5.4 Maintenance of Pond BMPs . . . . 5 - 17

Chapter Six
Types of Vegetative Biofilters and Their Ability to Remove Pollutants
6.1 Introduction . . . . 6 - 1
6.2 Grass Swale . . . . 6 - 1
6.3 Vegetative Filter Strip . . . . 6 - 5
6.4 Bioretention Cell . . . . 6 - 5
6.5 Role in Water Quality Improvement . . . . 6 - 5
6.6 Design of Grass Swales for Pollutant Removal . . . . 6 - 10
6.7 Design of Vegetative Filter Strips for Pollutant Removal . . . . 6 - 11
6.8 Design of Bioretention Cells for Pollutant Removal . . . . 6 - 15

Glossary G-1
References R-1

List of Figures

Figure 1-1 Change in Floodplain Elevations . . . . 1 - 5
Figure 1-2 Relationship Between Impervious Cover and the Volumetric Runoff Coefficient . . . . 1 - 6
Figure 2-1 Stormwater Control Points Along the RFS for Maryland . . . . 2 - 2
Figure 2-2 Fifteen Rain Zones of the United States . . . . 2 - 2
Figure 2-3 A Watershed Where the Drainage From a Small Development Site Joins the Flow From Large Watershed . . . . 2 - 9
Figure 2-4 Alternative Hydrographs From the Watershed . . . . 2 - 10
Figure 4-1 Urban Stormwater Treatment Train Process Flow Diagram . . . . 4 - 19
Figure 5-1 Wet Pond Typical Detail . . . . 5 - 2
Figure 5-2 Typical Dry Pond . . . . 5 - 3
Figure 5-3 Extended Detention Basin, Typical Detail . . . . 5 - 4
Figure 5-4 Infiltration Basin, Typical Detail . . . . 5 - 6
Figure 6-1 Grass Swale . . . . 6 - 3
Figure 6-2 Wet Swale . . . . 6 - 4
Figure 6-3 Typical Vegetative Filter Strip . . . . 6 - 6
Figure 6-4 Typical Bioretention Cell . . . . 6 - 7
Figure 6-5 Pollutant Removal Efficiency Versus Filter Strip Length . . . . 6 - 13

List of Tables

Table 1-1 Impacts of Urbanization on Receiving Waters . . . . 1 - 9
Table 1-2 Changes Due to Urbanization and Effects on Aquatic Organisms . . . . 1 - 11
Table 1-3 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms . . . . 1 - 12
Table 1-4 National Event Mean and Median Concentrations for Chemical Constituents of Stormwater . . . . 1 - 14
Table 1-5 Regional Groupings by Annual Rainfall . . . . 1 - 15
Table 1-6 Mean and Median Nutrient and Sediment Stormwater Concentrations for Residential Land Use Based on Rainfall Regions . . . . 1 - 16
Table 1-7 Percentage of Metal Concentrations Exceeding Water Quality Standards by Rainfall Region . . . . 1 - 16
Table 1-8 Stormwater Pollutant Event Mean Concentration for Different U.S. Regions . . . . 1 - 17
Table 1-9 Typical Urban Areas and Pollutant Yields . . . . 1 - 18
Table 1-10 Median Stormwater Pollutant Concentration for All Sites by Land Use . . . 1 - 19
Table 1-11 Comparison of Water Quality Parameters in Urban Runoff With Domestic Wastewater . . . . 1 - 19
Table 1-12 Runoff and Pollutant Characteristics of Snowmelt Stages . . . . 1 - 20
Table 1-13 Impairments Associated with Current Flow Control Strategies . . . . 1 - 24
Table 2-1 Typical Values of Individual Storm Event Statistics for 15 Zones of the United States . . . . 2 - 3
Table 2-2 Comparison of Model Attributes and Functions . . . . 2 - 6
Table 2-3 Design Storm Frequencies and Assumed Benefits . . . . 2 - 7
Table 2-4 Qualitative Assessment of Peak Discharge Control Strategies with Respect to the Physical Impact Category . . . . 2 - 8
Table 3-1 ASCE Source Control BMPs . . . . 3 - 2
Table 3-2 Treatment BMPs . . . . 3 - 2
Table 3-3 Summary of Studies on Environmental Impacts for Pond and Wetland BMPs . . . . 3 - 4
Table 3-4 Summary of Studies on Environmental Impacts for Vegetative Biofilter BMPs . . . . 3 - 5
Table 3-5 Summary of Studies on Environmental Impacts for Infiltration BMPs . . . . . 3 - 6
Table 3-6 Summary of Studies on Environmental Impacts for Filter BMPs . . . . 3 - 7
Table 3-7 Treatment BMPs vs Watershed Factors . . . . 3 - 12
Table 3-8 BMP Selection - Terrain Factors . . . . 3 - 14
Table 3-9 BMP Selection - Physical Suitability Factors . . . . 3 - 15
Table 3-10 BMP Selection - Community and Environmental Factors . . . . 3 - 17
Table 3-11 Permitting Checklist . . . . 3 - 18

Table 3-12 State or Regional Planning Authority Requirements for Water Quality Protection

. . . . 3 - 26
Table 3-13 Municipal or Regional Planning Authority Requirements . . . . 3 - 27
Table 3-14 Minimum Drainage Area Requirements for States . . . . 3 - 28
Table 3-15 Minimum Area Requirements for Local Agencies . . . . 3 - 28
Table 3-16 Peak Discharge Control Criteria for States . . . . 3 - 29
Table 3-17 Peak Discharge Rate Control Requirements, Municipalities . . . . 3 - 30
Table 3-18 Water Quality Regulatory Requirements, States . . . . 3 - 31
Table 3-19 Water Quality Requirements, Municipalities . . . . 3 - 31
Table 4-1 Median Pollutant Removal of Stormwater Treatment Practices . . . . 4 - 5
Table 4-2 Median Effluent Concentration of Stormwater Treatment Practice Groups . . 4 - 6
Table 4-3 Removal Processes Occurring in Treatment BMPs . . . . 4 - 13
Table 4-4 Treatment BMP Expected Performance . . . . 4 - 13
Table 4-5. Pollutant Removal (%) by Mulch from Stormwater Runoff . . . . 4 - 17
Table 4-5 Expected Median Effluent Concentration of Selected Pollutants . . . . 4 - 20
Table 5-1 Hydrologic and Hydraulic Design Criteria for Standard Extended Detention Wet Pond System . . . . 5 - 7
Table 5-2 Recommended Criteria for Wet Pond Design for Nutrient Removal . . . . 5 - 8
Table 6-1 Estimated Pollutant Removal Capability of Biofilters . . . . 6 - 8
Table 6-2 Land Use and Biofilter Suitability . . . . 6 - 9
Table 6-3 Physical Site Conditions and Biofilter Suitability . . . . 6 - 10
Table 6-4 Pollutant Removal Efficiencies for Grass Swales . . . . 6 - 11
Table 6-5 Pollutant Removal Performance of Bioretention Practices (% Removal) . . . 6 - 16

Acronyms and Abbreviations

ASCE	= American Society of Civil Engineers
BMP	= best management practice
BOD	= biochemical oxygen demand
CERCLA	= Comprehensive Environmental Response, Compensation and Liability Act
CZARA	= Coastal Zone Act Reauthorization Amendments
CZMA	= Coastal Zone Management Act
COD	= chemical oxygen demand
CWA	= Clean Water Act
EPA	= Environmental Protection Agency
EPT	= ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies)
ESA	= Endangered Species Act
EMC	= event mean concentration
FIFRA	= Federal Insecticide, Fungicide and Rodenticide Act
FWPCA	= Federal Water Pollution Control Act
IBI	= index of biotic integrity
MDE	= Maryland Department of the Environment
MTBE	= methyl tertiary butyl ether
NEPA	= National Environmental Policy Act
NGPE	= native growth protection easement
NMFS	= National Marine Fisheries Service
NOAA	= National Oceonographic and Atmospheric Administration
NPDES	= National Pollution Elimination Discharge Program
NRCS	= Natural Resources Conservation Service
NURP	= Nationwide Urban Runoff Program
OCZM	= Office of Coastal Zone Management
RCRA	= Resource Conservation and Recovery Act
RFS	= rainfall frequency spectrum
SCS	= Soil Conservation Service
SWMM	= StormWater Management Model
TMDL	= total maximum daily loads
TN	= total nitrogen
TP	= total phosphorus
TSS	= total suspended solids
UDFCD	= Urban Denver Flood Control District
USDA	= US Department of Agriculture
USFWS	= US Fish and Wildlife Service
USGS	= US Geological Survey

USTM	= Unitied Stormwater model
WEF	= Water Environment Federation
WEPP	= Water Erosion Prediction Model
Wq_v	= water quality volume
WWF	= wet weather flow

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Chapter One
Role of Best Management Practices (BMPs) in Improving Water Quality

1.1 Introduction

For the past three decades, municipalities in the United States have successfully addressed pollution in the watershed by collecting and treating their wastewater. Currently, all municipalities provide secondary level treatment, and in some cases tertiary treatment, and industries provide best available/best practicable treatment. This has had great benefits. More rivers are meeting water quality standards, and the public health is being protected from waterborne disease. The challenge now facing us is to address pollution associated with stormwater runoff since this is now the last major threat to water quality.

It is less costly to prevent the generation of runoff than to treat it. Today, many municipalities are looking at low-cost best management practices (BMPs) that prevent runoff. The lowest cost BMPs, termed nonstructural or source control BMPs, include practices such as limiting pesticide use in agricultural areas or retaining rainwater on residential lots (currently termed “low impact development”). There are higher cost BMPs, which involve building a structure of some kind to store stormwater and enable sedimentation. These can be more costly, especially in areas where land costs are high. BMPs have been classified a number of different ways including by stormwater runoff source, pollutant, land use and BMP type. For example, the Rouge River Restoration Project has seven classifications for BMPs: public information and participation, urban source control, treatment control, channel restoration/stabilization, construction erosion and sediment control, and agricultural. The American Society of Civil Engineers has nine categories (ASCE, 1998) and the State of Texas has three classes.

For the past ten years, the Environmental Protection Agency (EPA) has encouraged that water pollution controls be approached on a watershed basis. A watershed approach allows tradeoffs between pollution sources, point source treatment and pollution prevention, and optimal balances between these. It requires community-level involvement and often includes the use of both hard (structural) and soft (nonstructural) engineering approaches to protect or restore watersheds from chemical, physical, or biological stressors. The watershed approach allows simultaneous pollution, flood, and erosion-sedimentation control by properly siting BMPs within the watershed to maximize pollutant removals and reduce stormwater-associated stressors.

Historically, BMPs were employed to capture peak flows, assist in local drainage, and manage the quantity of runoff produced during wet-weather flow (WWF), i.e., flood control. While these objectives will probably remain a goal of watershed management planners, BMPs are now also considered for pollutant removal, stream restoration, and groundwater recharge infiltration.

Source control and pollution prevention are considered "good housekeeping" practices i.e., practices that keep pollutants out of runoff such as street cleaning, product substitution, and controlled application of pesticides/herbicides. Runoff source controls are used to reduce runoff generated at the source of specific activities and are divided into two types: those used on a temporary basis (e.g., runoff control at construction activities) and those used on a permanent basis (e.g., hot spot treatment at vehicle repair sites). End-of-pipe or treatment controls are used to remove pollutants from contaminated runoff.

The three most commonly used treatment BMPs are ponds (retention/detention), vegetative biofilters (swales, filter/buffer strips, and bioretention cells) and constructed wetlands. Two other categories of structural treatment BMPs are filters (notably sand filters) and innovative technology options (catchbasin inserts, filters, etc). This document concentrates on ponds and vegetative biofilters. BMPs that can be applied to agricultural lands will not be covered. The key aquatic stressors of concern in the United States are nutrients, suspended solids and sediments (SSASs), pathogens, flow, and toxic substances. These stressors have worldwide significance.

1.2 Impacts of Nonpoint Sources on Receiving Waters

WWF discharges are the leading cause of water quality impairment in the United States and pose significant risk to both human health and the downstream ecosystems. These discharges include stormwater and, in many urban areas, sewer overflows (from combined sewers and sanitary sewers). WWFs have the potential for widespread, short-term high exposures to infectious agents which result in gastrointestinal illness and even death. In addition, there is an increase in chronic long-term contamination of sediments and the aquatic food chain through the release of persistent, bioaccumulative toxic agents. The Office of Water, in its “National Water Program Agenda - 2001-2002" identifies the management of WWF dischargers as one of the key priority areas remaining to assure clean water and safe drinking water. Furthermore, this agenda states:

- Almost 40% of rivers, lakes, and coastal waters monitored by States do not meet water quality goals.
- Wet weather results in stormwater discharges and runoff from diffuse, nonpoint sources of pollution (e.g., agricultural operations, city streets, and construction) and causes significant water pollution problems throughout the country.

- Pollution from diffuse or non-point sources during and after rainfalls is now the single largest cause of water pollution.

WWF discharges cause significant negative impacts on the downstream ecosystems and create human health concerns since these downstream waters may be used for drinking water sources and recreational purposes. There may be significant pathogen microorganism counts *(salmonella, straphylococcus aureus, pseudomonas aeruginosa*) and viruses in stormwater. A recent epidemiology study in Santa Monica Bay, California, documented an increased risk of illness associated with swimming near storm drains. A special concern focuses on the public health aspects of beach closures and shellfish bed closures and minimizing the impacts of WWFs associated with body contact in swimming water during recreational activities. Exposure to these pathogens is of particular concern after major rainfall events which cause discharges from both point sources (e.g., sanitary sewer overflows (SSOs), combined sewer overflows (CSOs) and stormwater) and non-point sources (e.g., non-sewered urban runoff, animal feedlots, malfunctioning septic tanks, and other wild and domestic animal wastes). According to the Natural Resources Defense Council's eighth annual survey on beach water safety, at least 4,153 beach closings and advisories were caused by pollution in 1997 alone - "and adequate monitoring and notification procedures are still lacking at many of the nation's most popular beaches." This number of advisories may be an underestimate of incidents of contamination because many States and localities do not conduct, nor are they required to have, regular recreational water quality monitoring programs.

The 1992 National Water Quality Inventory cites numerous public health adversities associated with WWF: (1) toxic pollution from urban storm runoff into the Southern San Francisco Bay has caused heavy metal increases (copper, lead, nickel and zinc) and impairments to water quality for this salmon and herring fishery and recreational resource; (2) metals (copper, lead, zinc, mercury and cadmium) and organic toxicants (notably PCBs) have degraded water quality and contaminated sediments in the Duwamish River, Washington; (3) urban storm runoff in the New York metropolitan area has been implicated in increasing coliforms and reduced DO in the western end of the Long Island Sound, causing closure of beaches and commercial shellfish beds due to high fecal coliform concentrations; and (4) high concentrations of coliform bacteria observed after rainfall events in the Westport River, Massachusetts, have caused violations of primary contact recreation water quality criteria and forced the closure of shellfish beds.

WWFs have caused a decrease in flora/fauna species diversity, species types, and tissue bioassay impacts in many streams, as well as dissolved oxygen depletions. Urban storm runoff is a major cause of eutrophication, especially along the eastern coastal estuaries. In Lake Eola, Florida, urban runoff was found to be the sole cause of lake degradation associated with phosphorus increases and algal growth. The Village Creek in Birmingham, Alabama turned dark green with a putrid odor and contained considerable oil and grease due to upstream pollution; the creek was anaerobic with no fish or other biological life. Urbanization also creates higher stream flows causing bank and bottom erosion and deposition which has a high and significant national impact not only in terms of physical upsets but ecological as well.

There are localized economic losses associated with WWFs, including lost work hours due to illness; medical expenses; increased drinking water treatment costs (turbidity, metals, pathogens); lost tourist trade due to beach closings, fishing advisories; lost supply of shellfish and other fish (commercial shell fishing operations have been wiped out and economic losses also extend to recreational diggers); response, investigation, medical care, and insurance costs; and property value losses (e.g., to lake and river properties affected by floatables, siltation or eutrophication).

Flooding Impacts Flow events that exceed the capacity of the stream channel spill out into adjacent flood plains. These are termed "overbank" floods and can damage property and downstream drainage structures. While some overbank flooding is inevitable and even desirable, the historical goal of drainage design in many jurisdictions has been to maintain pre-development peak discharge rates for both the two and ten-year frequency storms after development, in an attempt to maintain the level of overbank flooding the same over time. This prevents costly damage or maintenance for culverts, drainage structures, and swales.

Overbank floods are ranked in terms of their statistical return frequency. For example, a flood that has a 50% statistical probability of occurring in any given year is termed a "two-year" flood. The two-year storm is also often used as a surrogate for the "bankfull flood", as researchers have demonstrated that most natural stream channels have just enough capacity to handle a runoff event with a return frequency of 1 to 2 years, before spilling into the floodplain (Wolman, 1960; Leopold, 1964, 1968).

Similarly, a flood that has a 10% probability of occurring in any given year is termed a "ten-year flood." Under traditional engineering practice, most channels and storm drains in many jurisdictions are designed with enough capacity to safely pass the peak discharge from the ten-year design storm.

The level areas bordering streams and rivers are known as flood plains. Operationally, the floodplain is usually defined as the land area within the limits of the l00-year storm flow water elevation. The l00-year storm has a l % statistical probability of occurring in any given year and typically serves as the basis for controlling development in many states and establishing insurance rates by the Federal Emergency Management Agency. These floods can be very destructive and can pose a threat to property and human life. Flood plains are natural flood storage areas and help to attenuate downstream flooding.

Flood plains are very important habitat areas, encompassing riparian forests, wetlands, and wildlife corridors. Consequently, many local jurisdictions restrict or even prohibit new development within the 100-year floodplain to prevent flood hazards and conserve habitats. Nevertheless, prior development that has occurred in the floodplain remains subject to periodic flooding during these storms.

As with overbank floods, development sharply increases the peak discharge rate associated with the 100-year design storm. As a consequence, the elevation of a stream's 100 year floodplain becomes higher and the boundaries of its floodplain expands (Figure 1-1). In some instances, property and structures that had not previously been subject to flooding are now at risk. Additionally, such a shift in a floodplain's hydrology can degrade wetlands and forest habitats.

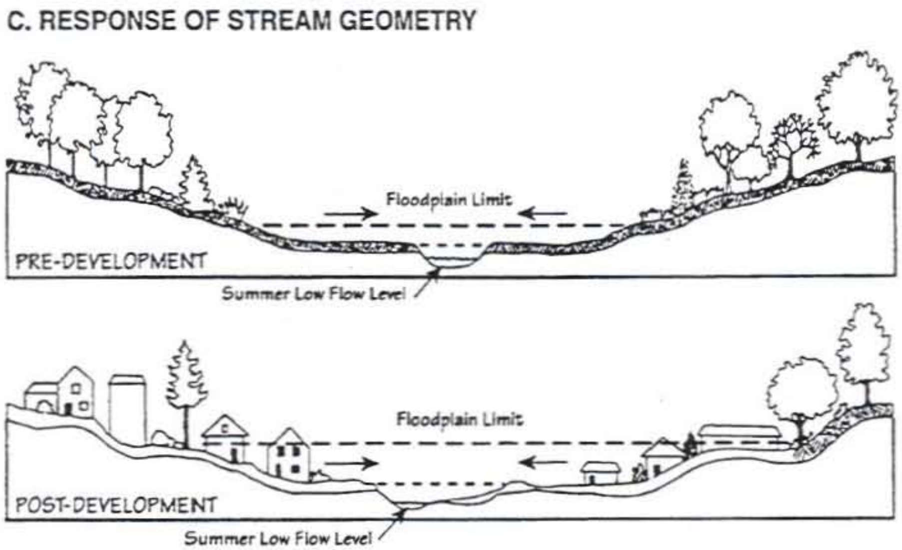

Figure 1-1 Change in Floodplain Elevations (MDE, 2000)

Hydrologic Regime Alterations Associated with Imperviousness Development increases the amount of impervious area in a watershed and thus can have a profound influence on the quality of receiving waters. Land use changes caused by agriculture, construction and urban development can dramatically alter the local hydrologic regime, primarily due to the increase in runoff due to impervious surfaces. The hydrology of an area changes during the initial clearing and grading that occur during construction. Trees, meadow grasses, and agricultural crops that had previously intercepted and absorbed rainfall are removed and natural depressions that had temporarily ponded water are graded to a uniform slope. Cleared and graded sites easily erode, are often severely compacted, and can no longer prevent rainfall from being rapidly converted into stormwater runoff. Very large errors in soil infiltration rates can be made if published soil maps and most available models are used for typical disturbed urban soils, as these tools ignore compaction (Pitt *et al*, 2000). Any disturbance of a soil profile can significantly change its infiltration characteristics and with urbanization, native soil profiles may be mixed or removed or fill material from other areas may be introduced (USDA, 1986). Some local agencies have attempted to address this issue by requiring that the pre-development hydrologic soil group (HSG) type be downgraded for post development hydrologic analysis. For example pre-development HSG types A, B, and C would be downgraded respectively to a B, C, and D.

The situation worsens after construction. Roof tops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is converted directly to stormwater runoff. This phenomenon is illustrated in Figure 1-2, which shows the increase in the volumetric runoff coefficient (Rv) as a function of area imperviousness. The runoff coefficient expresses the fraction of rainfall volume that is converted to runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one acre parking lot can produce 16 times more stormwater runoff than a one acre meadow each year (MDE, 2000).

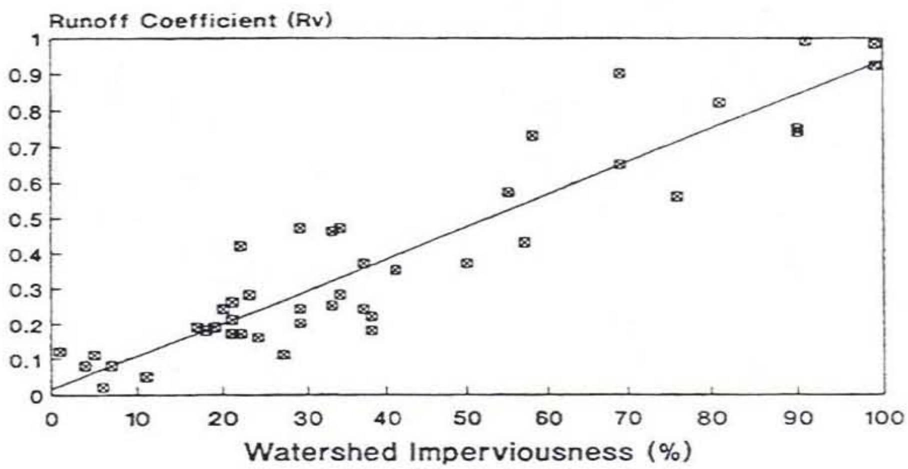

Figure 1-2 Relationship between Impervious Cover and the Volumetric Runoff Coefficient (Schueler, 1987)

Groundwater Recharge Impacts The slow infiltration of rainfall through the soil layer is essential for replenishing groundwater. The amount of rainfall that recharges groundwater varies, depending on the slope, soil, and vegetation.

Groundwater is a critical water resource in many areas of the U.S. Not only do many people depend on groundwater for their drinking water, but the health of many aquatic systems is also dependent on its steady discharge. For example, during periods of dry weather, groundwater sustains flows in streams and helps to maintain the hydrology of non-tidal wetlands. Because development creates impervious surfaces that prevent natural recharge, a net decrease in groundwater recharge rates may result in urban watersheds. As previously mentioned, many construction and development practices disturb the natural soil processes, through clearing of vegetation, grading and compaction, limiting infiltration in the post development landscape. Thus, during prolonged periods of dry weather, stream flow sharply diminishes. In smaller headwater streams, the decline in stream flow can cause a perennial stream to become seasonally dry.

Urban land uses and activities can also degrade groundwater quality if stormwater runoff is directed into the soil without adequate treatment. Certain land uses and activities are known to produce higher loads of metals and toxic chemicals and are designated as stormwater hot spots. Typical urban hot spots include industrial facilities, gasoline stations, parking lots, bus depots, golf courses and nurseries. The following land uses and activities are not normally considered hot spots: residential streets and rural highways; residential development; institutional development; commercial and office developments; non-industrial rooftops; pervious areas, except golf courses and nurseries.

Impacts on Stream Channel Stability Stormwater runoff is a powerful force that influences the geometry of streams. After development, both the frequency and magnitude of storm flows increase dramatically. Consequently, urban stream channels experience more frequent out of bank flows as well as intermediate flows that have sufficient energy to erode and destabilize the stream channel than they had prior to development.

As a result, the stream bed and banks are exposed to highly erosive flows more frequently and for longer periods. Streams typically respond to this change by increasing cross-sectional area to handle the more frequent and erosive flows either by channel widening or down cutting, or both. This results in a highly unstable phase where the stream experiences severe bank erosion and habitat degradation. In this phase, the stream often experiences some of the following changes as it adjusts to a new flow regime: rapid stream widening, increased streambank and channel erosion, change in sinuosity, decrease in slope, decline in stream substrate quality (through sediment deposition and embedding of the substrate), loss of pool/riffle structure in the stream channel, and degradation of stream habitat structure.

The decline in the physical habitat of the stream, coupled with lower base flows and higher stormwater pollutant loads, has a severe impact on the aquatic community including decline in aquatic insects, freshwater mussels, and fish diversity, and degradation of aquatic habitat. Traditionally, some local agencies have attempted to provide some measure of channel protection by imposing the two-year storm peak discharge control requirement, which requires that the discharge from the two-year post development peak rates be reduced to pre-development levels. However, hydrologic analysis (McCuen, 1987) and recent field experience indicate that the two-year peak discharge criterion is not capable of protecting downstream channels from erosion. For some receiving waters, controlling the two-year storm may actually accelerate streambank erosion because it exposes the channel to a longer duration of erosive flows than it would have otherwise received.

Thermal Impacts In some urbanized regions of the country, summer in-stream temperatures have been shown to increase significantly (5 to 12 F^o) in streams due to direct solar radiation, lack of riparian buffer, runoff from heat absorbing pavement and discharges from stormwater ponds. Increased water temperatures can preclude temperature sensitive species from being able to persist in urban streams.

Galli (1991) reported that stream temperatures throughout the summer are increased in urban watersheds, and the degree of warming appears to be directly related to the imperviousness of the contributing watershed. He monitored five headwater streams in the Maryland Piedmont over a six-month period, with each of the streams having differing levels of impervious cover. Each of the urban streams had mean temperatures that were consistently warmer than a forested reference stream, and the size of the increase appeared to be a direct function of watershed imperviousness. Other factors, such as lack of riparian cover and ponds, were also demonstrated to amplify stream warming, but the primary contributing factor appeared to be watershed impervious cover.

1.3 Impacts of Urbanization on Receiving Waters - Physical and Chemical

General impacts of pollutants on different receiving waters are reported in Table 1-1. Impervious surfaces accumulate pollutants deposited from the atmosphere, leaked from vehicles, or washed off/windblown from adjacent areas. During storm events, these pollutants quickly wash off and are rapidly delivered to downstream waters. Pervious areas are major contributors of erosion products (sediment), nutrients, and pesticide/herbicides.

Urban runoff has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, lakes, reservoirs and estuaries. In particular, excess nutrients have been documented to be a major factor in the decline of major estuarine areas such as the Chesapeake Bay and western Long Island Sound. Excess nutrients promote algal growth that blocks sunlight from reaching underwater grasses and depletes oxygen in bottom waters. Urban runoff has been identified as a key and controllable source.

Table 1-1 Impacts of Urbanization on Receiving Waters

	Sediment	Pathogens	Metal and Hydrocarbon Toxicity	Nutrients/ Eutrophication	Pesticide / Herbicide	Chloride	MTBE
Lakes	À	À	À		À		
Reservoirs	À	À	À		À		
Aquifers			À		À		
Wetlands	À		À		À		?
Streams		À	À	À		À	À
Shellfish	À		À	À	À		?
Beaches	À		À				
Estuaries	À	À	À		À	À	
Sea grasses	À		À		?		?

Standard violation concerns / significant concern / loss of beneficial use
À Occasional Standard violation / site specific concerns
Rarely affects receiving area
? Insufficient information

Sources of sediment include washoff of particles that are deposited on impervious surfaces and erosion of streambanks and construction sites. Both suspended and deposited sediments can have adverse effects on aquatic life in streams, lakes and estuaries. Sediments also transport other attached pollutants.

Organic matter, washed from impervious surfaces during storms, can present a problem in slower moving downstream waters. As organic matter decomposes, it can deplete dissolved oxygen in lakes and tidal waters. A modest number of currently used and recently banned insecticides and herbicides have been detected in urban streamflow at concentrations that approach or exceed toxicity thresholds for aquatic life uses.

Bacteria levels in stormwater runoff routinely exceed public health standards for water contact recreation. Stormwater runoff can also lead to the closure of adjacent shellfish beds and swimming beaches and may increase the cost of treating drinking water at water supply reservoirs. Viruses and protozoa (e.g., cryptosporidium and giardia) cause additional difficulties.

Motor vehicles leak oil and grease that contain a wide array of hydrocarbon compounds, some of which can be toxic at low concentrations to aquatic life. Cadmium, copper, lead and zinc are routinely found in stormwater runoff. These heavy metals can be toxic to aquatic life at certain concentrations and can also accumulate in the sediments of streams, lakes and estuaries. Deicing salts that are applied to roads and parking lots in the winter months appear in stormwater runoff and meltwater at much higher concentrations than many freshwater organisms can tolerate and have been known to cause closures of well water supplies.

Impervious surfaces may increase temperature in receiving waters, adversely impacting aquatic life that requires cold and cool water conditions (e.g., trout). Considerable quantities of trash and debris are washed through storm drain networks. The trash and debris accumulate in streams and lakes and detract from their natural beauty and decrease property value.

1.4 Impacts of Urbanization on Receiving Waters - Biological Communities

The physical and chemical impacts identified above cause a decline in both the quantity of the aquatic biota and the quality of their habitat. This section examines some of the impacts that urbanization exerts on the aquatic community, focusing specifically on macro-invertebrates, fish, amphibians and freshwater mussels. The fundamental change in hydrology, as well as the chemical composition of runoff in urban and urbanizing streams causes both a decrease in biological diversity and a shift from more pollutant sensitive to less sensitive aquatic organisms.

Urbanization can significantly alter the land surface, soil, vegetation, water quality and stream hydrology and create adverse impacts for aquatic organisms through habitat loss or modification. Table 1-2 summarizes some of the changes to aquatic ecosystems as a result of urbanization and the effects on the biological community.

The effects of urbanization on aquatic community structure has been the subject of several recent studies as summarized in Table 1-3. A number of the studies have examined the link between urbanization and its impact on aquatic organisms and habitat. These studies reveal that the onset of urbanization almost always has a negative affect on the aquatic biota of receiving waters. The degradation in the biological diversity of aquatic environments is the result of the variety of influences that added impervious cover exerts on aquatic systems. Table 1-3 presents some of the key findings of prior research involving aquatic organisms and the problems associated with increases in impervious cover.

Table 1-2 Changes Due to Urbanization and Effects on Aquatic Organisms

Impact	Effect on ecosystem	Effects on organisms
Chemical Impacts		
Heavy Metals Chemical Pollutants	Reduction in Water Quality	Reduced survival of eggs and alevins, toxicity to juveniles and adults, increased physiological stress, reduced biodiversity.
Sediment	Increase in Turbidity	Reduced survival of eggs, reduced plant productivity, physiological stress on aquatic organisms.
Nutrients	Algae Blooms	Oxygen depletion due to algal blooms, increased eutrophication rate of standing waters, possibly toxicity to eggs and juveniles from certain nutrients.
Physical Impacts		
Hydrologic	Increased Flow Volumes/ Channel Forming Storms	Alterations in habitat complexity, changes in availability of food organisms related to timing of emergence and recovery after disturbance, reduced prey diversity, scour-related mortality, long-term depletion of large woody debris, accelerated erosion of streambanks.
	Decreased Base Flows	Crowding and increased competition for foraging sites, increased vulnerability to predation, increased fine sediment deposition.
Geo-morphology	Increase in Sediment Transport	Reduced survival of eggs and alevins, loss of habitat due to deposition, siltation of pool areas, reduced macro-invertebrate production.
	Loss of Pools and Riffles	Shift in the balance of species due to habitat change, loss of deep water cover and feeding areas.
	Changes in Substrate Composition	Reduced survival of eggs, loss of inter-gravel spaces used for refuge by fry, reduced macroinvertebrate production, reduced biodiversity.
	Loss of Large Wood Debris	Loss of cover from predators and high flows, reduced sediment and organic matter storage, reduced pool formation, reduced organic substrate for macro-invertebrates
Thermal	Increase in Temperature	Changes in migration patterns, increased metabolic activity, increased disease and parasite susceptibility, higher mortality of sensitive species, reduced biodiversity in stream community.
Channel Modification	Loss of First Order Streams	Loss of valuable habitat especially for more sensitive species
	Creation of Fish Blockages	Loss of spawning habitat for adults; inability to reach overwintering sites, loss of summer rearing habitat, increased vulnerability to predation.
	Loss of Vegetative Rooting Systems	Creates problems with decreased channel stability, increased streambank erosion, reduced streambank integrity .
	Straightening or Hardening of Channel	Increased stream flows, loss of habitat complexity

Table 1-3 Recent Research Examining the Relationship of Urbanization to Aquatic Habitat and Organisms

Indicator	Key Finding	Reference	Location
Aquatic habitat	There is a decrease in the quantity of large woody debris (LWD) found in urban streams at around 10% impervious cover.	Booth *et al* 1991	Washington
Aquatic insects and fish	In a comparison of three stream types, urban streams had lower EPT {Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)}, (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and poor index of biotic integrity (IBI) scores.	Crawford & Lenat1989	North Carolina
Insects, fish, habitat water quality, riparian zone	Steepest decline of biological functioning after 6% imperviousness. There was a steady decline, with approx 50% of initial biotic integrity at 45% impervious area.	Horner *et al.* 1996	Puget Sound, Washington
Aquatic insects and fish	Macroinvertebrate and fish diversity decline significantly beyond 10-12% impervious area.	Klein1979	Maryland
Fish, Aquatic insects	A study of five urban streams found that as land use shifted from rural to urban, fish and macroinvertebrate diversity decreased.	Masterson & Bannerman 1994	Wisconsin
Insects, fish, habitat, water quality, riparian zone	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as the percentage of total impervious area exceeded the 5-10% range.	May *et al.* 1997	Washington
Aquatic insects and fish	There was significant decline in the diversity of aquatic insects and fish at 10% impervious cover.	MWCOG 1992	Washington, DC
Aquatic insects and fish	Evaluation of runoff effects in urban and non-urban areas found that native species dominated the non-urban portion of the watershed, but accounted for only 7% of the number of species found at the monitoring stations located in urban areas. Benthic taxa were more abundant in non-urbanized portions of the watershed.	Pitt 1982	California
Wetland plants, amphibians	Mean annual water fluctuation inversely correlated to plant & amphibian density in urban wetlands. Declines noted beyond 10% impervious area.	Taylor 1993	Seattle
Aquatic insects and fish	Residential urban land use in Columbus watersheds caused a significant decrease in fish attainment scores at around 33%. For Cuyahoga watersheds, a significant drop in IBI scores occurred at around 8%, primarily due to certain stressors which functioned to lower the non-attainment threshold. When watersheds smaller than $100mi^2$ were analyzed separately, the level of urban land use for a significant drop in IBI scores occurred at around 15%.	Yoder et. al 1999	Ohio
Aquatic insects and fish	All 40 urban sites sampled had fair to very poor IBI scores, compared to undeveloped reference sites.	Yoder 1991	Ohio

Increases in imperviousness appear to cause detrimental effects in the integrity of the biological community, beginning at fairly low levels of impervious cover. Studies suggest that above 10% watershed imperviousness levels, significant signs of degradation are easily found. These signs include loss of species diversity, reductions in overall species abundance, and reproductive failure and juvenile mortality. Additional research is required to firmly establish the exact level of imperviousness at which the biological community of a receiving water begins to face significant impacts to its health, to identify regional variations in the impervious cover levels at which aquatic diversity is affected and to assess the effects of disconnected impervious area vs directly connected pervious areas.

1.5 Pollutant Loadings Associated with Urban Stormwater

Water quality impacts of urbanization encompass a broad range of parameters. Essentially, any pollutant deposited or derived from an activity on the land surface will likely end up in stormwater runoff in some concentration. However, there are certain pollutants and activities that are consistently more likely to result in degradation of a stream or receiving water. These more frequently occurring pollutants can be grouped into several broad categories including: nutrients, sediment, metals, hydrocarbons, gasoline additives, pathogens, deicers, herbicides and pesticides.

The direct effects of these pollutants on receiving waters is often a function of the size of the receiving water and the sensitivity of the inhabiting organisms. Toxins tend to accumulate in lakes, ponds, estuaries, or other fixed receiving water bodies and concentrations in streams tend to rapidly rebound to background conditions. Toxic pollutants from stormwater tend to be a short term problem for fast moving waters. A small stream receiving a large load of hydrocarbons or metals from a well used parking lot is more likely to experience toxic effects than would a large river. Sensitive species such as trout and stoneflies may be more susceptible to a range of pollutants than more pollution tolerant organisms such as the black-nosed dace or certain leeches.

The beneficial use of the receiving water is an important consideration when evaluating the concentrations of pollutants in urban stormwater. Certain pollutants even at low levels are of greater concern when receiving waters have specific beneficial uses such as swimming or fishing. Drinking water reservoirs, especially ones without filtration, may be more sensitive to lower levels of pollutants because the water is being managed for human consumption.

Data in Table 1-4 represent typical concentrations of chemical constituents discussed in this section. Concentrations for most pollutants are derived from Smullen and Cave (1998). This study represents a compilation of NURP data, combined with later data from the USGS, as well as NPDES Phase I stormwater monitoring.

Table 1-4 National Event Mean and Median Concentrations for Chemical Constituents of Stormwater

Constituent (Units)	Source of Data (% detection)	Concentration		Number of Events
		Mean	Median	
Suspended Solids (mg/l)	Pooled NURP/USGS (1)	78.4	54.5	3047
Total Phosphorus (mg/l)	Pooled NURP/USGS (1)	0.315	0.259	3094
Soluble Phosphorus (mg/l)	Pooled NURP/USGS (1)	0.129	0.103	1091
Total Nitrogen (mg/l)	Pooled NURP/USGS (1)	2.39	2.00	2016
Total Kjeldhal Nitrogen (mg/l)	Pooled NURP/USGS (1)	1.73	1.47	2693
Nitrite and Nitrate (mg/l)	Pooled NURP/USGS (1)	0.658	0.533	2016
Copper (:g/l)	Pooled NURP/USGS (1)	13.35	11.1	1657
Lead (:g/l)	Pooled NURP/USGS (1)	67.5	50.7	2713
Zinc (:g/l)	Pooled NURP/USGS (1)	162	129	2234
BOD (mg/l)	Pooled NURP/USGS (1)	14.1	11.5	1035
COD (mg/l)	Pooled NURP/USGS (1)	52.8	44.7	2639
Organic Carbon (mg/l)	Nationwide - Stormwater Inflow (4)		11.9	19
Cadmium (:g/l)	NURP (3)	0.7		150
Chromium (:g/l)	Dallas-FW NPDES (2)	4		32
Oil and Grease (mg/l)	NURP (3)	3		NA
Fecal Coliform (col/100 ml)	Nationwide stormwater inflow (4)	15,038		34
Fecal Strep (col/100 ml)	Nationwide stormwater inflow (4)	35,351		17
Cryptosporidium (organisms)	NY (5)	37.2	3.9	78
Giardia (organisms)	NY (5)	41.0	6.4	78
MTBE (:g/l)	National Study 16 cities (6)		1.6	592
Chloride (snowmelt) (mg/l)	Minnesota (7)		116	49
Diazonon (:g/l)	Baseflow (75%) Stormflow (2) (92% - residential only)		0.025 0.55	326 76
Chlorpyrifos (:g/l)	Nationwide baseflow (41%)			327
Atrazine (:g/l)	Nationwide baseflow (86%)		0.023	327
Prometon (:g/l)	Nationwide baseflow (84%)		0.031	327
Simazine (:g/l)	Nationwide baseflow (88%)		0.039	327

(1) Smullen and Cave, 1998, (2) Brush et al. 1995, (3) Crunkilton et al. 1996, (4) Schueler 2000, (5) Stern et al. 1996, (6) Delzer 1996, (7) Oberts 1989.

National Data for Major Pollutants The amount of rainfall, temperature differences, and the period between rain events are important factors causing stormwater quality differences. Arid and semi-arid regions generally experience longer dry periods where pollutants build up from different sources and subsequently runoff in higher concentrations during storm events. In cold climates, snow accumulation in winter coincides with pollutant build up; therefore, greater concentrations of pollutants are found during runoff events.

The USGS National Stormwater Database of 1123 storms for 98 stations in 20 metropolitan cities is a primary data source. This regional analysis of stormwater data was chosen based on the lack of standard techniques across other data sources including NPDES, NURP, and USGS. Tasker and Driver (1988) performed regression analyses to determine which factors had the greatest influence on stormwater concentrations. Annual rainfall had the greatest influence on the majority of the parameters. The water quality data was then grouped based on the amount of yearly average rainfall. Table 1-5 shows the rainfall groupings and the cities represented.

Table 1-5 Regional Groupings by Annual Rainfall (Driver and Tasker, 1990)

Region	**Annual Rainfall**	**Cities monitored**	**Concentration Data**
Region I	Less than 20 inches	Anchorage, AK; Fresno, CA; Denver, CO; Albuquerque, NM; Salt Lake City, UT	*Highest mean and median values for TN, TP, TSS, COD, total ammonia + organic nitrogen*
Region II	20 to 40 inches	HA, IL, MI, MN, MI, NY, Austin,TX, OR, OH, WA, WI	Higher mean and median values than Region III for TSS, dissolved phosphorus and cadmium
Region III	More than 40 inches	FL, MD, Boston,MA; NC, Durham, NH, Long Island, NY; Houston TX, Knoxville, TN and Little Rock, AR	Lower values for many parameters likely due to the frequency of storms and the lack of build up in pollutants

Region I, the region with the lowest annual rainfall (less than 20 inches), typically had higher concentrations of a number of pollutants. Mean and median concentrations of total nitrogen, total phosphorus, dissolved phosphorus, total suspended solids and total ammonia + organic nitrogen were all much higher in Region I. Additionally, a large proportion of stream flow in arid or semi-arid regions comes from turbid urban sources such as municipal wastewater effluent, return flow from irrigation, and urban storm flow (Caraco, 2000). This is probably due to the greater amount of sediment eroded from pervious surfaces in arid or semi-arid regions, due to the sparsity of protective vegetative cover. In Tables 1-6 and 1-7, the higher concentrations of TSS, TP and TN from the regions with less rainfall are shown, as well as the tendency to exceed chronic toxicity standards for metals (Driver, 1988).

Table 1-6 Mean and Median Nutrient and Sediment Stormwater Concentrations for Residential Land Use Based on Rainfall Regions (adapted from Tasker and Driver, 1988)

	TN (median) mg/l	TP (median) mg/l	TSS (mean) mg/l
Region I (under 20 in)	4	0.45	320
Region II (20 to 40 in)	2.3	0.31	250
Region III (over 40 in)	2.3	0.31	120

Table 1-7 Percentage of Metal Concentrations Exceeding Water Quality Standards by Rainfall Region (Driver and Tasker, 1990)

		Water Quality Standard Freshwater and Chronic Toxicity			
Rainfall Region	Rainfall	10 :g/l	12 :g/l	32 :g/l	47 :g/l
		Cadmium	Copper	Lead	Zinc
I	<20 inches	1.5%	89%	97%	97%
II	20-40 inches	0	78%	89%	85%
III	> 40 inches	0	75%	91%	84%

Stormwater data gathered from different regions of this country, using disparate stormwater data sources such as NPDES, USGS, and local stormwater data, generally confirm the trend determined by Driver (1988). That values for nutrients, suspended sediment and metals tend to be higher in arid and semi-arid regions and tend to decrease as the amount of rainfall increases. Arid regions do not experience build up of pollutants such as PAHs because they are degraded rather rapidly by photo-degradation. Table 1-8 shows the distribution of rainfall and pollutant concentrations from various monitoring sources for a number of American cities.

Table 1-8 Stormwater Pollutant Event Mean Concentration for Different U.S. Regions (adapted from Caraco, 2000)

	Annual Rainfall (in.)	Events	SS (mg/l)	BOD (mg/l)	COD (mg/l)	Total N (mg/l)	Total P (mg/l)	Soluble P (mg/l)	Copper (:g/l)	Lead (:g/l)	Zinc (:g/l)
National	- -	2000-3000	78.4	14.1	52.8	2.39	0.32	0.13	14	68	162
Phoenix, AZ	7.1	40	227	109	239	3.26	0.41	0.17	47	72	204
San Diego, CA	10	36	330	21	105	4.55	0.7	0.4	25	44	180
Boise, ID	11	15	116	89	261	4.13	0.75	0.47	34	46	342
Denver, CO	15	35	242	- -	227	4.06	0.65	- -	60	250	350
Dalles, TX	28	32	663	112	106	2.7	0.78	- -	40	330	540
Marquette, MI	32	12	159	15.4	66	1.87	0.29	0.04	22	49	111
Austin. TX	32	- -	190	14	98	2.35	0.32	0.24	16	38	190
MD NPDES	41	107	67	14.4	- -	1.94*	0.33	- -	18	12.5	143
Louisville, KY	43	21	98	88	38	2.37	0.32	0.21	15	60	190
GA NPDES	51	81	258	14	73	2.52	0.33	0.14	32	28	148
FL NPDES	52	- -	43	11	64	1.74	0.38	0.23	1.4	8.5	55
MN Snowmelt	NA	49	112	- -	112	4.3	0.70	0.18	- -	100	- -

TKN - total Kjeldahl nitrogen.
NA - not applicable

Land development generates pollutants from traditional point sources, such as wastewater, and from more diffuse sources, such as stormwater runoff. The Clean Water Act has had stringent controls in force for decades to control point source discharges through the NPDES program. The diffuse sources are controlled in part by NPDES stormwater programs, which involve less rigorous controls. Table 1-9 (Burton and Pitt, 2002) presents typical urban areas and pollutant yields on an annual basis, while Table 1-10 provides median EMC values. Some of these pollutants are released at concentrations in excess of the woodland conditions that existed at some time prior to construction. These pollutants include nutrients, bacteria, and metals. Other pollutants are new to the receiving waters, such as forms of volatile synthetic materials. Various petroleum products and additives are also new to many receiving waters. Additional pollutants can also include trash, sediment loads, temperature, and even non-native and invasive biological species.

Table 1-9 Typical Urban Areas and Pollutant Yields (Burton & Pitt, 2002)

Pollutant	Land Use (lb/acre/year)[a]								
	Com-mercial	Parking Lot	Residential - Density			High-ways	Industry	Parks	Shopping Center
			High	Medium	Low [b]				
Total Solids	2100	1300	670	450	65	1700	670	NA[c]	720
SS	1000	400	420	250	10	880	500	3	440
Cl	420	300	54	30	9	470	25	NA	36
TP	1.5	0.7	1	0.3	0	0.9	1.3	0.03	0.5
TKN	6.7	5.1	4.2	2.5	0.3	7.9	3.4	NA	3.1
NH^3	1.9	2	0.8	0.5	0	1.5	0.2	NA	0.5
$NO^3 + NO^2$	3.1	2.9	2	1.4	0.1	4.2	1.3	NA	0.5
BOD_5	62	47	27	13	1	NA	NA	NA	NA
COD	420	270	170	50	7	NA	200	NA	NA
Pb	2.7	0.8	0.8	0.1	0	4.5	0.2	0	1.1
Zn	2.1	0.8	0.7	0.1	0	2.1	0.4	NA	0.6
Cr	0.15	NA	NA	0	0	0.09	0.6	NA	0.04
Cd	0.03	0.01	0	0	0	0.02	0	NA	0.01
As	0.02	NA	NA	0	0	0.02	0	NA	0.02

[a] The difference between lb/acre/year and kg/ha/yr is less than 15%, and the accuracy of the values shown in this table cannot differentiate between such close values

[b] The monitored low-density residential areas were drained by grass swales

[c] NA = Not available

Table 1-11 indicates that the concentration of pollutants in stormwater runoff can be comparable to treated domestic wastewater. Exceptions include nutrients and solids; a higher percentage of stormwater solids are inorganic from the local geology, which has implications for treatment. When the concentration is multiplied by the large quantity of water in runoff, the total loading from urban areas can be greater than that of treated domestic wastewater. Thus, when untreated urban runoff is discharged directly into receiving waters, the pollutant loads can be much greater than those from treated domestic sewage and are rightfully a matter of concern.

Table 1-10 Median Stormwater Pollutant Concentration for All Sites by Land Use (EPA, 1983)

Constituents	Land Uses							
	Residential		Mixed Land Use		Commercial		Open/ Non-urban	
	Median	COV[a]	Median	COV	Median	COV	Median	COV
BOD_5, mg/l	10	0.41	7.8	0.52	9.3	0.3	--	--
COD, mg/l	73	0.55	65	0.58	57	0.4	40	0.78
TSS, mg/l	101	0.96	67	1.14	69	0.9	70	2.92
Total Pb, µg/l	144	0.75	114	1.35	104	0.7	30	1.52
Total Cu, µg/l	33	0.99	27	1.32	29	0.8	--	--
Total Zn, µg/l	135	0.84	154	0.78	226	1.1	195	0.66
TKN, µg/l	1900	0.73	1289	0.5	1179	0.4	965	1
NO2+NO3(as N), µg/l	736	0.83	558	0.67	572	0.5	543	0.91
TP, µg/l	383	0.69	263	0.75	201	0.7	121	1.66
Soluble P, µg/l	143	0.46	56	0.75	80	0.7	26	2.11

[a] COV: coefficient of variation = standard deviation/mean

Table 1-11 Comparison of Water Quality Parameters in Urban Runoff With Domestic Wastewater (EPA, 1986)

Constituent	Urban Runoff		Domestic Wastewater		
	Separate Sewers		Before Treatment		After Secondary Treatment
	Range	Typical	Range	Typical	Typical
COD (mg/l)	10-275	75	250-1,000	500	80
TSS (mg/l)	20-2,890	150	100-350	200	20
Total P (mg/l)	0.02-4.30	0.36	36630	8	2
Total N (mg/l)	0.4-20.0	2	20-85	40	30
Lead (mg/l)	0.01-1.20	0.18	0.02-0.94	0.1	0.05
Copper (mg/l)	0.01-0.40	0.05	0.03-1.19	0.22	0.03
Zinc (mg/l)	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

Cold Region Snowmelt Data In cold regions, greater than 50% of the annual load for sediment, nutrients, PAHs, and some metals can come from snowmelt runoff during late winter and early spring (Oberts, 1989). In areas where there is infrequent melting, buildup of pollutants takes place in the snowpack, contributing to high concentrations of the pollutants during snowmelt runoff. Oberts (1994) describes four types of snowmelt runoff events and the resulting pollutants (Table 1-12).

Source areas for pollutants associated with snowmelt include snow dumps and roadside areas. Concentrations of pollutants in snow dumps can be more than five times greater than typical stormwater pollutant concentrations. These areas can build up a tremendous amount of pollutants over the winter months and many of these pollutants can be lost in just one rain or snow event in the early spring. Metals, PAHs, chloride, sediment and nutrients are all parameters which build up in the snowpack.

The only significant regional differences for PAHs and oil and grease were reported for snowmelt events. These pollutants can build up in snow in urban areas and be released during significant snowmelt events. Oberts (1994) and others have reported that 90% of the load can be released during the last 10% of the runoff event. The regional concentration data based on rainfall and the snowmelt process has implications for stormwater managers. Stormwater cannot be managed or regulated in the same manner across regional boundaries. Northern climates must use different strategies to manage runoff from snowmelt conditions and utilize stormwater practices which can treat a larger amount of runoff.

Table 1-12 Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)

Snowmelt Stage	**Duration / Frequency**	**Runoff Volume**	**Pollutant Characteristics**
Pavement Melt	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants, Cl, nitrate, lead. Total load is minimal.
Roadside Melt	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants.
Pervious Area Melt	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants, moderate to high concentrations of particulate pollutants, depending on flow.
Rain-on-Snow Melt	Short	Extreme	High concentrations of particulate pollutants, moderate to high concentrations of soluble pollutants. High total load.

Pollutant Concentrations and Loadings When developing a design estimate of pollutant concentrations and loadings, two general situations, or a combination of the two, may be encountered. The first case occurs when planning a new facility on previously undeveloped land, and an estimate of anticipated post-development pollutant loads is needed. This situation will require estimates based on data from similar land uses and the site specific geology for particle size and density characteristics.

The second situation occurs when the BMP design consists of a water quality retrofit for an existing developed area. In this case, actual data for the existing land uses and their runoff can be collected. Because water quality monitoring is very expensive and time consuming, however, the designer may choose to develop estimates based on available data associated with similar land uses. The designer can also use a combination of the two approaches using limited storm monitoring and sampling to verify and calibrated modeling estimates.

There are two well documented approaches for developing pollutant loading estimates from existing data. These include the nationwide regression equation method developed by the USGS (Tasker & Driver, 1988), and the simple method developed by the Metropolitan Washington Council of Governments (Schueler, 1987).

1.6 Stormwater Management - EPA Regulatory Requirements

In response to the 1987 Amendments to the Clean Water Act (CWA), EPA developed Phase I of the National Pollutant Discharge Elimination System (NPDES) stormwater program in 1990. The Phase I program addressed sources of stormwater runoff that had the greatest potential to negatively impact water quality at that time. Under Phase I, EPA required NPDES permit coverage for stormwater discharges from:

- "Medium" and "large" municipal separate storm sewer systems (MS4s) located in incorporated places or counties with populations of 100,000 or more; and
- Eleven categories of industrial activity, one of which is construction activity that disturbs five or more acres of land.

Operators of the facilities, systems, and construction sites regulated under the Phase I NPDES program can obtain permit coverage under an individually-tailored NPDES permit (developed for MS4s and some industrial facilities) or a general NPDES permit (used by most operators of industrial facilities and construction sites).

The Phase II Final Rule, published in the Federal Register on December 8, 1999, requires NPDES permit coverage for stormwater discharges from:

- certain regulated small municipal separate storm sewer systems (MS4s); and

- construction activity disturbing between 1 and 5 acres of land (i.e., small construction activities).

In addition to expanding the NPDES Storm Water Program, the Phase II Final Rule revises the "no exposure" exclusion and the temporary exemption for certain industrial facilities under Phase I of the NPDES Storm Water Program.

The number of watersheds implementing BMPs is expected to increase dramatically with the implementation of Phase II of the NPDES stormwater permitting regulations. The cornerstone of this regulation is to ensure that BMPs to prevent and minimize water quality impacts from runoff are implemented and maintained. Phase II requires NPDES permits for smaller systems (populations of 10,000 or more), primarily all those in urbanized areas and smaller construction sites (one to five acres in size). There are six minimum control measures outlined under the Phase II Rule: public education/outreach, public involvement and participation, illicit discharge detection and elimination, erosion control for construction sites from 1 to 5 acres, post-construction BMPs for control in new and redeveloped urban areas, and pollution prevention and good housekeeping. Many more industrial, commercial and institutional sites will be included under Phase II.

1.7 Role of BMPs in Developing an Urban Stormwater Management Plan

The primary method to control stormwater discharges in urban areas is through the use of BMPs (EPA website http://cfpub.epa.gov/npdes/stormwater/swphase1.cfm). These could be a combination of practices for source control and for treatment. The overall goal would be to get to a watershed condition that existed prior to development. Runoff from development has significant impacts on local streams, especially when areas are paved and the amount of impervious surface in the watershed increases.

Source control is a important component of a sound watershed management plan. Both the volume of runoff and its quality should be addressed. The volume can be reduced by allowing infiltration of the rainwater into ground surfaces. Use of low impact development approaches and retrofit of paved areas with bioretention cells demonstrates this approach. The quality of runoff can be improved by product substitution (e.g., replacing “hazardous” building materials) and treating hazardous “hot spot” sources on site where they occur. Reduction in the amount of impervious surfaces and minimizing soil compaction impacts during construction has major beneficial results.

There are a number of sources that describe BMPs and their role in urban watershed management:(http://www.bmpdatabase.org/, http://www.ce.utexas.edu/centers/crwr/index.htm, http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm, http://www.tnrcc.state.tx.us/admin/topdoc/rg/348/index.html, http://www.txnpsbook.org/ http://www.lowimpactdevelopment.org/mainhome.html,http://www.stormwatercenter.net/).

1.8 Current Peak Discharge Control Strategies

Urban drainage systems have been designed to remove stormwater runoff as rapidly as possible. For flood control, storm sewers were commonly designed for a 10-yr storm with a range from 2 - 4 in./hr of rainfall intensity in urban catchments, and the design frequency range from 25 to 100 years for culverts and small bridges in highway drainage systems. As a result, the increased magnitude and frequency of these flow peaks tend to aggravate stream channel erosion and increase downstream flooding. To restrain the peak flow affects, many municipalities now have ordinances requiring any storm that is greater than 0.2 in./hr with a greater than 2-yr return interval be controlled so the post-development peak flow for a given return interval storm (e.g., 2-yr; 10-yr; or 25-yr) does not exceed the pre-development peak flow for the same storm. This can be achieved by using local detention storage to shave the post-development peak flow. Although the controlled basin outflow may reduce downstream flooding, the effect on stream erosion still remains due to the prolonged period of discharging erosive flows.

Peak discharge control strategies represent a basic approach to control or mitigate impacts from urban runoff and are the oldest and most widely used strategy in urban watershed management. It is relatively straightforward and consists of a general policy that post-development runoff rates cannot substantially exceed existing pre-development runoff rates. Runoff (both the total volume and the peak discharge values) after development is usually much greater due to the establishment of impervious surfaces (roadways, rooftops, etc). The flow control approach generally requires that facilities be provided to temporarily store the additional runoff, which is then discharged after the storm at an allowable release rate (which is usually based on the discharge from a predisturbed design storm with the same return period).

This level of control is currently being provided by many states and municipalities under the NPDES stormwater regulatory approach. It provides two performance criteria that are closely related: (1) flood control and (2) peak discharge control. Peak discharge control is not necessarily flood control. Peak discharge control strategies are often used for a range of storm frequencies including the 1, 2, 5, 10, 25, 50 and 100 year storms. Typically the smaller frequencies 1 and 2 year are used to prevent channel erosion rather than flood protection. By definition flooding does not occur until a stream overtops its banks and spreads out into its floodplain. The limits of the flood prone area is often arbitrarily set as the limit of the 100 year storm, although the Corps of Engineers also looks at the Standard Project Flood which is the 500 year flood. Some practitioners have concluded that on a watershed-wide scale, uniform detention strategies are a failure because they do not maintain base flows, do not necessarily improve water quality, and in some case fail to control floods (Ferguson, 1998).

This peak discharge or flood control approach has some major drawbacks as summarized in Table 1-13.

Table 1-13 Impairments Associated with Current Flow Control Strategies (Collins et al., 2001)

Category	Impact Type / Metric		Impairment or Change to Beneficial Use
Physical	Hydrologic regime	Runoff volume	Flooding, Groundwater recharge, hydrologic balance, etc.
		Peak discharge	Flooding, channel erosion, habitat loss
		Flow duration & frequency	Channel erosion, habitat loss
		Groundwater recharge, water table elevation & baseflows	Water table, local wells, baseflows, habitat loss
	Geomorphic	Channel geometry	Channel erosion, sediment deposition, habitat loss
		Sediment transport	Aggradation, Degradation, Channel capacity
	Flooding		Loss of property
	Thermal		Habitat impairment
Habitat	Attachment Sites Embeddedness Fish Shelter Channel alteration Sediment deposition Stream velocity and depth Channel flow status Bank vegetation protection Bank condition score Riparian vegetation zone		Impairment or loss of habitat structure results in reduction or losses in biologic conditions and communities.
Biological	Total taxa *Ephemeroptera, Plecoptera, Tricoptera* (EPT) taxa % taxa % EPT Family Biotic Index (FBI)		Biologic conditions and communities can be reduced or eliminated as a result of impairment or loss of habitat structure caused by physical impacts resulting from construction and development activities.
Chemical (Water Quality)	Sediment Nutrients Metals Oil and Grease Pathogens Organic Carbon MTBE Herbicides and Pesticides Deicers		Water quality degradation or impairment can have many negative consequences: drinking water violations, increased water treatment costs, beach closures, shellfish bed closures, loss of boating use, fishery loss, reduction of reservoir and lake volumes due to sediment volume.

1.9 Design of Treatment BMPs to Improve Water Quality

There are many publications that address BMP design for flood control based on hydrological procedures; however most do not provide satisfactory guidance for water quality control. The most basic level of design is based upon flow to minimize flooding. Many stormwater controls were initially employed for flood control, i.e., to capture peak flows, assist in local drainage, and manage the quantity of runoff produced during WWF. In this regard, many states and municipalities only require the control of peak stormwater discharges.

In response to the provisions of the Clean Water Act, a number of activities (such as the nationwide urban runoff program (NURP)) were initiated to characterize and quantify the water quality impacts of WWF, and municipalities started to adapt BMPs for pollutant removal. In recent years, watershed approaches have considered that BMPs can result in water quality improvements, and procedures have been established to assure removal of pollutants. Coastal zone states, for example, must remove 80 percent of total suspended solids (TSS) from new construction areas under the Coastal Zone Management Act of 1972. Other approaches look toward controlling the first flush of pollutants associated with a storm, mandating the capture of the first ½ to 1 inch of runoff (typically generated in the first hours of the one year storm).

More recently in response to a growing national awareness and understanding of the wide range of environmental impacts associated with land use changes, particularly urbanization, BMPs have begun to be designed for stream channel protection and restoration, groundwater infiltration, and protection of riparian habitat and biota. Collected runoff has also been used for irrigation, toilet flushing and other non-potable purposes, including ponds and wetlands that also enhance urban aesthetics. This approach involves control of larger storms to achieve additional ecological benefits, such as preventing erosion of stream banks, recharging groundwaters, or minimizing thermal impacts.

1.10 Concerns with BMP Performances

The overriding concern with treatment BMPs is that it is often difficult to link their installation to water quality improvements. In fact, receiving water quality at times seems unchanged before and after the construction of BMP. Two other major concerns are the degree to which pollutant removal associated with a particular BMP can be predicted and whether identical designs, not considering suspended (particulate) and dissolved solids characteristics, can produce the same performance levels at different locations. Finally, there is a lack of methodologies/models to tell water quality managers where to place the BMP in the watershed to get optimal water quality results. Concerns about BMP performance leads to a research program that addresses how the BMPs work, how to design for water quality control what they cost, how effective they are, and where to best place them in the watershed.

Improved Understanding BMPs as Unit Processes Research is needed to improve the understanding of the key mechanisms working within the BMP to reduce the effluent load. Useful starting points have been established, however, not to the extent of a clear understanding of several independent mechanisms such as infiltration and settling. Residence time within the BMP likely will be the most important controlling factor. It is affected not only by design considerations, but also by rain event factors (duration, runoff volume, inter-event timing) or, in general, the combination of watershed hydrology with BMP hydraulics. An improved understanding of BMP unit processes would lead to better design of the commonly used BMPs.

Proper design must include:

- Better definitions of influent mass loadings (flowrate, pollutant concentrations, suspended solids size/settling velocity, dissolved solids, partitioning of pollutants to solids). Current design is often based on needing to capture a large (2-year) infrequent storm or based on typical/default stormwater characteristics, however much of the pollutant loading occurs during frequent small storms (typically up to 80% of annual pollutant load). This approach should be modified to better characterize the influent specific to that watershed. Design should be based on continuous (wet and dry weather) long-term rainfall-runoff-channel flow (BMP influent) simulation emanating from the BMP drainage area using appropriate urban hydrology.

- Better application of engineering principles. Traditional BMPs have been designed for flood protection rather than removal of pollutants. Typically longer detention time is required for treatment to be effective. Only recently have some States emphasized the water quality aspects of BMP design. Engineering principles should be applied more fully. For example, improved designs should be based on discharge rates that allow particulate settling, consideration of velocity/size distributions, allowance for removal of the dissolved solids fraction, and improved soil infiltration practices. As noted above, site-specific characterization of stormwater is imperative.

- Need to consider all pollutants. Examples of this are toxic and oxygen-demanding substances and thermal changes that could result in significant receiving-water upsets when they are overlooked. Avoidance of sediment resuspension is also important.

Design is an "inexact science" and that variations in performance should be expected. Current variations in sewage treatment plant sediment removals (established practice for over 100 years) range from 40 to 60%.

No Universally-Accepted Definition of Effectiveness A generally-accepted definition for the "effectiveness" of BMPs has not yet been obtained. Without this common metric, there will be no way to establish whether the BMP meets specified performance criteria, surpasses minimum needs, or fails to suffice. The EPA definition and the engineering definition must be precisely worded to convey the fully intended meaning. While some users have an ecological inference when discussing “effectiveness,” the definition may need to be revised to have an engineering foundation.

For example, “the fractional pollutant mass removed by the mature BMP in a climatically average calendar year,” according to one feasible and defensible definition, will not provide the same measure of efficiency as “the fractional concentration reduction across the BMP in a 1-year storm event,” or “the fractional mass reduction by a BMP over its useful lifetime”. None considers the real issue that highly seasonal considerations linked to the life-cycle needs of the indigenous fauna may exist. This becomes considerably messier when looking at non-chemical stressors (e.g., flow, temperature). Also BMP effluent performance typically approaches a limiting concentration regardless of influent concentration. Does this mean that they are less efficient for lower influent concentrations than higher concentrations? In all cases long-term pollutant mass loading removal must be the emphasis.

Further, the correct pollutants need to be managed. For example, concerns with removing total phosphorus, may be misguided as it is the bioavailable phosphorus that is most important to prevent water quality impacts. This suggests that the wrong stressor is being managed.

Quantifying the efficiency of BMPs has often centered on examinations and comparisons of “percent removal” defined in a variety of ways. BMPs do not typically function with a uniform percent removal across a wide range of influent water quality concentrations. For example, a BMP that demonstrates a large percent removal under heavily polluted influent conditions may demonstrate poor percent removal where low influent concentrations exist. The decreased efficiency of BMPs receiving low concentration influent has been demonstrated and it has been shown that in some cases there is a minimum concentration achievable through implementation of BMPs for many constituents (Schueler, 1996). Percent removal alone, even where the results are statistically significant, often does not provide a useful assessment of BMP performance.

High Degree of Uncertainty Associated with Load and Performance One of the major criticisms by the National Research Council of the TMDL Model process is the large amount of uncertainty associated with applying the models. In fact, many current models result in inaccurate predictions so when the controls are applied they do not work. There are large amounts of uncertainty in simple tasks such as flow measurement, leading to propagated error. Uncertainty in measurement and modeling leads to probable errors linked with the associated loads, the reductions within a BMP, or natural attenuation.

Inability to Link “Cause to Effect” - Post-BMP Complications It is difficult to link BMP performance with in-stream response. There are many “causes” (pollutant sources) in the watershed giving rise to receiving-water “effects”, and these represent complex interactions.

Receiving-water effects are further obscured by background (upstream) flow, ground-water (baseflow) entry, direct air pollutant deposition, bottom benthos/sediment legacy and resuspension, multi-stressor synergisms/antagonisms, pollutant fate and effect routing through to ecological "food-network," flow energy biota impacts, thermal impacts, and the inability to relate human disease risk to microbial indicators of pathogens

The in-receiving water mechanisms can be at least partially modeled, but a sufficient understanding of some relevant issues is yet to be achieved. Recovery time is an obvious example. Similarly, there is no mechanism to incorporate intermittent point sources with variable loadings which BMPs represent, within the permitted loading to the receiving waters.

Inadequate Basis for Placement of BMPs in an Urban Watershed There is no current basis for identifying the optimal location of BMPs in an urban watershed. All pollutant sources and surface runoff needs to be accounted for. The overall watershed drainage routing must include the interception and capture of the required amount of surface or pollution source-generated runoff causing the receiving-water problem.

Inability to Determine Changes in BMP Effectiveness Over Time Proper monitoring/evaluation techniques are hardly ever conducted. Proper monitoring requires continuous (wet- and dry-weather) pollutant quality sampling of the influent and effluent points synchronized with flowrate measurement of these points. This will allow determination of pollutant mass loading reduction. Sampling devices must be capable of handling both heavy and light particles at short time intervals in order to represent the pollutant loadigraph properly. The flow meters must be capable of measuring highly variable flowrates going from very low liquid levels to surcharge flow conditions.

This also involves administering proper long-term maintenance and monitoring for determination of BMP unit process effectiveness.

Responsibilities for Implementing BMPs At some point in the last few decades, municipalities shifted the burden of storm drainage to the developers and the future owners of the development. There are many possible problems with this approach, i.e., limited understanding of downstream flooding potential from multiple discharges, the lack of centralized treatment, and the tendency to discharge runoff to the nearest receiving water without consideration of water quality impacts.

This "delegation" in managing stormwater drainage was promulgated by most municipalities as a cost savings measure. However costs may actually be higher as monies are needed to restore eroded stream channels. More and more municipalities are turning to stormwater utilities or impervious area taxes to raise money to rectify damage to receiving waters. The current problem may have been averted if municipalities had adopted a more comprehensive shift in drainage control. Many municipalities had retained building codes for regional control, i.e. curb and gutter and drainage pipes for centralized stormwater collection system and discharge, when the municipalities were responsible for the drainage, but have in fact shifted to a local control practice for drainage control, where curb and gutter approaches are accentuating problems to receiving waters.

Discharges to small streams (e.g., non - navigable streams, headwaters) require multiple levels of control to slow the flows coming off impervious areas - dry detention ponds for floods is not enough. If regional controls are not used and discharges are continued to be made to the nearest receiving water body then a series of treatment BMPs will most likely be required.

No BMP design will be adequate unless the receiving water body is capable of assimilating the flow. In addition to pollution effects, high flows which cause stream channel erosion must be considered. A receiving water channel that is being eroded is often more likely to be a problem than “pollution” associated with runoff. Once the channel is stabilized by reducing the flows, than the pollutant constituents to the stormwater can be addressed.

Discharging stormwater runoff to the nearest waterway is intended to keep water in the channels. However, this approach is misguided as the flows from impervious areas have been documented to be too flashy in nature and do not maintain baseflows. Base flows can only be maintained by allowing for pervious areas and possibly increasing infiltration through infiltration capable BMPs in developments with impervious areas.

Chapter Two
Watershed Hydrology Pertinent to BMP Design

2.1 Introduction

Hydrology is the science dealing with the properties, distribution, and circulation of water on the land surface (including surface waters), and subsurface (including groundwater). In the context of watershed management, the focus is on the quantity of runoff produced by various storms and how it moves (or is routed) through the watershed. Hydrology depends highly on rainfall, topography, soil and drainage characteristics and will vary between regions of the country and land uses.

The hydrologic concepts of interest with respect to the design of BMPs are closely related to the design objectives of the BMP. Design of BMPs can be focused on flow control (normally control of peak discharges), runoff volume control, pollutant removal for water quality improvements, a host of ecological sustainability goals (e.g., groundwater recharge, stream channel protection, prevention of thermal impacts) or a combination of two or more of these objectives. Each objective has somewhat different hydrologic parameter requirements. The hydrologic data which must be understood in order to design effective BMPs and evaluate water quality impacts in urban watersheds include (1) the amount and distribution of rainfall intensity and volume; and (2) the amount of rainfall contributing to runoff volume, i.e., rainfall minus abstractions. These abstractions include interception, evapotranspiration, soil infiltration, and depression or pocket storage.

2.2 Amount and Distribution of Rainfall Intensity and Volume

A rainfall frequency spectrum (RFS), defined as the distribution of all rainfall events in an area, is a useful tool to place in perspective many of the relevant hydrologic parameters. Represented in this distribution is the rainfall volume from all storm events ranging from the smallest, most frequent events to the largest, most extreme events, such as the 100-year storm. An RFS example is shown in Figure 2-1.

The distribution and magnitude of the RFS varies across the country. Driscoll *et al.* (1989) subdivided the U.S. into 15 distinct rainfall regions, as shown in Figure 2-2 and summarized in Table 2-1.

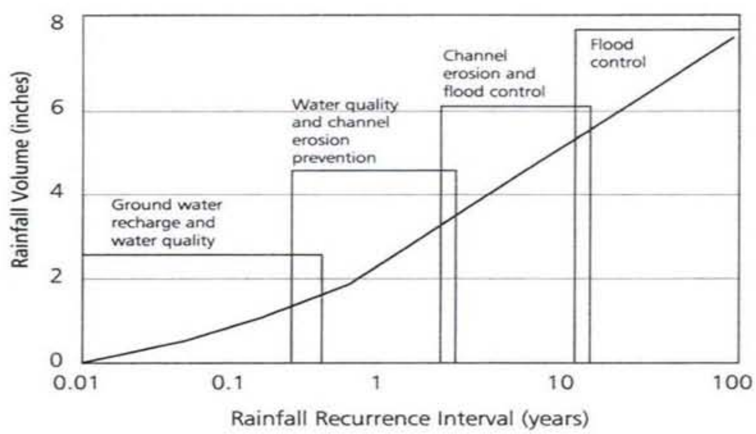

Figure 2-1 Stormwater Control Points Along the RFS for Maryland (CRC, 1996)

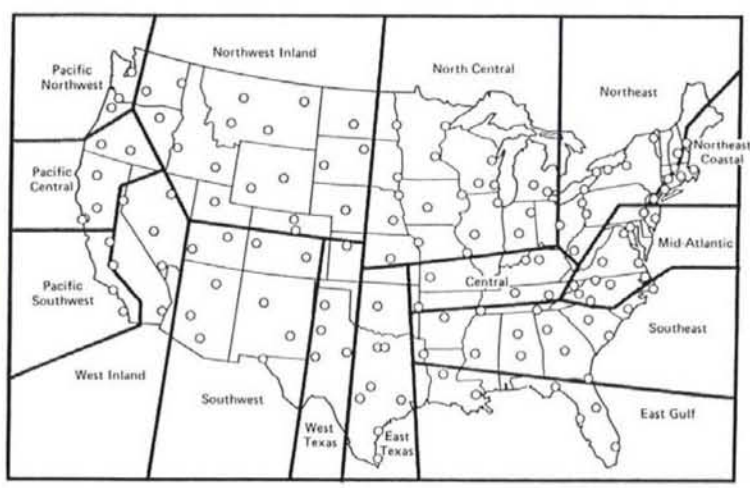

Figure 2-2 Fifteen rain zones of the United States (Driscoll *et al.*,1989)

Table 2-1 Typical Values of Individual Storm Event Statistics for 15 Zones of the United States (Driscoll, *et al.* 1989)

Rain Zone	**Annual No. of Storms**		**Duration (hr)**		**Intensity (in./hr)**		**Volume (in.)**		**Storm Separation (hr)**	
	Avg.	**CV**	**Avg.**	**CV**	**Avg.**	**CV**	**Avg.**	**CV**	**Avg.**	**CV**
Northeast	70	0.13	11.2	0.81	0.067	1.23	0.50	0.95	126	0.94
Northeast, coastal	63	0.12	11.7	0.77	0.071	1.05	0.66	1.03	140	0.87
Mid-Atlantic	62	0.13	10.1	0.84	0.092	1.20	0.64	1.01	143	0.97
Central	68	0.14	9.2	0.85	0.097	1.09	0.62	1.00	133	0.99
North Central	55	0.16	9.5	0.83	0.087	1.20	0.55	1.01	167	1.17
Southeast	65	0.15	8.7	0.92	0.122	1.09	0.75	1.10	136	1.03
East Gulf	68	0.17	6.4	1.05	0.178	1.03	0.80	1.19	130	1.25
East Texas	41	0.22	8	0.97	0.137	1.08	0.76	1.18	213	1.28
West Texas	30	0.27	7.4	0.98	0.121	1.13	0.57	1.07	302	1.53
Southwest	20	0.30	7.8	0.88	0.079	1.16	0.37	0.88	473	1.46
West, inland	14	0.38	9.40	0.75	0.055	1.06	0.36	0.87	786	1.54
Pacific Southwest	19	0.36	11.6	0.78	0.054	0.76	0.54	0.98	476	2.09
Northwest, inland	31	0.23	10.4	0.82	0.057	1.20	0.37	0.93	304	1.43
Pacific Central	32	0.25	13.7	0.80	0.048	0.85	0.58	1.05	265	2.00
Pacific Northwest	71	0.15	15.9	0.80	0.035	0.73	0.50	1.09	123	1.50

Notes: CV = coefficient of variation of the logarithm of the observations (CV=S/M); S = standard deviation of the logarithms of the observations, ($S=[3(x_i - M)^2 / (N-1)]^{½}$);

M = natural logarithm of the mean value of the EMC observations; x = natural logarithm of an individual EMC observations; N = number of observations

In the absence of site-specific information, the RFS can be used to establish reasonable design volumes for various BMPs. Runoff intensity and volume are the most important hydrologic variables for water quality protection and design; they are related to capture and treatment of the mass load of pollutants. Peak runoff rate is the most commonly used hydrologic variable for drainage system and flooding analysis used in current design practices. Stormwater BMPs designed to remove pollutants are built to treat a specified volume of runoff for the full duration of a storm event, as opposed to accommodating only an instantaneous peak at the most severe portion of a storm event.

A more accurate method to determine runoff specific to a particular watershed is to measure it using rain gauges, flow meters, and other monitoring equipment. These data can then be put into various rainfall/runoff models (there are a number of them) which can be used to predict runoff levels. The models can also predict pollutant loadings, but need specific data on the concentrations of contaminants in that region's runoff. The models run continuous evaluations of rainfall/runoff relationships: rainfall is typically modeled on a daily basis and runoff and loading predicted in response to the rainfall on a daily basis as well. Return period information is determined by conducting many years of simulation, typically 25 to 100 years, and doing a return period analysis on the predicted values.

2.3 Hydrologic Concepts for BMP Design

Most frequently recurrent rainfall events are small (less than 1 inch of daily rainfall). For example, 90% of the annual rainfall comes in storms smaller than 0.9 in./day in Cincinnati, OH (Roesner *et al.*, 2001). These often wash down the land surface, generating a relatively high "first flush" concentration of pollutants. The capture and treatment of these small storms would lead to improved water quality since the total pollutant load to receiving streams would be minimized.

Current design, however, focuses on capturing large storms to minimize flooding. These rainfall events typically range from 2 inches to 10 inches of daily rainfall and occur much less frequently (every 2 years to 100 years). Although these storms may contain significant pollutant loads (Chang *et al.*, 1990), their contribution to the annual average pollutant load is really quite small due to the infrequency of their occurrence.

The computational procedures for large storm hydrology refer to procedures to estimate or model runoff hydrographs from the larger storm events typically ranging from the 2-yr to the 100-yr storm. The procedures for conducting these analysis are well documented at both the national and regional level.

At the national level a variety of models are available and well documented to simulate the rainfall-runoff processes for watersheds and the design of BMPs. The selection of the appropriate modeling technique will often depend on the level of detail and rigor required for the application and the amount of data available for setup and testing of the model results. However, in many instances the local regulatory agencies may specify which models are acceptable for design and review purposes. For example in the state of Maryland, the state regulatory authority, the Maryland Department of the Environment requires that BMP design be performed using the NRCS TR-55 and TR-20 models. Table 2-2 summarizes a number of national and regional level models that are frequently used for BMP large storm design.

A number of large storm models have also been developed by local and regional government. Some of these models include:

- The Penn State Runoff Model (PSRM) which is used widely in Pennsylvania and Virginia
- The Illinois Urban Area Simulator (ILLUDAS) which was developed by the Illinois State Water Survey in concert with USEPA, based on the RRL (Roads Research Laboratory) research and is widely used in Illinois and neighboring mid-western states.
- The Urban Drainage and Flood Control District (UDFCD) model developed by the Denver Urban Drainage Flood Control District (UDFCD, 1999). This model is used widely in Colorado and adjoining states.
- The Santa Barbara Urban Runoff Hydrograph developed for the City of Santa Barbara, California. This model is widely used in California and other Pacific coast states (Oregon and Washington).

2.4 Peak Discharge Control Strategies

Peak discharge control is the oldest and most widely used strategy for controlling the drainage and flood impacts of urban runoff. The strategy is relatively straightforward and consists of a general policy that post-development discharge rates cannot substantially exceed existing or pre-development discharge rates. Post-construction runoff conditions (both total volume and the peak discharge values) are usually much greater than pre-development conditions. Therefore, the peak discharge approach generally requires that storage facilities be provided to temporarily store the additional runoff volume, which is then discharged at the allowable release rate, based on the "design storm".

Table 2-2 Comparison of Model Attributes and Functions

ATTRIBUTE	MODEL								
	National					Regional			
	HSPF	SWMM	TR-55/ TR-20	HEC-HMS	Rational Method	PSRM	ILLUDAS	UDFCD	Santa Barbara
Sponsoring Agency	USGS	USEPA	NRCS[1]	CORPS[2]		PSU[3]	ISWS[4]	UDFCD[5]	
Simulation Type	Continuous	Continuous	Single Event	Single Event	Single Event	Single Event	Single Event	Single Event	Single Event
Water Quality Analysis	Yes	Yes	None	None	None	Yes	None	None	None
Rainfall/Runoff Analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sewer System Flow Routing	None	Yes	None	None	None	Yes	Yes	Yes	None
Dynamic Flow Routing Equations	None	Yes	None	None	None	Yes	None	None	None
Regulators, Overflow Structures	None	Yes	None	None	None	None	None	None	None
Storage Analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Treatment Analysis	Yes	Yes	None	None	None	Yes	None	None	None
Data and Personnel Req.	High	High	Medium	Medium	Low	Medium	Medium	Low	Medium
Overall Model Complexity	High	High	Low	High	Low	Low	Low	Low	Low

[1] NRCS = National Resources Conservation Service
[2] CORPS = US Army Corps of Engineers
[3] PSU = The Pennsylvania State University
[4] ISWS = Illinois State Water Survey
[5] UDFCD = Urban Denver Flood Control District
[6] USGS = US Geologic Survey

Design Storms The design storm is the particular storm event which generates runoff rates and volumes which the BMP is designed to handle (the term design storm has other definitions as when used for sewer design capacity and in various models). The peak discharge control strategy is closely tied to the use of design storms. The selection of a specific design storm generally incorporates a number of implicit assumptions relating to the stormwater runoff impacts being controlled, and thus provides a good starting point for a scientific assessment relating to actual versus perceived benefits of this strategy.

As Table 2-3 documents, a number of the assumptions implicit in the selection of a design storm do not hold up under scientific scrutiny and have never been validated by field monitoring. As the table indicates, the implicit assumption that peak discharge control of the 2-year storm as a strategy for channel protection is not supported by geomorphic science or field monitoring data. On the contrary, the geomorphic data predicts that the strategy is flawed, and the prediction is being confirmed by limited field monitoring data.

Table 2-3 Design Storm Frequencies and Assumed Benefits

Design Storm	***Assumed Benefits***	***Comments***	***References***
½ - < 1 inch rainfall	70-80 percent control of annual runoff volume used for water quality volume control	Used by many municipalities on the east coast	
1-inch rainfall	90 percent control of annual runoff volume used for water quality volume control	Replacing ½ inch as basis for water quality control (predominantly east coast)	MDE 2000
1-year	Water quality management and stream channel protection	Used by some municipalities for water quality management. Maryland is now using for channel protection.	MDE 2000
2 -year	Used by most municipalities to provide protection from accelerated channel erosion and for habitat protection	Geomorphic science does not support this assumption. Very limited field monitoring indicates that the strategy is flawed.	Leopold, 1964; McCuen et al., 1987, MacRae, 1996; Jones, 1997; Maxted and Shaver, 1997
10-year	Used to provide flood protection from intermediate storm events	Use of this storm frequency is mostly a carryover from storm drainage design practices. Flood control benefits are very limited. In some cases increases potential for downstream flooding due to super-positioning of hydrograph peaks. There is no geomorphic basis for the use of this storm.	Skupien, 2000 , Ferguson, 1998, Debo & Reese, 1995
100-year	Used for flood control protection from major storms; also used to maintain 100-year floodplain limits	Flood control benefits are very limited. In some cases increases the potential for downstream flooding due to super-positioning of hydrograph peaks..	Skupien, 2000; Ferguson, 1998; Debo & Reese, 1995

Peak Discharge Strategies and Control of Physical Impacts Table 1-13 provided a summary of the major impact categories (physical, habitat, biological, and chemical), the impact types or metrics, and the impairment or change to the use of the receiving waters. With respect to the physical impact category, the major areas of impairment are:

- Increased flooding
- Channel instability and erosion
- Reduction in groundwater recharge and related issues
- Increased sediment transport
- Thermal impacts

Table 2-4 provides a qualitative assessment of the benefits provided by peak discharge control strategies with respect to the physical impacts category.

Table 2-4 Qualitative Assessment of Peak Discharge Control Strategies with Respect to the Physical Impact Category

Physical Impact Category	**Control Strategy**	**Assessment**
Increased flooding	Peak discharge control of 10- and 100-year storms	Peak discharge control of 10- and 100-year storms Peak discharge strategy provides limited downstream control. In some cases, it aggravates downstream flooding condition. Requires coordinated permitting at watershed scale. (Skupien, 2000; Ferguson, 1998; Debo & Reese, 1995)
Channel instability and erosion	Peak discharge control of 2-year storm	Both geomorphic science and limited field monitoring indicate that this strategy does not work. (McCuen et al., 1987; MacRae, 1996)
Reduction in groundwater recharge and related issues	Not addressed by peak discharge control	N/A
Increased sediment transport	Peak discharge of 2-year storm	Both geomorphic science and limited field monitoring indicate that this strategy does not work. (McCuen et al., 1987; MacRae, 1996)
Thermal impacts	Not addressed by peak discharge control	N/A

Control of Increased Flooding The ability of land use changes, and in particular land development activities, to increase runoff quantity and cause downstream flooding and erosion has been recognized for many decades. This has led many states, counties and municipalities, and other agencies to require onsite detention of increased project area runoff with peak site outflows set equal to the pre-developed conditions. This requirement has become popular, since it can be applied during development design and reviewed on a case-by-case basis without large-scale watershed analysis. This popularity has led to the frequent use of onsite detention and retention basins, which have become standard features on many land development projects.

However, the limitations of peak discharge control strategies documented by Leopold and Maddock (Leopold, 1954) have been largely ignored. At the exact spot where a detention basin discharges through its outlet, it reduces the peak rate of storm flow. We know this conclusively from the laws of physics and applied hydraulics. While there is no argument on this point, farther downstream, a basin's effect on peak rate depends partly on how its discharge combines with the flow from other tributaries. In practice, on any given site, detention should be applied with caution and should be based on an appropriate watershed-wide and downstream analysis.

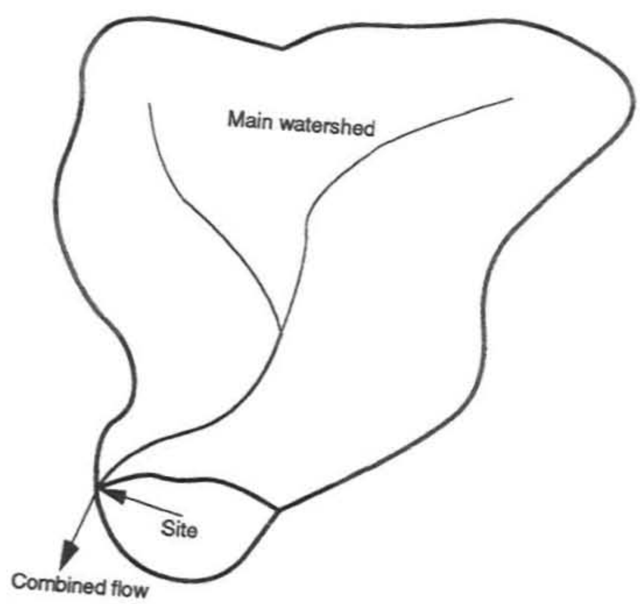

Figure 2-3 A Watershed Where the Drainage From a Small Development Site Joins the Flow From Large Watershed (Ferguson, 1998).

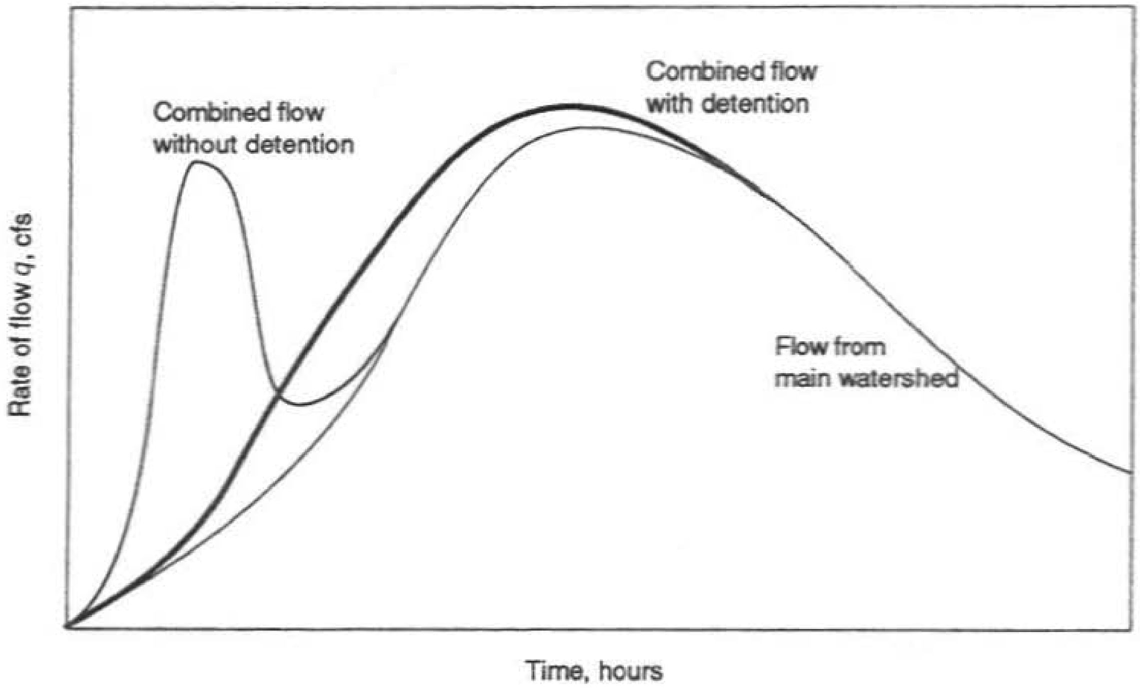

Figure 2-4 Alternative Hydrographs From the Watershed Shown in Figure 2-3 (Ferguson, 1998)

Ferguson (1998) has provided a good example of this condition as illustrated in Figures 2-3 and 2-4. Figure 2-3 shows a small development site discharging into the main stem of a larger watershed. As shown in Figure 2-4, the storm hydrograph from the development site is short and fast compared with that from the main watershed. Because the development site's flow drains out before the main watershed's peak arrives, it does not contribute to the magnitude of a flood downstream. But if detention is added to the developed site, outflow will be delayed, so that it overlaps onto the peak flow in the main stream and contributes to a new, higher combined peak flow.

One can imagine two detention basins on different sites in the same watershed, constructed by different developers at about the same time. When hydrographs from the two basins combine downstream, their delayed flows combine in a way that has never existed before development, and a larger flood may be created. In spite of this knowledge, numerous local governments are requiring every developer to reduce the peak rate during a design storm to its pre-development level. The effect of this approach has been a random proliferation of small detention basins over urbanizing watersheds, none of which is designed with regard to its specific location in the drainage network. The potential conflict between a basin and its watershed, first identified by Leopold and Maddock (1953) has been confirmed by a number of more recent studies. Independent modeling studies throughout the U.S., including the studies listed below have all confirmed that randomly sited basins have failed to provide downstream flood and channel protection:

- McCuen (1979) for a Maryland watershed;
- Ferguson (1991, 1995), Hess and Inman(1994) for watersheds in Colorado, Georgia and Virginia;
- Debo and Reese (1992) for watersheds in North and South Carolina; and
- Skupien (2000) for a watershed in New Jersey

Enough studies have been conducted and reported that the following generalizations can be drawn from them:

- Some watershed-wide systems of detention basins help, in the sense that they keep downstream peak discharges during a given storm lower than it would be without them.
- Other individual basins do the opposite of help; they actually increase downstream peak discharges as a result of the overlapping of their detained volumes with mainstream peaks.
- No watershed-wide system of uniform basins works to the extent for which they were designed. If they were designed to reduce peak discharges during a given storm to pre-development levels, then their aggregate effect, although it may result in a reduction in peak discharge, is usually not a reduction to the designed degree, because of the accumulation of runoff volumes downstream.

Detention basins can reduce flood peaks only when they are selectively located in their watersheds as explained by Leopold and Maddock (1953). Selective planning of publicly financed reservoirs led to the effective flood control for the Miami River in Ohio, when the Miami Conservancy District (Morgan, 1951) identified specific flood hazards in Dayton and other cities, then located a combination of multiple-purpose reservoirs, levees, and channels to work in concert to reduce flood damage at those points.

Downstream Analysis The issue of downstream analysis is often not addressed by local stormwater management ordinances. Debo and Reese (1992) conducted studies for the City and County of Greenville, South Carolina and Raleigh, North Carolina to demonstrate how such a policy could be developed. This study used a hydrologic-hydraulic computer model to analyze the downstream effects of storm runoff from developments of different size, shape, physical characteristics, and location within larger drainage basins. The study also examined different size flood events and different types of downstream drainage systems. The results of this study revealed that the effects of the development process stabilizes at the point where the proposed development represents 5 to 10 percent of the total drainage area, depending on the size of the development and the amount of increased impervious area. This analysis was used as the basis for the formulation of the following policy concerning downstream impacts (Debo and Reese, 1992):

> *"In determining downstream effects from stormwater management structures and the development, hydrologic-hydraulic engineering studies shall extend downstream to a point where the proposed development represents less than ten (10) percent of the total watershed draining to that point."*

Channel Instability, Bank Erosion, and Sediment Transport A related issue associated with the peak discharge control strategy is the well-documented problem of increases in the frequency and duration of stormwater discharges. Peak discharge control strategies using detention ponds do not eliminate runoff, they simply delay it. The volume discharging from a detention basin is the same as the inflow. When the post development volumes from different tributaries join downstream, there is nothing to prevent them from combining to produce inadvertently high peak rates. In the fortunate cases in which flood peaks are consistently reduced, the receiving streams may still erode and become unstable, because in accommodating the increased volume of runoff, relatively high erosive flows still pass through for longer periods (McCuen, *et al.*, 1987). As demonstrated by McCuen, *et al.* (1987), the practice of detaining the extra volume of stormwater runoff and discharging it at pre-construction peak discharge rates until the extra volume is fully dissipated has the result of creating more in-stream erosion than if no stormwater control were present. This occurs when the selected design storm focuses predominately on downstream flood control and not on in-stream erosion (channel protection) and the protection of aquatic habitat and biology.

Reduction in Groundwater Recharge and Related Issues Peak discharge control strategies are often referred to as end-of-pipe control strategies, because they typically make use of small BMP ponds placed at the low topographic point on development sites. This approach does not usually address groundwater recharge and related issues, such as lowering of groundwater levels and reduction or loss of base flows in small streams. There are two exceptions to this general case. One is where infiltration ponds are used as the BMP. The other exception to this condition consists of recent initiatives in the state of Florida, where stormwater management ponds are being used as sources of gray water for lawn watering. This initiative is in part a response to the alarming lowering of water tables in many areas of Florida.

Thermal Impacts A negative consequence of the peak discharge control strategy and the associated use of pond BMPs is the associated increase in thermal warming of runoff waters. The problem is particularly acute in regions of the country that support cold-water habitat, particularly trout and salmon fisheries.

Summary of Peak Discharge Strategies Peak discharge strategies represent an approach to control or mitigation of impacts from urban runoff. This level of control is currently being provided by many states and municipalities under the NPDES stormwater regulatory approach. It provides two performance criteria that are closely related: (1) flood control and (2) peak discharge control. Some practitioners have concluded that on a watershed-wide scale, uniform detention strategies are a failure because they do not maintain base flows, do not necessarily provide water quality improvement, and in some case fail to fulfill their single explicit purpose of controlling floods (Ferguson, 1998).

A recent technology assessment for the major impact categories as summarized in Table 1-13 concluded that approaches based solely on peak discharge control are not adequate to address the range of impacts associated with urban runoff issues (Collins et al., 2001). The following is a summary of findings:

- While this approach does provide some degree of flood control in the upstream areas it can in some instances actually transfer or aggravate flooding conditions downstream.
- This approach not only fails to provide protection for stream channel stability, but may actually aggravate and accelerate stream channel degradation and impacts.
- The approach does not address groundwater recharge issues including lowering of water tables and maintenance of stream base flows.
- The approach does not address, but can actually aggravate, thermal impacts on receiving waters.
- This approach does not address or guarantee water quality management and pollutant removal, although both can be achieved if the BMPs are properly designed.
- This approach does not provide control for the degradation and loss of riparian habitat.
- This approach does not provide control for the degradation and loss of biological communities.

Peak discharge control strategies, in and of themselves, appear unable to meet the objectives of the Clean Water Act and other legislation. Their effectiveness is limited primarily to some flood control in the upstream areas.

2.5 Water Quality Control Strategies

Water quality control of urban runoff is still a relatively new and developing technology. The addition of water quality considerations in the design of BMPs has introduced a new dimension to the traditional hydrologic considerations for BMP design. Prior to the introduction of water quality considerations hydrologic design methods were focused on flood event hydrology with focus on storms typically ranging from the 2-yr (bankfull); to the 10-year (storm drainage conveyance storm) to the 100-yr (floodplain storm). Water quality considerations created a shift from flood events to a continuous long-term rainfall-runoff BMP design volume approach and the pollutant loads associated with these volumes. This new focus has given rise to concepts such as the rainfall frequency spectrum (Figure 2-1) and small storm hydrology.

Need to Address Small Storms Early efforts in stormwater management focused on flood events ranging from the 2-year to the 100-year design storm. Increasingly stormwater professionals have come to realize that small storms (e.g., < 1 inch rainfall) dominate watershed hydrologic parameters typically associated with water quality management issues and BMP design.

Large storms occur infrequently and are of primary concern for overbank flows and flooding of structures located in the floodplains of stream channels and in urban areas. Most rainfall events are much smaller than design or large storms used for urban drainage models. In any given area, most frequently recurrent rainfall events are small (less than 1 inch of daily rainfall). For example, 90% of the annual rainfall comes in storms smaller that 0.9 in./day in Cincinnati, OH (Roesner et al., 2001). For small rains, impervious areas contributed most of the runoff flows and pollutants (Pitt, 1987). The capture and treatment of these small storms would lead to improved water quality since the total pollutant load to receiving streams would be minimized. These small storms are responsible for most annual urban runoff and groundwater recharge.

Urban runoff models play an important role in evaluations for stormwater BMPs. Unfortunately, many commonly used models incorrectly estimate runoff flows and the washoff of particles from impervious surfaces during small rains. Typical washoff prediction procedures used in urban runoff models greatly over-predict particulate residue washoff from impervious surfaces, especially for large particles (Pitt, 1987).

Current design, however, typically still focuses on capturing large storms to minimize flooding and control drainage. These rainfall events typically range from 2 to 10 inches of daily rainfall and occur over a much longer return period range from 2 to 100-years. Although these storms may contain significant pollutant loads (Chang et al., 1990), their contribution to the annual average pollutant load is really quite small due to the infrequency of their occurrence. In addition, longer periods of recovery are available to receiving waters between larger storm events. These periods allow systems to flush themselves and allow the aquatic environment to recover.

Storms with a return frequency of six months to 2 years are the dominant storms that determine the size and shape of the receiving streams. These storms will remain critical for design of BMPs to protect stream channels from accelerated erosion and degradation. However, the use of small storm (those with a return frequency under six months) approaches should dominate design of BMPs for pollutant removals.

Small Storm Hydrology Two different approaches to small storm hydrology computations are pertinent. The first approach is based on the probabilistic approach developed by the US EPA (1986) in the publication, "Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality". This approach is well suited to the design of water quality control BMPs for larger drainage areas. The following are related to this computational procedure:

- Long-term rainfall characteristics
- Capture of stormwater runoff
- An approach for estimating stormwater quality capture volume
- Example of a water quality capture volume estimate

A second approach is based largely on the work of Pitt (1994) that is tailored for very small urban sites and is closely linked to the presence of impervious surfaces. This approach has been adopted by the State of Maryland (MDE, 2000) and may provide a simpler computational tool that is better suited for use by Phase II communities. The following are related to this approach:

- Small site hydrology approach
- The 90% rule regarding cumulative rainfall volume for water quality treatment
- Short-cut method for estimating the water quality volume for BMP design using small storms.
- Estimating peak discharges for the water quality storm.

To treat the bulk of the pollutant loads from stormwater runoff, many states and municipalities specify a treatment volume that is designed to capture the initial component of the stormwater runoff. In practice this is achieved by specifying a rainfall amount (such as the first ½-inch, 1-inch, or other rainfall depth over impervious areas) or the capture of a stormwater runoff volume that correlates to a design storm (such as the 6-month, 1-year, or 2-year frequency storm).

Design Storm vs Continuous Flow Simulation Design storms, primarily derived from IDF (e.g., intensity, duration, frequency) or NRCS type curves, have been the primary tools used to predict runoff rates. These are used with a wide variety of single storm models including HEC-HMS (US Army Corps of Engineers, 2001), SWMM (US EPA, 1971), Sedimot II (Wilson et al., 1982) and Sedimot II (Barfield, et al., 1996). The assumption made in the single storm models is that the return period of the peak discharge is the same as the return period of the design rainfall event and that watershed parameters are invariant with return period rainfall. Studies have shown that constant watershed parameters are not a good assumption. For example, Haan and Edwards (1988) evaluated predictions of peak discharge on six watersheds in Ohio, Nebraska, Arizona, and Oklahoma using the NRCS curve number approach. For each storm on the watershed, they calculated the parameter ***S***, the maximum potential abstraction from rainfall, for each storm event. Their results showed that:

- The value of ***S***, varied widely for each storm event on each watershed due to changing soil moisture and vegetative characteristics.
- When considering the joint variability of both ***S*** and rainfall, the return period discharge was always greater than that predicted assuming a constant ***S*** and varying rainfall. This is because the probability distributions for both precipitation and ***S*** are skewed.
- In general, considering the variability of ***S*** improved predictions for the rare events but increased the error for the lower return period events (probability less than 80 percent).

One advantage of using continuous simulation models is that they could capture some of the variability occurring with input parameters. Another advantage is that they could, assuming accurate algorithms and input data, give a good representation of lower frequency, less than one year, events.

The problem of matching single storm predictions based on rainfall with return period flow rates is easy to evaluate when considering runoff. The problem is amplified when considering pollutants such as sediment, toxics, nutrients, and pathogens. The standard assumption is that the pollutant loading in runoff from a design storm, such as the NRCS Type storms, will match observed return period pollutant loadings.

An advantage of using continuous simulation models with pollutant loadings, and particularily with BMPs, is that the inter-arrival time between storms can have a significant impact on trapping performance of the BMP. Driscoll *et al.* (1986) addressed this issue in a model of sedimentation in reservoirs and developed procedures for estimating performance under these conditions. This model has potential to be used to estimate dynamic and quiescent condition settling in reservoirs used as BMPs. The WEPP model (Lane *et al.*, 1989) also contains a reservoir model known as WEPPSIE (Lindley *et al.*, 1998a and b).

The advantages of using a continuous simulation model must be weighed against the problems with such an approach. Specifically, these include:

- Greatly increased data set requirement for the models. The models must not only predict hydrologic and water quality responses, they must also predict changes in vegetative cover resulting from annual growth and death cycles. In addition, the models must have good climatic simulators to simulate rainfall and other climatic variables. Since algorithms within models are only as good as their inputs, assuring that the models have good predictors of watershed and climatic variables is critical.
- Greatly increased complexity in setting up and executing the models, thus increasing the knowledge base requirement of the user. The validity of a model prediction is as much dependent on the skill of the user as it is on the reliability of

the model algorithms. If the complexity of the model is such that an advanced degree in hydrology and water quality is required for its proper execution, the average user is not likely to generate good BMP designs from its use. Likewise, reviewers are not as likely to be competent in interpreting permit applications. Therefore, the modeling technique must be selected with the skill of the average user, both in the design community as well as in the regulatory organizations.

The continuous simulation models are most appropriate for larger regional watersheds and may be necessary for predicting the effect of discharges from many BMPS on a watershed scale; therefore, their development should be encouraged. Continuous simulation models are better at predicting accumulation and washoff of pollutants during the inter-arrival time between storms, and can thus have a significant impact on the trapping performance of the BMP. Continuous simulation is needed for watershed based approaches to solve habitat and water quality issues in urban streams (Strecker, 2002). Continuous simulation offers possibilities for design and management that do not currently exist. However, the widespread adoption in design and permit review depends in part on the models becoming sufficiently user friendly and the input guidelines developed that the user community can execute the models with confidence and competence.

Greated Use of Extended Detention The extended detention concept was introduced to overcome the limitations of early detention pond strategies and provide more and better control of the smaller and more frequent storm events. Basically, extended detention refers to designing the outlet so that the smaller storms which pass through ponds are now detained for longer periods than they would otherwise be held. Thus, trapping of those particles could be enhanced. The extended detention approach can be designed to provide extended detention of 6 to 48 hours which provides longer holding times, increased removal for lower settling velocity particles and thus higher pollutant removal performance.

BMPs that encompass both peak discharge hydrology and small storm hydrology would optimally use a system that incorporates on-site treatment and storage of stormwater for the smaller storms while protecting downstream areas from floods. Regardless of the specific method used for modeling the peak discharge design volume, the ultimate pond design will typically be greater than necessary for the water quantity volume alone. However, the outlet control structures have typically been designed more for the flood control volume than the discharge of the more frequent storms. Redesigning the discharge from the outlet control structures may be the most critical design aspect to prevent future deleterious downstream water quality effects and this may be the most cost effective measure to retrofit in existing detention ponds and improve water quality improvement performance of BMPs on a watershed basis.

Roesner et al. (2001) believe the problem with peak discharge BMPs is not the BMPs themselves but the design guidance for BMP outlet flow control which does not take into account the geomorphologic character of the receiving stream. The uncontrolled section of the flow frequency curve causes stream reaches downstream from BMPs to continue to exhibit habitat degradation and reduced biological indices. Because the recommended design storm for sizing most BMPs are small, it is often possible to retrofit existing regional flood control detention basins with small, low-level outlets thus providing extended detention basins for treatment of these small storms (Roesner *et al.* 2001). Newman *et al.* (2000) found that optimized designs (based on SWMM) of extended detention ponds provided superior pollutant removals compared to the original designs. The optimized designs used smaller outlet orifices to maximize detention times of the smaller storms.

In addition to extended detention, the limitations of peak discharge strategies can be supplemented with volume control techniques using control measures that include vegetated swales, infiltration trenches, and bioretention cells in a treatment train approach to achieve the goals of legal mandates. Retrofitting dry basins with permanent wet pools has been proposed. By including these supplemental measures using either distributed and/or centralized controls, the peak discharge control strategies can be upgraded to address water quality control.

Recognizing the Dominant Role of Sedimentation and Filtration Mechanisms promoting the removal of stormwater pollutants involve physical, chemical, and biological processes. Owing to the intermittent nature of stormwater inflow, physical processes associated with detention for sedimentation and filtration (either through vegetated systems or through an infiltration medium) are the principle mechanisms by which stormwater contaminants are first intercepted. Subsequent chemical and biological processes can influence the transformation of these contaminants. Wong *et al.* (2001) state that various stormwater treatment components by which the contaminants are first intercepted and detained can be described using a unified model. Grass swales, wetlands, ponds, and infiltration systems are considered to be a single continuum of treatment based around flow attenuation and detention, and particle sedimentation and filtration. Hydraulic loading, vegetation density and aerial coverage, hydraulic efficiency and the characteristics of the target pollutants (e.g. particle size distribution and contaminant speciation) largely influence their performance. In this context, the infiltration systems are simply vertical filtration systems compared to the horizontal filtration systems of grass swales and wetlands, reliant on enhanced sedimentation and surface adhesion (promoted by biofilm growth) for removal of fine particles.

The validity of this unified conceptual approach to simulating the operation of stormwater treatment measures is demonstrated by empirical analysis of observed water quality (primarily TSS) improvements in swales, wetlands, ponds and infiltration basins and also by fitting observed water quality data from these treatment systems to a unified stormwater model (USTM) developed by Wong et al. The USTM provides a mechanism by which the urban catchment and waterway managers can predict and assess the performance of stormwater treatment measures.

Chapter Three
Types of BMPs and Factors Affecting their Selection

3.1 Introduction

This chapter provides a brief review and summary of the major BMP types and the factors that govern the selection of the appropriate BMP for a specific site. The most important criterion governing selection for water quality improvement is the effectiveness of the BMP to remove pollutants. Guidance is also provided on the other important criteria, including stormwater management goals, on-site vs regional considerations, watershed and terrain factors, physical suitability factors, community and environmental factors, and location and permitting factors.

3.2 Types of BMPs

BMPs for control of urban runoff can be generally grouped into two major categories that include: 1) source control BMPs, and 2) treatment BMPs (ASCE, 1998). Source control BMPs are practices that prevent pollution by reducing potential pollutants at their sources before they come into contact with stormwater, while treatment BMPs are methods to treat or remove pollutants from stormwater. Many treatment BMPs are considered to be structural in that they involve some sort of earthen or concrete structure. Table 3-1 provides a list of typical source control BMPs and Table 3-2 is a list of treatment BMPs.

Table 3-1 ASCE Source Control BMPs (ASCE 1998).

Major Categories	Source Control Practice	
A. Public Education	A1- Public Education and Outreach	
B. Planning and Management	B1- Better Site Planning B2 - Vegetative Controls B3 - Reduce Impervious Areas	B4- Disconnect Impervious Areas B5 - Green roofs
C. Materials Handling	C1 - Alternative Product Substitution	C2 - Housekeeping Practices
D. Street / Storm Drain Maintenance	D1 - Street Cleaning D2 - Catch Basin Cleaning D3 - Storm Drain Flushing D4 - Road & Bridge Maintenance	D5 - BMP maintenance D6 - Storm Channel & creek Maintenance
E. Spill Prevention & Cleanup	E1 - Above Ground Tank Spill Control	E2 - Vehicle spill Control
F. Illegal Dumping Controls	F1 - Storm Drain Stenciling F2 -Household Hazwaste Collection	F3 - Used Oil recycling F4 - Illegal Dumping Controls
G. Illicit Connection Control	G1 - Illicit Connection Prevention G2 - Illicit Connection - Detection & Removal	G3 - Leaking Sanitary Sewer Control
H. Stormwater Reuse	H1 - Landscape watering	H2 - Toilet Flushing

Table 3-2 Treatment BMPs (adapted from ASCE 1998).

Major Categories	Treatment BMPs	
Ponds	Wet (Retention) Pond Dry Detention / Extended Detention Basin	Infiltration Pond
Vegetative Biofilters	Grass Swales (Wet, Dry) Filter Strip / Buffer	Bioretention Cells
Constructed Wetlands	Constructed Wetlands	
Filters	Sand Filter Perimeter Filter	Media Filter Underground Filter
Technology Options and Others	Inlet Filters Multi-Chambered Treatment Train	CDS Chemical Treatment

As managers seek to reduce pollutant loadings in their watersheds to meet total maximum daily load (TMDL) reduction requirements, a combination of BMPs will likely apply. Depending on the stormwater management goals and objectives identified for a specific site or area, a combination of source controls, as well as the use or one or more treatment BMPs may need to be used to meet the design objectives, in what is often referred to as a treatment train approach. The distinction between source controls and treatment controls is very clear in some cases, but less so in others. Street sweeping for pollutant removal is one BMP that could be considered either source control or treatment control. The use of vegetation to treat disconnected impervious surfaces such as rooftops, driveways, parking lots and streets is another example of a BMP that could be considered source control or a treatment BMP. Some of the newer concepts for urban runoff management such as the better site planning techniques (CWP, 1998) and low impact development (LID) technology (EPA, 2000a,b) focus on the use of planning techniques and micro scale integrated landscape based practices to prevent or reduce the impacts of urban runoff at the very point where this impacts would be generated. These approaches tend to have very close overlap between preventive source control approaches and small scale treatment approaches that blur the distinction between these two types of BMPs.

This document is focused primarily at selected treatment BMPs. Two major groups are presented, ponds and vegetative biofilters, with an aim to give design criteria that will improve their pollutant removal capacity and therefore improve water quality.

Historically stormwater management technology has focused more on the treatment BMPs, particularly pond BMPs. However the current trend in BMP technology, spurred by our growing awareness of the range and complexity of issues associated with our overall goals of maintaining the ecological integrity of our receiving waters, as mandated by the CWA, is towards the use of integrated stormwater management approaches that include one or more source controls, as well as one or more treatment (i.e., treatment train) controls.

3.3 BMP Selection Criterion - Meeting Stormwater Management Goals

Different regions of the United States (and localities within these regions) have differing needs and issues that lead them to adopt stormwater management programs. This document does not attempt to define what an appropriate level of stormwater management is for any given area, or what design goals and objectives should be used. Rather it recognizes that different goals exist and provides guidance on how to address and select the BMPs that are appropriate for a given design objective. A series of tables, Tables 3-3 thru 3-6, summarize the available qualitative or quantitative data concerning the chemical, physical and biological impacts associated with each major BMP group (Clar, et al., 2001). The percentage removals are presented without hydraulic parameters or pollution loadings and therefore cannot be used in comparison or as guidelines for expected removals.

Table 3-3 Summary of Studies on Environmental Impacts for Pond and Wetland BMPs

BMP	Chemical Impacts	Physical Impacts	Habitat and Biological Impacts
Wet (Retention) Pond	Over 33 studies reporting on the effectiveness of wet ponds at reducing / removing TSS, TP, TN, OP, NO3, Metals, Bacteria (ASCE, 1999*; CWP, 2000)	Implementation of BMPs has been largely ineffective in controlling the physical impacts on the stream channel resulting from urbanization. Ponds usually do not provide groundwater recharge. Ponds can provide peak discharge control, but sometimes increase downstream flooding.	Structural storm water practices have either little or no ability to mitigate the adverse impacts of urban storm water runoff on the macro invertebrate community. Ponds pose a risk to cold water systems because of their potential for stream warming.
Dry / Extended Detention Pond	Over 24 studies reporting on the effectiveness of dry / extended detention basins at reducing / removing TSS, TP, TN, OP, NO3, Metals, Bacteria (ASCE, 1999*; CWP, 2000)		
Pond-Wetland System / Extended Detention Wetland / Shallow Marsh	Over 15 studies reporting on the effectiveness of pond/wetland system / extended detention wetland and shallow marsh at reducing/removing TSS, TP, TN, NO3, Metals, Bacteria (ASCE, 1999*; CWP, 2000)	Wetlands can be designed for flood control by providing flood storage above the level of permanent pool, but are subject to the same limitations as ponds. Wetlands are ineffective at protecting channels. Wetlands usually do not provide groundwater recharge.	Wetlands pose a risk to cold water systems because of their potential for stream warming.
Submerged Gravel Wetland	1 study reporting on the effectiveness of pond/wetland system at reducing / removing TSS, TP, TN, NO3, Metals, Bacteria (ASCE, 1999*; CWP, 2000)		

*www.bmpdatabase.org

Table 3-4 Summary of Studies on Environmental Impacts for Vegetative Biofilter BMPs

BMP	Chemical Impacts	Physical Impacts	Habitat & Biological
Bioretention	Davis (1997) reported on the effectiveness of bioretention at removing TP (81%), TN (43%), NH4 (79%), Metals (93-99%). Yu (1999) reported the following performance parameters; TSS (86%), TP (90%), COD (97%), Oil & Grease (67%)	Bioretention practices are being designed to provide water quality, flood control, channel protection, and ground water recharge (Clar, 2000). There is emerging evidence that bioretention can help make post development runoff equivalent to pre-development runoff.	Field data information not available
Grassed Swales	3 studies have reported on the effectiveness of grassed channels at removing TSS, TP, TN, NO3, Metals, and Bacteria 4 studies have reported on the effectiveness of dry swales at removing TSS, TP, TN, NO3, and Metals 2 studies have reported on the effectiveness of wet swales at removing TSS, TP, TN, NO3, and Metals 7 studies have reported on the effectiveness of drainage channels at removing TSS, TP, TN, NO3, and Metals (ASCE, 1999; CWP, 2000)	Grassed swales can be used to reduce peak discharges for small storm events, and provide groundwater recharge (MDE, 2000).	Field data information not available
Grassed Filter Strips	1 study has reported on the effectiveness of 75 ft and 150 ft grassed filters strips at removing TSS (54%, 84%), Nitrate, Nitrite (-27%, 20%), TP (-25%, 40%), Lead (-16%, 50%), and Zinc (47%, 55%) (ASCE, 1999; CWP, 2000)	Grassed filter strips do not have the capacity to detain large storm events, but can be designed with a bypass system that routes these flows around the toe of the slope. Grassed filter strips can provide a small amount of groundwater recharge.	Field data information not available

Table 3-5 Summary of Studies on Environmental Impacts for Infiltration BMPs

BMP*	Chemical Impacts	Physical Impacts	Habitat & Biological
Infiltration Basin	Very little information available, one study reported that infiltration basin sized to treat runoff form 1-inch storm is effective at removing TSS (75%), P (60 to 70%), N (55 to 60%), Metals (85 to 90%), Bacteria (90%) (Schueler 1987; ASCE, 1999; CWP, 2000)	Full infiltration basins will control post-development peak discharge rates at or below pre-development levels (given that the basin has sufficient infiltration capacity). Basins are effective at recharging groundwater. Infiltration basins effectively reduce the increase in post-development runoff volume produced from small and moderate sized storms.	No information available
Infiltration Trench	Infiltration trench sized to treat runoff form 1-inch storm is effective at removing TSS (75%), P (60 to 70%), N (55 to 60%), Metals (85 to 90%), and Bacteria (90%) (Schueler; 1987; ASCE, 1999; CWP, 2000)	Effective at recharging groundwater	No information available
Pervious and Modular Pavement	A study in Prince William VA (Schueler, 1987) recorded pollutant removal effectiveness for TSS (82%), TP (65%), TN (80%) A study in Rockville, MD (Schueler, 1987) recorded pollutant removal effectiveness for TSS (95%), TP (65%), TN (85%), COD (82%), Metals (98 to 99%) (ASCE, 1999; CWP, 2000)	Effective at recharging groundwater (approximately 70 to 80% annual rainfall) (Gburek and Urban 1980)	No information available

* Under certain circumstances (e.g. near-surface water tables) there may be concerns about groundwater pollution.

Table 3-6 Summary of Studies on Environmental Impacts for Filter BMPs

<table>
<tr><th>BMP</th><th>Chemical Impacts</th><th>Physical Impacts</th><th>Habitat & Biological</th></tr>
<tr><td>Sand Filters</td><td>1 study reporting on the effectiveness of sand filters at removing TSS (87%), TN (44%), $N0_3$ (-13%), Metals (34-80%), Bacteria (55%)</td><td rowspan="7">Some groundwater recharge is possible with the exciter design, however, other sand filter designs cannot provide recharge. These systems are not expected to have significant role in preventing channel degradation or providing peak discharge control.</td><td rowspan="7">No field data information available. Some systems may help prevent thermal impacts.
These systems are not expected to have significant role in preventing habitat and biological impairment resulting from channel degradation.</td></tr>
<tr><td>Peat/Sand Filters</td><td>1 study reporting on the effectiveness of peat sand filters at removing TSS (66%), TN (47%), $N0_3$ (22%), Metals (26-75%)</td></tr>
<tr><td>Compost Filter System</td><td>2 studies reporting on the effectiveness of compost filter systems at removing TSS, Nitrate, and Metals</td></tr>
<tr><td>Multi-chambered Treatment Train</td><td>3 studies reporting on the effectiveness of multi-chamber treatment trains at removing TSS, and Metals</td></tr>
<tr><td>Perimeter Sand Filter</td><td>3 studies reporting on the effectiveness of perimeter sand filter at removing TSS, TP, TN NO_3, and Metals</td></tr>
<tr><td>Surface Sand Filter</td><td>6 studies reporting on the effectiveness of surface sand filter at removing TSS, TP, TN NO_3, Bacteria, and Metals</td></tr>
<tr><td>Vertical Sand Filter</td><td>2 studies reporting on the effectiveness of vertical sand filter at removing TSS, TP, TN NO_3, and Metals</td></tr>
</table>

3.4 BMP Selection Criterion - On-Site vs Regional Controls

The decision of whether to use an on-site or a regional approach can have a strong influence on the selection of the BMP type. Some treatment BMPs , such as ponds and wetlands, can be used either as stand-alone, on-site treatment controls, or as part of regional controls for stormwater management. Others, including swales, filters strips, infiltration and percolation, media filters, oil and water separators, are designed only for on-site use. Within the on-site use group there is a new subset of emerging practices referred to as micro-scale multi-functional management practices, known as LID, that are intended to be integrated into a site's landscape. Many of the onsite practices such as the swale, and filter strips fall within this group, as well as some new biofilters practices such as the bioretention cell.

On-Site Controls Three schools of thought have emerged in stormwater management technology, each of which reflects one of the three application identified above. The most widespread approach being used nationwide is the use of on-site controls where structural treatment practices on individual sites are designed to provide peak discharge control. While this approach has many flaws, it is often selected because of the ease of application and implementation. For many jurisdictions, the use of on-site controls is perceived to be the only practical institutional and political alternative. Every site that meets the minimum area requirements is required to provide on-site controls. Concerns expressed by public works practitioners include (ASCE, 1998):

- Because large numbers of on-site controls, sometimes exceeding several hundred or even thousand, can eventually be installed within an urban watershed, it becomes difficult to reliably quantify their cumulative effects on receiving waters.
- Large numbers of on-site controls complicate the quality assurance during design and construction because they are typically designed by a variety of individuals and are constructed by a variety of different contractors under varying degrees of quality control.
- Onsite BMPs may be maintained and operated in a variety of ways impossible to anticipate or control.
- Unless these on-site controls are coordinated at a watershed scale, which typically, they are not, these controls not only fail to provide downstream protection for peak discharge, but in many instances will accelerate the rate of channel degradation.

Regional Controls The second school of thought on stormwater management takes the position that using regional controls serving 80 to 600 ac offers a more rational approach over the use of on-site controls (ASCE, 1998). The proponents of the regional approach site the following advantages:

- Regional controls eliminate the uncertainty of large numbers of on-site controls
- Regional controls can use multistage outlets to “throttle “ and release small runoff events in 12 to 24 hours and empty the total water quality capture volume in 24 to 48 hours.
- Regional controls are perceived to be more cost effective because fewer controls are less expensive to build and maintain than a large number of on-site controls (Wiegand, *et al.*, 1986).
- By serving larger drainage areas the outlet works are larger and easier to design, build, operate, and maintain.
- Regional controls are generally under the control of a public agency and therefore more likely to receive ongoing maintenance.

- Regional controls can provide treatment for existing and new developments and typically will capture all runoff from public streets, which is often not addressed by on-site controls.
- Because regional controls cover large land areas, this allows other compatible uses such as recreation, wildlife habitat, or aesthetic open space to occur within their boundaries.

The regional approach to stormwater management is currently being successfully utilized by a number of metropolitan areas such as the Denver Metropolitan area. Some other areas of the U.S. such as Prince George's County (PGC) in Maryland, however, experimented with regional controls and found them to be unacceptable. PGC was requested by the permitting agencies to conduct a cumulative impact assessment of its regional facilities program, as a condition for continued issuance of permits. During the course of the cumulative impact assessment, PGC identified so many fatal flaws associated with its regional facilities program that it decided to abandon the regional approach and identify viable alternatives. Some of the fatal flaws associated with the regional approach identified by PGC included:

- The regional controls, which are typically a peak discharge control strategy, failed to provide downstream protection of stream channels
- The regional facilities typically failed to provide significant flood relief for downstream properties, and where such relief was provided, the downstream control were very limited. (PGC ultimately adopted a floodplain management program that includes early flood warning, flood insurance, flood proofing, and the purchase and removal of flood prone structures)
- Maryland receives over 40 inches of annual rainfall. Regional facilities, did not solve the targeted problems but also introduced additional environmental problems that are identified below.
- Regional facilities created fish passage blockages that were unacceptable to the permitting agencies
- Regional facilities tend to be located in perennial streams and their construction tends to create wetland impacts which were unacceptable to the permitting agencies.
- The regional facilities resulted in increased stream temperatures which were unacceptable in cold fisheries streams.
- By relying on the regional facilities the feeder stream to these facilities were left unprotected, and often experienced severe accelerated erosion that delivered large volumes of sediment to the regional facilities, which greatly accelerated the maintenance program.
- Disposal of pond and lake sediments in urban settings became extremely expensive.

Other problems with the implementation of regional approaches have been identified (ASCE, 1998):

- The regional facility approach requires advanced planning and up-front financing
- Lack of financing early in the watershed's land development process, before sufficient developer contributions are available, can preclude their timely installation.

Low Impact Development (LID) Technology The third school of thought relating to stormwater management technology, unlike the two approaches above that have been in use for over thirty years, is still in its early development and largely unknown to most local jurisdictions. This approach which is more commonly known as LID technology, was pioneered by Prince George's County, Maryland, after having applied both on-site and regional approaches. The proponents of this approach cite the following benefits of the LID approach (P.G. Co., 1997; EPA 2000 a,b; Coffman, *et al*, 1998; Clar 2000):

- Use of these techniques helps to reduce off-site runoff and ensure adequate groundwater recharge.
- Since every aspect of site development affects the hydrologic response of the site, LID control techniques focus mainly on site hydrology. Hydrologic functions such as infiltration, frequency and volume of discharges, and groundwater recharge can be maintained with the use of reduced impervious surfaces, functional grading, open channel sections, disconnection of hydrologic flowpaths, and the use of bioretention/filtration landscape areas.
- LID also incorporates multi-functional site design elements into the stormwater management plan. Such alternative stormwater management practices as on-lot micro-storage, functional landscaping, open drainage swales, reduced imperviousness, flatter grades, increased runoff travel time, and depression storage can be integrated into a multi functional site design.
- Specific LID controls called Integrated Management Practices (IMPs) can reduce runoff by integrating stormwater controls throughout the site in many small, discrete units.
- IMPs are distributed in a small portion of each lot, near the source of impacts, virtually eliminating the need for a centralized BMP facility such as a stormwater management pond.
- LID designs can also significantly reduce development costs through smart site design by:
  < Reducing impervious surfaces (roadways), curb, and gutters
  < Decreasing the use of storm drain piping, inlet structures, and
  < Eliminating or decreasing the size of large stormwater ponds.
- In some instances, greater lot yield can be obtained using LID techniques, increasing returns to developers (Clar, 2000)

- Reducing site development infrastructure can also reduce associated project bonding and maintenance costs
- LID techniques such as bioretention cells can be used as a water quality control technique for infill development (Clar, 2000)
- LID techniques can also be used as a water quality retrofit for existing urban areas (Clar, 2000)
- The LID approach can be used as a volume control method to provide downstream peak discharge protection for major storm events (Clar, 2000).
- The LID approach can be used as an improved approach to protect water supply reservoirs, as demonstrated in the High Point, NC case study (Tetra Tech, 2000; Clar, 2001).
- The LID approach can be used to address total impervious area (TIA) limitations (Clar, 2000).

Some practitioners have found LIDs site oriented micro-scale control approach to be controversial, as it sometimes conflicts with building codes, challenges conventional stormwater management paradigms and is perceived by some to accommodate urban sprawl. A recent critique of the LID approach questioned the use of the term “low impact”, and also critiqued the adequacy of the hydrological design procedures utilized to substantiate the effectiveness of the techniques (Strecker, 2001).

Integration of Approaches Clearly the discussion above reveals that there is no clear consensus on which school of thought is the right approach. It appears that perhaps no single approach is adequate for all cases, and that the one size fits all approach is not the way to proceed. The appropriate approach for a semi-arid mountain region such as Colorado or Utah, may be considerably different from the approach selected in a humid climates such as are found in the Mid Atlantic or Pacific Northwest. In addition, within a specific state or region, the appropriate approach for an existing degraded urban area may be considerably different from the approach selected to protect a high quality rural area. Ultimately each region or municipality will need to identify its watershed and water resources protection goals and objectives and select the approach or combination of approaches that are appropriate to meet these goals.

3.5 BMP Selection Criterion - Watershed Factors

The design of urban BMPs can be strongly influenced by the nature of the downstream water body that will be receiving the stormwater discharge. Consequently, designers should determine the Use Designation of the watershed in which their project is located prior to design.

In some cases, higher pollutant removal or environmental performance may be needed to fully protect aquatic resources and/or human health and safety within a particular watershed or receiving water. Therefore, a shorter list of BMPs may need to be considered for selection within these watersheds or zones. The areas of concern are summarized in Table 3-7 and include: cold-water streams, sensitive streams, aquifer protection, reservoir protection, shellfishing, and recreational contact.

Table 3-7 Treatment BMPs vs Watershed Factors (modified from MDE, 2000**)**

BMPs	**Watershed Factors**				
	Cold Water	**Sensitive Stream**	**Aquifer Protection**	**Reservoir Protection**	**Recreational Contact**
Ponds and Wetlands	Restricted due to thermal impacts Offline design recommended	May be limited or require additional volume for channel erosion impacts	May require liner if A soils are present and water table high Pretreat hot spots	May be limited due to channel erosion May require additional volume control	May require use of permanent pools to increase bacteria removal
Infiltration	Yes, if site has suitable soils	Yes, if site has suitable soils	Requires safe distance from wells & water table Pretreat hot spots	Requires safe distance from bedrock & water table	Yes, but needs safe distance to water table
Vegetative Biofilters	OK	OK, if channel protection volume is met	OK	OK	OK, but wet swale has poor bacteria removal
Filters (Sand, Perimeter, Underground)	OK for small volumes	OK for WQ, no channel protection	OK for WQ, no recharge	OK for WQ	OK, moderate to high bacteria removal

Coldwater Streams Cold and cool water streams have habitat qualities capable of supporting trout and other sensitive aquatic organisms. Therefore, the design objective for these streams is to maintain habitat quality by preventing stream warming, maintaining natural recharge, preventing bank and channel erosion, and preserving the natural riparian corridor. Techniques for accomplishing these objectives may include:

- Minimizing the creation of impervious surfaces,
- Minimizing surface areas of permanent pools,
- Preserving existing forested areas
- Bypassing existing baseflow and/or springflow, or
- Providing shade-producing landscaping

Some BMPs, especially those with permanent pools with large surface areas can have adverse downstream impacts on cold water streams and their use is highly restricted.

Sensitive Streams Sensitive streams are defined as streams with a watershed impervious cover of less than 15%. These streams may also possess high quality cool water or warm water aquatic resources. The design objectives are to maintain habitat quality through the same techniques used for cold water streams, with the exception that stream warming is not as severe of a design constraint. These streams may also be specially designated by local authorities.

Aquifer Protection Areas that recharge existing public water supply wells present a unique management challenge. The key design constraint is to prevent possible groundwater contamination by preventing infiltration of hotspot runoff. At the same time, recharge of unpolluted stormwater is needed to maintain flow in streams and wells during dry weather. These issues are particularly important in areas with Karst geology.

Reservoir Protection Watersheds that deliver surface runoff to a public water supply reservoir or impoundment are of special concern. Depending on the treatment available at the water intake, it may be necessary to achieve a greater level of pollutant removal for the pollutants of concern such as bacteria pathogens, nutrients, sediment or metals. One particular management concern for reservoirs is ensuring that stormwater hot spots are adequately treated so that they do not contaminate drinking water.

Shellfish/Beach Protection Watersheds that drain to specific shellfish harvesting areas or public swimming beaches require a higher level of BMP treatment to prevent closings caused by bacterial contamination from stormwater runoff. In these watersheds, BMPs are explicitly designed to maximize bacteria removal.

Other Criteria Designers should consult with the appropriate review authority to determine if their development project is subject to additional stormwater BMP criteria as a result of an adopted local watershed plan or protection zone. Table 3-7 provides a summary assessment of the suitability of the treatment practices with respect to the watershed factors discussed above.

3.6 BMP Selection Criterion - Terrain Factors

Three key terrain factors to consider are low-relief, karst and mountainous terrain. Special geotechnical testing requirements may be needed in karst areas. Table 3-8 summarizes the key issues that need to be considered for each BMP type with respect to the three terrain factors.

Table 3-8 BMP Selection - Terrain Factors (Modified from MDE, 2000)

BMPs	Terrain Factor		
	Low Relief	**Karst**	**Mountainous**
Ponds	May be limited by depth to water table	Geotechnical testing reqd May require liner Ponding depth may be limited	Embankment heights restricted
Wetlands	OK		
Infiltration	Minimum distance to water table of 2 feet	May be prohibited by local authority	Max slope 15%
Vegetative Biofilter	OK	OK	Swales may be limited by steep slopes
Filter	Some designs limited by head requirements	Require liner	OK

The type of structure used can be impacted by terrain factors. For example, in very flat areas, it is difficult to construct a basin with a dam as would be possible in steeper sloped watersheds. In the case of the flatter areas, it may be necessary to construct the basin by excavation. Also, the type of outlet can be controlled by the terrain with drop inlets being useful in steeper slopes but weir and open channel outlets favored for flat terrain.

3.7 BMP Selection Criterion - Physical Suitability Factors

The watershed and terrain factors should enable the BMP designer to narrow the BMP list to a manageable number and proceed to the consideration of the physical suitability factors that characterize the physical conditions at a site. Table 3-9 cross-references testing protocols needed to confirm physical conditions at the site. The six primary physical suitability factors include: soils, water table, drainage area, slope, head, and urban conditions.

Soils The key evaluation factors are based on an initial investigation of the USDA (1986) hydrologic soils groups (HSGs) at the site. The HSG is defined by 4 groups: A - sand, loamy sand, or sandy loam; B - silt loam or loam; C - sandy clay loam; and, D - clay loam, silty clay loam, sandy clay, silty clay or clay. More detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Table 3-9 BMP Selection - Physical Suitability Factors (modified from MDE, 2000)

BMP	**Soils**	**Water Table**	**Drainage Area (acre)**	**Slope**	**Head (ft)**	**Urban**
Ponds **- Wet** **- Dry**	"A" soils may require liner "B" soils may require testing	$4 ft[2] if Hotspot or Aquifer	25 minimum[3] for wet pond	None	6 - 8	Not practical; Requires too much area to be functional
Wetlands	"A" soils may require liner	$4 ft[2] if Hotspot or Aquifer	25 minimum[3] for wet pond	None	3 - 5	
Infiltration **- Trench** **- Basin**	0.52 in./hr minimum	$4 ft ($2 ft for flatter areas)	 5 maximum 10 maximum	15% maximum	 $1 $3	 Yes Not practical
Biofilters **- Bioretention** **- Swales** **- Filter strip**	Uses made soil	$2 ft	 2 maximum 5 maximum N/A	 None #4% #10%	 $5 $4 None	 OK Not practical Not practical
Filters **- Sand** **- Perimeter** **- Underground**	OK	$2 ft.	 10 maximum 2 maximum 2 maximum	None	 $5 2 - 3 5 - 7	OK

Notes: OK = not restricted
1 = Should be based on the erosion resistance of soils; some circumstance may require structural reinforcement.
2 = Four feet separation distance to the seasonally high water table elevation
3 = Unless adequate water balance and anti-clogging device installed

Water Table This column indicates the minimum depth to the seasonally high water table from the bottom or floor of a BMP.

Drainage Area This column indicates the recommended minimum or maximum drainage area that is considered suitable for the practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is permitted or more than one practice can be installed. The minimum drainage areas indicated for ponds and wetlands to maintain a permanent pool are flexible depending on water availability (baseflow or groundwater).

Slope Restriction This column evaluates the effect of slope on the practice. Specifically, the slope restrictions refer to how flat the area where the practice may be.

Head This column provides an estimate of the elevation difference needed at a site (from the inflow to the outflow) to allow for gravity operation within the practice.

Urban Sites This column identifies BMPs that work well in the downtown urban environment, where space is limited and original soils have been disturbed. These BMPs are frequently used at redevelopment sites.

3.8 BMP Selection Criterion - Community and Environmental Factors

Another group of factors that should be considered by the BMP designer includes the community and environmental factors. This group of factors includes the following four factors: ease of maintenance, community acceptance, construction costs, and habitat quality. Table 3-10 employs a comparative index approach indicating whether the BMP has a high or low benefit.

Maintenance Requirements This column assesses the relative maintenance effort needed for a BMP in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging) and reported failure rates. All BMPs require routine inspection and maintenance.

Community Acceptance This column assesses community acceptance as measured by three factors: market and preference surveys, reported nuisance problems, and visual aesthetics. A low rank can often be improved by a better landscaping plan.

Construction Cost The BMPs are ranked according to their relative construction cost per impervious acre treated as determined from cost surveys and local experience.

Habitat Quality BMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features and vegetative cover of the BMP and its buffer.

Other Factors This column indicates other considerations in BMP selection.

Table 3-10 BMP Selection - Community and Environmental Factors (modified from MDE, 2000)

BMP	Maintenance Requirements	Community Acceptance	Cost	Habitat Quality*	Other Factors
Ponds - Dry - Wet	 Easy Medium	 Medium High	 Low High	 Low High	Trash and debris can be a problem
Wetlands	Medium	Medium	Medium	High	Limited depth
Infiltration - Trench - Basin	 High Medium	 High Low	 Medium Medium	 Low Low	 Avoid large stone Frequent pooling
Biofilters	Varies	High	Medium	Medium	Landscaping
Filters	High	High	High	Low	Out of sight Traffic bearing Filter media

* Habitat quality refers to ability to provide habitat quality in the BMP facility

3.9 BMP Selection Criterion - Location and Permitting Factors

The checklist in Table 3-11 provides a condensed summary of current BMP restrictions as they relate to common site features that may be regulated under local, State or federal law. These restrictions fall into one of three general categories:

- Locating a BMP within an area that is expressly prohibited by law.
- Locating a BMP within an area that is strongly discouraged and is only allowed on
  a case by case basis. Local, State and/or federal permits shall be obtained and the applicant will need to supply additional documentation to justify locating the BMP within the regulated area.
- BMPs must be setback a fixed distance from the site feature.

This checklist is only intended as a general guide to location and permitting requirements as they relate to siting stormwater BMPs. Consultation with the appropriate regulatory agency is the best strategy.

Table 3-11 Permitting Checklist (Modified from MDE, 2000)

Feature	Location and Permitting Guidance
Jurisdictional Wetland	• Wetlands should be delineated prior to siting stormwater BMPs • Use of wetlands for stormwater treatment strictly discouraged and requires federal permit • BMPs require 25 ft setback from wetlands • Buffers can be used as nonstructural filter strip • Stormwater must be treated prior to discharge into a wetland
Stream Channels	• Stream channels should be delineated prior to design • Instream ponds may require review and permit. • Instream ponds may be restricted or prohibited in cold water streams • May need to implement measures that reduce downstream warming.
100 Year Floodplains	• Grading and fill for BMP construction is strongly discouraged within the ultimate 100 year floodplain, as delineated by FEMA flood insurance rate, FEMA flood boundary and floodway, or local floodplain maps. • Floodplain fill cannot raise floodplain water surface elevation more than a tenth of a foot.
Stream Buffer	• Consult local authority for stormwater policy. • BMPs are strongly discouraged in the stream-side zone (within 25 feet of streambank). • Consider how outfall channel will cross buffer to reach stream. • BMPs can be located within the outer portion of a buffer.
Forest Conservation	• Check with local regulatory agency for applicable forest conservation requirements • BMPs are strongly discouraged within Priority 1 Forest Retention Areas. • BMPs must be setback at least 25 feet from the critical root zone of specimen trees • Designers should consider the effect of more frequent inundation on existing forest stands. • BMP buffers are acceptable as reforestation sites if protected by conservation agreement
Critical Areas	• Check with local regulatory agency for applicable critical areas requirements • BMPs w/in the Critical Area shoreline buffer may be prohibited unless a variance is obtained from the local review authority. • BMPs are acceptable within mapped buffer exemption areas.
Utilities	• Note the location of proposed utilities to serve development. • BMPs are discouraged within utility easements or rights of way (public or private).
Roads	• Consult local DOT or DPW for any setback requirement from local roads. • Obtain approval for any discharges to local or State-owned conveyance channel.
Structures	• Consult local review authority for BMP setbacks from structures.
Septic Drain Fields	• Consult local health authority. • Recommended setback is a minimum of 50 feet from drain field edge.
Water Wells	• 100 foot setback for stormwater infiltration. • 50 foot setback for all other BMPs. • Water appropriation permit needed if well water used for water supply to a BMP.
Sinkholes	• Infiltration or pooling of stormwater near sinkholes is prohibited. • Geotechnical testing may be required within karst areas

3.10 Federal Regulations That Impact Stormwater BMP Design

The design of stormwater management BMPs is mandated and regulated by regulatory requirements at several levels including; federal, state, regional and/or local. This section provides a brief review of the regulatory requirements that drive the design of these BMPs.

At the federal level, the requirements of the following agencies are summarized:

- U.S. Environmental Protection Agency (EPA)
- The National Oceanographic and Atmospheric Administration (NOAA) of the Department of Commerce
- The U.S. Fish and Wildlife Service (USFWS)

In addition a recent compilation of the stormwater management requirements of state, regional and local government agencies is summarized.

Clean Water Act Originally, this act was entitled the Federal Water Pollution Control Act of 1948 (FWPCA) which prescribed a regulatory system consisting mainly of State-developed ambient water quality standards applicable to interstate or navigable waters. In 1972, FWPCA amendments established a system of standards, permits and enforcement aimed at "goals" of "fishable and swimmable waters by 1983" and "total elimination of pollutant discharges into navigable waters by 1985." (33 U.S.C. § 1251 (a) (2)). Further amendments were passed in 1977, when the Act was officially denominated The Clean Water Act (CWA). Today, the CWA is the nation's primary mechanism for protecting and improving water quality. The broad purpose of the Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters," (33 U.S.C. § 1251 (a)), and its emphasis is to declare unlawful the unregulated discharge of pollutants into all waters of the United States.

The strength of the CWA lies in its comprehensive, nationwide approach to water quality protection which requires Federal, State, and local governments to act cooperatively for the achievement of common goals. The Act makes the States and the EPA jointly responsible for identifying and regulating both point and nonpoint sources (NPS) of pollution. Point sources are controlled by a permit-based system, while nonpoint sources are approached with a management strategy. The Act's framework thus allows for both environmental quality (water quality standards) and technology-based (treatment processes and Best Management Practices) approaches to water pollution control. Each State is required to develop and adopt water quality standards which enumerate the designated uses of each water body as well as specific criteria deemed necessary to protect or achieve those designated uses. The CWA requires States to develop and implement water quality standards in accordance with EPA regulations and guidance.

Under current EPA regulations, water quality management planning is focused on priority water quality issues and geographic areas. This process requires the development of Total Maximum Daily Loads (TMDLs), which set the amount of pollution that may be discharged while still complying with water quality standards (WQS). These allocations are implemented through the issuance of permits for point sources and the use of BMPs for nonpoint sources (NPS). In addition, State water quality programs are required to integrate three components (1) a designation of uses for all State waters, (2) criteria to meet those uses, and (3) an antidegradation policy for waters that meet or exceed criteria for existing uses (40 CFR § 131.10- 131.12). State water quality management plans are also required to identify priority point and nonpoint problems, consider alternative solutions, and recommend control measures. In order to comply with the CW A, State water quality standards must, theoretically, include indicators of the health of ecological habitats and the level of biological diversity, and ambient water quality standards were to be supplemented by discharge standards in the form of effluent limitations applicable to all point sources.

The Act also specifically provides that State water quality criteria must include both numeric standards for quantifiable chemical properties and "narrative criteria or criteria based upon biomonitoring." (33 U.S.C. §1313(c)(2)(a)). As defined in the Act, the term "biological monitoring" means: the determination of the effects on aquatic life, including accumulation of pollutants in tissue, in receiving waters due to the discharge of pollutants by techniques and procedures, including sampling of organisms representative of appropriate levels of the food chain appropriate to the volume and the physical, chemical, and biological characteristics of the effluent, and at appropriate frequencies and locations (33 U.S.C. § 1362).

CWA amendments, EPA regulations, and State water quality programs addressing point and nonpoint sources have continued to evolve over the years as increased knowledge is accumulated on the impacts of urban development. Stormwater runoff from increased impervious surfaces in urban areas has emerged as a significant threat to water quality. Several sections of the CWA apply to urban runoff, both as a point and nonpoint source of pollution, as well as impacts of any activities which may result in the disturbance of natural wetlands, regulated by section 404 of the Act. The following paragraphs describe these sections, with emphasis on their relevance to stormwater runoff and land development activities, both during the construction phase and the post construction phase..

Section 304(m) of the CWA, added by the Water Quality Act of 1987, requires EPA to establish schedules for (i) reviewing and revising existing effluent limitations guidelines and standards and (ii) promulgating new effluent guidelines. On January 2, 1990, EPA published an Effluent Guidelines Plan (55 FR 80), in which schedules were established for developing new and revised effluent guidelines for several industry categories. Natural Resources Defense Council, Inc., challenged the Effluent Guidelines Plan in a suit filed in the U.S. District Court of the District of Columbia (NRDC et al. v. Browner, Civ. No. 89-2980). The Court entered a consent decree (the “304(m) Decree”), which established schedules for, among other things, EPA's proposal and promulgation of effluent guidelines for a number of point source categories. The Effluent Guidelines Plan was published in the *Federal Register* on September 4, 1998 (63 FR 47285).

The most recent update to this plan occurred in April 1999, when EPA announced that it was preparing to develop effluent limitations guidelines for construction and development. EPA is proposing regulatory options to address storm water discharges from construction sites under the authority of Sections 301, 304, 306, 307, 308, and 501 of the Clean Water Act (CWA) (the Federal Water Pollution Control Act), 33 United States Code (U.S.C.) 1311, 1314, 1316, 1317, 1318, and 1361. The public may submit comments on the proposal through October 22, 2002. Effluent limitations guidelines may be finalized sometime thereafter; refer to http://www.epa.gov/OST/guide/construction for updates.

NPDES Phase I and Phase II Stormwater Rules The National Pollutant Discharge Elimination System (NPDES) is a permit system established under the CWA to enforce effluent limitations. Operators of construction activities, including clearing, grading and excavation are required to apply for permit coverage under the NPDES Phase I and II storm water rules. Under the Phase I rule (promulgated in 1990), construction sites of 5 or more acres must be covered by either a general or an individual permit. General permits covering the Phase I sites have been issued by EPA regional offices and state water quality agencies. Permittees are required to develop storm water pollution prevention plans that include descriptions of BMPs employed, although actual BMP selection and design are at the discretion of permittees (in conformance with applicable state or local requirements). There exists considerable variability throughout the states and localities with respect to these requirements which are summarized below.

Construction sites between 1 and 5 acres in size are subject to the NPDES Phase II storm water rule (promulgated in 1999). The construction activities covered under Phase II are termed small construction activities and exclude routine maintenance that is performed to maintain the original line and grade, hydraulic capacity, or original purpose of the facility. Under the Phase II program, NPDES permit requirements for construction activities are similar to the Phase I requirements because they are covered under similar general permits.

Water Quality Certifications (Section 401) The purpose of section 401 of the CWA is to ensure that federally permitted activities comply with the Act, State water quality laws and any other appropriate State laws. This is accomplished through a State certification process. Any applicant for a Federal permit for any activity that could result in a discharge of a pollutant to a State's waters is required to obtain a certification from the State in which the activity is to occur (EPA, Region 2, 1993). In essence, the State certifies that the materials or pollutants discharged comply with the effluent limitation, water quality standards, and any other applicable conditions of State law. Examples of Federal permits and licenses requiring State certification include: NPDES permits, section 404 permits, permits for activities regulated by the Rivers and Harbors

Act, and hydroelectric discharge-related activities (Doppelt, et a1., 1993). If the State denies the certification, the Federal permitting agency must deny the permit application. If the State imposes conditions on a certification, the conditions become part of the Federal permit (EPA, Region 2, 1993). A certification obtained for construction activities must also pertain to the subsequent operation of the structure (EPA, Region 2, 1993).

Certification processes differ from state to state, with some states participating early enough in a project's development to have an impact on determining alternatives and mitigation processes (Doppelt, *et al.*, 1993). Typically, the process begins when the State receives the permit information from the Federal agency receiving the request from the applicant. The State regulatory agency designated with certification authority notifies the Federal permitting authority of its decisions concerning certification for the proposed activity. States must act to grant or deny certification within a reasonable time (not to exceed one year) after a request is received, or certification authority will be deemed to have been waived (Doppelt, *et al.*, 1993).

Pollution Prevention Act of 1990 The Pollution Prevention Act of 1990 (PPA) (42 U.S.C. 13101 et seq., P. L. 101-508, November 5, 1990) "declares it to be national policy of the United States that pollution should be prevented or reduced whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible; pollution that cannot be recycled should be treated in an environmentally safe manner whenever feasible; and disposal or release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner" (Section 6602; 42 U.S.C. 13101 (b)). In short, preventing pollution before it is created is preferable to trying to manage, treat, or dispose of it after it is created. The Pollution Prevention Act directs EPA to, among other things, "review regulations of the Agency prior and subsequent to their proposal to determine their effect on source reduction" (Section 6604; 42 U.S.C. 13103(b)(2)).

This regulation has not yet been widely or systematically applied to stormwater management technology. Situations where it has been applied include the use of source control measures to reduce or prevent the generation of pollutants. A recent innovation in stormwater management technology, the low impact development (LID)approach does address this regulation through its stated goal of mimicking the pre-development hydrology of sites in order to preclude or reduce the environmental impacts traditionally associated with these hydrologic changes and the use of end-of-pipe approaches for stormwater management control.

Coastal Zone Management Act (CZMA) The Coastal Zone Management Act of 1972 (CZMA) was passed by Congress in order to "preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations." (16 U.S.C. §1452) The Act established a program to encourage States and territories to develop comprehensive programs to protect and manage coastal resources, including the Great Lakes (Terrene Institute, 1994). Much of the Act is geared toward managing and steering development of coastal energy resources. To encourage States to develop coastal zone management programs, Congress incorporated several major incentives in the CZMA. For example, the Act provides Federal grants to States for the development and administration of coastal management programs. The Act also provides a mechanism by which a State can allocate some of its funds to a local government or interstate agency, thus encouraging the coordination of coastal management on a regional level.

The CZMA is overseen by the Secretary of Commerce, acting through the National Oceanic and Atmospheric Administration (NOAA). However, the Act focuses on the States as being key players in the management of coastal zone areas. The legislation emphasized the State leadership in the program, and allowed States to participate in the Federal program by submitting their own coastal zone management proposals to the Office of Coastal Zone Management (OCZM) at NOAA for approval. To receive Federal approval and implementation funding, States and territories had to demonstrate programs and enforceable policies sufficiently comprehensive and specific to regulate land and water uses and coastal development, and to resolve conflicts between competing uses (Terrene Institute, 1994). Once the OCZM has approved a State program., Federal agency activities within a coastal zone must be consistent "to the maximum extent practicable." with the program.

Areas subjected to CZMA planning include wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitat. Management plans developed by States must include an inventory and designation of coastal resources, designate those of national significance and establish standards to protect those so designated. The State plans should also include a process for assessing and controlling shoreline erosion, and a description of the organizational structure proposed to implement the program with specific references to the inter-relationships and responsibilities between various jurisdictions. States are also encouraged to prepare special area management plans addressing such issues as natural resources, coastal dependent economic growth, and protection of life and property in hazardous areas. These resource management and protection plans are accomplished through State laws, regulations, permits, and local plans and zoning ordinances. Section 307(c) of the CZMA requires any applicant seeking a Federal permit to furnish a certification that the proposed activity will comply with the State's coastal zone management program. No Federal permit will be issued until the State has concurred with the applicant's certification of consistency (U.S. Environmental Protection Agency, Region 2, 1993).

The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) These specifically charged State coastal programs and State nonpoint source programs to address nonpoint source pollution issues affecting coastal water quality. Under CZARA, coastal States must develop appropriate management programs in order to continue to receive funding and participate in the CZMA. EPA has developed technical guidance to help States develop the CZARA mandated control programs. The guidance specifies management measures for sources of nonpoint pollution in coastal waters, including coastal stormwater control. Management measures are defined as "economically achievable measures to control the addition of pollutant to coastal waters; that is, they reflect the greatest degree of pollutant reduction available through the application of the best available nonpoint pollution control practices, technologies, processes, site criteria, operating methods or other alternatives" (Terrene Institute, 1994). Coastal stormwater control programs are not intended to supplant existing coastal zone management programs or nonpoint source management programs (Camp, Dresser, and McKee, 1993a). Rather they serve to update and expand existing programs and are to be coordinated closely with other nonpoint source management plans (U.S. Environmental Protection Agency, 1991).

Many States have an approved coastal zone management plan which may apply to activities in specific local regions, jurisdictions, or areas within the State. In these designated areas, projects affecting coastal waters, ecology, or land use may require additional permitting and/or compliance with State laws or local zoning regulations and ordinances.

Endangered Species Act (ESA) This Act seeks to conserve endangered and threatened species through requiring Federal agencies, in consultation with the Secretaries of the Interior and Commerce, to ensure that their actions “do not jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modifications of the critical habitat of such species” (16 U.S.C. § 1536). An endangered species is “any species which is in danger of extinction throughout all or a significant portion of its range” (16 U.S.C. § 1532). A species is threatened if it is “likely to become an endangered species within the foreseeable future through all or a significant portion of its range” (16 U.S.C. § 1532). The Fish and Wildlife Service (FWS) takes jurisdiction over listings for terrestrial and native freshwater species, and the National Marine Fisheries Service (NMFS) is responsible for listings of marine species or anadromous species (Doppelt, *et al.*, 1993). Under the Act, the FWS and NMFS determined critical habitat for the maintenance and recovery of endangered species, and requires that the impacts of human activities on species and habitat be assessed. While States can compile their own lists of species and the degrees of protection required, species on the Federal list are under the jurisdiction and protection of the Federal Government, and a violation of the act carries Federal penalties (Corbitt, 1990). Another important provision of the Act is the establishment of an Endangered Species Committee to grant exemptions from the Act.

When a species is listed under the ESA, the lead Federal agency is required to issue a biological assessment whenever an action in which the Federal Government is involved (as in the issuance of Department of Army permits) "may affect" a listed or threatened species (16 U.S.C. § 1536). The agency must consult with the Fish and Wildlife Service if the results of the biological assessment show a listed species may be affected by the project. If an action will jeopardize a listed species or its habitat, the lead agency must provide mitigation measures for, or alternatives to, the proposed activity (Corbitt, 1990).

Projects that impact such areas may be subject to ESA regulation even if a "water right" exists through Federal or State compact in compliance with State water laws or the Clean Water

Act. As a matter of law, the ESA supersedes most other Federal laws and policies. Given this, it is still unclear whether State water law and water rights are immune to ESA regulation. However, the case law indicates that the ESA does authorize a reduction in the power of existing water rights through regulation (Doppelt, et al., 1993).

The ESA applies to activities directly affecting water resources designated as “critical habitat” areas, and may include receiving waters from highway or urban runoff. For example, stream quality in the Pacific Northwest has become an important issue in regards to protection of the salmon population. Highway construction, runoff quality, mitigation activities, and maintenance may be subject to review under the ESA due to the identification of certain receiving waters as "critical habitat" for salmon runs. In many cases, the NEPA process required for all significant Federal activities uncovers the existence of a listed species, and the subsequent EIS must deal with potential adverse impacts, project modifications or the project site relocation.

3.11 State and Municipal Requirements That Impact Stormwater BMP Design

States and municipalities have been regulating discharges of runoff from construction and land development industry to varying degrees for some time. A recent compilation of state and selected municipal regulatory approaches was prepared in support of EPA’s ongoing development of effluent limitations guidelines for the construction and land development industries (Tetra Tech, 2000) to help establish the baseline for national and regional levels of control. Data were collected by reviewing state and municipal web sites, summary references, state and municipal regulations and storm water guidance manuals. All states (and the selected municipalities) were contacted to confirm the data collected and to fill in data gaps; however, only 87 percent of the states and a much smaller percentage of municipalities responded. The state and municipal regulatory information is presented only to demonstrate that there is a considerable amount of variance in state and local regulatory requirements related to stormwater management. Many states and local agencies are currently in the process of revising and updating their requirements and consequently the data provided in the tables is subject to constant updates and revisions.

The compilation of state and municipal regulations was prepared to determine national and regional approaches towards controlling storm water. The data were collected by reviewing state and municipal web sites, summary references, and state and municipal regulations and storm water guidance manuals. States and municipalities were contacted to confirm the data collected and to fill in data not available by these methods. Many months were allocated to collecting the regulatory data and repeated attempts to obtain and confirm regulatory data ceased at the end of August 2000.

A summary of criteria and standards that are implemented by states and municipalities as of August 2000 are presented in Tables 3-12 and 3-13, respectively. State requirements are generally equal to or less stringent than municipalities that are covered under the federal Clean Water Act NPDES Storm Water Program because state requirements apply to all development within their boundaries including single site development and low to high density developments. NPDES Storm Water Program designated municipalities generally have a population of 100,000 or more and can collect and fund the resources necessary to design, implement, and monitor separate and potentially more stringent storm water management programs. Table 3-12 contains responses from 47 of the 54 state controlling agencies. The total is greater than 50 because Florida has 5 regional authorities that are self-regulating. Some state data were uncertain and repeated contacts to the responsible state agencies to confirm the data were not returned. For the same reason, some of the data sought from municipal agencies also are not available for this report.

The data collected reflect a cross section of the U.S. geography but are representative primarily of municipalities that have a population of 100,000 or greater and only a few municipalities of smaller population. Thirty-one municipalities are included in the summary tables, which is a small data set compared to the approximately 240 municipalities with NPDES programs and nearly 3000 municipalities nationwide. Therefore, the relative use of control measures that are presented for the states on Table 3-12 is considered to be fairly accurate while the relative use

Table 3-12 State or Regional Planning Authority Requirements for Water Quality Protection

Generic Standard	States with Requirement (%)	States without Requirement (%)	No Data (%)
Solids or sediment percent reduction	24	61	15
Numeric effluent limits for TSS, settleable solids, or turbidity	11	76	13
Minimum design depth or volume for water quality treatment	53	28	19
Habitat/biological measures	7	80	13
Physical in-stream condition controls	17	70	13
Chemical monitoring control	6	83	11

for the municipalities presented on Table 3-13 is not considered to be accurate but does reflect the diversity of control measures used at the municipal level.

Table 3-13 Municipal or Regional Planning Authority Requirements

Generic Standard	Existing Requirement (%)	No Requirement (%)	Unknown (%)
Design storm for peak discharge control	39	45	16
Solids or sediment percent reduction	7	77	16
Numeric design depth, storm, or volume for water quality treatment	–	–	--
Design storm for flood control	39	16	23
Habitat/biological measures	3	65	32
Physical in-stream condition controls	10	58	32

Tables 3-12 and 3-13 show that the following key control measures employed by states and municipal/regional authorities generally meet the intent of the federal, state, and municipal regulations that address features of the CWA NPDES Stormwater Program:

- storms designed for peak discharge control
- storms designed for water quality control

The state and local regulations at the state and local level can be grouped into 3 major categories; maximum drainage areas that can be disturbed prior to requiring a NPDES permit; requirements for flood control and peak discharge; and requirements for water quality management.

Drainage Area The compilation of state regulations revealed that the minimum drainage area requirement among states that triggered a requirement for a NPDES permit ranged from 5000 square feet to 5 acres. The results of the compilation are summarized in Table 3-14.

The compilation for regional and local governments found a wider breakdown for drainage area limits for local governments especially for the smaller drainage area limits. The drainage area requirements ranged from 500 square feet to 5 acres. The results of the compilation are summarized in Table 3-15.

Table 3-14 Minimum Drainage Area Requirements for States (Tetra Tech, 2000)

Drainage Area	Comments
5 acres	The majority of States (34 of 48) have adopted the NPDES Phase 1 requirement of 5 acres. Most of these States will increase this requirement to one acre as the Phase II NPDES requirements go into effect.
3 acres	The State of West Virginia uses a 3 acre limit.
1 acre	Currently 2 States (Geogia and Washington) are already using a one acre limit.
5000 ft^2	4 States (DE, MD, NJ, and PA) use a 5,000 ft^2 limit
No area requirement	2 States have no maximum statewide area limit that requires an NPDES permit. Only MS4 areas in these States comply with NPDES Phase I requirements

Table 3-15 Minimum Area Requirements for Local Agencies (Tetra Tech, 2000)

Drainage Area	Comments
5 acre	Of the 35 municipalities that were sampled, 17 use the NPDES Phase I requirement of 5 acres. These municipalities will change to a one acre requirement when Phase II is implemented.
2 acres	2 municipalities use a 2 acre.
1 acre	5 municipalities are currently using a one acre limit
10,000 ft^2	1 municipality reported using a 10,000 ft^2 limit
5,000 ft^2	3 municipalities reported using a 5,000 ft^2 limit
< 5,000 ft^2	the following size limits were reported by one or more communities 4,000 ft^2; 2,500 ft^2; 1,350 ft^2; and 500 ft^2

Peak Discharge Rate Requirements for Flood Control The second major grouping of regulatory requirements consisted of agency requirements to control peak discharges to a pre-development level in order to control increased flooding, channel protection or water quality.

The peak discharge requirements were usually expressed as a design storm event. Design storm frequencies found in these regulations ranged from the ½ -year or six month storm to the 100 year storm. The results of the compilation are summarized in Table 3-16.

Table 3-16 Peak Discharge Control Criteria for States (Tetra Tech, 2000)

Peak Discharge Control Criteria	**Comments**
No statewide control requirements	The majority of the states (30) do not currently have any statewide requirements for peak discharge control
2 yr., 24 h storm	3 States (CA, ME, VT) require peak discharge of the 2 yr., 24 h duration
5 yr., 24 h storm	Pennsylvania requires peak discharge control of the 5 yr., 24 h duration storm
2 & 10 yr., 24 h storms	Virginia requires peak discharge control of the 2 & 10 yr., 24 h duration storms
10 yr., 24 h storms	North Carolina requires control of the 10 yr storm
1, 10, 100 yr., 24 h duration	Maryland requires control of 3 storms
2, 10 & 100 yr., 24 h storm	Massachusetts requires control of these 3 storms
2, 25, 100 yr., 24 h storms	Rhode Island also requires control of 3 storm frequencies
25 yr	Florida requires peak discharge control of the 25 yr. storm. The southern district uses the 3 day duration storm; while the SW and St. John’s River districts use the 24 h duration storm.

The compilation for regional and local governments found similar peak discharge requirements usually expressed as a design storm event. Design storm frequencies found in these regulations closely followed the range of storms addressed by the state regulations did not reveal as much range as the state requirements, but instead appear to focus on the 2, 10 and 100-yr storms. The results of the compilation are summarized in Table 3-17.

Table 3-17 Peak Discharge Rate Control Requirements, Municipalities (Tetra Tech, 2000)

Peak Discharge Rate Control	Comments
No Requirement	17 of the 35 municipalities in the sample do not have peak discharge rate control requirements
2 & 10 yr., 24 h	4 municipalities use this requirement
2, 10 & 100 yr, 24 h	4 municipalities use this requirement
1 yr, 24 h 0.5 yr (6 mo), 24 h 10 yr., 24 h duration 10 & 25 yr., 24 h 10 & 100 yr., 24 h 25 & 100 yr., 24 h 50 & 100 yr., 24 h 100 yr, 24 h	These requirements are each used by one of the municipalities in the sample.
NA	Requirements were not identifiable for 4 municipalities

Water Quality Control Requirements The compilation of state regulations revealed that the states typically used one of two criteria for water quality control; 1) a specified runoff depth, and/or 2) a percent removal rate. Table 3-18 summarizes the results of the compilation. The runoff depth required was either ½ inch or 1 inch. With respect to the percent removal requirement the most frequently used requirement is 80 percent removal of TSS. The compilation revealed a similar trend at the regional and municipal level. The results are shown are summarized in Table 3-19.

Table 3-18 Water Quality Regulatory Requirements, States (Tetra Tech, 2000)

Water Quality Requirements	**Comments**
None	38 of the 48 States in the sample currently have no requirements for water quality control in stormwater management
Runoff Depth None 0.5in 1.0 in	44 of the 48 States in the sample reported no specific volume requirement for water quality control 2 States (DE, FLA) require management of the first ½ inch of runoff 2 States (MA, MD) require management of the first inch of runoff
% Removal None 80% TSS Other	37 of the States sample do not have specific pollutant removal requirements 10 States reported this requirement which is based on CZARA 1 State (IN) requires 70% removal of TSS The St. John's River District of FLA requires 80% removal of all pollutants The Chesapeake District of VA requires 10% removal of TP

Table 3-19 Water Quality Requirements, Municipalities (Tetra Tech, 2000)

Water Quality Requirements	**Comments**
None	28 of the 35 municipalities in the sample reported no water quality requirements for stormwater
Runoff Depth None 0.5 in 0.75 in 1.0 in	25 municipalities reported no specific volume requirements 5 municipalities require control of the first 0.5 inch of runoff 2 municipalities require control of the first 0.75 inch of runoff 4 municipalities require control of the first ½ inch of runoff
% Removal None 80% TSS Other	28 municipalities reported no specific pollutant removal requirements 2 municipalities reported this requirement which is based on CZARA 20% reduction in annual copper loadings by 2001 (Alameda, Co., CA) 65% TP (Washington Co., OR) 0.5 mg/L - TN, 0.1 mg/L - TP, 0.5 mg/L - Iron, 20NTU - Turbidity, 50 mg/L - TSS, 2 mg/L - grease and oil (Lahontan RWQCB Lake Tahoe) 50% TP (Prince William Co., VA) 100% all pollutants (Montgomery Co, MD) 80% TSS - all site; 50%TP - discharge to sensitive lake; 50% ZN - discharge to stream resource area; <10 mg/L Alkalinity, 50% TP, 40% nitrates + nitrites - discharge to sphagnum bogs (King Co., Washington)

Chapter Four
BMP Effectiveness in Removing Pollutants

4.1 Introduction

As indicated in Chapter 1, the most basic level of design is based upon controlling peak discharges to minimize flooding. Many stormwater controls were initially employed for flood control, i.e., to capture peak flows, assist in local drainage, and manage the quantity of runoff produced during wet weather flow (WWF). In this regard, many States and municipalities require the control of peak stormwater discharges. As pollution removals for point source discharges are nearing the point of diminishing returns, increasingly states and municipalities are relying on the water quality/pollutant removal potential of BMPs as a factor in watershed management to improve receiving water quality.

Land use changes associated with development invariably increase runoff quantity and cause downstream flooding and erosion. This has led many states, counties and municipalities, and other agencies to require onsite detention of this increased runoff with the objective of peak outflows from detention basins being equal to the pre-developed conditions. This requirement has become popular, since it can be applied during the development design and review process on a case-by-case basis without large-scale watershed analysis. This popularity has led to the frequent use of onsite detention and retention basins, which have become standard features on many land development projects.

4.2 Current Flow Control Watershed Management Strategies

Pond and wetland BMPs can be designed to provide effective pollutant removal. Water quality control designs are focused more on the annual volume of runoff rather than peak storm events. Effective water quality control requires management of the smaller storm events, such as the 1-inch rainfall events and smaller storms, that typically account for approximately 90 percent of the annual rainfall and runoff volumes. Many of the older detention facilities used for peak discharge control include low flow pilot channels that allow these frequent storm events to flow through the facilities with little or no management.

The most widely used approach to water quality design currently in use throughout the U.S. consists of a volume-based approach to BMP design. This typically uses a predetermined control volume (i.e., water quality volume, WQv, the volume needed to treat or capture 90% of average annual stormwater runoff) such as the first 0.5-in. or first 1-in. of runoff, in conjunction with a diverse set of other design criteria. The State and local jurisdictions assume that if these volumes and criteria are properly applied then typical pollutant removal percentages will be achieved. Where possible it is best to incorporate water quality control and peak discharge control in the same BMP for economic reasons, though this is not always a necessary or desirable approach. Water quality control can be improved in older BMPs designed under the older peak discharge principles by retrofitting.

4.3 Pollutant Loading Estimates

There are many methods to estimate the concentration and loading of pollutants to surface waters. Physically based models attempt to mimic the accumulation and removal of pollutants as well as the chemical reactions within the receiving streams. More empirical models rely on general data and information on pollution concentrations in surface runoff and then predict pollution through an estimation of surface runoff volumes. Regression equations use significant variables to predict loadings of various constituents based on data sets. This type of model can be used with little or no data but are very rough in their estimates. They are less effective for "what if" analysis which may extend the situation beyond the limits of data bases, nor are they very accurate in prediction of acute or shock loadings. Physically based models require substantial data for calibration over the range of expected conditions but can be very effective when data exist and can simulate the most important physical, biological and/or chemical aspects of the problem.

EPA (1983) determined that, based on the sampling done during the Nationwide Urban Runoff Program (NURP), there are certain pollutants that may be typically found in urban storm water. Some of the conventional pollutants show up in significant concentrations in most samples, notably the metals, but most others were present in measurable quantities in less than 15 percent of the samples. Many of these constituents are related to automotive traffic or industrial activities, while others are characteristic of fertilizing and insect control practices. Automotive sources and street locations are generally the two key factors, other than illicit connections and dumping pollutant sources. Common pollutants addressed in studies include: coliform bacteria; total suspended sediment (TSS), total phosphorus (TP), total nitrogen, (TN), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total copper (TCu), total lead (TPb), total zinc (TZn), and oil and grease.

Event Mean Concentration Method NURP was designed and executed under the auspices of EPA in the late 1970's and early 1980's. Its main goal was to provide reliable data and information characterizing runoff from urban sites (USEPA, 1983). Twenty-eight sites were monitored from across the United States. While there were some differences in the objectives and procedures of the sites, a common base of information emerged. Later sampling data from municipalities with NPDES permits confirm NURP's findings. Because of the variability of measurements within storms, among different storms at one site and among sites it was desirable to use a measure which tended to reduce this variability somewhat.

The measure of the magnitude of urban runoff pollution chosen is termed the event mean concentration (EMC). EMC is defined as the total constituent mass discharge divided by the total runoff volume for a given storm event. With few exceptions EMCs were not found to vary significantly for similar land uses from site to site for the same constituent and were found to be distributed log-normally. Therefore measures of central tendency (median and mean) and scatter (standard deviation, coefficient of variation), as well as expected values at any frequency of occurrence, could be calculated by using the logarithmic transformation of the raw data. Standard statistical tests and sampling theory can also be used on the log-normally distributed data.

In selecting a method for estimation of potential washoff loads for a particular site, it is often decided to use methods that estimate washoff loads by land use type. Total loadings are then determined based on EMCs of pollutants and runoff volumes. Table 1-4 presented typical EMC for various land uses and percent imperviousness based on the NURP data and other sources. This information should be compared to local information, when available. Initial data from a number of municipalities throughout the East and Midwest indicate that, other than lead, most constituents did not vary significantly from the NURP information. The reduction in lead is thought to be based on the use of lead-free gasoline since the NURP data were collected.

Nationwide Regression Equations Method Reconnaissance studies of urban storm-runoff loads commonly require preliminary estimates of mean seasonal or mean annual loads of chemical constituents at sites where little or no storm runoff or concentration data are available. To make preliminary estimates, a regional regression analysis can be used to relate observed mean seasonal or mean annual loads at sites where data are available for physical, land use, or climate characteristics. As discussed in Section 1.5, a major study by the U.S. Geological Survey and the U.S. Environmental Protection Agency resulted in the development of regression equations that can be used to estimate mean loads for COD, SS, dissolved solids, total nitrogen, total ammonia nitrogen, total phosphorous, dissolved phosphorous, total copper, total lead, and total zinc (Tasker and Driver, 1988).

USGS has developed equations for determining pollutant loading rates based on regression analyses of data from sites throughout the country (Driver and Tasker, 1990). This method consists of three sets of equations for analysis of runoff pollutant load. The first set of equations allows for calculation of storm pollutant constituent loads and storm runoff volumes. The second set of equations is used to calculate the storm runoff mean concentrations. The third set of equations is used to calculate mean seasonal and annual pollutant loads.

The country is divided into three regions based on mean annual rainfall to increase the precision of the regression equations. Region I consists of States with a mean annual rainfall of less than 51 mm (20 in.) and includes the Western States, excluding Hawaii, Oregon, and

Washington. Region II consists of States with a mean annual rainfall between 508 mm (20 in.) and 1,020 mm (40 in.) and includes the Midwestern and Great Lakes States, the Pacific Northwest, and Hawaii. Region III consists of States with a mean annual rainfall of more than 1,020 mm and includes the Southern States and the coastal Northeastern States. All of the constituents are modeled for regions I and II; dissolved solids and cadmium are not modeled for Region III due to a lack of data.

The Simple Method The Simple Method, as its name implies, is an easy-to-use empirical equation for estimating pollutant loadings of an urban watershed (Schueler, 1987). The method is applicable to watersheds less than 1 square mile in area, and can be used for analysis of smaller watersheds or for site planning. The method was developed using the database generated during a NURP study in the Washington, D.C., area and the national NURP data analysis. The equations, however, may be applied anywhere in the country. Some precision is lost as a result of the effort to make the equation general and simple.

Data and Measurement Needs While use of literature values is helpful in a first cut analysis or preliminary design work, it is important to characterize SS on a site-specific basis; the transport of settleable solids is a function of local conditions which include topography, geology, and antecedent dry period. Topography influences slope or gradient, with milder slopes causing greater solid amounts to be deposited; subsequently, these solids are resuspended during intensive storm flows. The surrounding geology, or more specifically the soil, affect the SS and settleable solids concentration and particle-settling-velocity distribution. Seasonal effects may also be considered.

The monitoring and analyses needed prior to installation for proper assessment, design, and application of BMPs may be expensive and complex in the short term; however, reliable data collection may save even more expensive construction costs and may help designs improve water quality. Sampling devices must be able to capture the heavier SS or settleable solids and not manifest biased results due to stratification of the heavier solids.

Site-specific solids characterization is necessary for the satisfactory design of physical treatment, e.g., sedimentation. Sedimentation in BMPs is dependent upon the (1) fraction of settleable solids and SS, (2) SS-settling-velocity distribution, and (3) hydraulic loading ($gal/ft^2/min$). Common sieve analysis or more advanced light scattering techniques can be used for particle-size-distribution analyses. These analyses will enable a site-specific estimate of the percent of SS and their associated pollutants that the intended CSO control facility may be capable of removing. The settling characteristic analyses (settleable solids) should be the gravimetric type with data presented in mg/L to determine the fraction of settleable solids in the storm flow. Indicator organism and pathogenic analyses may also require some special procedures before analysis.

Technological advances and improvements in real-time monitors can also allow continuous measurements of certain parameters, e.g., pH and turbidity; however, even modern probe-type-monitoring devices must remain wet (submerged) which becomes a problem.

4.4 Effectiveness of Treatment BMPs using Current Design Approaches

The existing data bases on pollutant removal by BMPs may or may not identify the design method used. Many of the BMPs monitored will have been designed using water quality measures such as control of first flush, extended detention or retention; however some of the data are representative of peak discharge control strategies. The levels reported in databases such as the EPA-ASCE National BMP Database and others as illustrated in Table 4-1 and Table 4-2:

Table 4-1 Median Pollutant Removal of Stormwater Treatment Practices (Brown and Schueler, 1997)

Treatment BMP	Median Pollutant Removal Efficiency (%)						
	TSS	TP	Sol P	TN	NOx	Cu	Zn
Stormwater Detention Ponds	47	19	–6.0	25	4	26[1]	26
Stormwater Retention Ponds	80 (67)	51(48)	66 (52)	33 (31)	43 (24)	57 (57)	66 (51)
Stormwater Wetlands	76 (78)	49 (51)	35 (39)	30 (21)	67 (67)	40 (39)	44 (54)
Filtering Practices [2]	86 (87)	59 (51)	3 (-31)	38 (44)	-14 (-13)	49 (39)	88 (80)
Infiltration Practices	95 [1]	70	85 [1]	51	82 [1]	N/A	99 [1]
Water Quality Swales [3]	81 (81)	34 (29)	38 (34)	8 (41)	31	51 (51)	71 (71)

1. Data based on fewer than five data points
2. Excludes vertical sand filters and filter strips
3. Refers to open channel practices designed for water quality

Notes:

- Data in parentheses represent values from the First Edition;
- N/A = data are not available, TSS = Total Suspended Solids; TP = Total Phosphorus; Sol P = Soluble Phosphorus; TN = Total Nitrogen; NOx = Nitrate and Nitrite Nitrogen; Cu = Copper; Zn = Zinc

Table 4-2 Median Effluent Concentration of Stormwater Treatment Practice Groups (Brown and Schueler, 1997)

Treatment BMP	Median Effluent Concentration (mg/L)						
	TSS	TP	OP	TN	NOx	Cu[(1)]	Zn[(1)]
Stormwater Detention Ponds	28 [(2)]	0.18 [(2)]	0.13 [(2)]	0.86 [(2)]	N/A [(3)]	9.0 [(2)]	98 [(2)]
Stormwater Retention Ponds	17	0.11	0.03	1.3	0.26	5	30
Stormwater Wetlands	22	0.2	0.09	1.7	0.36	7	31
Filtering Practices [(2)]	11	0.1	0.08	1.1 [(2)]	0.55 [(2)]	10	21
Infiltration Practices	17 [(2)]	0.05 [(2)]	0.003 [(2)]	3.8 [(2)]	0.09 [(2)]	4.8 [(2)]	39 [(2)]
Water Quality Swales [(4)]	14	0.19	0.08	1.12	0.35	10	53

1. Units for Zn and Cu are micrograms per liter.
2. Data based on fewer than five data points
3. Excludes vertical sand filters and filter strips.
4. Refers to open channel practices designed for water quality

Notes:
N/A = data are not available, TSS = Total Suspended Solids; TP = Total Phosphorus; OP = Ortho-Phosphorus; TN = Total Nitrogen; NOx = Nitrate and Nitrite Nitrogen; Cu = Copper; Zn = Zinc

These databases and their associated summary tables at the very best should be used only to very roughly provide information on BMP effectiveness. There is no single value for pollutant removal which is based on influent loadings and characteristics. A treatment train approach (discussed later) and source controls could increase the pollutant removals, which is a benefit for the receiving stream and is more important than achieving targeted removals. These tables are also presented without stating the "margin of safety" or uncertainty.

Percent Removal of Pollutant is a Poor Measure of BMP Performance The quantification of efficiency of BMPs has often centered on examinations and comparisons of "percent removal" defined in a variety of ways. BMPs do not typically function with a uniform percent removal across a wide range of influent water quality concentrations. For example, a BMP that demonstrates a good percent removal under heavily polluted influent conditions may demonstrate poor percent removal when low influent concentrations exist. The decreased efficiency of BMPs receiving influent with low contaminant concentration has been demonstrated. For many constituents, there is a minimum concentration necessary to achieve any reduction. Percent removal alone, even where the results are statistically significant, often does not provide a useful assessment of BMP performance.

The goal in watershed management is to reduce the pollutant load either through source control (the most effective way to do it) or through multi-stage treatment (treatment trains). Although individual BMPs may be less effective on a percent basis, if they cumulatively still result in a lower effluent concentration (or load), they benefit the watershed. BMPs should therefore not be designed for percent removal but for pollutant removal to achieve a given effluent level.

Other recommended parameters for measuring BMP efficiency include measurements of how performance varies from pollutant to pollutant, with large or small storm events, with rainfall intensity, and whether the BMP reduces toxicity and whether it can cause an improvement in downstream biotic communities (Strecker *et al*, July 2000).

Monitoring and Current Evaluations of Treatment BMP Effectiveness BMP monitoring is difficult, complex, and costly to conduct properly. It is almost impossible to locate a BMP in the field that has been evaluated and monitored properly for its effectiveness, including the aforementioned and other databases. Proper BMP evaluation must include:

- Mass-balance (synchronized flowrate measurement with sampling times) monitoring of all influent and effluent points (vectors whether point or diffuse). This becomes extremely complex when monitoring wetlands, filter strips, and swales having multiple, changing or diffuse influent/effluent locations and variable groundwater infiltration/exfiltration.
- Representative and satisfactory monitoring equipment, i.e., sampling devices (capable of withdrawing stratified, heavy particles and surface films), flowmeters (capable of accurate/precise measurement under the adverse stormflow conditions of unsteady, surcharged, low, and non-uniform flow), and non-fouling sensors.
- Continuous and representative monitoring of the influent and effluent during both wet- and dry-weather flow conditions.
- Long-term (at least one year) monitoring covering all seasons.
- Monitoring of soil-infiltration capacity representative of the entire BMP bottom and sides/embankments.
- Satisfactory and uniform quality parameters and standard analytical methods (with an approved QA/QC program) to enable reliable site-to-site comparisons and achieve proper evaluation. Details and results of the QA/QC program should be reported in monitoring study reports and summarized in applicable papers.
- Pollutant removal as it relates to BMP size (volume, plan area) and BMP influent flowrate and volume. For example, 100% pollutant removal is achievable in an oversized BMP retention infiltration pond having a very high bottom/side soil-infiltration rate that is capable of capturing its total long-term inflow volume and allows quick draw-down between storms.
- An adequate sample population of each specific BMP type evaluated.

If a BMP relies heavily on particle settling for its effectiveness, then without particle-settling-velocity laboratory analyses, effectiveness evaluation will fall short. This can be explained by using the case of a BMP that relies on settling that is situated in an area that contains unsettleable surface particles (e.g., fine clay). In this case treatment by settling will be minimal and without knowing particle-settling velocity distributions an improper BMP effectiveness assessment could be made. Also, if BMP treatment relies on filtration, then it is important to use particle-size distribution as an evaluation parameter.

At best, the available databases today have only limited sample populations per BMP type. Some of these were designed under the peak discharge control approach to stormwater management which happen to include water quality design approaches currently in use and, therefore, can be listed under both categories.

4.5 Importance of Particle Size Distribution

Treatment of contaminated stormwater runoff relies almost exclusively on sedimentation with the added assumption that a majority of the pollutants are present as adsorbed species on the finer fraction of the suspended solids /sediments. Particle-size-distribution of solids directly affects the SS settling characteristics. Therefore, determination of the particle-size-distribution of solids in the stormwater and analysis of the various fractions of the sediment are necessary for selecting and designing an efficient BMP treatment-train system.

Müller (2001) and his colleagues studied the distribution of heavy metals in different fractions of river sediment and recommended that ‘preference should be given to the rapid, simple, and economic separation by sieving (20:m); this fraction corresponds fairly closely to the former suspended load of a riverine transport.’ Studies show that sorption of pollutants by particulate matter is bimodal in nature. For example, Charlesworth and Lees (1999) studied speciation of heavy metals vs particle size (<63 :m and 2 :m) in urban sediments and found that both size fractions contained similar amounts of heavy metals. Furthermore, the majority of the metals, irrespective of size fraction, are associated with organic matter of that fraction. Distributions of heavy metals and hydrocarbons in urban stormwater are associated with their particulate fractions and the relative size of SS. Particles finer than 250 :m contain more heavy metals and total petroleum hydrocarbons (TPHs) than particles larger than 250 :m, and about 70% of the heavy metals are attached to particles finer than 100 :m (Ellis and Revitt 1982).

Gao (1977) found that distribution of pesticides (atrazine and bifenox) in sediments is also bimodal, governed both by the particle size and their organic matter content. Wang (2001) reported that the majority of the PAHs occurred in the coarser fractions (>250 :m) of the sediment. Their study also showed that particulate organic matter like charcoal and plant detritus in the sediment appear to absorb PAHs more strongly than organic matter associated with clay. Walling and his colleagues (Walling, 2001) studied sediment-associated nutrient transport during a storm event and found that:

- particle size has limited influence on the nutrient content of the suspended solids,
- sediment properties, like iron and manganese content, control the phosphorous content of the sediment,
- TOC content of the sediment appears to be related to nitrogen content of the sediment,
- Total nitrogen (TN) content of sediment is predominantly (94-98%) in organic form.

4.6 Approaches to Implementing BMPs for Improved Water Quality in the Urban Watershed

There are several strategies being used to improve water quality in the urban watershed, including setting standard pollutant reduction levels, establishing maximum pollutant levels for new development, using annual flow volumes rather than flood events, basing design on first flush principals, and developing designs using treatment train BMPs. These are discussed below and in subsequent sections of this document.

Setting Standard Pollutant Reduction Levels A strategy for controlling the mass of pollutants released into receiving waters is to require that a specified amount of pollutant be removed from the stormwater runoff before it is discharged. The reduction has been commonly specified as a percent decrease of the pollutant. Pollution reduction standards can be applied to impervious areas or to the entire developed area (including open space and pervious areas). The pollution reduction strategy may require a specific reduction in the average mass of pollutant or may require that the average mass of pollutants after development be reduced to preconstruction levels.

An example is the federal guideline issued pursuant to the CZARA that specifies that urban runoff from a new and stabilized development site have 80 percent of the TSS removed before it is discharged from a construction site. This is a voluntary program and applies only to new land development in municipalities not covered by the NPDES stormwater program in coastal states. When calculating the average mass of total suspended solids, the CZARA considers only discharges generated by the 2-year, 24-hour frequency storm or smaller storms.

Implementing the pollution reduction strategy requires knowledge of the preconstruction and post development average mass of pollutant. This is usually derived by using pollutant loading factors from a developed site or by using event mean concentrations (EMCs) from sites that are comparable to a proposed development site. It is possible to conduct long-term monitoring to determine the mass of preconstruction pollutants, but the post development masses need to be estimated so that stormwater management controls can be designed and permitted. Actual loadings may also be used when there is sufficient data available. This is the most accurate approach and is proposed for use in watershed TMDL modeling. Post development monitoring has not been normally required or implemented as part of the permit approval process in the past, but some municipalities are beginning to require it. The stormwater management controls that are proposed for a site development are designed and approved by permitting agencies based on the best available knowledge. Once the design is approved and constructed as designed, developers are not usually expected to retrofit stormwater controls even if monitoring indicates that they do not achieve the expected pollutant reduction goal.

The pollution reduction strategy is an effective means of reducing the mass of new and additional pollutants arising from land development activities. It also specifies a goal to be achieved without mandating the specific controls that to are be used. The strategy is generally considered to be effective if the regulating municipality selects the appropriate pollutant reduction percentage and ensures that the stormwater controls are properly selected, designed, constructed, operated, and maintained. There are several limits to the effectiveness of this approach, including:

- The strategy permits an increase in total pollutant mass released into receiving waters since the allowable percentage discharged may actually exceed the pre-disturbed loadings.
- The strategy is designed to control pollutants discharged from a development site. It does not explicitly require protections at the receiving waters, so discharges from numerous development sites could combine to exceed desired pollutant masses in receiving waters.
- The reduction goal needs to be generic to accommodate the variety of site conditions in a municipality. Pre construction effluent characteristics and receiving water requirements will vary across a municipality as will post development characteristics. Criteria and standards developed to control water quality pollution from the broad range of environmental conditions present could be too lenient in some cases and too strict in others.
- The pollutant removal efficiencies of stormwater technologies have not been well defined in the past. Existing guidance on the design of stormwater controls have typically used a broad range of pollutant removal efficiencies based on existing monitoring methods (which are poor in many cases). This range in reported effectiveness leads to uncertainties in the selection and design of the treatment processes used to meet the pollutant reduction goals.

Some of these concerns are being addressed by ongoing investigations and innovative approaches that are being developed and tested by some municipalities.

With regards to monitoring, evaluating compliance with the pollutant reduction strategy may entail a subjective judgment because monitoring standards and guidance generally are not well documented and implemented. A continuing study jointly funded by the ASCE and USEPA seeks to provide tools that describe stormwater control monitoring and expand a database that can be used to estimate stormwater control effectiveness. This project has resulted in the development of the ASCE/EPA BMP database web site (http/www.bmpdatabase.com). Several municipalities and professional organizations are also studying the impacts of pollutant loads on receiving water quality and aquatic biology. These studies are expected to refine the relationship between development activities, stormwater controls, and receiving water responses

Establishing Maximum Pollutant Levels for New Development Another strategy designed to prevent short- and long-term harm to humans and the environment is to specify that pollutants of concern in stormwater discharged at the MS4s from developed sites cannot exceed specified concentrations. A number of states and municipalities have established maximum permissible concentration criteria and standards for pollutants such as TSS or turbidity, and some have also developed criteria and standards for nutrients, oil and grease, metals, and other pollutants. While these concentrations are typically specified at the MS4 discharge locations from developments, States or municipalities may require that the development activity not cause impacts to the receiving waters that exceed minimum concentrations of some pollutants such as dissolved oxygen.

By requiring that pollutants in stormwater effluent not exceed predetermined concentrations, municipalities can control worst-case conditions. As commonly implemented, however, such a requirement does not prevent the average pollutant load released from a development site from exceeding pre-construction conditions. The design of structures that achieve these controls are subject to the same degree of uncertainty as described above for the percentage reduction strategy, but the not-to-exceed concentration strategy gives the governing municipality a ready means (i.e., effluent monitoring) of ensuring that its goal is met and puts the responsibility on the developer to properly design, and retrofit if necessary, the stormwater controls needed to achieve the effluent concentration requirements. Another drawback to the strategy is that the establishment of concentration limits is based on the existing understanding of how water quality and aquatic biology respond to changes in pollutant loads. The current understanding is an estimate of both the ability of the receiving water to accommodate changes in pollutant loads and the impacts that aquatic biology can withstand in the short- and long-terms.

Using Annual Flow Volumes for Design The addition of water quality considerations in the design of BMPs has introduced a new dimension to the traditional hydrologic considerations for BMP design. Prior to the introduction of water quality considerations hydrologic design methods were focused on flood event hydrology with focus on storms typically ranging from the 2-yr (bankfull); to the 10-year (storm drainage conveyance storm) to the 100-yr (floodplain storm). Water quality considerations created a shift from flood events to annual rainfall volumes and the pollutant loads associated with these volumes. This new focus has given rise to concepts such as the rainfall frequency spectrum and small storm hydrology.

Basing Design on First Flush Principles The tendency for solids and associated constituents to be washed off of paved areas during the initial portion of the storm event is referred to as the first flush. In general, the potential for first flush is determined by the storm characteristics, the size of the subwatershed, and the partitioning characteristics of the pollutants of concern.

To treat the bulk of the pollutant loads from stormwater runoff, many states and municipalities specify a treatment volume that is designed to capture the first flush component of the stormwater runoff. In practice this is achieved by specifying a rainfall amount (such as the first ½-inch, 1-inch, or other rainfall depth) over impervious areas or the capture of a stormwater runoff volume that correlates to a design storm (such as the 6-month, 1-year, or 2-year frequency storm).

Working with a very small (300-square-meter) highway segment, Sansalone, et al. (1994) found a pronounced first flush for solids, dissolved zinc and dissolved copper, but not dissolved lead. The first flush for the particulate-bound fractions of these metals was not well defined. While the first flush is commonly treated using settling technologies, filtering and cation exchange technologies may also be warranted depending upon the subwatershed characteristics and the pollutants of concern.

In some cases, such as Austin and San Antonio, TX, the first flush of water is diverted to a separate treatment system for settling followed by sand filtration. The remainder of the storm is directed into a stormwater detention basin that may be a retention or detention pond.

Designing Using Treatment Train BMPs As discussed in subsequent sections, targeted pollutant removals can usually be achieved using a series of BMPs in a treatment train. This can apply to new designs as well as to retrofit existing BMP facilities. Simply put a treatment train is comprised of several BMPs, e.g., filter strips draining to swales that convey the stormwater to a retention pond designed with a forebay.

A treatment train BMP process should be capable of achieving the targeted pollutant(s) removal or degradation in the designed treatment system. Effectiveness may be assessed in terms of specific stressor of concern (e.g., flow, nutrients, pathogens, sediment, or toxics) or groups of pollutants. If there are no existing pollutant removal or water quality control measures currently being implemented and the planned BMP provided certain degrees of treatment, then the BMP system may be considered effective by default. Furthermore, the designed BMP treatment train (or multi-tiered approach) should achieve pollutant reduction sufficient to produce effluent water quality parameters that comply with the regulatory requirements. Otherwise the recommended BMP treatment system should not be considered effective.

4.7 Removal Processes Occurring in Treatment BMPs

The processes occurring in treatment BMPs (Table 4-3) include: settling, sorption, filtration, infiltration, biodegradation/bioassimilation, nitrification/denitrification, volatilization and phytoremediation. One or more of these treatment processes may occur in the treatment BMP systems to remove pollutants. Table 4-4 summarizes expected performance values of each treatment BMP.

Table 4-3 Removal Processes Occurring in Treatment BMPs

Pollutant Constituents	Treatment BMP Type and Process Mechanism				
	Pond	Wetland	Infiltration	Biofilter	Sand Filter

Heavy Metals	Sorption Settling	Sorption Settling Phytoremediation	Sorption Filtration	Sorption Filtration Phytoremediation Settling	Sorption Filtration
Toxic Organics	Sorption Biodegradation Settling Phytovolatilization	Sorption Biodegradation Settling Phytovolatilization	Adsorption Filtration	Sorption Filtration Settling Phytovolatilization	Sorption Filtration
Nutrients	Bioassimilation	Bioassimilation Phytoremediation	Sorption	Sorption Bioassimilation Phytoremediation	Sorption
Solids	Settling	Sorption Settling	Sorption Filtration	Sorption Filtration Settling	Filtration
Oil & Grease	Sorption Settling	Sorption Settling	Sorption	Sorption Settling	Sorption
BOD_5	Biodegradation	Biodegradation	Biodegradation	Biodegradation	Biodegradation
Pathogens	Settling UV (sunlight)	UV (sunlight) Predation	Filtration	Filtration Settling	Filtration Predation

Table 4-4 Treatment BMP Expected Performance (ASCE, 2001)

BMP Type	Expected Pollutant Removal Efficiency (%)			
	Suspended Solids	**Total Nitrogen**	**Total Phosphorus**	**Total Heavy Metals**
Detention Pond	70	10	20	30 – 70
Retention Pond	85	40	50	25 – 70
Alum System	90	50	90	80 – 90
Sand Filters	70 – 90	30 – 40	50 – 60	20 – 80
Swales	60 – 80	0 – 20	30 – 40	30
Buffer Strips	20 – 80	20 – 60	20 – 60	20 – 80
Infiltration Trenches	70 – 90	40 – 70	50 – 70	70 – 90

Settling Also known as sedimentation, settling occurs when particles have a greater density than the surrounding liquid. The settling process in stormwater management is determined by the particle size and settling velocity, turbulence or short-circuiting, peak flow-through rate, and volume of water (Stahre and Urbonas, 1990). Soil particles and TSS are removed primarily through settling. In addition because many of the other pollutants including nitrogen, phosphorus, metals, and bacteria are attached to the soil particles they are also removed from the water column.

Particle size directly affects the pollutant settling ability: the smaller the particle size, the longer it takes to settle. Conversely, the larger the particle, the faster its settling velocity. Particle size, however, is not the only factor in settling ability. This relationship also depends on the difference between the density of the fluid suspending the particle and the density of the particle. Large, dense particles, such as sand, will fall through fluid at a faster rate than smaller, less dense particles, such as clay. The volume of particles suspended within the fluid also factors into this process. Stahre and Urbonas (1990) indicates that the more particles suspended within the fluid, the faster the rate of settling but at some point, the rate of settling will bottom out.

Turbulence, eddies, multilayered flows, circulation currents, and diffusion at inlets and outlets affect the settling ability of particles. Each of these factors can resuspend particles into the water column. Kuo (1976) found that sedimentation would improve as flow-through rate and surface loading decreases. The difference was most significant for larger particles; however, this study did not go beyond the laboratory. Actual field conditions must take into account the particle settling velocity and surface loading rates during runoff conditions. Sediment removal under these conditions varies with storm intensity. The size of the body of water relative to stormwater runoff will also determine the settling ability of sediment. The larger the stormwater loading rate, the lower the removal of sediment by settling. Settling also occurs after stormwater is trapped and ponded between storms. Because the intervals between storm events are a random process, understanding the effective ratio of storage volume to mean runoff rate and the ratio of sediment volume removed to mean runoff rate is essential to predicting long-term averages.

The most widely used stormwater management practices that employ the sedimentation process are retention and detention structures such as ponds and constructed wetlands. These can be designed to effectively remove sediment from stormwater. Several factors are considered during the design processes: retention or detention feature, detention time, and period storms.

Stormwater management basins with a permanent pool of water have a removal percentage of total suspended solids of about 50 to 90 percent (Wotzka and Oberts, 1988; Yousef et al., 1986; Cullum, 1985; Driscoll, 1983, 1986; MWCOG, 1983; OWML, 1983; Holler, 1989; Martin, 1988; Dorman et al., 1989; City of Austin, 1990). Extended detention ponds have a similar percentage of removal (MWCOG, 1983; City of Austin, 1990; OWML, 1987). Some researchers have found, however, that detention ponds will have a lower sediment removal efficiency over the long term than retention ponds. This is because an opportunity exists for new storm flows to resuspend sediments deposited on the detention pond bed from previous storm events.

The typical detention time for detention basins in the United States is from 12 to 48 hours. The longer the detention time, the more time particles have to settle before the stormwater is discharged to the receiving water. The detention time must be long enough for the desired particulates to settle from the storm water, yet the full volume of storage should also be available for the next storm event. Thus a 2-day period for the temporary storage and treatment of stormwater is the typical maximum period since this seems to balance the pollutant removal goals with the between-storm interval during the rainy season in many locations.

As mentioned earlier, the settling process can remove particulate materials and those dissolved materials which may adsorb to settleable particles. However, the removal rate by settling of pollutants other than sediment particles is inconclusive. Part of the confusion is related to which removal process in a stormwater management structure is responsible for removing a pollutant. In retention ponds, for example, several processes occur simultaneously: settling, biological uptake, volatilization, infiltration to groundwater, and adsorption. While nitrogen, phosphorus, and bacteria may be removed to some extent by absorption to larger particulates, this is not expected to be a primary mechanism for their treatment. Metals, however, are present in particulate and dissolved form and some metals species can be removed by coagulation and sedimentation.

With respect to speciation, recent runoff data from a heavily traveled highway site in Cincinnati, OH, indicate that, in general, cadmium, copper, and zinc can be found substantially in the dissolved form, depending on the storm event (Sansalone *et al.*, 1994). For a series of five storm events, the event mean dissolved fraction ranged from 0.535 to 0.955 mg/L for zinc, from 0.446 to 0.964 mg/L for cadmium, and from 0.310 to 0.713 mg/L for copper. In contrast, lead tends to be in the particulate form; the dissolved fraction ranged from 0.179 to 0.451 mg/L. Factors cited by Sansalone et al. (1994) that affect the event-to-event variation in dissolved fraction include rainfall pH and the average residence time of the runoff. Similar results have been found for runoff from parking lots on the west coast (Woodward-Clyde, 1996).

With respect to particle size fractions, a number of researchers have found that the smaller particles tend to be more mobilized during storm events and the concentration of metals was found to increase with decreasing particle size (Sartor *et al.*, 1974). Recent highway runoff particle fraction data show that the surface area per unit of mass within different size fractions increases as particle size decreases (Sansalone *et al.* 1994), and thus metal concentrations would similarly increase with the smaller sized particles. On the basis of 13 monitored events from the highway runoff site in Cincinnati, the median particle diameter was about 570 µm (Sansalone *et al.*,1994).

Filtration The filtration process can remove sediment and other pollutants as stormwater passes through a filtering system. Typically, stormwater filters remove particulates and adsorbed pollutants, such as sediment, organic carbon, phosphorus, and many trace metals. Particulate pollutants are trapped by cation/anion exchange (discussed in the following paragraph) or are prevented from moving beyond the filter. In some cases, the filtration process can increase the pollutant level of storm water. Filters that inadvertently become anaerobic and nitrify organic nitrogen can release ammonia and nitrate into storm water. Existing media filtration practices commonly use trenches filled with sand or peat. Once the treatment volume is achieved during a given storm the excess runoff bypasses the filter and is untreated.

Sorption The clay and organic particles in soil hold a negative charge. The ability of soil and organic matter to hold cations, such as phosphorus and aluminum, represent the soil's cation exchange capacity. This process is most readily used to filter pollutants from storm water. Organic matter, such as peat or leaf matter, in the filter media will use its cation exchange capacity to bind pollutants to the filter. The treatment of all runoff through filter media (Stewart, 1992), and biofilters, such as the bioretention cell (Clar, 1993) are other examples of cation exchange processes. A shallow basin collects the runoff and gradually discharges through a filter media filled with planting soil, peat or composted leaf media. The media traps particulates (through filtration), adsorbs organic chemicals, and removes up to 90 percent of solids, 85 percent of oil and grease, and 82 to 98 percent of heavy metals (through cation exchange from leaf decomposition).

The extent to which a given metal is adsorbed is affected by a number of factors, including competitive effects of other ionic metals, the presence of iron and manganese oxides, the presence of organic carbon, and especially pH (Maidment, 1993). Treatment trains that include adsorptive media may provide effective treatment for dissolved metals. Such media include compost, granulated activated carbon, or diatomaceous earth, all of which work on a cation exchange principle. Pilot laboratory testing of different filter media conducted by Robert Pitt at the University of Alabama/Birmingham show the following removal efficiencies (Pitt, 1986):

- Sand filter - 45 percent (zinc)
- Composted leaves - 88 percent (zinc), 67 percent (copper)
- Peat moss - 80 percent (trace metals in general)

An in-house research by EPA (Wojtenko *et.al*, 2002) demonstrated the capability of common tree mulches used for landscaping to remove pollutants commonly found in urban stormwater runoff. In an experiment 2L of stormwater spiked with a mixture of heavy metals (Cu, Cd, Cr, Pb, and Zn (each at 5,000 :g/L) and priority organic pollutants benzo(a)pyrene, naphtahalene, fluoranthene, 1.3-dichloro benzene, and butyl-benzyl phthalate (each at 1,000 :g/L) were mixed with known weights of mulch. Pollutant removals are shown in Table 4-5.

Table 4-5. Pollutant Removal (%) by Mulch from Stormwater Runoff (Wojentko *et. al*, 2002)

Pollutant	**Initial Concentrations of Pollutants (2L solution)**	
	Metals each 5,000 :g/L; Organics each 1,000 :g/L	
	Mass of Mulch	
	100 g	**500 g**
Cd	94	99
Cu	50	100
Cr	100	100
Pb	100	100
Zn	75	99
Benzo(a)pyrene	100	100
Naphthalene	100	99
Floranthene	100	100
1,3 Dichloro benzene	100	100
Butylbenzyl phthalate	100	100

Phytoremediation Plants are able to degrade (break down) organic pollutants through their metabolic processes. Aquatic plants have been used to treat wastewater, such as wetlands have been used to treat farming effluent and mining runoff. Phytoremediation refers to the use of plants to degrade, sequester, and stabilize organic and metal pollutants in stormwater. Plants are able to volatilize contaminants (volatile organic compounds, i.e., solvents, etc.) from soil or water (i.e., phytovolatilization). More recently, the bacterial activity associated with the roots of grasses and other plants has been explored for its organic degradation potential. The efficiency of phytoremediation may vary depending on the depth of soil and the type and species of pollutants in water that are most available for plant uptake.

4.8 Treatment-Train Approach to Improve Water Quality

Several treatment processes are applicable to treat stormwater runoff. The following unit processes can be selected to compose a treatment-train for a site-specific application:

- settling
- infiltration
- filtration
- sorption

- biodegradation
- nitrification/denitrification
- bioassimilation
- phytoremediation

One or more of these treatment processes may be used to achieve the desired effluent quality of stormwater released from urban watershed. Depending on the stormwater management goals and objectives identified for a specific site or area, a combination of one or more treatment BMPs may need to be used to meet the design objectives, in what is often referred to as a treatment train approach. No single BMP is as effective as a "train" (that is, series) of practices and controls (ASCE & WEF 1998).

Pretreatment is recommended where the site has sufficient space, to aid in reducing incoming velocities as well as capturing coarser sediment particles to extend the design life and reduce replacement maintenance of the primary BMP downstream. The pretreatment method may include a vegetative filter strip, swale or incorporate other techniques to aid in extending the design life of the primary BMP. Historically, the primary purpose of a vegetated filter strips has been to enhance the quality of stormwater runoff on small sites in a treatment system approach, or as a pretreatment device for another BMP. The dense vegetative cover facilitates conventional pollutant removal through detention, filtration by vegetation, sediment deposition, infiltration and adsorption to the soil (Yu and Kaighn, 1992). Vegetated filter strips may be used as a pretreatment BMP in conjunction with a primary BMP. Retention and detention basins should be designed to promote sediment deposition near the point of inflow. A forebay with a volume equal to approximately 10% of the total design volume can help with the maintenance of the basin, and extend the service life of the remainder of the basin. This reduces the sediment and particulate pollutant load that would reach the primary BMP, which, in turn, would reduce the BMP's maintenance costs and enhance its pollutant removal capabilities.

Because detention ponds operating alone have been documented to be ineffective, it is not possible to recommend them as a viable water quality control measure (Moffa *et al.* 2000). However, they can be very effective when used in conjunction with other stormwater control practices. At a minimum, a two-stage basin is preferable for extended detention ponds. The lower stage has a micropool that fills frequently. This reduces the periods of standing water and sediment deposition in the remainder of the basin. These recommendations does not necessarily apply to large, regional extended detention basin and the impact of these considerations varies with climate and soil types.

Integrated Treatment-Train Systems The basic treatment BMPs indicated in the previous section are essentially singular processes; however, system optimization should be considered to enhance overall treatment BMP effectiveness to meet water quality goal. An integrated treatment train to produce four different levels of effluent water quality. The various unit BMPs form the following control or treatment trains as presented in Figure 4-1:

- Control/pretreatment - source control and natural drainage system followed by storage basins constructed with spillway for by-passing high-intensity and long-duration storm generated flows to regional ponds.
- Primary treatment - detention and retention ponds with polishing constructed wetland [Class D].
- Secondary treatment - primary treatment with chemical addition and disinfection [Class C].
- Tertiary treatment - secondary treatment plus filtration and disinfection [Class B].
- Advanced treatment - tertiary treatment plus activated-carbon adsorption with disinfection [Class A].

Each treatment train is expected to produce a different degree of effluent water quality to meet the receiving water quality criteria as illustrated in Table 4-5. The effluent presented are based solely on expected unit process removals. Only effluent D is indicative of the potential removals using the current "passive" management of stormwater based solely on gravity flow, as opposed to a more "active" management typified by wastewater treatment plants.

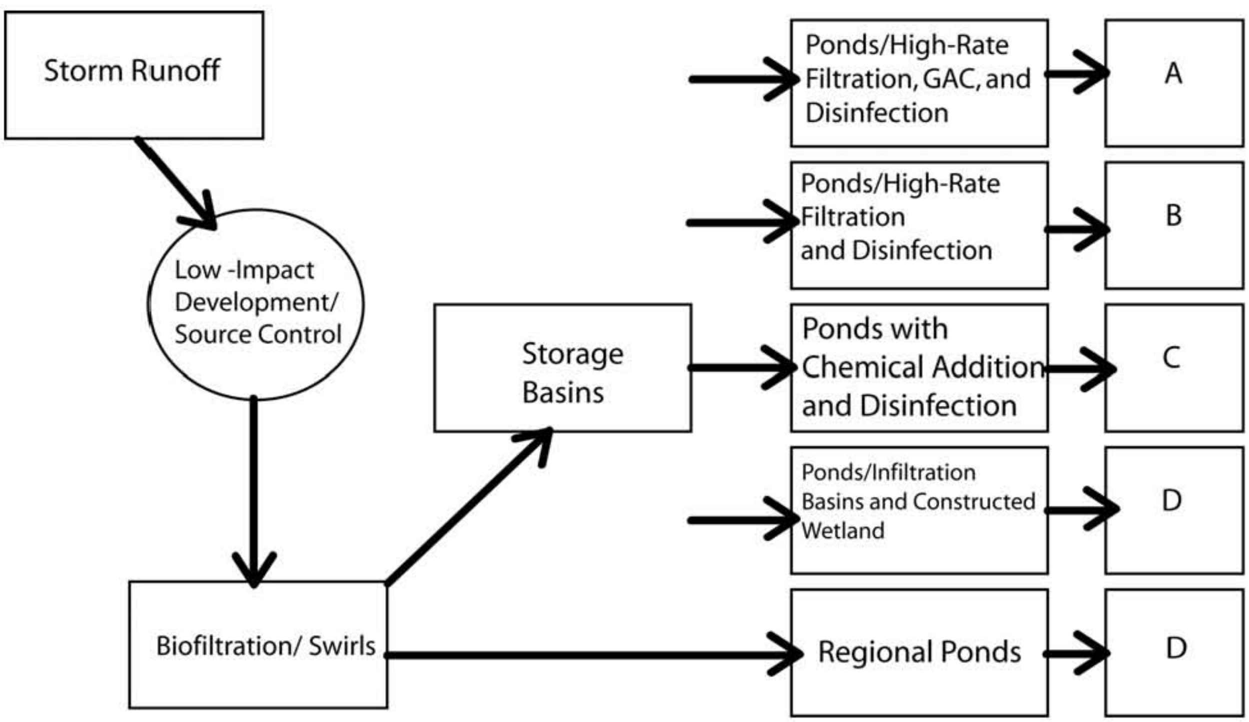

Figure 4-1 Urban Stormwater Treatment Train Process Flow Diagram

Table 4-5 Expected Median Effluent Concentration of Selected Pollutants

Water Quality Constituent	Potential Effluent Water Quality Concentration			
	A	**B**	**C**	**D**
Suspended solids (mg/L)	5	10	10	30
BOD_5 (mg/L)	5	10	10	30
Total nitrogen (mg/L)	< 0.1	0.5	< 1	1.5
Total phosphorus (mg/L)	< 0.1	< 0.1	<0.1	1
Total coliform (MPN per 100 ml)	< 100	< 100	100	– –
Oil and grease (mg/L)	1	5	10	15

Chapter Five
Types of Pond BMPs and Their Ability to Remove Pollutants

5.1 Introduction

Ponds are probably the most frequently used stormwater BMP in the United States. For the purposes of this document, pond BMPs are grouped into three types: wet ponds or retention ponds; dry basins or ponds including detention basins (ponds) and extended detention basins (ponds); and infiltration basins.

Group 1 - Wet Ponds/Retention Ponds A wet pond is a small artificial lake often with emergent wetland vegetation around the perimeter and littoral zone, designed to capture runoff and remove pollutants from stormwater. This BMP is sometimes referred to as a "retention pond" or a "wet retention basin". In this document, it is referred to as a wet pond to distinguish it from the extended detention basin (a type of dry pond) described below. Removal rates of solids by wet ponds typically outperform detention basins. The larger permanent pool of wet ponds allows water to reside in the interval between storms while further treatment occurs. A wet pond can be sized to remove nutrients (10-40%) and dissolved constituents; however settling is the primary mechanism of treatment. Permanent pools that may be associated with an extended detention basin are smaller and are provided for aesthetics, as discussed under the extended detention discussion above. Figure 5-1 illustrates the elements of a wet retention pond.

Group 2 – Dry Ponds/Detention Ponds/Dry Detention Basins and Extended Detention Ponds/Basins Detention of urban stormwater runoff began appearing as an urban stormwater management practice in the 1960s in North America to control runoff peaks from new land development sites. Figure 5-2 shows a typical dry pond. While many jurisdictions initially applied this approach to control the 10-, 25-, 50-, or 100-year flow rates, a small number of jurisdictions also mandated detention (i.e., storage of stormwater in the dry pond for a short period of time) to control the 2-year peak flow rate for stream bank erosion control purposes. Unfortunately, this policy has not been able to achieve its objective of stream channel protection.

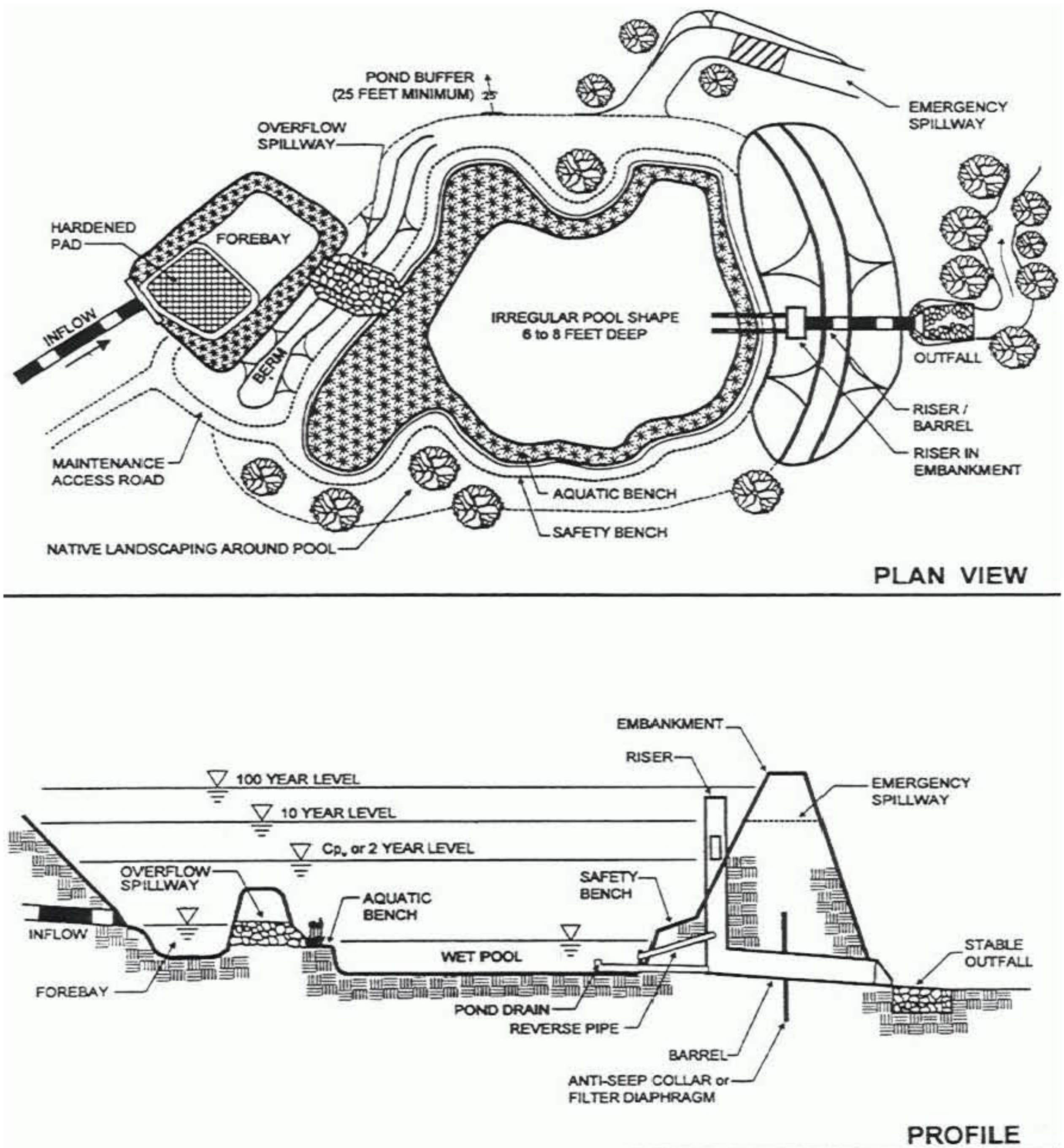

Figure 5-1 Wet Pond Typical Detail (MDE, 2000)

Figure 5-2 Typical Dry Pond

In the early 1980s, watershed managers began to restrict the flow out of the dry ponds even further so that a pool of stormwater would remain (be detained) in the pond for much longer periods of time. This approach to dry pond design was called extended detention ponds (see Figure 5-3). . Extended detention for stormwater quality began to be used for new installations of extended detention ponds or as retrofits of old dry ponds. By the late 1980s, sufficient empirical data were available to design extended detention basins for water quality purposes with reasonable confidence in their performance. Extended detention refers to a basin designed to extend detention beyond that required for stormwater control to provide some water quality affect. Extended detention basins are best at removing settleable constituents. They are as effective in removing soluble solids as other BMPs that incorporate other treatment mechanisms.

The amount of pollutant reduction achievable in ponds depends on a wide variety of factors, including: continuous long term-inflow, surface area and effective volume of the basin, peak outflow rate, size distribution of the particles, specific gravity of particles, fraction of the sediment that is active clay, type of associated pollutant concentrations, and fraction of influent solids that are colloidal, dissolved and or unsettleable.

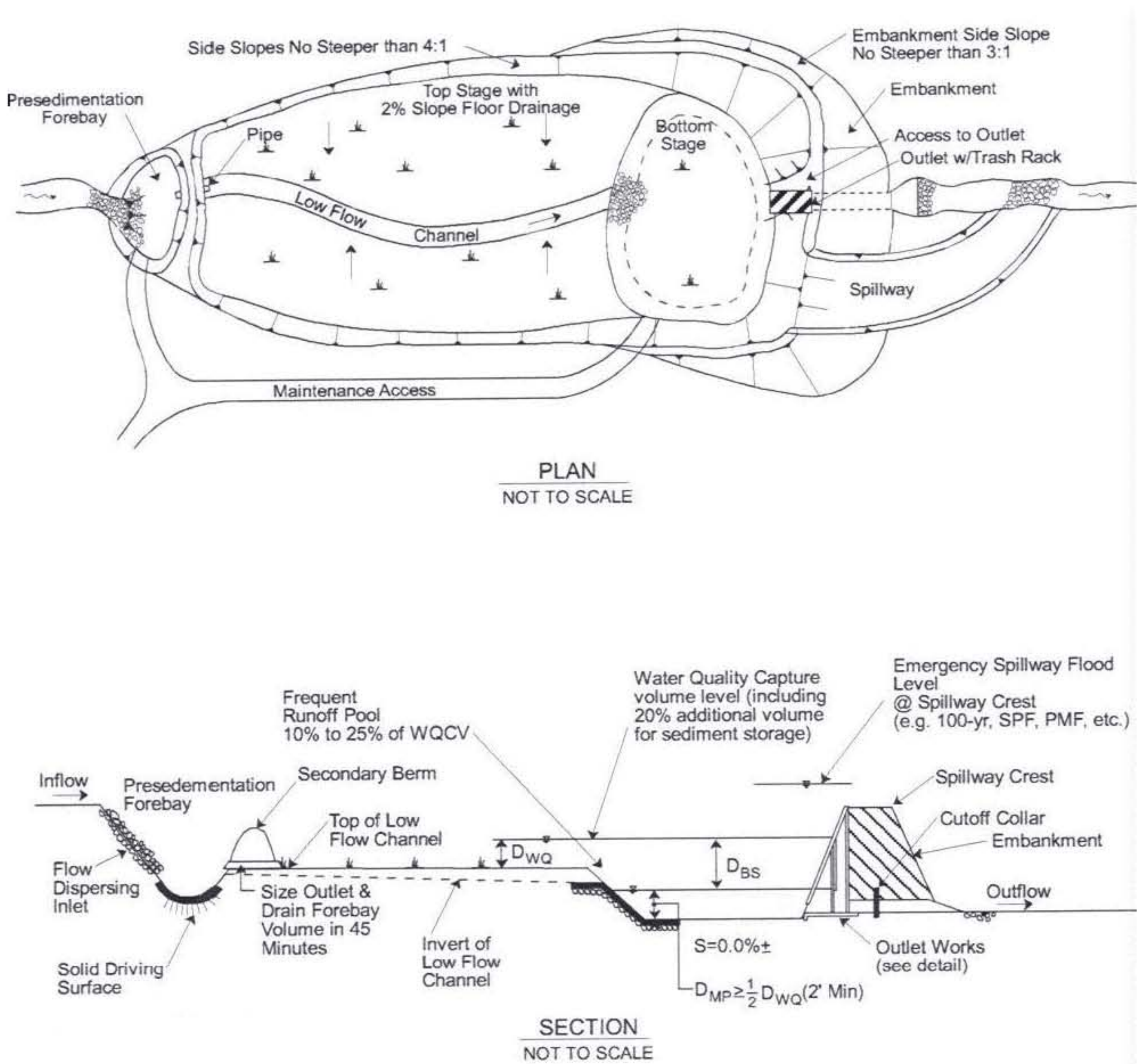

Figure 5-3 Extended Detention Basin, Typical Detail (UDFCD, 1999)

Extended detention basins sometimes have a small permanent pool below the invert of the low flow outlet. This is normally so small that it does not materially impact trapping of suspended solids and chemicals and is typically included for aesthetics or to cover deposited sediments.

Regional facilities often offer economies of scale and greater reliability in capturing stormwater when they are used, while on-site facilities offer institutional and fiscal advantages of implementation as the land is urbanized. The advantages and disadvantages of regional and on-site facilities are described in Chapter Three.

Group 3 - Infiltration Basins Infiltration basins are dry ponds constructed to allow infiltration to occur simultaneously with other treatment processes. Figure 5-4 provides a typical detail for an infiltration basin. The operating characteristics of infiltration basins is essentially the same as for dry detention ponds, with a few significant exceptions:

1. Infiltration basins also remove dissolved and colloidal solids in the volume of infiltrated water, whereas extended detention ponds can only remove the fraction of colloidal solids sorbed to settleable solids
2. The settling velocities of sediment particles and particulate (settleable) chemicals are increased by a value equal to the infiltration rate in the basin. The impact would, of course be more important for the clay (colloidal) sized particles than for silt, sand, and small or large aggregates.
3. Infiltration practices differ from typical dry basins because they contribute to groundwater recharge, therefore providing an additional element of performance.
4. Because they can provide volume control, infiltration basins can effectively address the issues of increased frequency and duration of peak flows that are important in providing downstream channel protection.
5. Because they operate by infiltration of runoff into the subsurface soils, infiltration basins are able to preclude the thermal impacts issues associated with detention , extended detention and wet ponds.

The use of infiltration practices depends on careful site investigation. Table 3-7 and 3-8 previously addresses some of the concerns with infiltration, which primarily focus on possible contamination of groundwater. If allowed by local conditions, i.e. allowed by local regulation and provided that the infiltrating soil has sufficient infiltration capacity, infiltration basins are an excellent watershed management tool to enhance water quality.

5.2 Design of Wet Ponds to Maximize Sedimentation

The primary removal mechanism for pollutants in wet ponds is by settling of the solid materials. Thus, wet ponds should be designed to maximize sedimentation within the permanent pool. The permanent pool of water is equal to some fraction or multiple of the runoff volume. The runoff displaces a portion of the pool volume and is treated during the dry period and in turn is displaced by the next storm. A schematic of this wet pond design is illustrated in Figure 5-1. Schueler and Helfrich (1989) summarized some typical design criteria for this approach in Table 5-1.

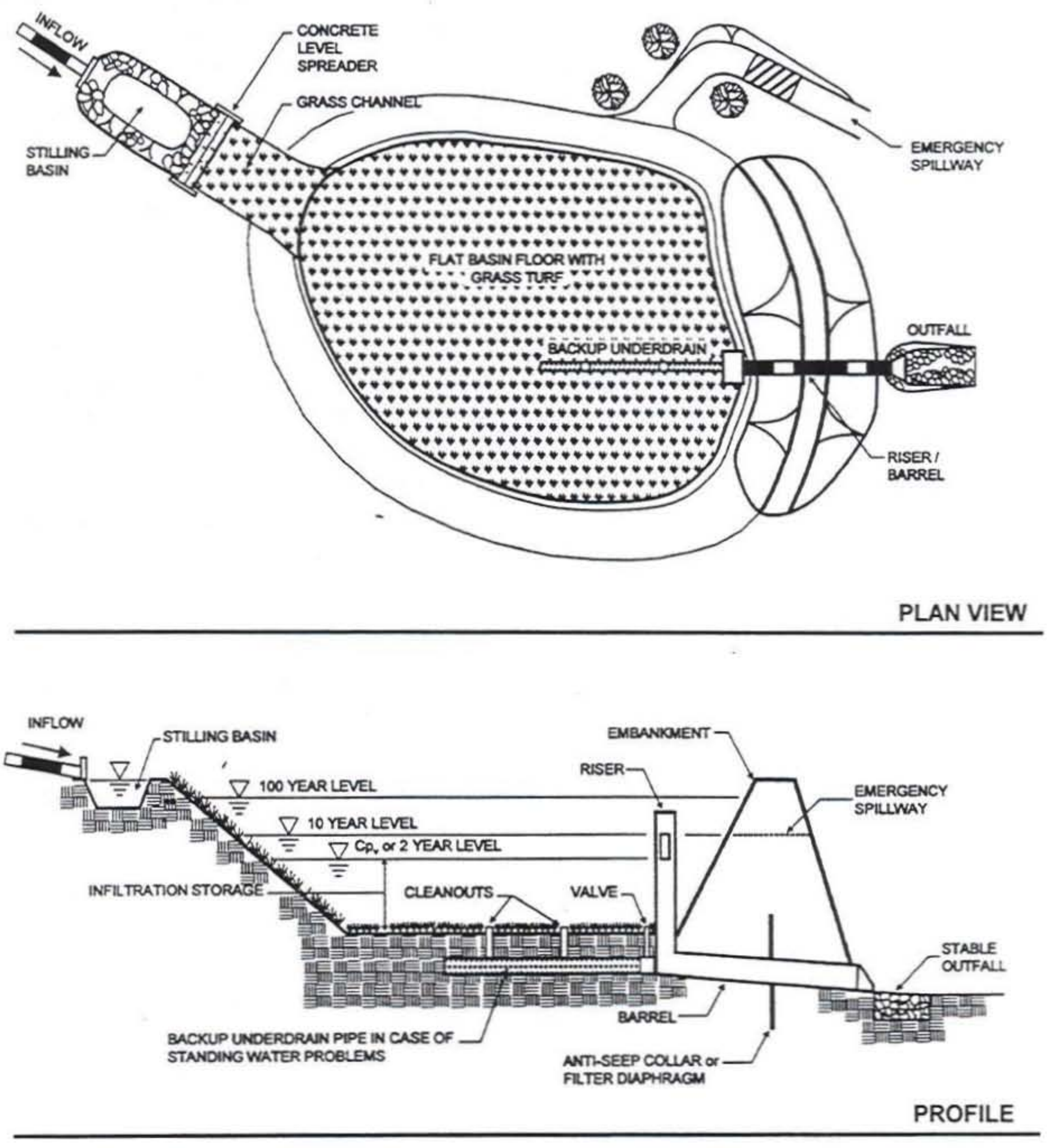

Figure 5-4 Infiltration Basin, Typical Detail (MDE, 2000)

Table 5-1 Hydrologic and Hydraulic Design Criteria for Standard Extended Detention Wet Pond System (Schueler and Helfrich, 1989)

Permanent Pool Storage	
Design criteria	Treat first flush of runoff
Storage volume	For first inch of rainfall = Rv * drainage area (sq ft)/12, where Rv = 0.05 + (0.009 * percent imperviousness) - see footnote
Water surface elevation	Established by invert of ED Pipe
Pipe Sizing (Pool drain)	Drain pool volume within 24 hours
Extended Detention Storage	
Design criteria	Provide minimum 24 hours of detention for next one-half inch watershed runoff
Storage volume	One-half inch * watershed area
Water surface elevation	Upper limit set at beginning of 2 year stormwater storage
Pipe sizing - Allowable release rate (Qr)	(Qr) = [(0.5 acre - in.)(43560 cf / acre) (ft / 12 in)] / [2(24hrs)]
Two Year Storm Event Peak Discharge Control Storage	
Design criteria	Maintain Pre-Development Peak Discharge for the Two Year Design Storm Event
Storage volume	Obtained from TR-55, short cut method , TR-20, HEC-HMS or other methods which produce similar results
Water surface elevation (W.S.E.)	Upper limit: bottom of 100-year storage. Lower limit: top of extended detention storage.
Safety Storm / Emergency Spillway	
Design criteria	Safety storm (SS): Design event depends on hazard class Emergency Spillway: Must pass safety storm
Storage volume	SS: Obtained from TR-20 (NRCS, 1982) ES: Obtained from NRCS Spillway charts (NRCS, 1982)

Footnote: Using this formula, to control the first inch of rainfall at a 5 acre development with 25% imperviousness, you would need: storage volume = ((0.05 + (0.009 * 25)) * 217,800/12 = 4,990 cu ft. 25% is 25 in this equation, not 0.25. Also, one-drainage area inch * drainage area is the volume of rain falling on the drainage area in inch-square feet.

A second approach treats the wet pond as a lake with controlled levels of eutrophication to account for the biological and physical/chemical processes that are principal mechanisms for nutrient removal (Hartigan, 1989 and Walker, 1987). General criteria for this approach are summarized in Table 5-2. Both approaches relate the pollutant removal efficiencies to hydraulic residence time.

Table 5-2 Recommended Criteria for Wet Pond Design for Nutrient Removal* (Hartigan et al, 1989)

Design Parameter	**Recommended Criteria**	
	On-Site Wet Pond	Regional
1. Storage Volume (Permanent Pool)	a. T = 2 weeks or more b. VB / VR > 4 or more	Same as onsite
2. Mean Depth (Permanent Pool)	3 to 6 feet	Same as onsite
3. Surface Area (Permanent Pool)	> 0.25 acres	3 to 5 acres or more
4. Drainage area	Minimum of 20 - 25 acres	100 - 300 acres depending on impervious cover
5. Side slopes	5:1 to 10:1 (H:V)	
6. Length/width ratio	2:1 or greater	
7. Soils at site	Hydrologic Soil Groups B,C, and D (Compaction may be required on A and B soils)	

T = average hydraulic residence time
* Projected Nutrient removal (P=65%, Solids 85-90%)

The design approach should be selected based upon the target of the control efforts as well as site and economic constraints. The controlled eutrophication approach requires longer residence times and larger storage volumes comparable to those of the solids settling approach. However, where the chief concern is to control nutrient levels in waters such as lakes and reservoirs, it is then advantageous to use the controlled eutrophication. If the major goal is the removal of a broad spectrum of pollutants, especially those adsorbed onto suspended matter, it may be preferable to base the design criteria on the sedimentation models. Presently, most pond water quality practice designs for runoff pollution control rely heavily on the sedimentation process.

Volume of the Permanent Pool This volume, in relation to the drainage area or runoff volume, is the most critical parameter in the sizing of the wet pond and its ability to remove pollutants. Various design criteria or rules of thumb are expressed in terms of the VB/VR ratio where VB is the volume of the permanent pool and VR is the volume of runoff for an average storm. A starting point for selecting a design would be to size the pool for a hydraulic detention time, which is a simple calculation to make. An estimate of the detention time T (in years) is given by dividing the permanent pool volume VB by the product of the total number of runoff events per year, n, namely:

$$T = \frac{VB}{n\,VR}$$

Field studies indicate that an optimum nutrient removal of approximately 50% occurs at *T* values of 2 to 3 weeks for pools with mean depths of 3 to 6 ft (Hartigan, 1989). In the eastern U.S., this optimum range for T values corresponds to *VB/VR* ratios of 4 to 6. Ponds with values of *T* greater than 2 to 3 weeks have a greater risk of thermal stratification and anaerobic bottom waters, resulting in an increased risk of significant export of nutrients from bottom sediments and possible odor problems if the pond becomes anaerobic.

State and regional stormwater management regulations and guidelines often address design criteria for the permanent pool storage volume in terms of either average hydraulic retention time, *T,* the ratio *VB/VR*, or minimum total suspended sediment removal rate. For example, the State of Florida requires an average hydraulic retention time of 14 days, equivalent to *VB/VR* of 4; the Urban Drainage and Flood Control District's BMP criteria manual in the Denver, Colorado, area (UDFCD, 1992) specifies that the permanent pool storage volume should be 1.0 to 1.5 times the "water quality capture volume," which is equivalent to *VB/VR* on the order of 1.5 to 2.5. A municipal BMP handbook published by the California State Water Resources Control Board (Camp Dresser & McKee et al., 1993) recommends that retention pond permanent pools be sized for a *VB/VR* of 3.

Some State or local regulations require detention of a specified runoff volume as surcharge above the permanent pool. Storage in the surcharge zone is released during a specified period through an outlet structure. This surcharge detention requirement is intended to reduce short circuiting and enhance settling of total suspended sediments. Settling-solids analysis shows that retention ponds sized for nutrient removal with a minimum detention time, *T*, of 2 weeks and a minimum *VB/VR* of 4 achieve total suspended sediment removal rates of 80 to 90%. North Carolina's stormwater disposal regulations for coastal areas and water supply watersheds specify that the permanent pool should be sized to achieve a total suspended sediment removal rate of 85%, which is equivalent to a *VB/VR* in the range of 3 to 4 when no surcharge extended detention is provided. With surcharge extended detention, 85% removal of total suspended sediments has been achieved with a *VB/VR* of 2 or less.

Addition of an extended detention zone above the permanent pool is unlikely to produce measurable increases in the removal of total suspended sediments. Still, a surcharge extended detention volume is recommended whenever the VB/VR, is less than 2.5. Whenever one is used or required, it is suggested that the maximized event-based volume with a 12-hour drain time be used. In cases where relatively permeable soils (HSG A and B) are encountered and infiltration basins are not an option, the risk of drawdown may be minimized by installing a six inch clay liner at the bottom of the pond (HSG A), or simply by compacting the pond soils (HSG B).

Pool Depth The depth of the permanent pool is an important design parameter since it affects solids settling. Mean depth of the pool is obtained by dividing the storage volume by the pool surface area. The pool should be shallow enough to ensure aerobic conditions and avoid thermal stratification, yet be deep enough to minimize algal blooms and resuspension of previously deposited materials by major storms and wind generated disturbances. Prevention of thermal stratification will minimize short-circuiting and maintain aerobic bottom waters, thus maximizing pollutant uptake and minimizing the potential release of nutrients to the overlying waters. An average depth of 3 to 6 ft is sufficient to maintain the environment within the pool. A ten-foot wide and one-foot deep bench is needed around the perimeter of the pool to promote native aquatic vegetation and to reduce a potential safety hazard to the public. Shallow depth near the inlet structure is desirable to concentrate sediment deposition in a smaller and easily accessible area. The riser should be located in a deeper area to facilitate withdrawal of cold bottom water for the mitigation of downstream thermal impacts, if any.

Mean depth of the permanent pool is calculated by dividing the storage volume by the surface area. The minimum depth of the open water area should be greater than the depth of sunlight penetration to prevent emergent plant growth in this area, namely, on the order of 6 to 8 ft. A mean depth of approximately 3 to 10 ft should produce a pond with sufficient surface area to promote algae photosynthesis and should maintain an acceptable environment within the permanent pool for the average hydraulic retention times recommended above, although separate analyses should be performed for each locale. If the pond has more than 2 ac of water surface, mean depths of 6.5 ft will protect it against wind generated resuspension of sediments. The mean depths of the more effective retention ponds monitored by the NURP study typically fall within this range. A water depth of approximately 6 ft over the major portion of the pond will also increase winter survival of fish (Schueler, 1987).

A maximum depth of 10 to 13 ft should be used to reduce the risk of thermal stratification. However, in the State of Florida, pools up to 30 ft deep have been successful when excavated in high groundwater areas. This is probably because of improved circulation at the bottom of the pond as a result of groundwater moving through it.

Readily visible stormwater management facilities receive more and better maintenance than those in less visible, more remote locations. Readily visible facilities can also be inspected faster and more easily by maintenance and mosquito control personnel. If maintained at the recommended 3 to 6 ft depth, the permanent pool can serve as aquatic habitat.

Minimum Surface Area of Permanent Pool Minimum surface area will be contingent upon local topography, minimum depth and solids settling guidelines. For on-site wet pond water quality basins, the typical minimum pool surface area is 0.25 acres.

Minimum Drainage Area and Pond Volume The minimum drainage area for an on-site wet pond water quality structure should be large enough to sustain the wet pond during the summer periods. The drainage area should permit sufficient base flow to prevent excessive retention times or severe drawdown of the permanent pool during dry seasons. Unless regional experience is available for determining the minimum drainage area required in a particular location, it is recommended that a water balance calculation be performed using local runoff, evapotranspiration, exfiltration, and base flow data to ensure that the base flow is adequate to keep the pond full during the dry season. Baseflow will, of course, vary considerable from watershed to watershed in a region. However, a regional analysis would be helpful. This information is typically available from the USGS offices in a state or possibly the local NRCS office.

The maximum tributary catchment area should be set to reduce the exposure of upstream channels to erosive stormwater flows, reduce effects on perennial streams and wetlands, and reduce public safety hazards associated with dam height. Again, regional experience will be useful in providing guidelines. For example, in the southeastern U.S., some stormwater master plans have restricted the maximum tributary catchments to 100 to 300 acres, depending on the amount of imperviousness in the watershed, with highly impervious catchments restricted to the lower end of this range and vice versa. On the other hand, experience in semiarid areas has shown that even a small area of new land development can cause downstream erosion and that drainage way stabilization is needed between the new development and the pond for relatively small catchments.

As a rule of thumb, a minimum drainage area of 20 acres is required to sustain the desired dry weather inflow. In general, 4 acres of contributing drainage area are needed for each acre-foot of storage. As indicated earlier, however, a local analysis is needed.

Side Slopes Side slopes along the shoreline of the retention pond should be 4H:1V or flatter to facilitate maintenance (such as mowing) and reduce public risk of slipping and falling into the water. In addition, a littoral zone should be established around the perimeter of the permanent pool to promote the growth of emergent vegetation along the shoreline and deter individuals from wading. The emergent vegetation around the perimeter serves several other functions: it reduces erosion, enhances the removal of dissolved nutrients in urban stormwater discharges, may reduce the formation of floating algal mats, and provides habitat for aquatic life and wetland wildlife. This bench for emergent wetland vegetation should be at least l0 ft wide with a water depth of 0.5 to 1.5 ft. The total area of the aquatic bench should be 25 to 50% of the permanent pool's water surface area. Local agricultural agencies or commercial nurseries should be consulted about guidelines for using wetland vegetation within shallow sections of the permanent pool.

Pond Configuration Length-to-width ratio of the pond should be as large as possible to simulate conditions found in plug flow reaction kinetics. Under the ideal plug flow conditions, a “plug” or “pulse” of runoff enters the basin and moves as a plug through the pond without mixing. Relatively large length-to-width ratios can help reduce short circuiting, enhance sedimentation, and help prevent vertical stratification within the permanent pool (Griffin et al., 1988) showed that the dead storage for length to width ratios less than 2:1 was in the range of 27 percent and for length to width ratios greater than 2:1 was in the range of 17 percent. A minimum length-to-width ratio of 2:1 is therefore recommended for the permanent pool. The permanent pool should expand gradually from the basin inlet and contract gradually toward the outlet, maximizing the travel time from the inlet to the outlet. Baffles or islands within the pool can increase the flow path length and reduce short circuiting. Hartigan et al. (1989) recommendations of a minimum 3:1 ratio for optimal sedimentation (Table 5-1) did not consider the use of baffles.

To reduce the frequency of major clean out activities within the pool area, a sediment forebay with a hardened bottom should be constructed near the inlet to trap coarse sediment particles. A frequently used value for the forebay storage capacity is approximately 10% of the permanent pool storage. Access for mechanized equipment should be provided to facilitate removal of sediment. The forebay can be separated from the remainder of the permanent pool by one of several means: a lateral sill with wetland vegetation, two ponds in series, differential pool depth, rock-filled gabions, a retaining wall, or a horizontal rock filter placed laterally across the permanent pool.

Outlets An outlet for a retention pond typically consists of a riser with a hood or trash rack to prevent clogging and an adequate antivortex device for basins serving large drainage areas. Antiseep collars should be installed along outlet conduits passing through or under the dam embankment. If the pond is a part of a larger peak-shaving detention basin, the outlet should be designed for the desired flood control performance. Typically, the riser structure should be sized to drain the permanent pool within 40 hours so that sediments may be removed mechanically when necessary. The drain pipe should be controlled by a lockable gate valve at the outlet. Flat areas may require the use of weirs instead of risers.

An emergency spillway must be provided and designed using accepted engineering practices to protect the basins embankment. The return period of the design storm for the emergency spillway depends on the hazard classification, which can vary from region to region. The designer should make certain that the pond embankment and spillway are designed in accordance with federal, state, and local dam safety criteria.

Documentation of the classification of dams is normally required for plan approval by the local regulatory agency. Such documentation typically includes, but is not limited to, location and description of dam, configuration of the valley, description of existing development (houses, utilities, highways, railroads, farm or commercial buildings, and other pertinent improvements), potential for future development, and recommended classification. The classification of a dam is normally the responsibility of the designer, and subject to review and concurrence by the approving authority. The classification of a dam is normally determined only by the potential hazard from failure. Classification factors can be obtained in the NRCS National Engineering Manual.

The inlet design should dissipate flow energy and diffuse the inflow plume where it enters the forebay or permanent pool. Examples of inlet designs include drop manholes, energy dissipaters at the bottom of paved rundown, a lateral bench with wetland vegetation, and the placement of large rock deflectors.

Thermal Effects Thermal effects of the wet pond must be considered since the pool acts as a heat sink during the summer period, between the storm events. When the water is displaced from the pool, it may be as much as 10 degrees Fahrenheit warmer than naturally occurring baseflow. Large impervious surfaces can also significantly raise the temperature of runoff in the summer months. The net result of elevated pool temperatures may have an adverse impact on downstream coldwater uses such as trout production. Most streams in mature urban areas do not fall into this category. However, in newly urbanizing areas, the pond designer should pay special attention to the potential of thermal effects on downstream water bodies supporting cold water fisheries. Thermal impacts in such areas may be eliminated or mitigated by: (a) prohibiting wet ponds altogether, (b) diverting most of the baseflow and bypassing the wet pond entirely, (c) utilizing a design with a drastically undersized permanent pool, (d) using a design with a deep pool and positioning the inlet of the outlet pipe to withdraw cooler water from near the bottom, (e) planting shade trees on the periphery of the pool (other than the dam) to reduce warming in the summer, (f) directing baseflow through the wetland while channeling storm flow to a fringe pool area and (g) employing a series of pools in sequence rather than a single one.

Other Considerations A wet pond basin contains a permanent pool in addition to the flood control storage. To maintain water quality (oxygen levels), control mosquito breeding and prevent stagnation, a sufficient inflow of water (either surface or ground water) is necessary on a regular basis. A fountain or solar powered aerator may be used for oxygenation of water. The potential effects of sediment loading on the permanent pool should be considered when determining if a site is suitable for a wet pond basin. The use of existing lakes and ponds as wet ponds for treatment of stormwater is sometimes prohibited.

A well designed pond will accumulate considerable quantities of sediment. A typical clean out cycle for a wet pond in a stabilized watershed is approximately 10 years, with sediment removal at each cycle costing as much as 20 - 40% of the initial construction cost.

5.3 Design of Extended Detention Basins for Water Quality Improvements

Design Considerations - Sizing the Basin Extended detention basins are normally sized to store the peak storm flow and then discharge it after the rainfall subsides. This means that the peak flow after urbanization matches the pre-development peak flow. Procedures for making this design are straightforward and equations range from simple relationships to those that require the use of computer models such as HEC-HMS (U.S. Army Corps of Engineers, 2001) and the NRCS TR20 (USDA, 1986) program. The design can be for an average storm or for 2, 10, 25, 50, and 100 year storms, depending on the regulatory authority.

Basin Configuration Extended detention basins should be made an integral part of the community as much as possible. Consideration should be given to multiple uses, aesthetics, safety, and the way the facility will fit into the urban landscape. Also, maintenance is an important consideration, and the design layout must provide access for maintenance equipment. Although these basins provide passive treatment with no operational attention, continued successful performance will depend on good maintenance.

Figure 5-3 shows an idealized layout for an extended detention basin. The individuality of each on-site or regional facility and its place within the urban community make it incumbent on the designer to seek out local input, identify site constraints, identify the community's concerns, and consider a wide array of possibilities during design.

Storage Volume Storage volume, sometimes called capture volume, is needed to detain the flow long enough to capture the desired pollutants and keep the peak discharge less than the pre-developed peak. If significant sedimentation is occurring, an additional volume should be added to account for the deposited solids. For critical areas, a complete sediment yield analysis over a period of years (e.g., 20 years) would need to be made to determine the probable build-up of deposited sediment. For less critical areas, an addition of 20% to this detention volume to provide for sediment accumulation is a reasonable assumption. Randall et al. (1982) and Whipple and Hunter (1981) suggest that such detention basins be designed to promote sedimentation of small particles, namely smaller than 60 microns in size, which account for approximately 80% of the suspended sediment mass found in stormwater (Urbonas and Stahre, 1993).

Selection of pond volumes and design of outlets should allow time for most of the stormwater particles to settle. This includes particles in the first part of the storm, so consideration should be given to providing an outlet to empty less than 50% of the design volume in the first one-third of the design emptying period (that is, 12 to 16 hours). This ensures that small runoff events will be detained long enough to remove small suspended solids. Also, the discharge from the pond will be slower immediately after a storm than hours later, while releasing small rain events more slowly than larger ones. A long emptying time-thus the term extended detention-permits smaller particles to attach to the bottom of the basin and become trapped.

Flood Control Storage Whenever feasible the functions of the extended detention basin should be incorporated within a larger flood control facility. The designer may want to consider combining water quality and flood control functions in a single detention basin.

Basin Geometry The basin should gradually expand from the inlet and contract toward the outlet to reduce short circuiting. Griffin et al. (1985) found that an aspect ratio (length to width ratio) of 2:1 or greater reduces short circuiting within the pond.

Two-Stage Design A two-stage basin is preferable. The lower stage has a micropool that fills frequently. This reduces the periods of standing water and sediment deposition in the remainder of the basin. The upper stage should be 2 to 6 ft deep, its bottom sloping at approximately 2% toward a low-flow channel. The bottom pool should be 1.5 to 3 ft deeper and should be able to store 15 to 25% of the capture volume. These recommendations do not necessarily apply to large, regional extended detention basins. The impact of these considerations varies with climate and soil types.

Basin Side Slopes Basin side slopes must remain stable under saturated soil conditions. They also need to be sufficiently gentle to limit rill erosion, facilitate maintenance, and address the safety issue of individuals falling in when the basin is full of water. Side slopes of 4:1 H:V and flatter provide well for these concerns.

Forebay The basin should be designed to encourage sediment deposition to occur near the point of inflow. A forebay with a volume equal to approximately 10% of the total design volume can help with the maintenance of the basin, and the service life of the remainder of the basin can be extended. A stabilized access and a concrete or soil cement lined bottom should be used to prevent mechanical equipment from sinking into the bottom. This should also facilitate sediment removal, since the procedure of scraping material from a concrete bottom will not necessitate reforming the bottom or resetting/repairing liners.

Basin Inlet Most erosion and sediment deposition occurs near the inlet. An ideal inflow structure will convey stormwater to the basin while preventing erosion of the basin's bottom and banks, reducing resuspension of previously deposited sediment and facilitating deposition of the heaviest sediment near the inlet. These design goals are achievable in most cases, allowing for minor compromises. Inflow structures can be drop manholes, rundown chutes with an energy dissipater near the bottom, a baffle chute, a pipe with an impact basin, or one of the many other types of diffusing devices.

Low-Flow Channel A low-flow channel may be required by local regulation to convey trickle flows and the last of the captured volume to the outlet. This device prevents water logging and enhances the growth of vegetation. It also accelerates flows from small storms and is not recommended from a receiving water quality standpoint.

Outlet Type and Protection An outlet capable of slowly releasing the design capture volume over the design emptying time should be used. An arrangement of an outlet was suggested by Schueler et al. (1992), wherein a hooded and perforated riser is located in a small permanent pool, such that a micro pool is formed. Additionally, a number of alternative details for outlet structures are available.

Because extended detention basins are designed to encourage sediment deposition and urban stormwater has substantial quantities of settleable and floatable solids, basin outlets are prone to being clogged. This can make the design of reliable outlet structures for extended detention basins difficult. A clogged outlet will invalidate the hydraulic function of even the best design.

The diameter of the low flow orifice is a key element of outlet design. ASCE (1985), ASCE (1992), DeGroot (1982), Roesner et al. (1989), Schueler (1987), Schueler et al. (1992), Urbonas and Roesner (Eds.) (1986), and Urbonas and Stahre (1993) reported many reasons for outlet problems, which include clogging by trash and debris, burial by silt, vandalism, animals blocking an outlet (i.e., rodent nests) and other factors that modify its discharge characteristics. Each outlet has to be designed with clogging, vandalism, maintenance, aesthetics, and safety in mind. An orifice that is too large may result in high discharge rates for smaller storms. The smaller storms which contain the bulk of the annual pollution load would have short residence times in the BMP and this would result in limited water quality benefit. Smaller outlet orifices are necessary to maximize detention times of smaller storms (Newman et al., 2000).

If the outlet is not protected by a gravel pack, some form of a trash rack should be provided. Wrapping a perforated outlet in a geotextile filter cloth, which will clog quickly, is not a recommended practice.

Dam Embankment The dam embankment should be designed and built so that it will not fail during storms larger than the water quality design storm. An emergency spillway should be provided or the embankment designed to withstand overtopping commensurate with the size of the embankment, the volume of water that can be stored behind it, and the potential of downstream damages or loss of life if the embankment fails. Emergency spillway designs vary widely with local regulations. Embankments for small on-site basins should be protected from at least the 100-year flood, while the larger facilities should be evaluated for the probable maximum flood. Consulting the state's dam regulatory agency is always a good idea..

Embankment slopes should typically be no steeper than 3:1, preferably 4:l or flatter. They also need to be planted with turf-forming grasses. Embankment soils should be compacted to 95% of their maximum density at optimum moisture.

Vegetation A basin's vegetation provides erosion control and enhances sediment entrapment. The basin can be planted with native grasses or with irrigated turf, depending on the local setting, basin design, and its intended other uses (such as recreation). Sediment deposition, along with frequent and prolonged periods of inundation, make it difficult to maintain healthy grass cover on the basin's bottom. Options for an alternative bottom liner include a marshy wetland bottom, bog, layer of gravel, riparian shrub, bare soil, low weed species, or other type that can survive the conditions found on the bottom of the basin.

Maintenance Access Vehicular maintenance access to the forebay should be available along with the outlet areas with grades that do not exceed 8 to 10% and have a stable surface of gravel-stabilized turf, a layer of rock, or concrete pavement.

5.4 Maintenance of Pond BMPs

Regular inspection and maintenance of BMPs are necessary if these facilities are to consistently perform up to expectations. Stormwater management systems are expected to perform quality and quantity control functions as long as the land use they serve exists. Failure to maintain these systems can create the following adverse impacts:

- Increased discharge of pollutants downstream.
- Increased risk of flooding downstream.
- Increased downstream channel instability, which increases sediment loadings and reduces habitat for aquatic organisms.
- Potential loss of life and property, resulting from catastrophic failure of the facility.
- Aesthetic or nuisance problems, such as mosquitoes or reduced property value, due to a degraded facility appearance.

Most of these impacts can be avoided through proper and timely inspection and maintenance. A major concern associated with these impacts is the general public's expectations relating to the quality of life provided, in part, by construction of these systems. Inadequate maintenance means the general public may have a false sense of security. The most common cause of stormwater system failure is the lack of adequate and proper operation, inspection, maintenance, and management. If stormwater management systems are not going to be adequately maintained, the facilities should not be constructed in the first place.

Good design and construction can reduce subsequent maintenance needs and costs but they cannot eliminate the need for maintenance altogether. Maintenance requires a long term commitment of time, money, personnel, and equipment. Monitoring the overall performance of the stormwater management system is a major aspect of any maintenance program. Wet detention and wetland systems are especially complex environments which require a healthy aquatic ecosystem to provide maximum benefits and to minimize needed maintenance.

Chapter Six
Types of Vegetative Biofilters and Their Ability to Remove Pollutants

6.1 Introduction

Historically vegetative biofilters, such as grass swales, were used primarily for stormwater conveyance (Ree, 1949; Chow, 1959; Temple, 1987). However with the passage of the Clean Water Act, and the focus on water quality management of urban runoff, the potential for the application of these techniques has begun to be reconsidered and many additional benefits have been identified. Today biofilters are being applied to address design objectives of urban stormwater management. These include: reduction of urban runoff impacts, groundwater recharge, water quality control, stream channel protection, and peak discharge control for both small storms (6-month and 1-year frequency storms), and large storms (2, 10 and 100-year storms). The most common application of the biofilters, however, is typically their use as the first stage of the treatment train approach and their purpose is to partially address groundwater recharge and water quality control for small headwater areas.

Three different types of vegetative biofilter BMP types have been identified and are described in this document. These are: grass swales, vegetated filter strips, and bioretention cells. Grass swales include three variations: traditional grass swales, grass swales with media filters and wet swales.

6.2 Grass Swale

Grass swales have traditionally been used as a low cost stormwater conveyance practice in low-to-medium density residential developments (e.g., ½- acre lots). Most public works agencies throughout the U.S. have a typical rural road sectional that allows the use of vegetated swales within the public right of way. During the early years of stormwater management technology the focus was on peak discharge control and grass swales were not given much consideration. As the focus of stormwater management programs expanded to include water quality considerations and pollutant reduction, the grassed swale has been perceived to represent a potentially important element of the treatment train approach to total stormwater management (Yousef, et al, 1986; Yu, 1992; Yu, 1993).

Grass swales have a number of desirable attributes with respect to total stormwater management (MDE, 2000; ASCE, 1998; CRC, 1996; Yu, 1993;) including:

- slower flow velocities than pipe systems that result in longer times of concentration and corresponding reduction of peak discharges;
- ability to disconnect directly connected impervious surfaces, such as driveways and roadways thus reducing discharge;
- filtering of pollutants by grass media;
- infiltration of runoff into the soil profile thus reducing discharges, providing additional pollutant removal, and increasing groundwater recharge; and
- uptake of pollutants by plant roots (phytoremediation)

A typical grass swale is shown in Figure 6-1. The section shows that the water quality volume (WQv) is a fraction of the typical 2 and 10 year design storms.

Grass Swale with Media Filters Also known as a dry swale, this grass swale consists of an open channel that has been modified to enhance its water quality treatment capability by adding a filtering medium consisting of a soil bed with an underdrain system (CRC, 1996). It is designed to temporarily store the design water quality volume (WQv) and allow it to percolate through the treatment medium. The system is designed to drain down between storm events within approximately one day. The water quality treatment mechanisms are similar to bioretention cells except that the pollutant uptake is likely to be more limited since only a grass cover crop is available for nutrient uptake.

Wet Swale The wet swale also consists of a broad open channel capable of temporarily routing and storing the water quality volume (WQv) but does not have an underlying filtering bed (CRC, 1996). It is constructed directly within existing soils and may intercept the water table. Like the dry swale, the WQv within the wet swale should be stored for approximately 24 hours. The wet swale has water quality treatment mechanisms similar to stormwater wetlands, both of which rely primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems. Figure 6-2 illustrates the design components of the wet swale (MDE, 2000).

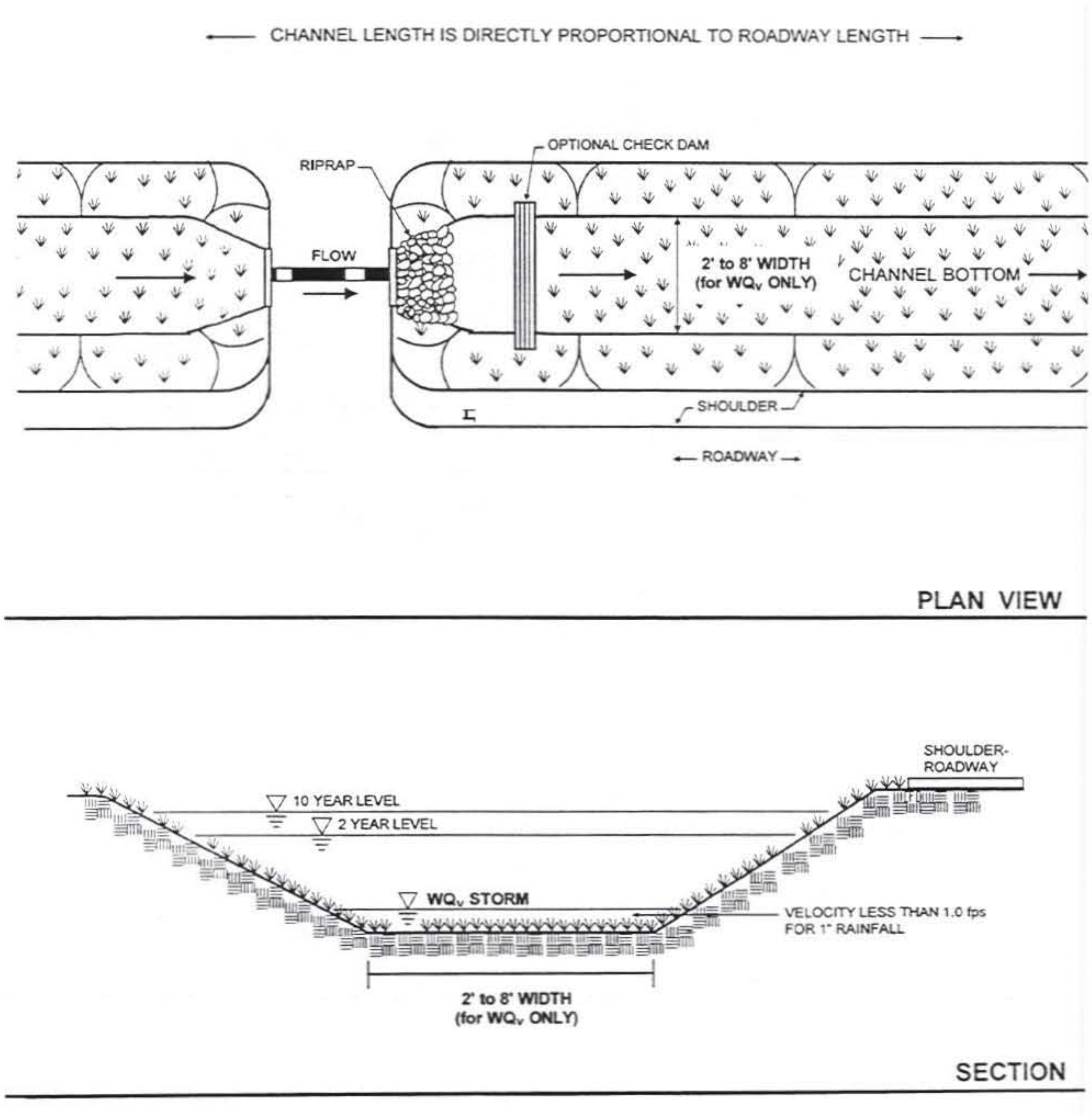

Figure 6-1 Grass Swale (MDE, 2000)

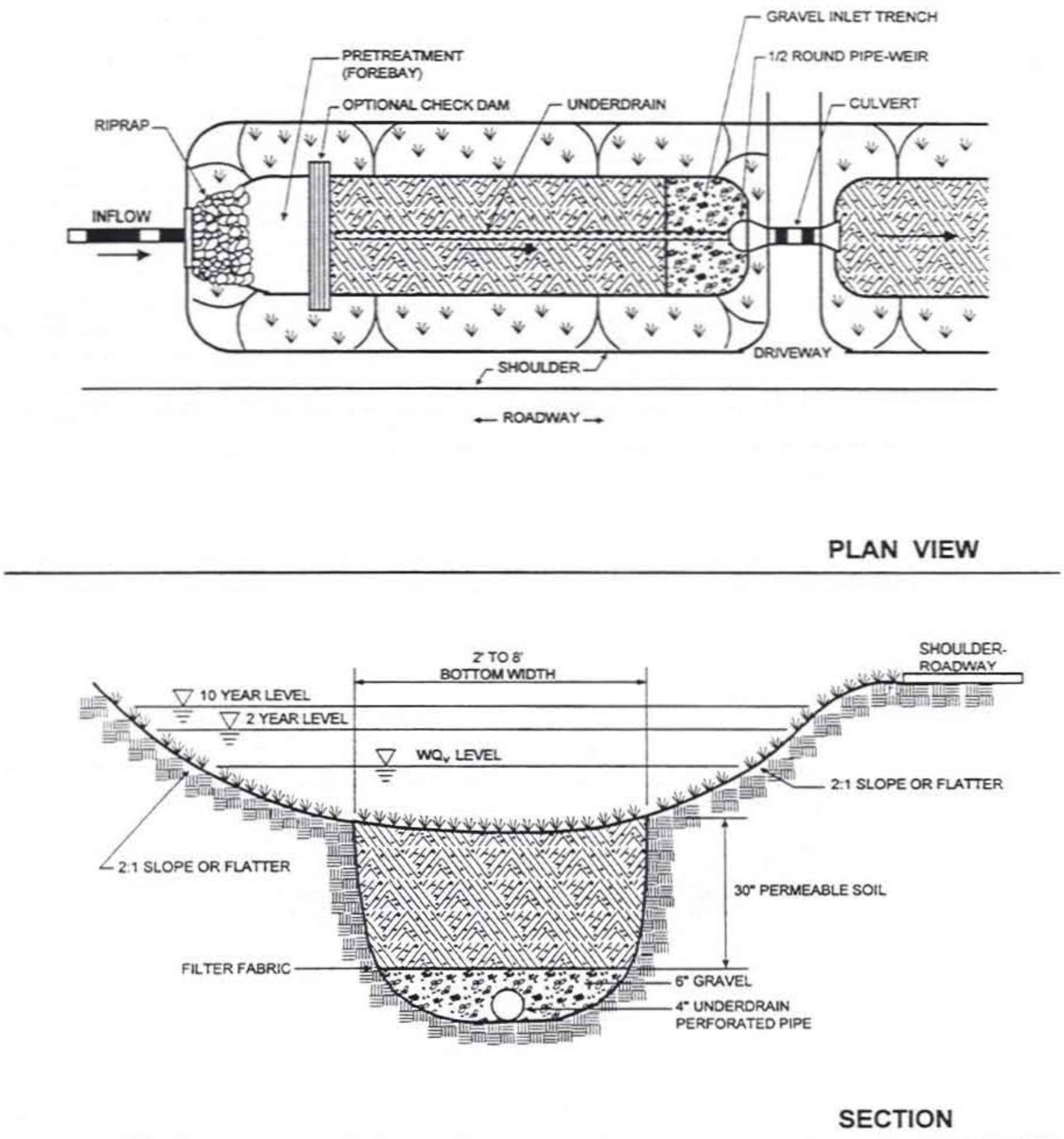

Figure 6-2 Wet Swale (MDE 2000)

6.3 Vegetative Filter Strip

Vegetative filter strips (VFSs) and buffers are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. They can either be constructed or existing. Dense vegetative cover facilitates sediment attenuation and pollutant removal for the design storms. Unlike grass swales, vegetated filter strips are primarily designed for overland sheet flow. Grading and level spreaders can be used to create a uniformly sloping area that distributes the runoff evenly across the filter strip. For small storms that do not discharge, infiltration becomes the primary removal mechanism.

Filter strips have been used to treat runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They can also be used as the "outer zone" of a stream buffer but are usually most effective as pretreatment to another treatment BMPs such as infiltration basins or trenches. Figure 6-3 illustrates the primary design components of the filter strip (CRC, 1996).

6.4 Bioretention Cell

The bioretention concept was originally developed in the early 1990's as an alternative to traditional BMP structures (Clar, *et al.*, 1993, 1994). Bioretention is a practice to manage and treat stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. The method combines physical filtering and adsorption with biological processes and usually takes place in a bioretention cell. The system consists of a flow regulation structure, a pretreatment filter strip or grass channel, a sand bed, a pea gravel overflow curtain drain, a shallow ponding area, a surface organic layer of mulch, a planting soil bed, plant material, a gravel underdrain system, and an overflow system. Figure 6-4 illustrates these primary design components of the bioretention cell (MDE, 2000).

6.5 Role in Water Quality Improvement

Table 6-1 summarizes the pollutant removal capability reported as percent removal of biofilter BMPs for the following constituents: TSS, total phosphorus (TP), total nitrogen (TN), Nitrates, (NO3), and metals. Biofilters have some similarities with respect to performance, but their flow reduction and pollution removal capabilities are basically a function of their size relative to the inflow drainage volume (or long-term infiltration capacity volume) ratio (volume/area). For example, all of these facilities typically report relatively high removal rates of suspended sediment, ranging from 68% for the grass channel to 90% or more for the dry swale and the bioretention cell. The bioretention cell is typically much smaller than the other units; therefore, the total loading would be smaller.

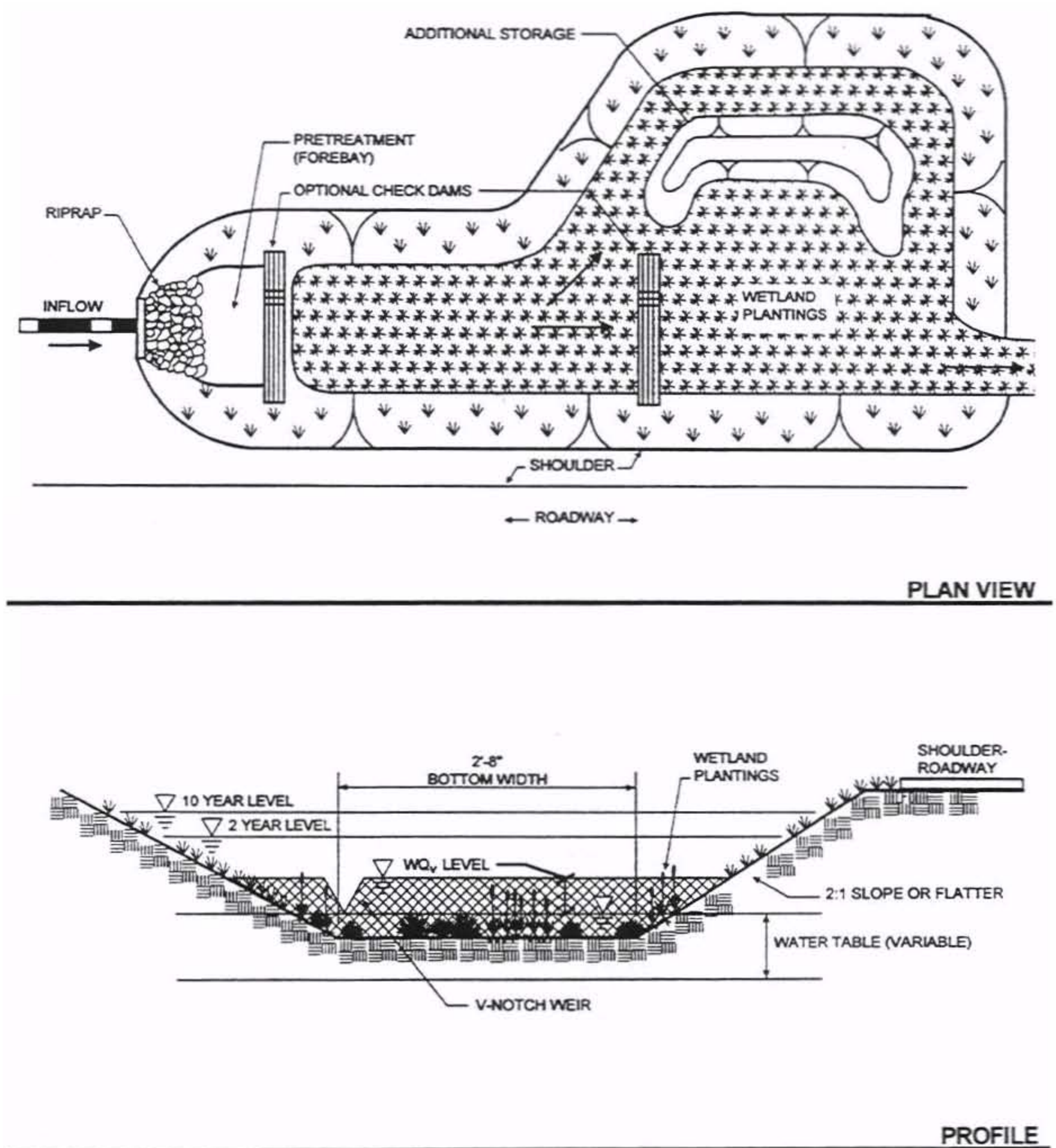

Figure 6-3 Typical Vegetative Filter Strip (CRC, 1996)

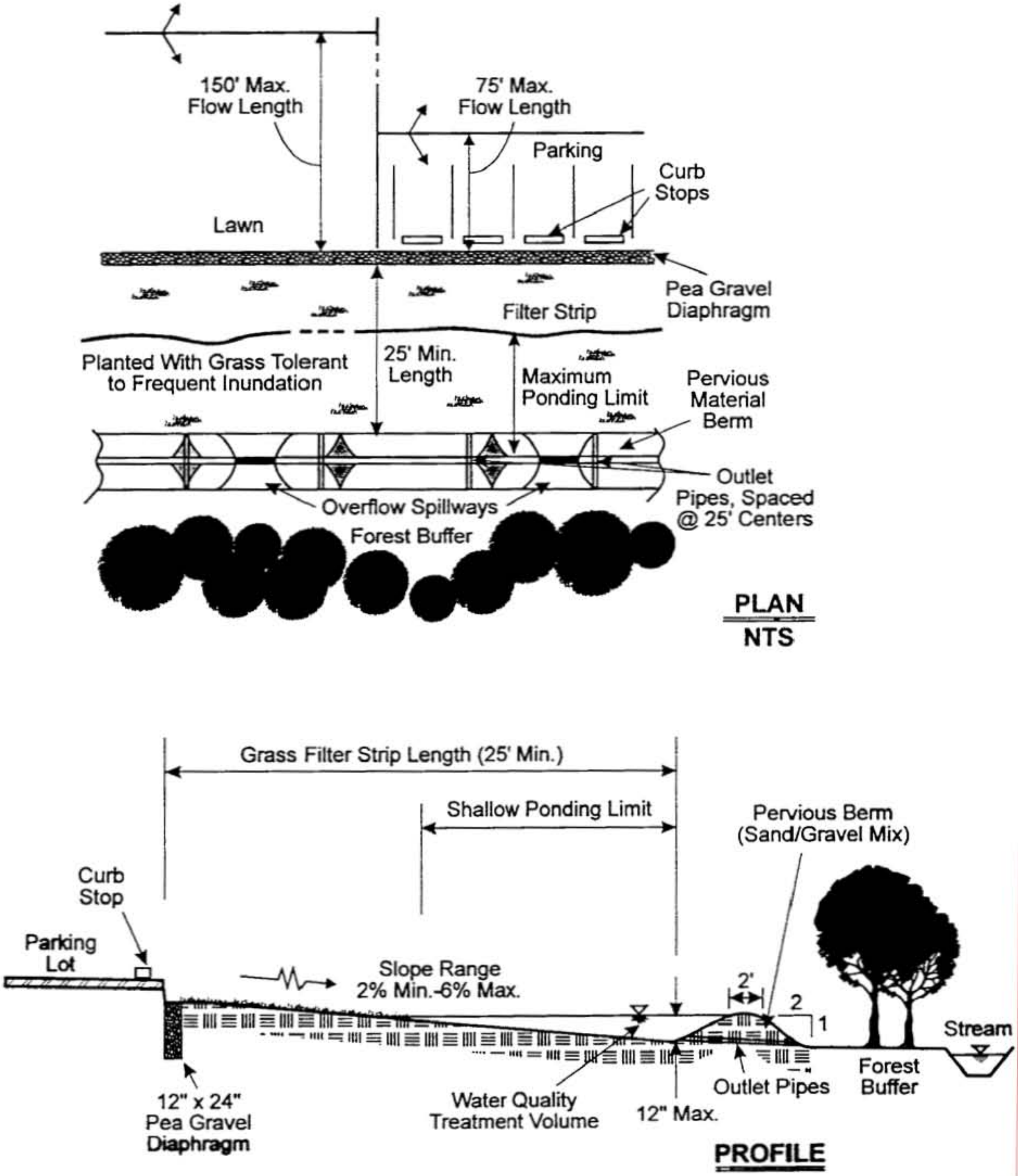

Figure 6-4 Typical Bioretention Cell (MDE, 2000)

Table 6-1 Estimated Pollutant Removal Capability of Biofilters (Winer, 2000; Yu and Kaighn, 1992, Davis et al., 1998)

Biofilter	**TSS***	**TP**	**TN**	**NO_3**	**Other / Comments**
Grass Swale	68	29	N/A	-25	Metals: Cu (42); Zn (45) Hydrocarbons: 65% Bacteria: Negative
Dry Swale	93	83	92	90	Metals: Cu (70); Zn (86)
Wet Swale	74	28	40	31	Metals: Cu (11); Zn (33)
Filter Strip	70	25	NA	10	Metals: 40-50%
Bioretention	95	83	43	23	Metals: 93-99%

* Removals shown as percentages

Some differences have been observed in the comparative ability to remove total phosphorus. The best performers were the dry swale and bioretention cells with removal rates of 83% and 70% respectively. Grass channels, wet swales and filter strips were less reliable, at 10 to 29% average removal. Vegetative biofilters display a wide range of total nitrogen removal. The dry swale exhibited a very high removal rate of 92%.

While all biofilter designs showed at least moderate capacity to remove trace metals such as copper, lead, and zinc, most of the removed metals were already attached to particles. Designs that showed promise in removing dissolved metals include the dry swale and bioretention cell.

Pollutant removal and mechanisms rely on processes in a generally aerobic environment, as opposed to anaerobic environment. Filters which go anaerobic tend to release previously captured phosphorous as iron phosphates break down.

Compatibility with Land Use Type As a group, vegetative biofilters can be applied to a diverse range of land use types. However, individual designs are limited to a much narrower range. These common land use situations include ultra-urban sites, parking lots, road and streets, small residential subdivisions and backyard/rooftop drainage. Table 6-2 is a matrix that illustrates the most economical and feasible biofilter designs for each of these five broad categories of development, as well as those that are not applicable. As previously discussed, devices that rely on infiltration should take into consideration the fate of possible pollutants in the groundwater.

Table 6-2 Land Use and Biofilter Suitability

Urban Retrofit	Bioretention cell has proven very versatile for use in retrofit conditions. Swales are usually not well suited.
Parking Lots	Bioretention cell is well suited for use in parking lots. Swales may be suitable under certain conditions (space, soils, water table). Filter strips can be effective (Figure 6-1)
Roads & Highways	City streets generally do not provide enough space for any biofilter Suburban areas, specially large to medium lot subdivision can accommodate all of the biofilters. Highways may accommodate biofilters if sufficient space is available in median or side slopes.
Residential	Low density residential affords opportunities for all biofilter uses. High density residential may offer limited opportunity based on space availability.
Rooftops	Roof drain disconnections to filter strips or bioretention areas are recommended where feasible.

For example, in ultra-urban or retrofit settings where space is at a premium, the bioretention cell is one of the most versatile biofilters. In most cases, the space requirements of swales and filter strips are so great that they can be eliminated from consideration in downtown urban areas, but bioretention cells may be considered as a retrofit to partially treat urban runoff.

Compatibility with Site Conditions Table 6-3 compares how each biofilter design compares with respect to a number of site conditions, including soils, water table, drainage area, slope head and space consumed.

6.6 Design of Grass Swales for Pollutant Removal

Pollutants are removed in swales by settling, deposition in low velocity areas, or by infiltration into the subsoil. The primary pollutant removal mechanism is through sedimentation of suspended materials for larger particles and infiltration for colloidal particles and dissolved solids. Therefore, suspended solids and adsorbed metals are most effectively removed through the traditional grass swale (rather than the swale with filter media or wet swale). Removal efficiencies reported in the literature vary, but generally fall into the low-to-medium range, with some swale systems recording no water quality effects at all. Schueler (1992), reported that of 10 swales monitored, 50 percent registered moderate pollutant removal, while the remainder showed negligible or negative removal.

The amount of pollutant removed will depend on the length of the swale. Table 6-4 presents the pollutant removal efficiencies for 200 ft and 100 ft swale lengths. Although research results varied, these data clearly indicate increased pollutant removal efficiencies with longer swales.

Table 6-3 Physical Site Conditions and Biofilter Suitability
(modified from MDE, 2000)

Biofilter	Soils	Water Table (depth)	Drainage Area (acres)	Slope Limits	Head	Area Required
1) Grass Swale	OK	2 feet	5 max	6% max.	2 feet	6.5%
Dry Swale	Filter Media	2 feet	5 max	6% max	3 to 6 feet	10-20%
Wet Swale	OK	Below WT	5 max	6% max	1 foot	10-20%
2) Filter strip	OK	2 feet	N/A	15% max	N/A	100%
3) Bio-retention Cell	Filter Media	2 feet	2 max	None	5 feet	5.0%

Notes: Soils - the key evaluation factors are based on an initial investigation of the USDA HSG at the site. More detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors
Water table - the minimum depth to the seasonally high water table from the bottom or floor of a BMP.
Drainage Area - the recommended minimum or maximum drainage area that is considered suitable for the practice. If
the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is permitted or more than one practice can be installed.
Slope Restriction - the effect of slope on the practice. Specifically, the slope restrictions refer to how flat the area where the practice may be.
Head - an estimate of the elevation difference needed at a site (from the inflow to the outflow) to allow for gravity operation within the practice.
Area Required - indicates percentage of total drainage area requirement for BMP.

Table 6-4 Pollutant removal efficiencies for grass swales (Barret, et al., 1993; Schueler, 1991; Yu,1993; Yousef, et al,, 1985; Horner, 1996)

Design	Pollutant Removal Efficiencies (%)							
	Solids	Nutrients		Metals			Other	
	TSS	TN	TP	Zn	Pb	Cu	Oil & Grease	COD**
200-ft grass swale	83	25*	29	63	67	46	75	25
100-ft grass swale	60	0	45	16	15	2	49	25

*Some swales, particularly 100-ft systems, showed negligible or negative removal for TN.
**Data is very limited.

In general, the current literature reports that a well-designed, well-maintained swale system can be expected to remove 70% of total suspended solids (TSS), 30 percent for total phosphorus (TP), 25 percent for total nitrogen (TN), and 50 to 90% for trace metals (Barret, et al., 1993; GKY, 1991). The TN removals may be fairly optimistic, given that studies conducted by Yousef et al. (1985) and others produced negative nitrogen removal in many cases, possibly due to the remobilization of nitrogen from grass clippings and other organic materials.

Seasonal differences in swale performance can be important. In temperate climates, fall and winter temperatures force vegetation into dormancy, thereby reducing uptake of runoff pollutants, and removing an important mechanism for flow reduction. Decomposition in the fall, and the absence of grass cover in the winter can often produce an remobilization of nutrients, and may expose the swale to erosion during high flows, increasing sediment loads downstream. Pollutant removal efficiencies for many constituents can be markedly different during the growing and dormant periods (Driscoll and Mangarella, 1990).

6.7 Design of Vegetative Filter Strips for Pollutant Removal

Pollutants are removed in filter strips mainly by settling for larger particles and by soil infiltration for colloidal particles. Under low-to-moderate velocity, filter strips effectively reduce particulate pollutant levels by removing sediments and organic materials and trace metals (Schueler, 1992). Research has shown removal of 70% for TSS, 40% to 50% for phosphorus (particulate) and zinc, 25% for lead, and 10% for nitrate/nitrite (Florida Department of Transportation, 1994). Settling of aggregate containing clay particles removes sorbed nutrients and other pollutants. Removal of free soluble pollutants in filter strips is accomplished when pollutants infiltrate into the soil, some of which are subsequently taken up by rooted vegetation. Therefore, removal of solubles depends on the infiltration rates. The mechanism for infiltration is minor in most filter strips during design storms or larger storms since only a modest portion of the incoming runoff is infiltrated and most discharges, resulting in low removal rates for solubles, but is the dominant mechanism for small storms that totally infiltrate.

Pollutant removal in filter strips is a function of length, slope, soil permeability, size of contributing runoff area and its long-term contributing inflow volume, particle size and settling velocity, and runoff velocity (Schueler, 1987 and Hayes et al., 1984). A wide range of values for minimum length in the flow direction have been reported in the literature. Frequently cited values range from 20 ft to lengths of l00 to 300 ft for adequate removal of the smaller particles. The design guidance that follows provides analytical procedures for computing these values.

Regardless of vegetation type, the length of the filter strip is shown to have significant influence on pollutant removal. Figure 6-5 provides one example of percent pollutant removal efficiency versus length (Yu and Kaighn, 1992). In Figure 6-5, the relative value of adding additional length to a filter strip for pollutant removal levels off significantly after 59 ft, with the most significant rise in removal occurring between 19 to 59 ft. However, strip length alone does not entirely define pollutant removal. The existing longitudinal slope and soil infiltration capacity will also influence the ultimate length of the system. These factors may dictate a strip longer than would be necessary if pollutant removal alone was the only consideration.

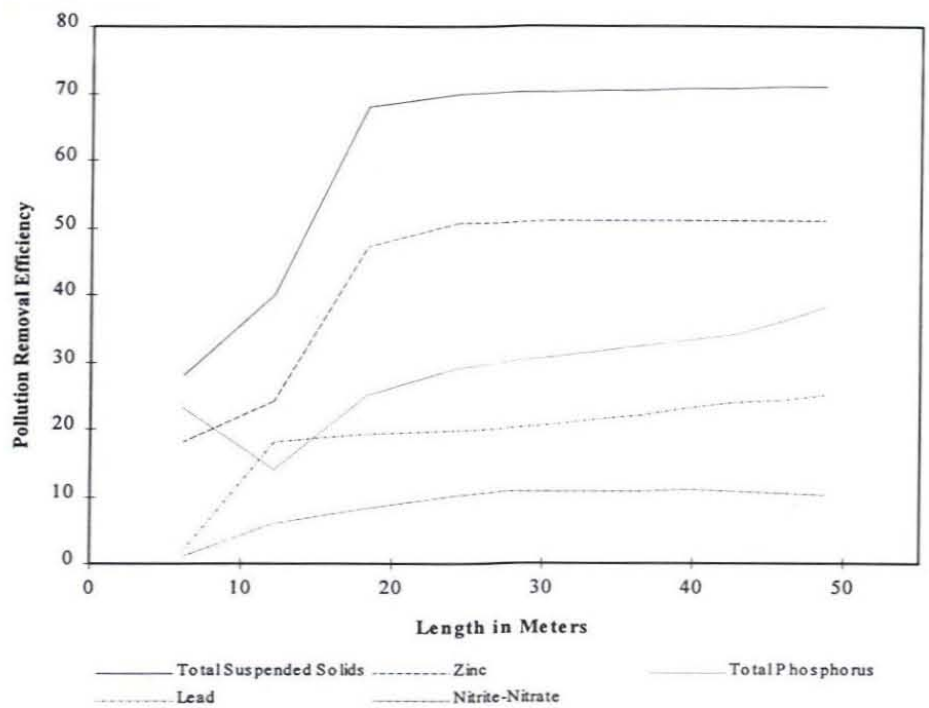

Figure 6-5 Pollutant Removal Efficiency Versus Filter Strip Length
(Yu and Kaighn, 1992)

In design, the variables that can be effectively manipulated include length and slope of the strip, soil characteristics and vegetative cover. According to Yu and Kaighn (1992), optimum lengths were between 20 to 30 m for a given sheetflow over the filter strip and inflow to outflow pollutant removals. Higher pollutant removal rates for longer lengths were feasible; however, further improvements in pollutant removal are relatively minor. The design length would be expected to vary widely with slope, settleable particle size, soil type, infiltration capacity and vegetation type. Avoiding the potential for concentrated flows and "gullies" will effectively "short-circuit" the filter strip and significantly reduce removal rates. Width can also influence pollutant removal but is often constrained by the area available.

VFS Enhancements - Level Spreader A level spreader should be provided at the upper edge of a vegetated filter strip when the width of the contributing drainage area is greater than that of the filter. Runoff may be directed to the level spreader as sheet flow or concentrated flow. However, the design must ensure that runoff fills the spreader evenly and flows over the level lip as uniformly as possible. The level spreader should extend across the width of the filter, leaving only 10 feet open on each end.

There are many alternative spreader devices, with the main consideration being that the overland flow spreader be distributed equally across the strip. Level spreader options include porous pavement strips, stabilized turf strips, slotted curbing, rock-filled trenches, concrete sills, or plastic-lined trenches that act as a small detention pond (Yu and Kaighn, 1992). The outflow and filter side lip of the spreader should have a zero slope to ensure even runoff distribution (Yu and Kaighn, 1992). Once in the filter strip, most runoff from high storm flow events will not be infiltrated and will require a collection and conveyance system. Grass-lined swales are often used for this purpose and can provide another BMP level. A filter strip can also drain to a storm sewer or street gutter (Urbonas, 1992).

VFS Enhancements - Pervious Berm A pervious berm may be installed at the foot of the strip to force ponding in a VFS. It should be constructed using a moderately permeable soil such as ASTM ML, SM, or SC. Soils meeting USDA sandy loam or loamy sand texture, with a minimum of 10 to 25% clay, may also be used. Additional loam should be used on the berm (± 25%) to help support vegetation. An armored overflow should be provided to allow larger storms to pass without overtopping the berm. Maximum ponding depth behind a pervious berm should be 1 foot.

VFS Enhancements - Types of Vegetation to Use A VFS should be densely vegetated with a mix of erosion resistant plant species that effectively bind the soil. Certain plant types are more suitable than others for urban stormwater control. The selection of plants should be based on their compatibility with climate conditions, soils, and topography and the their ability to tolerate urban stresses from pollutants, variable soil moisture conditions and ponding fluctuations.

A filter strip should have at least two of the following vegetation types: deep-rooted grasses and ground covers; or deciduous and evergreen shrubs; or under- and over-story trees. Native plant species should always be specified . This will facilitate establishment and long term survival. Non-native plants may require more care to adapt to local hydrology, climate, exposure, soil and other conditions. Also, some non-native plants may become invasive, ultimately choking out the native plant population. This is especially true for non-native plants used for stabilization.

Newly constructed stormwater BMPs will be fully exposed for several years before the buffer vegetation becomes adequately established. Therefore, plants which require full shade, are susceptible to winter kill or are prone to wind damage should be avoided. Plant materials should conform to the American Standard for Nursery Stock, current issue, as published by the American Association of Nurserymen. The botanical (scientific) name of the plant species should be according to the landscape industry standard nomenclature. All plant material specified should be suited for USDA Plant Hardiness Zones.

Grassed filter strips should be constructed of dense, soil-binding deep-rooted water-resistant plants. Dense turf is needed to promote sedimentation and entrapment, and to protect against erosion (Yu and Kaighn, 1992). Turf grass should be maintained to a blade height of 50 to 60 mm (2 to 4 in). Most engineered, sheet-flow systems are seeded with specific grasses. Common grasses established for filter strip systems are rye, fescue, reed canary, and Bermuda (Horner, 1996). Tall fescue and orchard grasses grow well on slopes and under low nutrient conditions (Horner, 1996). The grass species chosen should be appropriate for the climatic conditions and maintenance criteria for each project.

Retaining existing trees and woody vegetation have been shown to increase infiltration and improve performance of filter strips. Trees and shrubs provide many stormwater management benefits by intercepting some rainfall before it reaches the ground, and improving infiltration and retention through the presence of a spongy, organic layer of materials that accumulates underneath the plants (Schueler, 1987). As discussed previously in this section, wooded strips have shown significant increases in pollutant removal over grass strips. Maintenance for wooded strips is lower than grassed strips, another argument for using trees and shrubs. However, there are drawbacks to using woody plants. Since the density of the vegetation is not as great as a turf grass cover, wooded filter strips need additional length to accommodate more vegetation. In addition, shrub and tree trunks can cause uneven distribution of sheet flow, and increase the possibility for development of gullies and channels. Consequently, wooded strips require flatter slopes than a typical grass cover strip to ensure that the presence of heavier plant stems will not facilitate channelization.

Filter strips managed to allow "natural succession" of vegetation from grasses to shrubs and trees provides excellent urban wildlife habitat. Judicious planting of selected native shrub and trees can be used to enhance the quality of food and cover for a variety of animal species (Schueler, 1987). Compaction of soils during construction may not be appropriate for planting of shrubs and trees as growth of a healthy root structure may be inhibited. To facilitate this approach, a landscaping plan should be included in the project specifications.

Construction Guidelines Overall, widely accepted construction standards and specifications, such as those developed by the USDA Natural Resources Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable to construct a vegetated filter strip. The specifications should also satisfy all requirements of the local government.

Sequence of Construction Vegetated filter strip construction should be coordinated with the overall project construction schedule. Rough grading of the filter strip should not be initiated until adequate erosion controls are in place.

6.8 Design of Bioretention Cells for Pollutant Removal

Since this is a relatively new BMP, the available data on the pollutant removal performance of bioretention cells is scarce. The preliminary reports from field monitoring activities (Table 6-5) are verifying that this BMP not only met local water quality control criteria, but actually ranked as one of the most effective pollutant removal BMPs available. Percent removals will depend on filter media used, influent pollution concentrations, hydraulic loadings and other factors.

Table 6-5 Pollutant Removal Performance of Bioretention Practices (% Removal) (Davis et al, 1997)

	Cu	**Pb**	**Zn**	**P**	**TKN**	**NH_4**	**NO_3**	**TN**
Upper Zone	90	93	87	0	37	54	-97	-29
Middle Zone	93	99	98	73	60	86	-194	0
Lower Zone	93	99	99	81	68	79	23	43

The University of Virginia, Charlottesville, Virginia has initiated a long term study of the performance of a bioretention cell. This study differs from the two bioretention studies conducted in Maryland that monitored a single storm event (3 inches of rainfall). The UVA study is providing performance data based on an annual hydrologic budget. Initial, first year results indicate that the performance of the bioretention cells will exceed all expectations. First year removal results are as follows: 86% for TSS, 90% for TP, 97% for COD and 67% for oil and grease (Yu, et al. 1999).

Unlike the other vegetative biofilters that have a dual function of stormwater transport or detention and pollutant removal, bioretention cells primary function is pollutant removal. For this reason, bioretention cells would perform best as part of a treatment train. Bioretention can also be an effective retrofit BMP for existing urban areas that already have stormwater drainage systems.

Glossary

Acute: A stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.

Adjacent Steep Slope: A slope with a gradient of 15 percent or steeper within 500 feet of the site.

Adsorption: The adhesion of a substance to the surface of a solid or liquid; often used to extract pollutants by causing them to be attached to such adsorbents as activated carbon or silica gel. Hydrophobic, or water repulsing adsorbents, are used to extract oil from waterways when oil spills occur. Heavy metals such as zinc and lead often adsorb onto sediment particles.

Antidegradation: Policies which ensure protection of water quality for a particular water body where the water quality exceeds levels necessary to protect fish and wildlife propagation and recreation on and in the water. This also includes special protection of waters designated as outstanding natural resource waters. Antidegradation plans are adopted by each state to minimize adverse effects on water.

Anti-seep Collar: A device constructed around a pipe or other conduit and placed through a dam, levee, or dike for the purpose of reducing seepage losses and piping failures.

Anti-vortex Device: A device designed and placed on the top of a riser or the entrance of a pipe to prevent the formation of a vortex in the water at the entrance.

Aquatic Bench: A bench which is located around the inside perimeter of a permanent pool and is normally vegetated with aquatic plants; the goal is to provide pollutant removal and enhance safety in areas using stormwater pond BMP's.

Aquifer: A porous water bearing geologic formation generally restricted to materials capable of yielding an appreciable supply of water

"As-Built": Drawing or certification of conditions as they were actually constructed.

Baffles: Guides, grids, grating or similar devices placed in a pond to deflect or regulate flow and create a longer flow path.

Bankfull Discharge: A flow condition where streamflow completely fills the stream channel up to the top of the bank. In undisturbed watersheds, the discharge conditions occurs on average every 1.5 to 2 years and controls the shape and form of natural channels.

Barrel: The closed conduit used to convey water under or through an embankment; part of the principal spillway.

Baseflow: The stream discharge from groundwater.

Berm: A shelf that breaks the continuity of a slope; a linear embankment or dike.

Best Available Technology Economically Achievable (BAT): Technology-based standard established by the Clean Water Act (CWA) as the most appropriate means available on a national basis for controlling the direct discharge of toxic and nonconventional pollutants to navigable waters. BAT effluent limitations guidelines, in general, represent the best existing performance of treatment technologies that are economically achievable within an industrial point source category or subcategory.

Best Conventional Pollutant Control Technology (BCT): Technology-based standard for the discharge from existing industrial point sources of conventional pollutants including BOD, TSS, fecal coliform, pH, oil and grease. The BCT is established in light of a two-part "cost reasonableness" test which compares the cost for an industry to reduce its pollutant discharge with the cost to a POTW for similar levels of reduction of a pollutant loading. The second test examines the cost-effectiveness of additional industrial treatment beyond BPT. EPA must find limits which are reasonable under both tests before establishing them as BCT.

Best Management Practice (BMP): Permit condition used in place of or in conjunction with effluent limitations to prevent or control the discharge of pollutants. May include schedule of activities, prohibition of practices, maintenance procedure, or other management practice. BMPs may include, but are not limited to, treatment requirements, operating procedures, or practices to control plant site runoff, spillage, leaks, sludge or waste disposal, or drainage from raw material storage.

Physical, structural, and/or managerial practices that, when used singly or in combination, reduce the downstream quality and quantity impacts of stormwater.

Best Practicable Control Technology Currently Available (BPT): The first level of technology-based standards established by the CWA to control pollutants discharged to waters of the U.S. BPT effluent limitations guidelines are generally based on the average of the best existing performance by plants within an industrial category or subcategory.

Bioassay: A test used to evaluate the relative potency of a chemical or a mixture of chemicals by comparing its effect on a living organism with the effect of a standard preparation on the same type of organism.

Biochemical Oxygen Demand (BOD): A measurement of the amount of oxygen utilized by the decomposition of organic material, over a specified time period (usually 5 days) in a wastewater sample; it is used as a measurement of the readily decomposable organic content of a wastewater.

Biofiltration: The simultaneous process of filtration, infiltration, adsorption, and biological uptake of pollutants in stormwater that takes place when runoff flows over and through vegetated areas.

Biofiltration Swale: A sloped, vegetated channel or ditch that provides both conveyance and water quality treatment to stormwater runoff. It does not provide stormwater quantity control but can convey runoff to BMPs designed for that purpose.

Biological Control: A method of controlling pest organisms by means of introduced or naturally occurring predatory organisms, sterilization, the use of inhibiting hormones, or other means, rather than by mechanical or chemical means.

Bioretention: A stormwater management practice that utilizes shallow storage, landscaping and soils to control and treat urban stormwater runoff by collecting it in shallow depressions before filtering through a fabricated planting soil media.

Buffer: The zone contiguous with a sensitive area that is required for the continued maintenance, function, and structural stability of the sensitive area. The critical functions of a riparian buffer (those associated with an aquatic system) include shading, input of organic debris and coarse sediments, uptake of nutrients, stabilization of banks, interception of fine sediments, overflow during high water events, protection from disturbance by humans and domestic animals, maintenance of wildlife habitat, and roomfor variation of aquatic system boundaries over time due to hydrologic or climatic effects. The critical functions of terrestrial buffers include protection of slope stability, attenuation of surface water flows from stormwater runoff and precipitation, and erosion control.

Catchbasin: A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow.

Catchment: Surface drainage area.

Channel: A natural stream that conveys water; a ditch or channel excavated for the flow of water and is open to the air.

Channelization: Alteration of a stream channel by widening, deepening,straightening, cleaning, or paving certain areas to change flow characteristics.

Channel Stabilization: Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, structural linings, vegetation and other measures.

Check Dam: A small dam constructed in a gully or other small watercourse to decrease flow velocity (by reducing the channel gradient), minimize scour, and promote deposition of sediment.

Chemical Oxygen Demand (COD): A measure of the oxygen-consuming capacity of inorganic and organic matter present in wastewater. COD is expressed as the amount of oxygen consumed in mg/l. Results do not necessarily correlate to the biochemical oxygen demand (BOD) because the chemical oxidant may react with substances that bacteria do not stabilize.

Chronic: A stimulus that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic should be considered a relative term depending on the life span of an organism. The measurement of a chronic effect can be reduced growth, reduced reproduction, etc., in addition to lethality.

Chute: A high velocity, open channel for conveying water to a lower level without erosion.

Clay Lens: A naturally occurring, localized area of clay which acts as an impermeable layer to runoff infiltration.

Clay (Soils): 1. A mineral soil separate consisting of particles less than 0.002 millimeter in equivalent diameter. 2. A soil texture class. 3. (Engineering) A fine grained soil (more than 50 percent passing the No. 200 sieve) that has a high plasticity index in relation to the liquid limit. (Unified Soil Classification System)

Clean Water Act (CWA): The Clean Water Act is an act passed by the U.S. Congress to control water pollution. It was formerly referred to as the Federal Water Pollution Control Act of 1972 or Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), 33 U.S.C. 1251 et. seq., as amended by: Public Law 96-483; Public Law 97-117; Public Laws 95-217, 97-117, 97-440, and 100-04.

Closed Depression: An area which is low-lying and either has no, or such a limited, surface water outlet that during storm events the area acts as a retention basin.

Coconut Rolls: Also known as coir rolls, these are rolls of natural coconut fiber designed to be used for streambank stabilization.

Cohesion: The capacity of a soil to resist shearing stress, exclusive of functional resistance.

Combined Sewer Overflow (CSO): A discharge of untreated wastewater from a combined sewer system at a point prior to the headworks of a publicly owned treatment works. CSOs generally occur during wet weather (rainfall or snowmelt). During periods of wet weather, these systems become overloaded, bypass treatment works, and discharge directly to receiving waters.

Combined Sewer System (CSS): A wastewater collection system which conveys sanitary wastewaters (domestic, commercial and industrial wastewaters) and storm water through a single pipe to a publicly owned treatment works for treatment prior to discharge to surface waters.

Compaction (Soils): Any process by which the soil grains are rearranged to decrease void space and bring them in closer contact with one another, thereby increasing the weight of solid material per unit of volume, increasing the shear and bearing strength and reducing permeability.

Composite Sample: Sample composed of two or more discrete samples. The aggregate sample will reflect the average water quality covering the compositing or sample period.

Conduit: Any channel intended for the conveyance of water, whether open or closed.

Constructed Wetland: A wetland that is created on a site that previously was not a wetland. This wetland is designed specifically to remove pollutants from stormwater runoff.

Contour: 1. An imaginary line on the surface of the earth connecting points of the same elevation. 2. A line drawn on a map connecting points of the same elevation.

Core Trench: A trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

Conventional Pollutants: Pollutants typical of municipal sewage, and for which municipal secondary treatment plants are typically designed; defined by Federal Regulation [40 CFR 401.16] as BOD, TSS, fecal coliform bacteria, oil and grease, and pH.

Conveyance: A mechanism for transporting water from one point to another, including pipes, ditches, and channels.

Conveyance System: The drainage facilities, both natural and manmade, which collect, contain, and provide for the flow of surface and stormwater from the highest points on the land down to a receiving water. The natural elements of the conveyance system include swales and small drainage courses, streams, rivers, lakes, and wetlands. The human-made elements of the conveyance system include gutters, ditches, pipes, channels, and most retention/detention facilities.

Cradle: A structure usually of concrete shaped to fit around the bottom and sides of a conduit to support the conduit, increase its strength and, in dams, to fill all voids between the underside of the conduit and the soil.

Created Wetland: A wetland that is created on a site that previously was not a wetland. This wetland is created to replace wetlands that wereunavoidably destroyed during design and construction of a project. This wetland cannot be used for treatment of stormwater runoff.

Crest: 1. The top of a dam, dike, spillway or weir, frequently restricted to the overflow portion. 2. The summit of a wave or peak of a flood, volume.

Criteria: The numeric values and the narrative standards that represent contaminant concentrations that are not to be exceeded in the receiving environmental media (surface water, ground water, sediment) to protect beneficial uses.

Curve Number (CN): A numerical representation of a given area's hydrologic soil group,plant cover, impervious cover, interception and surface storage derived in accordance with Natural Resources Conservation Service methods. This number is used to convert rainfall depth into runoff

Cut: Portion of land surface or area from which earth has been removed or will be removed by excavation; the depth below original ground surface to excavated surface.

Cut-and-Fill: Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

Cutoff: A wall or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata.

CZARA: Acronym used for the Coastal Zone Act Reauthorization Amendments of 1990. These amendments sought to address the nonpoint source pollution issue by requiring states to develop coastal nonpoint pollution control programs in order to receive federal funds.

Dam: A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, sediment or other debris.

Dead Storage: The permanent pool volume located below the out structure of a storage device. Dead storage provides water quality treatment but does not provide water quantity treatment.

Depression Storage: The amount of precipitation that is trapped in depressions on the surface of the ground.

Design Storm: A prescribed hyetograph and total precipitation amount (for a specific duration recurrence frequency) used to estimate runoff for a hypothetical storm of interest or concern for the purposes of analyzing existing drainage, designing new drainage facilities or assessing other impacts of a proposed project on the flow of surface water.

Detention: The temporary storage of stormwater runoff in a BMP with the goals of controlling peak discharge rates and providing gravity settling of pollutants.

Detention Facility / Structure: An above or below ground facility, such as a pond or tank, that temporarily stores stormwater runoff and subsequently releases it at a slower rate than it is collected by the drainage facility system. There is little or no infiltration of stored stormwater, and the facility is designed to not create a permanent pool of water.

Detention Time: The theoretical time required to displace the contents of a stormwater treatment facility at a given rate of discharge (volume divided by rate of discharge).

Dike: An embankment to confine or control water, for example, one built along the banks of a river to prevent overflow to lowlands; a levee.

Discharge: Outflow; the flow of a stream, canal, or aquifer. One may also speak of the discharge of a canal or stream into a lake, river, or ocean. (Hydraulics) Rate of flow, specifically fluid flow; a volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day.

Disturbed Area: An area in which the natural vegetative soil cover has been removed or altered and, therefore, is susceptible to erosion.

Diversion: A channel with a supporting ridge on the lower side constructed across the slope to divert water to areas where it can be used or disposed of safely. Diversions differ from terraces in that they are individually designed.

Drainage: Refers to the collection, conveyance, containment, and/or discharge of surface and storm water runoff.

Drainage Area (Watershed): That area contributing runoff to a single point measured in a horizontal plane, which is enclosed by a ridge line.

Drainage Basin: A geographic and hydrologic sub-unit of a watershed.

Drainage Channel: A drainage pathway with a well-defined bed and banks indicating frequent conveyance of surface and stormwater

Drainage Course: A pathway for watershed drainage characterized by wet soil vegetation; often intermittent in flow.

Drainage Divide: The boundary between one drainage basin and another.

Drain: A buried pipe or other conduit (closed drain). A ditch (open drain) for carrying off surplus surface water or ground water.

Drainage Easement: A legal encumbrance that is placed against a property's title to reserve specified privileges for the users and beneficiaries of the drainage facilities contained within the boundaries of the easement.

Drainage, Soil: The removal of water from a soil.

Drop Structure: A structure for dropping water to a lower level and dissipating surplus energy; a fall.

Dry Pond: A facility that provides stormwater quantity control by containing excess runoff in a detention basin, then releasing the runoff at allowable levels.

Dry Swale: An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media.

Dry Vault/Tank: A facility that treats stormwater for water quantity control by detaining runoff in underground storage units and then releases reduced flows at established standards.

Effluent Limitation: Any restriction imposed by the Director on quantities, discharge rates, and concentrations of pollutants which are discharged from point sources into waters of the United States, the waters of the contiguous zone, or the ocean.

Effluent Limitations Guidelines (ELG): A regulation published by the Administrator under Section 304(b) of CWA that establishes national technology-based effluent requirements for a specific industrial category.

Emergency Spillway: A dam spillway, constructed in natural ground, that is to discharge low in excess of the principal spillway design discharge.

Energy Dissipator: Any means by which the total energy of flowing water is reduced. In stormwater design, they are usually mechanisms that reduce velocity prior to, or at, discharge from an outfall in order to prevent erosion. They include rock splash pads, drop manholes, concrete stilling basins or baffles, and check dams.

Enhancement: To raise ecological value, desirability, or attractiveness of an environment associated with surface water.

Erosive Velocities: Velocities of water that are high enough to wear away the land surface. Exposed soil will generally erode faster than stabilized soils. Erosive velocities will vary according to the soil type, slope, structural, or vegetative stabilization used to protect the soil.

Erosion: 1. The process by which the land surface is worn away by the action of water, wind, ice, or gravity. 2. Detachment and movement of soil or rock fragments by water, wind, ice or gravity. The following terms are used to describe different types of water erosion:

Accelerated erosion - Erosion much more rapid than normal, natural or geologic erosion,primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophes that expose base surfaces.

Gully erosion - The erosion process whereby water accumulates in narrow channels and removes the soil from this narrow area to considerable depths ranging from 1 or 2 feet to as much as 75 to 100 feet.

Rill erosion - An erosion process in which numerous small channels only several inches deep are formed. See rill.

Sheet erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not subsequently be removed by surface runoff.

Erosion and Sediment Control: Any temporary or permanent measures taken to reduce erosion, control siltation and sedimentation, and ensure that sediment-laden water does not leave a site.

Erosion and Sediment Control Facility: A type of drainage facility designed to hold water for a period of time to allow sediment contained in the surface and stormwater runoff directed to the facility to settle out so as to improve the quality of the runoff.

Exfiltration: The downward movement of water through the soil; the downward flow of runoff from the bottom of an infiltration BMP into the soil.

Existing Site Conditions: The conditions (ground cover, slope, drainage patterns) of a site as they existed on the first day that the project entered the design phase. Projects which drain into a sensitive area designated by a federal, state, or local agency may be required to use undisturbed forest conditions for the purposes of calculating runoff characteristics instead of using existing site conditions

Extended Detention: A stormwater design feature that provides for the gradual release of a volume of water in order to increase settling of pollutants and protect downstream channels from frequent storm events.

Filter Bed: The section of a constructed filtration device that houses the filter media and the outflow pipe.

Filter Fence: A geotextile fabric designed to trap sediment and filter runoff.

Filter Media: The sand, soil, or other organic material in a filtration device used to provide a permeable surface for pollutant and sediment removal.

Filter Strip: A strip of permanent vegetation above ponds, diversions and other structures to retard the flow of runoff, causing deposition of transported material, thereby reducing sedimentation.

Fines (Soil): Generally refers to the silt and clay size particles in soil.

Floodplain: Areas adjacent to a stream or river that are subject to flooding or inundation during a storm event that occurs, on average, once every 100 years (or has a likelihood of occurrence of 1/100 in any given year).

Flood Frequency: The frequency with which the flood of interest may be expected to occur at a site in any average interval of years. Frequency analysis defines the “n-year flood” as being the flood that will, over a long period of time, be equaled or exceeded on the average once every “n”years.

Flood Fringe: That portion of the floodplain outside of the floodway which is covered by floodwaters during the base flood. It is generally associated with standing water rather than rapidly flowing water.

Flood Peak: The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge.

Flood Routing: An analytical technique used to compute the effects of system storage dynamics on the shape and movement of flow represented by a hydrograph.

Flood Stage: The stage at which overflow of the natural banks of a stream begins.

Floodway: The channel of the river or stream and those portions of the adjoining flood plains which are reasonably required to carry and discharge the base flood flow. The portions of the adjoining flood plains which are considered to be “reasonably required” is defined by flood hazard regulations.

Flow Splitter: An engineered, hydraulic structure designed to divert a percentage of storm flow to a BMP located out of the primary channel, or to direct stormwater to a parallel pipe system or to bypass a portion of baseflow around a BMP.

Forebay: An easily maintained, extra storage area provided near an inlet of a BMP to trap incoming sediments before they accumulate in a pond or wetland BMP.

Freeboard (Hydraulics): The distance between the maximum water surface elevation anticipated in design and the top of retaining banks or structures. Freeboard is provided to prevent overtopping due to unforeseen conditions.

French Drain: A type of drain consisting of an excavated trench filled with pervious material, such as coarse sand, gravel or crushed stone; water percolates through the voids in this material and flows to an outlet.

Frost-Heave: The upward movement of soil surface due to the expansion of water stored between particles in the first few feet of the soil profile as it freezes. May cause surface fracturing of asphalt or concrete.

Frequency of Storm (Design Storm Frequency): The anticipated period in years that will elapse, based on average probability of storms in the design region, before a storm of a given intensity and/or total volume will recur; thus a 10-year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.

Functions (wetlands): The ecological (physical, chemical, and biological) processes or attributes of a wetland without regard for their importance to society (see also Values). Wetland functions include food chain support, provision of ecosystem diversity and fish and wildlife habitat, flood flow alteration, ground water recharge and discharge, water quality improvement, and soil stabilization.

Gabion: A rectangular or cylindrical wire mesh cage filled with rock and used as a protecting agent, revetment, etc., against erosion. Soft gabions, often used in stream bank stabilization, are made of geotextiles filled with dirt, in between which cuttings are placed.

Gabion Mattress: A thin gabion, usually six or nine inches thick, used to line channels for erosion control.

Gage: Device for registering precipitation, water level, discharge, velocity, pressure, temperature, etc.

Gaging Station: A selected section of a stream channel equipped with a gage, recorder, or other facilities for determining stream discharge.

Gauge: A measure of the thickness of metal; e.g., diameter of wire, wall thickness of steel pipe.

Grab Sample: A sample which is taken from a wastestream on a one-time basis without consideration of the flow rate of the wastestream and without consideration of time.

Grade: 1. The slope or finished surface of a road, channel, canal bed, roadbed, top of embankment, bottom of excavation, or natural ground; any surface prepared for the support of construction, like paving or laying a conduit. 2. To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.

Grass Channel: An open vegetated channel used to convey runoff and to provide treatment by filtering pollutants and sediments.

Gravel: 1. Aggregate consisting of mixed sizes of 1/4 inch to 3 inches which normally occur in or near old streambeds and have been worn smooth by the action of water. 2. A soil having particle sizes, according to the Unified Soil Classification System, ranging from the No. 4 sieve size, angular in shape, as produced by mechanical crushing.

Gravel Diaphragm: A stone trench filled with small, river-run gravel used as pretreatment and inflow regulation in stormwater filtering systems.

Gravel Filter: Washed and graded sand and gravel aggregate placed around a drain or well screen to prevent the movement of fine materials from the aquifer into the drain or well.

Gravel Trench: A shallow excavated channel backfilled with gravel and designed to provide temporary storage and permit percolation of runoff into the soil substrate.

Ground Water Table: The free surface of the ground water, that surface subject to atmospheric pressure under the ground, generally rising and falling with the season, the rate of withdrawal, the rate of restoration, and other conditions. It is seldom static.

Gully: A channel or miniature valley cut by concentrated runoff through which water commonly flows during and immediately after heavy rains or snow melt. The distinction between gully and rill is one of depth. A gully is sufficiently deep such that it would not be obliterated by normal tillage operations, whereas a rill is of lesser depth and would be smoothed by ordinary farm tillage or grading activities.

Harmful Pollutant: A substance that has adverse effects to an organism including immediate death, chronic poisoning, impaired reproduction, cancer or other effects.

Heavy Metals: Metals of high specific gravity, present in municipal and industrial wastes, that pose long-term environmental hazards. Such metals include cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc.

Head (Hydraulics): 1. The height of water above any plane of reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various terms such as pressure head, velocity head, and head loss.

High Marsh: A pondscaping zone within a stormwater wetland that exists from the surface of the normal pool to a six inch depth and typically contains the greatest density and diversity of emergent wetland plants.

Hotspot: Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

Hydraulic Gradient: The slope of the hydraulic grade line. That includes static and potential head.

Hydrodynamic Structure: An engineered structure to separate sediments and oils from stormwater runoff using gravitational separation and/or hydraulic flow.

Hydrograph: A graph of runoff rate, inflow rate or discharge rate, past a specific point over time.

Hydrologic Soil Groups (HSG): A soil characteristic classification system defined by the U.S. Soil Conservation Service in which a soil may be categorized into one of four soil groups (A, B, C, or D) based upon infiltration rate and other properties.

Hydrology: The science of the behavior of water in the atmosphere, on the surface of the earth, and underground.

Hydroperiod: A seasonal occurrence of flooding and/or soil saturation; it encompasses depth, frequency, duration, and seasonal pattern of inundation.

Hydroseed: An application of seed or other material applied with forced water in order to revegetate.

Hyetograph: A graph of precipitation versus time.

Impervious Surface / Cover (I): A hard surface area which either prevents or retards the entry of water into the soil. Common impervious surfaces include roof tops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled surfaces.

Industrial Stormwater Permit: An NPDES permit issued to an identified land use that regulates the pollutant levels associated with industrial stormwater discharges or specifies onsite pollution control strategies.

Infiltration: The downward movement of water from the surface to the subsoil.

Infiltration Facility (or system): A drainage facility designed to use the hydrologic process of surface and stormwater runoff soaking into the ground, commonly referred to as a percolation, to dispose of surface and stormwater runoff.

Infiltration Pond: A facility that provides stormwater quantity control by containing excess runoff in a detention facility, then percolating that runoff into the surrounding soil.

Infiltration Rate (*f*): The rate at which stormwater percolates into the subsoil measured in inches per hour.

Inflow Protection: A water handling device used to protect the transition area between any water conveyance (dike, swale, or swale dike) and a sediment trapping device.

Inlet: A form of connection between surface of the ground and a drain or sewer for the admission of surface and stormwater runoff.

Invert: The lowest point on the inside of a sewer or other conduit.

Invert Elevation: The vertical elevation of a pipe or orifice in a pond which defines the water level.

Isopluvial Map: A map with lines representing constant depth of total precipitation for a given return frequency.

Karst Geology: Regions that are characterized by formations underlain by carbonate rock and typified by the presence of limestone caverns and sinkholes.

Lag Time: The interval between the center of mass of the storm precipitation and the peak flow of the resultant runoff.

Land Disturbing Activity: Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land disturbing activities include, but are not limited to demolition, construction, clearing, grading, filling and excavation.

Leachate : Liquid that has percolated through soil and contains substances in solution or suspension.

Leaching: Removal of the more soluble materials from the soil by percolating waters.

Level Spreader: A temporary BMP used to spread stormwater runoff uniformly over the ground surface as sheet flow. The purpose of level spreaders are to prevent concentrated, erosive flows from occurring. Level spreaders will commonly be used at the upsteam end of wider biofilters to ensure sheet flow into the biofilter.

Low Flow Channel: An incised or paved channel from inlet to outlet in a dry basin which is designed to carry low runoff flows and/or baseflow, directly to the outlet without detention.

Major Storm: A precipitation event that is larger than the typically largest rainfall for a year.

Mass Wasting: The movement of large volumes of earth material downslope.

Mean Depth: Average depth; cross-sectional area of a stream or channel divided by its surface or top width.

Mean Velocity: The average velocity of a stream flowing in a channel or conduit at a given cross-section or in a given reach. It is equal to the discharge divided by the cross-sectional area of the reach.

Metals: Elements, such as mercury, lead, nickel, zinc and cadmium, that are of environmental concern because they do not degrade over time. Although many are necessary nutrients, they are sometimes magnified in the food chain, and they can be toxic to life in high enough concentrations. They are also referred to as heavy metals.

Micropool: A smaller permanent pool which is incorporated into the design of larger stormwater ponds to avoid resuspension of particles and minimize impacts to adjacent natural features.

Million Gallons per Day (mgd): A unit of flow commonly used for wastewater discharges. One mgd is equivalent to 1.547 cubic feet per second.

Mitigation: means, in the following order of preference:

1. Avoiding the impact altogether by not taking a certain action or part of an action;

2. Minimizing impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts;

3. Rectifying the impact by repairing, rehabilitating or restoring the affected environment;

4. Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and

5. Compensation for the impact by replacing, enhancing, or providing substitute resources or environments.

Monitor: To systematically and repeatedly measure something in order to track changes.

Monitoring: The collection of data by various methods for the purposes of understanding natural systems and features, evaluating the impacts of development proposals on such systems, and assessing the performance of mitigation measures imposed as conditions of development.

Municipal Stormwater Permit: An NPDES permit issued to municipalities to regulate discharges from municipal separate storm sewers for compliance with EPA regulations.

Municipal Separate Storm Sewer System (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains) owned by a state, city, town or other public body, that is designed or used for collecting or conveying storm water, which is not a combined sewer, and which is not part of a publicly owned treatment works. Commonly referred to as an "MS4" [40 CFR 122.26(b)(8)].

National Pollutant Discharge Elimination System (NPDES): The national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 318, 402, and 405 of CWA.

NGVD: National Geodetic Vertical Datum

Native Growth Protection Easement (NGPE): An easement granted for the protection of native vegetation within a sensitive area or its associated buffer. The NGPE shall be recorded on the appropriate documents of title and filed with the County Records Division.

New Development: Includes the following activities: land disturbing activities, structural development, including construction, installation or expansion of a building or other structure; creation of impervious surfaces; Class IV — general forest practices that are conversions from timber land to other uses; and subdivision and short subdivision of land as defined in RCW 58.17.020. All other forest practices and commercial agriculture are not considered new development.

New Impervious Area: The impervious area that is being created by the project.

Nonconventional Pollutants: All pollutants that are not included in the list of conventional or toxic pollutants in 40 CFR Part 401. Includes pollutants such as chemical oxygen demand (COD), total organic carbon (TOC), nitrogen, and phosphorus.

Nonpoint Source Pollution: Pollution that enters a water body from diffuse origins on the watershed and does not result from discernible, confined, or discrete conveyances.

Non-Structural BMPs: Stormwater runoff treatment techniques which use natural measures to reduce pollution levels, do not require extensive construction efforts and/or promote pollutant reduction by eliminating the pollutant source.

Normal Depth: The depth of uniform flow. This is a unique depth of flow for any combination of channel characteristics and flow conditions. Normal depth is calculated using Manning’s Equation.

Nutrients: Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to degradation of water quality and algal blooms. Some nutrients can be toxic at high concentrations.

Off-Line: A management system designed to control a storm event by diverting a percentage of stormwater events from a stream or storm drainage system.

Off-site: Any area lying upstream of the site that drains onto the site and any area lying downstream of the site to which the site drains.

One Year Storm: A stormwater event which occurs on average once every year or statistically has a 100% chance on average of occurring in a given year.

One Hundred Year Storm: An extreme flood event which occurs on average once every 100 years or statistically has a 1% chance on average of occurring in a given year.

On-Line: A management system designed to control stormwater in its original stream or drainage channel.

Orifice: An opening with closed perimeter, usually sharp-edged, and of regular form in a plate, wall, or partition through which water may flow, generally used for the purpose of measurement or control of flow.

Outlet: Point of water disposal from a stream, river, lake, tidewater, or artificial drain.

Outlet Channel: A waterway constructed or altered primarily to carry water from man-made structures, such as terraces, tile lines, and diversions. Also known as swale, grass channel, and biofilter. This system is used for the conveyance, retention, infiltration and filtration of stormwater runoff.

Overflow: A pipeline or conduit device, together with an outlet pipe, that provides for the discharge of portions of combined sewer flows into receiving waters or other points of disposal, after a regular device has allowed the portion of the flow which can be handled by interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.

pH: A measure of the hydrogen ion concentration of water or wastewater; expressed as the negative log of the hydrogen ion concentration in mg/l. A pH of 7 is neutral. A pH less than 7 is acidic, and a pH greater than 7 is basic.

Peak Discharge Rate: The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Permanent Seeding: The establishment of perennial vegetation which may remain for many years.

Permeability Rate: The rate at which water will move through a saturated soil.

Permeable Soils: Soil materials with a sufficiently rapid infiltration rate so as to greatly reduce or eliminate surface and stormwater runoff. These soils are generally classified as SCS hydrologic soil types A and B.

Permeable Cover: Those surfaces in the landscape consisting of open space, forested areas, meadows, etc. that infiltrate rainfall.

Permissible Velocity (Hydraulics): The highest average velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. A safe, non-eroding or allowable velocity

Perviousness: Related to the size and continuity of void spaces in soils; related to a soil's infiltration rate.

Pesticide: A general term used to describe any substance, usually chemical, used to destroy or control organisms; includes herbicides, insecticides, algicides, fungicides, and others. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.

Piping: Removal of soil material through subsurface flow channels.

Point Source: Any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fixture, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged.

Pollutant: Dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water.

Practicable: Available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes.

Pretreatment: The removal of material such as gross solids, grit, grease,and scum from flows prior to physical, biological, or physical treatment processes to improve treatability. Pretreatment may include screening, grit removal, stormwater, and oil separators.

Pond Buffer: The area immediately surrounding a pond which acts as a filter to remove pollutants and provide infiltration of stormwater prior to reaching the pond. Provides a separation barrier to adjacent development.

Pond Drain: A pipe or other structure used to drain a permanent pool within a specified time period.

Pondscaping: Landscaping around stormwater ponds which emphasizes using native vegetative species to meet specific design intentions. Species are selected for up to six zones in the pond and its surrounding buffer based on their ability to tolerate inundation and/ or soil saturation.

Porosity (*n*): Ratio of pore volume to total volume.

Pretreatment: Techniques employed in stormwater BMPs to provide storage or filtering to help trap coarse materials and other pollutants before they enter the system.

Principal Spillway: The primary pipe or weir which carries baseflow and storm flow through a dam embankment.

Rare, Threatened, or Endangered Species: Plant or animal species that are regionally relatively uncommon, are nearing endangered status, or whose existence is in immediate jeopardy and is usually restricted to highly specific habitats. Threatened and endangered species are officially listed by federal and state authorities, whereas rare species are unofficial species of concern that fit the above definitions.

Rational Method: A means of computing storm drainage flow rates (Q) by use of the formula Q = CIA, where C is a coefficient describing the physical drainage area, I is the rainfall intensity and A is the area.

Reach: A length of channel with uniform characteristics.

Receiving Waters: Bodies of water or surface water systems receiving water from upstream manmade (or natural) streams.

Recharge: The flow to ground water from the infiltration of surface and stormwater runoff.

Recharge Rate: Annual amount of rainfall which contributes to groundwater as a function of hydrologic soil group.

Recharge Volume: The portion of the water quality volume (WQv) used to maintain groundwater recharge rates at development sites.

Redevelopment: Any construction, alteration, or improvement exceeding five thousand square feet of land disturbance performed on sites where existing land use is commercial, industrial, institutional, or multifamily residential.

Regional: An action (here, for stormwater management purposes) that involves more than one discrete property.

Regional Detention Facility: A stormwater quantity control structure designed to correct existing excess surface water runoff problems of a basin or subbasin. The area downstream has been previously identified as having existing or predicted significant and regional flooding and/or erosion problems. This term is also used when a detention facility is used to detain stormwater runoff from a number of different businesses, developments or areas within a catchment.

Release Rate: The computed peak rate of surface and stormwater runoff for a particular design storm event and drainage area conditions.

Restoration: Actions performed to reestablish wetland functional characteristics and processes that have been lost by alterations, activities, or catastrophic events in an area that no longer meets the definition of a wetland.

Retention: The process of collecting and holding surface and stormwater runoff with no surface outflow. The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

Retention/Detention Facility (R/D): A type of drainage facility designed either to hold water for a considerable length of time and then release it by evaporation, plant transpiration, and/or infiltration into the ground; or to hold surface and stormwater runoff for a short period of time and then release it to the surface and stormwater management system.

Retrofitting: The renovation of an existing structure or facility to meet changed conditions or to improve performance.

Return Interval: A statistical term for the average time of expected interval that an event of some kind will equal or exceed given conditions (e.g., a stormwater flow that occurs every 2 years).

Reverse-Slope Pipe: A pipe which draws from below a permanent pool extending in a reverse angle up to the riser and determines the water elevation of the permanent pool.

Right-of-Way: Right of passage, as over another's property. A route that is lawful to use. A strip of land acquired for transport, conveyance or utility construction.

Rill: A small intermittent watercourse with steep sides, usually only a few inches deep. Often rills are caused by an increase in surface water flow when soil is cleared of vegetation.

Riprap: A facing layer or protective mound of stones placed to prevent erosion or sloughing of a structure or embankment due to flow of surface and stormwater runoff.

Riparian: Pertaining to the banks of streams, wetlands, lakes or tidewater.

Riser: A vertical pipe extending from the bottom of a pond BMP that is used to control the discharge rate from a BMP for a specified design storm.

Roughness Coefficient (Hydraulics): A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.

Runoff: That portion of the precipitation on a drainage area that is discharged from the area in the stream channels. Types include surface runoff, groundwater runoff or seepage.

Safety Bench: A relatively flat area above the permanent pool and surrounding a stormwater pond designed to provide a separation to adjacent slopes.

Sanitary Sewer: A pipe or conduit (sewer) intended to carry wastewater or water-borne wastes from homes, businesses, and industries to the POTW.

Sanitary Sewer Overflow (SSO): Untreated or partially treated sewage overflow from a sanitary sewer collection system.

SBUH: Santa Barbara Urban Hydrograph Method. An event-based hydrographic method of analysis used to determine stormwater runoff from a site.

SCS: Soil Conservation Service, U.S. Department of Agriculture.

Sediment: Fragmented material that originates from weathering and erosion of rocks or unconsolidated deposits, and is transported by, suspended in, or deposited by water.

Sedimentation: The depositing or formation of sediment.

Seepage: 1.Water escaping through or emerging from the ground. 2. The process by which water percolates through soil.

Seepage Length: In sediment basins or ponds, the length along the pipe and around the antiseep collars that is within the zone of saturation through an embankment.

Setbacks: The minimum distance requirements for locating certain structures in relation to roads, wells, septic fields, or other structures.

Settleable Solids: Those suspended solids in stormwater that separate by settling when the stormwater is held in a quiescent condition for a specified time.

Sheetflow: Runoff which flows over the ground surface as a thin, even layer, not concentrated in a channel.

Short Circuiting: The passage of runoff through a BMP in less than the design treatment time.

Siltation: The process by which a river, lake, or other water body becomes clogged with sediment. Silt can clog gravel beds and prevent successful salmon spawning.

Soil Group: A classification of soils by the Soil Conservation Service into four runoff potential groups. The groups range from A soils, which are very permeable and produce little or no runoff, to D soils, which are not very permeable and produce much more runoff.

Soil Permeability: The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil.

Soil Stabilization: The use of measures such as rock lining, vegetation or other engineering structures to prevent the movement of soil when loads are applied to the soil.

Source Control BMP: A BMP that is intended to prevent pollutants from entering stormwater. A few examples of source control BMPs are erosion control practices, maintenance of stormwater facilities, constructing roofs over storage and working areas, and directing wash water and similar discharges to the sanitary sewer or a dead end sump.

Spillway: A passage such as a paved apron or channel for surplus water over or around a dam or similar obstruction. An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled, to regulate the discharge of excess water.

Stabilization: Providing vegetative and/or structural measures that will reduce or prevent erosion.

Stage (Hydraulics): The variable water surface or the water surface elevation above any chosen datum.

Steep Slope: Slopes of 25 percent gradient or steeper.

Stilling Basin: An open structure or excavation at the foot of an outfall, conduit, chute, drop, or spillway to reduce the energy of the descending stream of water.

STORET: EPA's computerized STOrage and RETrieval water quality data base that includes physical, chemical, and biological data measured in waterbodies throughout the United States.

Storm Frequency: The time interval between major storms of predetermined intensity and volumes of runoff for which storm sewers and other structures are designed and constructed to handle hydraulically without surcharging and backflooding, e.g., a 2-year, 10-year or 100-year storm.

Stormwater: That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels or pipes into a defined surface water channel, or a constructed infiltration facility.

Stormwater Drainage System: Constructed and natural features which function together as a system to collect, convey, channel, hold, inhibit, retain, detain, infiltrate, divert, treat or filter stormwater.

Stormwater Facility: A constructed component of a stormwater drainage system, designed or constructed to perform a particular function, or multiple functions. Stormwater facilities include, but are not limited to, pipes, swales, ditches, culverts, street gutters, detention basins, retention basins, constructed wetlands, infiltration devices, catchbasins, oil/water separators, sediment basins and modular pavement.

Stormwater Filtering: Stormwater treatment methods which utilize an artificial media to filter out pollutants entrained in urban runoff.

Stormwater Ponds: A land depression or impoundment created for the detention or retention of stormwater runoff.

Stormwater Quality: A term used to describe the chemical, physical, and biological characteristics of stormwater.

Stormwater Quantity: A term used to describe the volume characteristics of stormwater.

Stormwater Site Plan: A plan which shows the measures that will be taken during and after project construction to provide erosion and sediment control and stormwater control.

Stormwater Wetlands: Shallow, constructed pools that capture stormwater and allow for the growth of characteristic wetland vegetation.

Stream Buffers: Zones of variable width which are located along both sides of a stream and are designed to provided a protective natural area along a stream corridor.

Stream Gaging: The quantitative determination of stream flow using gages, current meters, weirs, or other measuring instruments at selected locations. See gaging station.

Streams: Those areas where surface waters flow sufficiently to produce a defined channel or bed. A defined channel or bed is indicated by hydraulically sorted sediments or the removal of vegetative litter or loosely rooted vegetation by the action of moving water. The channel or bed need not contain water year-round.

Structural BMPs: Devices which are constructed to provide temporary storage and treatment of stormwater runoff.

Subbasin: A drainage area which drains to a water course or waterbody named and noted on common maps and which is contained within a basin.

Subgrade: A layer of stone or soil used as the underlying base for a BMP.

Suspended Solids: Organic or inorganic particles that are suspended in and carried by the water. The term includes sand, mud, and clay particles (and associated pollutants) as well as solids in stormwater.

Swale: A shallow drainage conveyance with relatively gentle side slopes, generally with flow depths less than one foot.

Tailwater: Water, in a river or channel, immediately downstream from a structure.

Technical Release No. 20 (TR-20): A Soil Conservation Service (now NRCS) watershed hydrology computer model that is used to compute runoff volumes and provide routing of storm events through stream valleys and/or ponds.

Technical Release No. 55 (TR-55): A watershed hydrology model developed by the SoilConservation Service (now NRCS) used to calculate runoff volumes and provide a simplified routing for storm events through stream valleys and/or ponds.

Ten-Year Storm: The 24 hour storm event which exceeds bankfull capacity and occurs on average once every ten years (or has a likelihood of occurrence of 1/10 in a given year).

TESC: Temporary Erosion and Sediment Control (Plan).

Time of Concentration: The time period necessary for surface runoff to reach the outlet of a subbasin from the hydraulically most remote point in the tributary drainage area.

Toe of Slope: A point or line of slope in an excavation or cut where the lower surface changes to horizontal or meets the existing ground slope; or a point or line on the upper surface of a slope where it changes to horizontal or meets the original surface.

Toe Wall: Downstream wall of a structure, usually to prevent flowing water from eroding under the structure.

Topography: General term to include characteristics of the ground surface such as plains, hills, mountains; degree of relief, steepness of slopes, and other physiographic features.

Topsoil: Fertile or desirable soil material used for the preparation of a seedbed.

Total Maximum Daily Load (TMDL): The amount of pollutant, or property of a pollutant, from point, nonpoint, and natural background sources, that may be discharged to a water quality-limited receiving water. Any pollutant loading above the TMDL results in violation of applicable water quality standards.

Total Phosphorus (TP): The total amount of phosphorus that is contained within the water column.

Total Solids: The solids in water, sewage, or other liquids, including the dissolved, filterable, and nonfilterable solids. The residue left when the moisture is evaporated and the remainder is dried at a specified temperature, usually 130/C.

Total Suspended Solids (TSS): A measure of the filterable solids present in a sample, as determined by the method specified in 40 CFR Part 136.

Toxic Pollutant: Pollutants or combinations of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available to the Administrator of EPA, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring. Toxic pollutants also include those pollutants listed by the Administrator under CWA Section 307(a)(1) or any pollutant listed under Section 405(d) which relates to sludge management.

Trash Rack: Grill, grate or other device installed at the intake of a channel, pipe, drain or spillway for the purpose of preventing oversized debris from entering the structure.

Travel Time: The estimated time for surface water to flow between two points of interest.

Truncated Hydrograph: A method of computing the required design infiltration storage volume utilizing the differences from post-developed and pre-developed hydrograph volumes over a specific time frame.

Two-Year Storm: The 24 hour storm event which exceeds bankfull capacity and occurs on average once every two years (or has a likelihood of occurrence of 1/2 in a given year).

Underdrain: Plastic pipes with holes drilled through the top, installed on the bottom of an infiltration BMP which are used to collect and remove excess runoff.

Unstable Slopes: Those sloping areas of land which have in the past exhibited, are currently exhibiting, or will likely in the future exhibit, mass movement of earth.

Urbanized Area: Areas designated and identified by the U.S. Bureau of Census according to the following criteria: an incorporated place and densely settled surrounding area that together have a maximum population of 50,000.

USEPA: The United States Environmental Protection Agency.

Ultimate Condition: Full watershed build-out based on existing zoning.

Ultra-Urban: Densely developed urban areas in which little pervious surface exists.

Vactor Waste: The waste material that is found in the bottom of a catch basin.

Values: Wetland processes or attributes that are valuable or beneficial to society (also see Functions). Wetland values include support of commercial and sport fish and wildlife specie s, protection of life and property from flooding, recreation, education, and aesthetic enhancement of human communities.

Vegetative Filter Strip: A facility that is designed to provide stormwater quality treatment of conventional pollutants but not nutrients through the process of biofiltration.

Velocity Head: Head due to the velocity of a moving fluid, equal to the square of the mean velocity divided by twice the acceleration due to gravity (32.16 feet per second per second)[*v2/2g*].

Volumetric Runoff Coefficient (Rv): The value that is applied to a given rainfall volume to yield a corresponding runoff volume based on the percent impervious cover in a drainage basin.

Water Quality BMP: A BMP specifically designed for pollutant removal.

Water Quality Criteria: Comprised of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal.

Water Quality Standard (WQS): A law or regulation that consists of the beneficial use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Water Quality Volume (Wqv): The volume needed to capture and treat 90% of the average annual stormwater runoff volume equal to 1" (or 0.9" in Western Rainfall Zone) times the volumetric runoff coefficient (Rv) times the site area.

Water Quantity BMP: A BMP specifically designed to reduce the peak rate of stormwater runoff.

Water Surface Profile: The longitudinal profile assumed by the surface of a stream flowing in an open channel; the hydraulic grade line.

Wedges: Design feature in stormwater wetlands that increases flow path length to provide for extended detention and treatment of runoff.

Wetlands: Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. This includes wetlands created, restored or enhanced as part of a mitigation procedure. This does not include constructed wetlands or the following surface waters of the state intentionally constructed from sites that are not wetlands: irrigation and drainage ditches, grass-lined swales, canals, agricultural detention facilities, farm ponds, and landscape amenities.

Wet Pond: A facility that treats stormwater for water quality by utilizing a permanent pool of water to remove conventional pollutants from runoff through sedimentation, biological uptake, and plant filtration.

Wet Swale: An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

Wetted Perimeter: The length of the wetted surface of the channel.

Wet Vaults/Tanks: Underground storage facilities that treat stormwater for water quality through the use of a permanent pool of water that acts as a settling basin.

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