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Urban Runoff Pollution Prevention and Control Planning

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Chapter 1
Introduction

Purpose of Handbook

Urban runoff pollution sources, including storm water, combined sewer overflows, and diffuse or nonpoint sources of water pollution, are formidable obstacles to achieving water resource goals in many municipalities. Because these types of pollution sources are best addressed locally, the U.S. Environmental Protection Agency (EPA) has prepared this handbook to provide local officials with a practical planning approach for developing and implementing urban runoff pollution prevention and control plans in urban settings.

This handbook is designed to serve as an overall reference. Other references and guidance manuals have addressed specific aspects of storm water and urban nonpoint source (NPS) control, such as best management practice (BMP) design (Schueler, 1987; Tourbier and Westmacott, 1981), monitoring (U.S. EPA, 1988), and regulatory compliance (U.S. EPA, 1991, 1992a,b,c). This handbook, however, presents a step-by-step planning approach that municipal officials can use to develop technically feasible, targeted, affordable, and comprehensive urban runoff pollution prevention and control plans. Based on information from numerous references, this handbook is both an information source for urban runoff pollution issues and a guide to the planning and implementation of effective pollution prevention measures and controls. It will also help municipalities comply with evolving environmental regulations related to urban runoff management and control.

The handbook is divided into chapters that outline a step-by-step planning process. The planning process emphasizes and addresses the following considerations:

- A multitude of diffuse pollution sources exist (e.g., combined sewer overflows (CSOs), storm water, and NPS), and each type of source often has specific regulatory requirements. The planning approach is designed to be flexible enough to address these numerous sources (including point sources) and regulations or to focus on specific sources or regulations.
- While a high level of complexity and uncertainty is unavoidable in urban runoff control planning, this handbook is designed to minimize such difficulties by identifying a clear series of logical steps for the analysis. These steps are founded on what various regulations require, what is described in the technical literature, and what is standard practice for planning. Each chapter in the handbook describes one of these steps.
- Municipalities need a flexible approach based on the problems to be solved and available resources. The handbook, therefore, presents a range of options (from simple to complex) for the major steps in the planning process. Examples of these options are provided and case study descriptions are included to demonstrate their use.
- Numerous published resources address particular aspects of or steps in the planning process. Rather than repeat this literature, this handbook refers to the best sources and shows where and how to apply them in the planning process.
- It is more cost effective to prevent potential urban runoff pollution problems and protect existing resources than to implement pollution controls once a problem exists. Therefore, this handbook emphasizes pollution prevention and the implementation of regulatory controls designed to protect existing resources.

This chapter provides an overview of urban runoff pollution issues including types of pollutants, their origins and modes of transport, and their effects on receiving waters. Chapter 2 discusses the regulatory framework and the agencies and programs that deal with urban runoff pollution prevention and control. Chapter 3 describes the planning process set forth in this document. It stresses the iterative nature of storm water and urban NPS pollution prevention and control planning, and the need to set goals that can be reassessed and refined as efforts progress. Subsequent chapters discuss each step in the planning process for the development of an urban runoff pollution prevention and control plan. The process includes assessment of existing conditions using available data (Chapter 4), collection and analysis of supplemental data (Chapter 5), problem assessment and ranking (Chapter 6), screening (Chapter 7) and selection (Chapter 8) of pollution prevention and control strategies, and definition of the selected plan (Chapter 9).

Target Audience of the Handbook

This handbook has been prepared for municipalities seeking to comply with evolving urban runoff regulatory requirements and to improve or protect water resources and their uses through efficient and cost-effective pollution prevention and control strategies. The information in this handbook is primarily oriented to urban and suburban communities with residential, commercial, and industrial areas. Rural communities with extensive agricultural areas are not directly addressed, although some techniques discussed in the handbook are applicable. This document can also be used by state agencies, local environmental groups, and other entities responsible for or interested in protecting water resources. The handbook can be a resource to persons of diverse backgrounds implementing an urban runoff pollution prevention and control project. For example, it can be used by a multidisciplinary team (from city or county governments) that might include engineers, biologists, planners, chemists, political officials, environmental group members, and residents, all contributing their expertise and resources to the project.

Overview of Urban Runoff Pollution

Urban runoff pollution results from numerous sources. It is the result of rainfall and snow melt that becomes contaminated as it travels through the atmosphere, along the land surface, and makes its way to a water body. Urban runoff can enter a water body from an identifiable point source, such as a separate storm sewer outfall or a combined sewer overflow. It can also flow directly into a water body without an easily identified point of entry. Regardless of the point of entry, urban runoff has diffuse origins and, therefore, is difficult to manage and control.

EPA regulates certain point source discharges of urban runoff through the National Pollutant Discharge Elimination System (NPDES) permit program. NPDES permit requirements currently apply to urban runoff discharges from separate storm sewer systems of many large municipalities and urban counties across the country; to urban runoff discharged through a combined sewer overflow; and to urban runoff discharges from separate storm sewer outfalls that violate state water quality standards.

Since urban runoff that enters water bodies from diffuse or unidentifiable locations and sources can cause significant water quality degradation, it certainly should be addressed as part of a municipality's overall urban runoff pollution prevention and control program.

To benefit fully from the nation's urban water resources, widespread implementation of urban runoff pollution prevention measures and controls is necessary. Unlike point source control, however, institutional frameworks and funding sources to deal with urban runoff pollution are usually not well established, especially in smaller communities.

Urban runoff pollution prevention and control programs present unique challenges. Management and control programs must often be developed and implemented at the municipal level by local officials who might not be familiar with the technical and regulatory issues surrounding urban runoff pollution. The development of an urban runoff pollution prevention and control plan typically requires dealing with an extraordinary amount of ambiguity. To illustrate this complexity, Table 1-1 compares various types of water resource improvement projects. Municipal wastewater treatment projects are driven by regulations and the NPDES program requirements to control point sources with large, typically end-of-pipe methods (biological or chemical wastewater treatment), which generally do not call for land use control or involvement of multiple agencies. At the other end of the spectrum, urban runoff and nonpoint sources are inherently difficult to address because of the large number and types of diffuse discharges, the quantity and effects of which are difficult to assess. Control of such sources can require structural BMPs, stricter regulations, more comprehensive municipal maintenance programs, and environmental education for homeowners and businesses. (BMPs as used in this handbook can indicate any type of pollution control measure, including structural, regulatory, maintenance, education, or others.) A successful local urban runoff pollution prevention and control program depends on the involvement and support of multiple entities including federal agencies, state agencies, local government departments, watershed protection groups, and private citizens. Each of these groups has a stake in the program's outcome and could have significant resources to contribute.

The promulgation of EPA's storm water regulations and the evolution and strengthening of other programs, such as those dealing with nonpoint source pollution (see Chapter 2), reflect a trend—municipalities are being required to address diffuse sources of pollution to greater and greater degrees. These programs typically emphasize management, rather than treatment, and rely heavily on local control measures. Given the complexity of urban runoff pollution control and the typical scarcity of resources, municipal departments

Table 1-1. Comparison of Water Quality Planning Projects

Project Type	Engineering Facilities	CSO Facilities	Storm Water Management	Nonpoint Source Control	Lake Restoration	Watershed Management
Regulatory basis	National Environmental Policy Act; State Construction Grant Program	EPA National Strategy; State CSO policies	Storm Water Permit Rule, 40 CFR Part 122	CWA, Section 319	CWA, Section 314	SDWA, Surface Water Treatment Rule
Type and number of pollutant sources	One or few point source(s)	Few to multiple point sources	Few to multiple piped and direct discharges	Multiple nonpoint sources	Multiple point and nonpoint sources	Multiple point and nonpoint sources
Reliability of predicting pollutant loads and impacts	High	High	Moderate	Low to moderate	Moderate	Low to moderate
Type of alternatives	Engineering	Engineering with some BMPs	BMPs and engineering	BMPs with some engineering	BMPs and in-lake	Engineering, BMPs, and in-lake
Emphasis on regulatory/land use control	Limited	Limited	High	High	High	High
Agencies needed for implementation	Few	Few	Some	Many	Some	Many

must share responsibilities, and state and federal agencies, as well as local groups, ideally should network and build coalitions. Successful control efforts require effective planning and decision-making to make the best use of available resources. Identification of high-priority problem areas and development of effective pollution prevention and control strategies are critical to a successful program.

Land development and intensive land use lead directly to many of the pollution problems associated with urban runoff. These problems can be divided into two basic categories: hydrologic impacts and pollution.

Hydrologic Impacts of Urbanization

When precipitation contacts the ground surface, it can take several paths. These include returning to the atmosphere by evaporation; evapotranspiration, which includes direct evaporation and transpiration from plant surfaces; infiltration into the ground surface; retention on the ground surface (ponding); and traveling over the ground surface (runoff). Altering the surface that precipitation contacts alters the fate and transport of the runoff. Urbanization replaces permeable surfaces with impervious surfaces (e.g., roof tops, roads, sidewalks, and parking lots), which typically are designed to remove rainfall as quickly as possible. As seen in Figure 1-1, increasing the proportion of paved areas decreases the infiltration and evapotranspiration paths of precipitation, thus increasing the amount of precipitation leaving an area as runoff.

In addition to magnifying the volume of runoff, urban development increases the peak runoff rate and decreases travel time of the runoff. When mechanisms that delay entry of runoff into receiving waters (i.e., vegetation) are replaced with systems designed to remove and convey storm water from the surface, the storm water's travel time to the receiving waters is greatly reduced, as is the time required to discharge the storm water generated by a storm. Figure 1-2 shows an urban area's typical predevelopment and postdevelopment discharge rates over time.

The following changes to hydrology might be expected for a developing watershed:

- Increased peak discharges (by a factor of 2 to 5).
- Increased volume of storm runoff.
- Decreased time for runoff to reach stream.
- Increased frequency and severity of flooding.
- Reduced streamflow during periods of prolonged dry weather (loss of base flow).
- Greater runoff and stream velocity during storm events.

Each of these hydrologic changes can lead to increased pollutant transport and loading to receiving waters. As peak discharge rates increase, erosion and channel scouring become greater problems. Eroded sediments carry nutrients, metals, and other pollutants. In addition, increases in runoff volume result in greater discharges of pollutants. Pollution problems, therefore, multiply with increased urbanization.

Changes in hydrology affect receiving waters through channel widening and subsequent streambank erosion

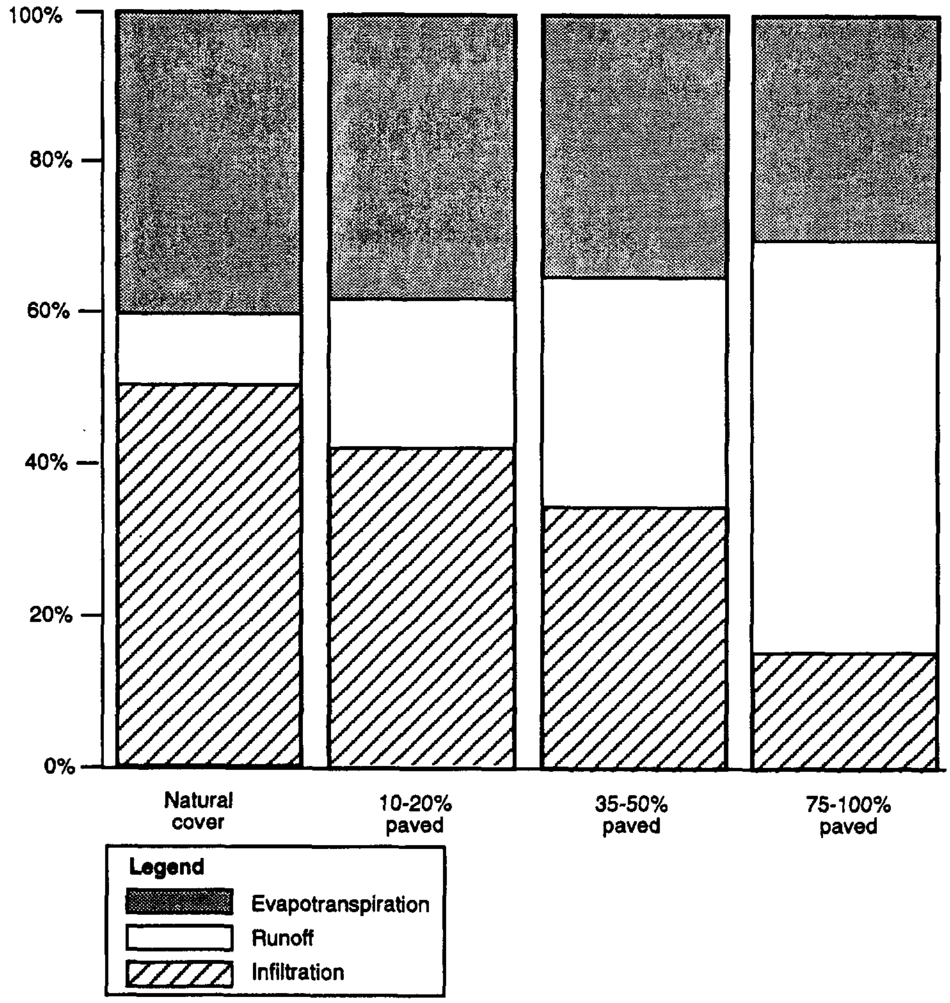

Figure 1-1. Typical changes in runoff flow resulting from paved surfaces (MPCA, 1989).

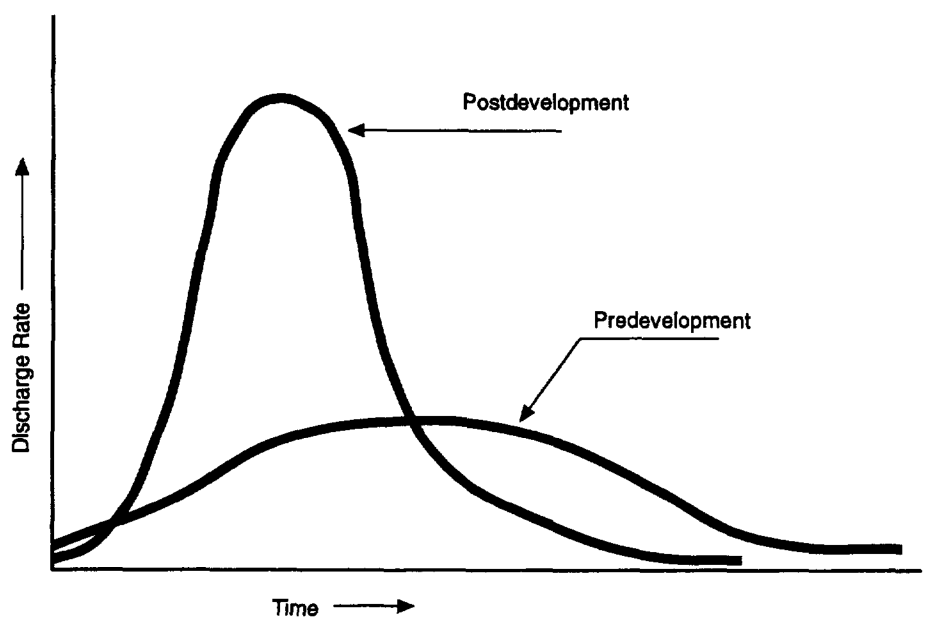

Figure 1-2. Pre- and postdevelopment hydraulics (MPCA, 1989).

and deposition, increased stream elevation due to greater discharge rates, and an increased amount of sedimentary material within a stream due to streambank erosion. The decrease in the ground surface's infiltration capacity and loss of buffering vegetation undermines a significant mechanism for pollutant removal, thereby increasing the load entering the receiving waters. Hydrologic changes can result in more subtle but equally important impacts. Removal or loss of riparian vegetation due to erosion, for example, can increase stream temperature as levels of direct sunlight increase, which can in turn change the biological community structure. With increased sunlight, algae in nutrient-rich receiving waters grow faster and the dominant species changes, which affects the composition of higher organisms. Increased imperviousness and loss of ground-water resupply can lead to more frequent low-flow conditions in perennial streams. The effects of hydrologic changes due to urbanization therefore should be prevented or mitigated to minimize urban runoff pollution.

Further discussion of urban runoff hydrologic analysis is presented in Chapter 6. Appendix A lists sources of additional, more detailed information on the effects of urbanization on runoff and stream hydrology.

Urban Runoff Pollution

Prevention and control of urban runoff pollution requires an understanding of pollutant categories, of the major urban sources of these pollutants, and of the pollutants' effects. Table 1-2 lists the primary categories of urban runoff pollutants, pollutants associated with each category, typical urban runoff pollutant sources, and potential effects. Table 1-3 summarizes the relative contribution of predominant NPS pollution sources to the degradation of U.S. rivers, lakes, and estuaries. Additional pollutant sources often included in these categories are shown in Table 1-2. For municipalities, urban storm-generated runoff and construction are the most prevalent sources; outlying agricultural activities also can play a significant role in many urban areas.

The effects of urban runoff pollutants vary for different water resource types. A given municipality's pollutants of concern, therefore, depend on the types of water resources in and downstream of the community, and

Table 1-2. Summary of Urban Runoff Pollutants

Category	Parameters	Possible Sources	Effects
Sediments	Organic and inorganic Total suspended solids (TSS) Turbidity Dissolved solids	Construction sites Urban/agricultural runoff CSOs Landfills, septic fields	Turbidity Habitat alteration Recreational and aesthetic loss Contaminant transport Navigation/hydrology Bank erosion
Nutrients	Nitrate Nitrite Ammonia Organic nitrogen Phosphate Total phosphorus	Urban/agricultural runoff Landfills, septic fields Atmospheric deposition Erosion	Surface waters Algal blooms Ammonia toxicity Ground water Nitrate toxicity
Pathogens	Total coliforms Fecal coliforms Fecal streptococci Viruses *E. Coli* Enterococcus	Urban/agricultural runoff Septic systems Illicit sanitary connections CSOs Boat discharges Domestic/wild animals	Ear/intestinal infections Shellfish bed closure Recreational/aesthetic loss
Organic enrichment	Biochemical oxygen demand (BOD) Chemical oxygen demand (COD) Total organic carbon (TOC) Dissolved oxygen	Urban/agricultural runoff CSOs Landfills, septic systems	Dissolved oxygen depletion Odors Fish kills
Toxic pollutants	Toxic trace metals Toxic organics	Urban/agricultural runoff Pesticides/herbicides Underground storage tanks Hazardous waste sites Landfills Illegal oil disposal Industrial discharges	Bioaccumulation in food chain organisms and potential toxicity to humans and other organisms
Salts	Sodium chloride	Urban runoff Snowmelt	Vehicular corrosion Contamination of drinking water Harmful to salt-intolerant plants

Table 1-3. Relative Contribution of Nonpoint Source Loading (U.S. EPA, 1990a)

Source	Relative Impacts, %		
	Rivers	Lakes	Estuaries
Agriculture	55.2	58.2	18.6
Storm sewers/urban runoff*	12.5	28.0	38.8
Hydrological modification	12.9	33.1	4.8
Land disposal	4.4	26.5	27.4
Resource extraction	13.0	4.2	43.2
Construction	6.3	3.3	12.5
Silviculture	8.6	0.9	1.6

* Includes combined sewer overflows.

their desired uses. While conditions are very site specific, the water resources generally most affected by certain pollutants are discussed in the following sections.

Sediments

Sediment is made up of particulate matter that settles and fills in the bottoms of ditches, streams, lakes, rivers, and wetlands. Sediment loading occurs primarily from soil erosion and runoff from construction sites, urban land, agricultural areas, and streambanks. While some sedimentation is natural, construction, farming, and urbanization accelerate the process by increasing the rates of storm water runoff, by removing cover vegetation, and by changing slopes and affecting soil stability. Increased runoff from developed areas transports solids from various sources, including deposition from erosion, litter (both manmade and naturally produced), and road sanding. These solids also carry nutrients, metals, and other substances that can affect water resources adversely.

Sedimentation can have substantial biological, chemical, and physical effects in receiving waters. Solids can either remain in suspension and settle slowly, or settle quickly to the bottom. Suspended solids can make water look cloudy or turbid, diminishing a water body's aesthetic and recreational qualities. Decreased light penetration into the water column due to increased turbidity reduces the growth of microscopic algae and submerged aquatic vegetation. Suspended solids can also threaten the survival of filter-feeding organisms (e.g., shellfish and small aquatic invertebrates), which could stop feeding or feed less efficiently. Sight-feeding predators (e.g., game fish and microscopic predatory feeders) have trouble locating prey in turbid waters and, as a result, can suffer from increased stress and decreased survival.

Deposited sediments that change the physical nature of the bottom can greatly alter hydrology and habitat and affect navigation. Sedentary, bottom-dwelling species can be smothered by accumulating sediment, and the habitat change can threaten many species that use the bottom habitat to feed, spawn, or live. Depositional sediments are also a sink for adsorbed pollutants, such as nutrients, toxic metals, and organics, which can affect both water-column and bottom-dwelling organisms. These toxic pollutants can be remobilized if sediments are disturbed and can pose a health hazard to humans through the consumption of fish and shellfish. Solids can cause problems in either the suspended or the deposited state. While less of an issue for ground water, solids can affect all surface water resource types.

Nutrients

Runoff can contain high concentrations of nitrogen and phosphorus, the nutrients of primary concern to water quality. Nutrients are associated with agricultural and urban runoff, atmospheric deposition, leachate from landfills and septic systems, and erosion. Nutrient additions can cause eutrophication, or over-enrichment, of receiving waters, stimulating algal growth. In many cases, nutrients from urban runoff originate from chemical fertilizers and thus are in a dissolved form which algae in the receiving waters can readily utilize. Traditionally, phosphorus is considered the growth-limiting nutrient in freshwater systems, while nitrogen is considered growth-limiting in marine systems. According to research in estuarine systems, however, seasonal shifts can occur between nitrogen and phosphorus enhancement of algal growth (D'Elia et al., 1986a,b).

Nutrient enrichment can result in severe algal blooms, either in the water column or in stream and lake beds (by attached forms of algae). Blooms in the water column can occur either as surface scums of blue-green algae (e.g., *Anacystis* or *Oscillatoria* blooms) or throughout the water column by numerous species of floating algae. In all cases, blooms can be transported by wind and currents, and are often concentrated along the downwind shoreline; these blooms can cause unpleasant odors and otherwise detract from the aesthetic value of the water resource. High densities of certain algal species can create taste and odor problems in drinking water from reservoirs. Some marine algal species potentially stimulated by eutrophication of coastal waters contain toxins that can be harmful to humans consuming affected fish or shellfish. In addition to increased algal densities, nutrient enrichment can lead to shifts in species composition that can profoundly affect the transfer of carbon through the food web (Sanders et al., 1987; Duguay et al., 1989).

One of the most profound effects of eutrophication is the depletion of dissolved oxygen in the water column.

Algal cells from blooms and aquatic plants not utilized as food by fish or other aquatic species eventually settle to the bottom sediments. Bacterial decomposition of this material consumes oxygen and can lead to anoxic conditions (little or no dissolved oxygen) in the near-bottom waters. These conditions can persist for months during the summer, damaging fish habitat, creating odors, and releasing more nutrients from the sediments. This phenomenon can occur on a small scale, such as in a pond, small lake, or the quiescent embayments of lakes and rivers used for spawning, or on a very large scale such as in the Chesapeake Bay. While mobile organisms, such as many species of fish, can frequently move away from oxygen-stressed waters, sessile organisms, such as shellfish, or fish species that require high levels of oxygen, such as trout, are at much higher risk. In highly nutrient-enriched waters, a diurnal variation in dissolved oxygen concentration might occur. During daylight hours, algae produce oxygen through photosynthesis; then at night, algae consume dissolved oxygen through endogenous respiration.

Generally, nutrients cause problems that allow for the development of algal blooms in slow-moving waters, such as lakes, coastal areas, large rivers, and wetlands. Nutrients are not considered a significant problem in fast-moving urban streams, except when such streams contribute nutrient loading to other water resources.

Pathogens

Pathogens are bacteria, protozoa, and viruses that can cause disease in humans. Although not pathogenic themselves, the presence of bacteria such as fecal coliform or fecal enterococci are used as indicators of pathogens and of potential risk to human health. While detecting these indicator organisms in runoff does not conclusively prove the presence of pathogens, no more reliable system has been developed.

According to data from the Nationwide Urban Runoff Program (NURP) study (U.S. EPA, 1983), urban runoff typically contains fecal coliform densities of 10,000 (10^4) to 100,000 (10^5) organisms per 100 milliliters. While these high densities of indicator organisms do not necessarily indicate the presence of pathogens, potential health risks are associated with primary contact recreation, such as swimming; with secondary contact recreation, such as boating; and with consumption of contaminated fish and shellfish in areas affected by urban runoff.

The primary sources of bacterial and viral pathogens are runoff from livestock in agricultural areas and runoff from pet wastes and other contaminants in urban areas (ASIWPCA, 1985). Other sources of these disease-causing organisms include failed septic systems, landfills, bathers, combined sewer overflows, and unauthorized sanitary sewer connections to storm drains.

Pathogens generally cause water quality degradation in slow-moving waterways and water resources used by humans for primary and secondary contact recreation or shellfishing. Pathogens are considered pollutants of concern in drinking-water sources, slow-moving rivers, lakes, and estuaries. Pathogen-contaminated discharges to wetlands or to fast-moving urban streams are typically less of a concern because of the lack of recreational use and fishing in such waters.

Oxygen-Demanding Matter

As microorganisms consume organic matter deposited in water bodies via storm-water runoff, oxygen is depleted from the water. Organic enrichment can arise from agricultural and urban runoff, combined sewer overflows (CSOs), and leachate from septic tanks and landfills. A sudden release of oxygen-demanding substances into a water body during a storm can result in total oxygen depletion and fish kills. Organic enrichment can also have long-term effects on sediment quality, increasing organic content and the tendency of sediments to deplete surface waters and benthos of oxygen, referred to as sediment oxygen demand (SOD). The solid and dissolved organic content of water and its potential to deplete oxygen is measured by its biochemical oxygen demand (BOD).

Oxygen-demanding matter is primarily a concern in water bodies that support aquatic life, such as rivers, lakes, and estuaries. While generally a less important consideration for fast-moving urban streams and wetlands, high organic loads have been shown to cause oxygen depletion in some urban streams.

Toxic Pollutants

Toxic pollutants include metals and organic chemicals. Heavy metals in urban runoff result from sources such as the breakdown of galvanized and chrome-plated products (e.g., trash cans and car bumpers), vehicular exhaust residue, and deicing agents. Potential sources of toxic organic pollutants include vehicular residues, industrial areas, landfills, hazardous waste sites, leaking underground and aboveground fuel storage tanks, and fertilizers and pesticides. In the NURP studies (U.S. EPA, 1983), copper, lead, and zinc were detected in more than 90 percent of storm water samples from residential, commercial, and light industrial sites; 14 toxic organic compounds were detected in more than 10 percent of samples.

Potentially toxic compounds in urban runoff pollution include oil and grease products from vehicles and construction equipment. These products enter waterways in runoff from roads, parking lots, service areas, and construction sites, and can be constituents of landfill leachate. Such hydrocarbons frequently become adsorbed to sediment particles and are deposited in bottom sediments. These compounds are toxic to aquatic organisms and can bioaccumulate in fish and shellfish, potentially resulting in toxic effects to humans consuming this tainted food. Because of the potentially acute and chronic effects of toxic pollutants, their discharge to all water resource types should be limited.

Sodium and Chloride

Discharges of sodium and chloride to surface waters result primarily from road salting during the winter, and snowmelt during the early spring thaws. These discharges can affect the taste of drinking water, can harm people who require low sodium diets, and can result in corrosion. Also affected are salt-intolerant plant species. Sodium and chloride concentrations in runoff are typically small enough to not cause serious problems in water resources with continuous flushing (e.g., in rivers and streams). Sodium and chloride discharges are more of a concern in drinking-water supplies and water resources that are not well flushed (e.g., lakes and ground water).

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

ASIWPCA. 1985. Association of State and Interstate Water Pollution Control Administrators. America's clean water: the states' nonpoint source assessment. Washington, DC.

D'Elia, C.F., J.G. Sanders, and W.R. Boynton. 1986a. Nutrient enrichment and phytoplankton dynamics in the Patuxent River estuary. Final Report to Maryland Office of Environmental Programs. [UMCEES] Chesapeake Biological Laboratory Ref. No. 86-30.

D'Elia, C.F., J.G. Sanders, and W.R. Boynton. 1986b. Nutrient enrichment studies in a coastal plain estuary: phytoplankton growth in large-scale continuous cultures. Can. J. Fish Aquat. Sci. 43:397-406.

Duguay, L., G. Muller-Parker, S. Cibik, J. Love, J. Sanders, and D. Capone. 1989. Effects of insolation and nutrient loading on the response of natural phytoplankton. Final Report to the Maryland Department of the Environment. [UMCEES] Chesapeake Biological Laboratory Ref. No. 89-134.

MPCA. 1989. Minnesota Pollution Control Authority. Protecting water quality in urban areas: best management practices for Minnesota. St. Paul, MN.

Sanders, J.G., S.J. Cibik, C.F. D'Elia, and W.R. Boynton. 1987. Nutrient enrichment in a coastal plain estuary: changes in phytoplankton species composition. Can. J. Fish. Aquat. Sci. 44(1):83-90.

Schueler, T.R. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments Publication 87703.

Tourbier, J.T., and R. Westmacott. 1981. Water resources protection technology. A handbook of measures to protect water resources in land development. Urban Land Institute, Washington, DC.

U.S. EPA. 1983. U.S. Environmental Protection Agency. Results of the Nationwide Urban Runoff Program, vol. 1. Final report (NTIS PB84-185552). Washington, DC.

U.S. EPA. 1988. U.S. Environmental Protection Agency. Guide for preparation of quality assurance project plans for the National Estuary Program. Washington, DC.

U.S. EPA. 1990. U.S. Environmental Protection Agency. National water quality inventory—1988 report to Congress. EPA/440/4-90/003. Washington, DC.

U.S. EPA. 1991. U.S. Environmental Protection Agency. Guidance manual for the preparation of part 1 of the NPDES permit applications for discharges from municipal separate storm sewer systems. EPA/505/8-91/003A. Office of Water, Washington, DC.

U.S. EPA. 1992a. U.S. Environmental Protection Agency. Storm water management for industrial activities: developing pollution prevention plans and best management practices. EPA/832/R-92/006. Office of Water, Washington, DC.

U.S. EPA. 1992b. U.S. Environmental Protection Agency. Storm water management for construction activities: developing pollution prevention plans and best management practices. EPA/832/R-92/005. Office of Water, Washington, DC.

U.S. EPA. 1992c. U.S. Environmental Protection Agency. Guidance manual for the preparation of part 2 of the NPDES permit applications for discharges from municipal separate storm sewer systems. EPA/833/B-92/002. Washington, DC.

Chapter 2
Regulatory Framework

The structure of urban runoff regulations includes all levels of government. Responsibility for enforcement and oversight of these regulations can be held by federal, state, local, or in some cases regional agencies. Despite this array of programs and regulations, the primary responsibility for developing approaches to solve urban runoff pollution problems generally resides with municipalities. Such pollution problems are considered to be best handled locally because of the site-specific nature of pollution sources and of potential pollution prevention and control activities.

The major direction for prevention and control of urban runoff pollution has come from the federal government through the 1972 Clean Water Act (CWA) and its amendments. Several sections of the Act deal with diffuse source pollution. Additional federal statutes that address urban runoff pollution include the Pollution Prevention Act, the Safe Drinking Water Act (SDWA), and the Coastal Zone Management Act (CZMA).

This chapter discusses the major federal regulations, policies, and programs related to urban runoff pollution prevention and control. Given the national scope of this handbook and the site-specific nature of state, regional, and local regulations, this chapter focuses on regulations and programs at the federal level. Currently, the major federal statutes, regulations, and programs that provide a framework for storm water runoff and NPS pollution prevention and control are:

- Storm Water NPDES Permit Program
- Combined Sewer Overflow Strategy
- Pollution Prevention Act
- Safe Drinking Water Act
- Nonpoint Source Management Program
- Coastal Zone Nonpoint Source Pollution Control
- Clean Lakes Program
- National Estuary Program
- Agricultural Nonpoint Source Programs

This chapter includes a general discussion of each of these statutes, regulations, and programs and of how they relate to urban runoff pollution control at the municipal level. Because of the dynamic, evolving nature of most of these regulations and programs, municipalities must keep up to date on specific schedules and requirements. In addition, local officials need to be familiar with urban runoff pollution prevention and control programs initiated and overseen by state, county, and local entities. These programs might stem from federal regulatory authority but will be more tailored and directly applicable to local issues and needs.

Storm Water NPDES Permit Program

Under Section 402 of the 1972 CWA, point source discharges of pollutants to navigable waters are prohibited unless authorized by an NPDES permit. Initially, the focus of the permit program was on point source discharges of industrial and municipal wastewaters. As controls for point source discharges were implemented, however, it became apparent that to achieve the water quality goals of the CWA, more diffuse sources of pollutants, including urban and agricultural runoff, also would have to be addressed.

In the 1987 amendments to the CWA, Congress introduced new provisions and reauthorized existing programs that address diffuse sources. The development of a workable program to regulate storm water discharges was challenging given the number of individual discharges, the diffuse nature of the sources and related water quality effects, and limited state and federal resources. After extended development and review, EPA promulgated the NPDES storm water regulations in November 1990. These regulations represent the most comprehensive program to date for controlling urban and industrial storm water runoff pollution. The storm water regulations apply to municipal separate storm sewer systems that serve either incorporated populations greater than 100,000 or unincorporated, urbanized populations greater than 100,000 based on the 1980 decennial census. In addition, EPA defined a discharge associated with industrial activity; activities that fall within 11 industrial categories are required to obtain a NPDES storm water permit (U.S. EPA, 1990a).

The 1990 NPDES storm water permit regulations directly affect approximately 200 municipalities and 47 counties across the country, as well as an estimated 125,000 industries and 10,000 construction sites annually. Under this extensive program, affected municipalities and industries must conduct storm water runoff sampling and collect site characterization information for each permit application. The municipal permit application requirements include:

- Proof of the municipality's legal authority to enforce the regulations.
- Characterization of the municipality's storm water runoff through wet-weather sampling.
- Location of illicit storm drain connections and development of a plan to eliminate those connections.
- Description of existing urban runoff control programs and development of a proposed storm water management program.
- Analysis of the municipality's fiscal resources to implement the program.

Once a permit application is filed and a permit issued, both municipalities and industries are required to comply with permit conditions as specified by EPA or the responsible state permitting authority. EPA has developed general permits designed to cover many industrial storm water discharges. These general permits require the elimination of non-storm water discharges from drainage systems and the development of a storm water pollution prevention plan, including:

- Development of a pollution prevention team.
- Description of sources expected to add pollution to runoff.
- Implementation of source control practices, such as:
  - good housekeeping,
  - preventive maintenance,
  - spill prevention and response procedures,
  - equipment inspections,
  - employee training,
  - recording and internal reporting procedures,
  - removal of non-storm water discharges,
  - sediment and erosion control, and
  - management of runoff.
- Implementation of annual site-compliance evaluations.

Most municipalities in the United States have populations under 100,000 and therefore are not currently required to file municipal storm water permit applications. EPA is considering regulations to address storm water runoff pollution from smaller communities (CWA Section 402), which could be required to develop storm water management plans. In addition, existing NPDES regulations allow EPA or a responsible state permitting authority to require permits for any storm water discharges that cause violations of water quality standards.

Combined Sewer Overflow Strategy

Combined sewer overflows (CSOs) are discharges from sewer systems that are designed to carry storm water rainfall and snowmelt runoff, along with sanitary sewage, pretreated industrial wastewater, and a certain quantity of flow from storm and ground-water infiltration. Combined systems were constructed in more than 1,200 municipalities throughout the United States, particularly in the Northeast, East, and Midwest. Combined sewer systems have overflow points designed to discharge wet-weather flows that exceed the carrying capacity of the system (usually designed to carry peak dry-weather flow). Such combined sewer discharges, if not treated before overflowing into receiving waters, can significantly affect water resources and threaten human health.

Many municipalities have begun to address these pollution sources through various means, such as storing and treating the discharges, implementing low-cost BMPs, and replacing combined sewers with separate sanitary and storm sewer systems. Separating combined systems can be a long and relatively expensive process and results in a separate storm drainage system that could eventually require an NPDES permit.

To address CSO discharges, EPA developed a national strategy (Federal Register, 1989), which sets forth three major objectives in NPDES permitting for CSOs:

- To ensure that no CSOs occur during dry-weather flow conditions.
- To bring all wet-weather CSOs into compliance with the technology-based requirements of the CWA and applicable state water quality standards.
- To minimize impacts on water quality, aquatic biota, and human health from wet-weather generated overflows.

To achieve these objectives, recommended strategies include the application of the best conventional pollutant control technology (BCT), or best available technology economically achievable (BAT), based on best professional judgment (BPJ).

The technology-based effluent limitation for CSOs were mandated to include six minimum technologies:

- Proper operation and maintenance

- Maximization of collection system storage
- Pretreatment
- Maximization of flow to treatment plant
- Elimination of dry-weather overflows
- Control of solids and floatables

Following the development of a guidance document for implementing the National CSO Strategy, three more minimum technologies were added to the list:

- CSO inspection, monitoring, and reporting
- Pollution prevention
- Public notification of CSO impacts

EPA, with input from numerous state, municipal, and environmental organizations, released a new Draft CSO Control Policy on January 19, 1993. The final policy will provide guidance to permittees on developing consistent CSO control strategies, and to NPDES permitting authorities on developing permit language and enforcement strategies that will ensure consistent implementation of control strategies.

Pollution Prevention Act

With the passage of the Pollution Prevention Act of 1990, Congress established a national policy that emphasizes pollution prevention over control or treatment. With this policy, Congress defined a pollution prevention hierarchy for all pollution reduction programs:

- Pollution should be prevented or reduced at the source whenever feasible.
- Pollution that cannot be prevented should be recycled in an environmentally safe manner.
- Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner.
- Disposal or other release to the environment should be a last resort and should be conducted in an environmentally safe manner.

As stated in Chapter 1, one goal of this handbook is to integrate pollution prevention into urban runoff pollution control planning. Summarizing the goals of EPA's pollution prevention program, the National Pollution Prevention Strategy serves two basic purposes:

- To provide guidance and direction for incorporating pollution prevention in EPA regulatory and nonregulatory programs.
- To set forth a program that will achieve specific pollution prevention objectives in a reasonable time period.

To address the first objective, EPA is investigating changes to the institutional barriers to pollution prevention within the Agency by:

- Designating special assistants for pollution prevention in each assistant administrator's office.
- Developing incentives and awards for Agency staff who engage in pollution prevention efforts.
- Incorporating prevention into each program office's comprehensive 4-year strategic plans.
- Providing pollution prevention training to Agency staff.
- Supporting technology innovation.
- Including prevention-related activities in the Agency's operating guidance, accountability measures, and regulatory review and development process.

To address the second objective, EPA is targeting high-risk chemicals and seeking to reduce releases of these chemicals through a voluntary program.

This pollution prevention policy was originally developed to address industrial waste issues. Since it also applies to storm water and diffuse source pollution, EPA is now emphasizing pollution prevention at the municipal level in dealing with urban runoff pollution. Municipalities are encouraged to employ techniques and policies that reduce the amount of pollutants available for transport in urban runoff. Municipalities can implement activities and use management practices that are consistent with EPA's pollution prevention policies. Such activities include public education; household hazardous waste collection; location and elimination of illicit connections to separate storm systems; reduction of roadway sanding and salting; and reduction of pesticide, herbicide, and fertilizer use. Such programs, which are discussed in later chapters, can reduce the availability of pollutants for washoff.

Safe Drinking Water Act

The Surface Water Treatment Rule (SWTR) of the SDWA outlines requirements for watershed protection. Municipalities that use surface water for drinking-water supplies are required by EPA or the approved state agency to develop a watershed protection plan for such surface waters (AWWA, 1990). Municipalities are required to:

- Develop a watershed description, including:
  - the watershed's geographic location and physical features;
  - the location of major components of the water system in the watershed;
  - annual precipitation patterns, streamflow characteristics, and other hydrology information;

- agreements and delineation of land use and ownership.

- Identify the watershed characteristics and activities detrimental to water quality, such as:
  - the effects of precipitation, terrain, soil types, and land cover;
  - the effects of animal population;
  - point sources of contamination;
  - nonpoint sources of contamination, such as road construction, pesticides, logging, grazing animals, and recreational activities.
- Control detrimental activities by implementing appropriate control practices.
- Conduct ongoing routine and specific monitoring.

Under the SDWA, watershed control programs also must:

- Minimize potential contamination by *Giardia* cysts and viruses in the water source.
- Characterize the watershed hydrology and land ownership.
- Identify watershed characteristics and activities that threaten or harm source water quality.
- Monitor activities that threaten or harm source water quality.

These watershed control programs are designed to protect surface drinking water supplies from urban runoff and NPS pollutants, and to reduce the need for subsequent water treatment.

Nonpoint Source Management Program

A 1975 federal program designed to address NPS pollution, called the 208 program, did not lead to significant implementation. A more recent program, initiated under the 1987 CWA amendments, is one of the few federal programs that specifically addresses and provides funding for NPS control. Through this program under CWA Section 319, states must submit a Nonpoint Source Assessment Report which:

- Identifies navigable waters that do not meet applicable water quality standards.
- Identifies categories of nonpoint sources that add significant pollution to the waters not meeting water quality standards.
- Describes the process for identifying BMPs to address the identified nonpoint sources.
- Identifies and describes state programs for controlling pollution from identified nonpoint sources.

To be eligible for funding under CWA Section 319, states can use the information in Nonpoint Source Assessment Reports to develop and gain EPA approval for Nonpoint Source Management Plans. These management plans provide a framework to address the state's NPS control issues and to develop priorities for implementation. At a minimum, management plans must include:

- An identification of the BMPs selected to address the nonpoint sources identified in the Assessment Report.
- An identification of the programs to implement these BMPs.
- A schedule with annual milestones for program implementation.
- A certification of existing adequate legal authority to implement the program.
- A description of available federal and state funding sources to be used.

Through CWA Section 319, EPA has the authority to base annual NPS funding on its review and approval of these management plans. EPA usually grants funds to the state authority overseeing NPS control and allows the state authority to earmark the funds for specific programs, which are to be implemented on a watershed basis to the maximum extent possible. The priorities set in a state's management plan influence how the funds will be spent each year. Depending on the state, funding through this program could be available for a municipality, or a group of municipalities, to implement aspects of an NPS management program in a high-priority watershed. Funds from this program, however, are limited and are available mainly for demonstration projects to educate or establish the effectiveness of particular controls.

Coastal Zone Nonpoint Source Pollution Control

Under Section 6217(g) of the 1990 Coastal Zone Act Reauthorization, states with existing coastal zone management programs are required to establish coastal NPS programs approved by EPA and the National Oceanic and Atmospheric Administration (NOAA). These programs will be incorporated into the existing state NPS management plans (CWA Section 319) and state Coastal Zone Management Programs (CZMA Section 306). The purpose of Section 6217(g) is to encourage states to work with local authorities and other states to develop and implement a program of NPS pollution management to restore and protect coastal waters (U.S. EPA, 1991). This program is limited to NPS pollution control in coastal areas and the contribution of inland sources of pollution to degraded coastal water quality. In order to maintain a federally approved coastal zone program, states must act to reduce NPS pollution through:

- Implementing EPA-specified management measures and additional state-developed measures to control NPS pollution in impaired or threatened coastal waters.
- Modifying the state coastal zone boundary, if necessary.
- Developing enforceable policies and mechanisms to implement the Coastal Zone Act Reauthorization management measures.
- Coordinating activities with existing CWA programs, such as basin planning (Section 303), NPS planning (Section 319), and the National Estuary Program (Section 320).
- Developing a technical assistance program for local governments and the public to implement the management measures.
- Developing a public participation program.

The coastal NPS program can directly affect municipalities in coastal areas with impaired or threatened waters if they are not covered by the NPDES municipal permit program (CWA Section 402). They will likely be required by the state coastal NPS control agency to implement management practices to address NPS pollution. In addition, since this program includes a requirement for states to reassess their coastal zone boundaries, municipalities that formerly were not within coastal areas might now be included.

EPA and NOAA, along with other federal and state agencies, are developing guidance materials: a document to assist states in developing their coastal NPS pollution control program (U.S. EPA, 1991) and a document specifying management measures for controlling NPS pollution in coastal areas (U.S. EPA, 1993). This management measures guidance document includes the following information for each management measure discussed:

- A description of activity categories and applicable locations.
- A listing of the pollutants addressed.
- A description of the water quality effects of implementation.
- An outline of the expected pollutant reductions achievable.
- A cost description.
- An outline of specific factors to be considered in adapting management measures to specific sites.

The major management measure categories are agriculture, forestry, urban, marinas and recreational boating, hydromodification, shoreline erosion, and wetlands. Where the proposed management measures do not address pollution problems adequately, states must develop additional management measures to prevent and reduce nonpoint sources of pollution. States with existing coastal zone management programs will be required to implement management measures in conformity with the approved NPS measures. This requirement could result in additional urban runoff pollution prevention and control requirements on affected coastal municipalities.

Clean Lakes Program

The Clean Lakes Program, initiated in 1972 under CWA Section 314, sets goals for defining the cause and extent of pollution problems in each state's lakes and for developing effective techniques to restore these lakes. Lake protection or restoration projects should include the development of watershed assessments that consider all point and nonpoint sources affecting lake quality. Each state is encouraged to organize and administer its own lakes program and to apply for EPA grants for lakes projects that meet state and EPA criteria.

A review of statewide lake quality, to be part of the biennial state Section 305(b) report, must include:

- Identification and classification of all publicly owned lakes.
- Description of the procedures, processes, and methods to control sources of pollution.
- Description of the methods and procedures to restore lake quality.
- Description of methods and procedures to control high acidity.
- List of the lakes for which uses are known to be impaired.
- Assessment of the water quality status and trends.

Clean Lakes projects are conducted in several phases: a diagnostic/feasibility study, implementation of recommendations, and long-term monitoring. The diagnostic section of the study must consist of the following information:

- Name, location, and hydrologic characteristics of the lake to be studied.
- Geologic description of the drainage basin.
- Public access to the lake.
- Size and economic structure of the watershed's population.

- Summary of historical lake uses.
- Adverse impacts caused by lake degradation.
- Water uses of the lake.
- Point sources of pollution to the lake and abatement actions to reduce this pollution.
- Land uses in the lake watershed.
- Discussion and analysis of historical baseline limnological data and 1 year of current limnological data as described in 40 CFR Part 35.
- Identification and discussion of biological resources in the lake.

The feasibility section should include:

- Identification and discussion of pollution control alternatives.
- Benefits expected from implementing the project.
- Long-term monitoring schedule.
- Proposed milestone implementation schedule.
- Description of how nonfederal funds will be obtained for the project.
- Relationship between the proposed lake project and other water pollution control initiatives in the area.
- Summary of public participation in developing and assessing the project.
- Operation and maintenance plan.
- Copies of all permits and impending permits applicable to the project.

Once a diagnostic/feasibility report has been submitted and approved, federal grants may be available to implement project recommendations.

National Estuary Program

With the 1987 passage of CWA amendments (Section 320), Congress created the National Estuary Program (NEP) to identify nationally significant estuaries, protect and improve their water quality, and enhance their living resources (U.S. EPA, 1990b). NEP estuary selection is based on the estuaries' potential to include environments of significant national concern and the demonstrated commitment by involved local parties to protect these valuable resources. Currently, 21 estuaries are part of the NEP (see Table 2-1). Common problems found in these estuaries include pollution from agricultural and urban runoff and waste disposal activities, as well as high levels of toxins and pathogens, excess nutrient loading, habitat loss, and declining abundance of living marine resources.

Table 2-1. Estuaries in the National Estuary Program as of 1993

Albemarle-Pamlico Sounds, NC	Narragansett Bay, RI
Buzzards Bay, MA	New York/New Jersey Harbor, NY/NJ
Casco Bay, ME	Peconic Bay, NY
Chesapeake Bay, MD/PA/VA	Puget Sound, WA
Corpus Christi, TX	San Francisco Bay, CA
Delaware Bay, DE	San Juan Bay, PR
Delaware Inland Bays, DE	Santa Monica Bay, CA
Galveston Bay, TX	Sarasota Bay, FL
Indian River Lagoon, FL	Tampa Bay, FL
Long Island Sound, CT/NY	Tillamook Bay, OR
Massachusetts Bay, MA	

Once an estuary is accepted into the NEP, EPA formally convenes a Management Conference of Agency and local representatives to develop a Comprehensive Conservation and Management Plan (CCMP) to protect the estuary. The Management Conference must also build support to carry out the CCMP recommended actions, conduct extensive research, and implement projects to improve the water quality of the estuary. These projects are usually demonstration activities implemented on a small scale, but can be applicable to larger areas of an estuary.

The NEP is not specifically designed to address the issue of NPS pollution. All 21 estuaries currently in the program have identified storm water runoff and diffuse source pollution as problems. Municipalities located within an NEP estuary's watershed might be encouraged as part of the CCMP, therefore, to address diffuse source pollution issues. In addition, the NEP is a potential funding source for urban runoff control projects. Municipalities in the watersheds of major coastal embayments should be aware of this program and understand the management structure and program objectives of local NEPs.

Agricultural Nonpoint Source Programs

While this handbook focuses primarily on storm water and NPS pollution issues in urban watersheds, many municipalities have outlying agricultural and other areas that contribute solids, nutrients, pesticides, herbicides, and pathogenic organisms to urban receiving waters. In many areas of the country, a basinwide approach must be taken to correct receiving-water impacts, and the basin is likely to contain agricultural activities. The U.S. Department of Agriculture (USDA) administers programs that address agricultural NPS problems. These programs are managed by the Soil Conservation Service (SCS) and the Agricultural Stabilization and Conservation Service (ASCS), which conduct research; undertake demonstration projects; develop technologies; and provide education, technical assistance, and funding (Margheim, 1990).

USDA programs do not set specific regulatory controls on agricultural practices to prevent or reduce diffuse source pollution. Rather, they provide technical assistance and cost-sharing-based funding to farmers for implementing agricultural BMPs, such as animal waste control systems, conservation tillage, vegetative buffer strips, and filter strips. Also, informational and educational services are provided through these programs by the Cooperative Extension Service.

Examples of USDA pollution control activities include:

- *Conservation operations*: Provides basic funding for technical assistance to farmers, other landowners, and units of government.
- *Small watershed projects:* Provides planning, technical, and financial assistance for implementation of BMPs in small watersheds.
- *Resource conservation and development projects:* Provides funding for personnel to coordinate interorganizational cooperation and coordination on certain environmental activities in designated multicounty areas.
- *Hydrologic unit areas:* Provides technical assistance to targeted agricultural watersheds to improve and protect water quality.
- *Demonstration projects:* Provides funding for planning, educational, technical, and financial assistance in agricultural watersheds for demonstrating and accelerating the adoption and implementation of new and innovative technologies that emphasize protecting ground water from agrichemicals.
- *Agricultural conservation program:* Shares cost of implementing agricultural conservation practices (BMPs) on farmland
- *Special projects:* Shares cost of implementing water quality BMPs in identified watersheds.
- *Other:* Accelerate technical assistance to regional projects such as National Estuary Programs; develop and transfer water quality technology, training, and public involvement; promote many locally oriented and organized water quality projects (e.g., Lakes Lay Monitoring Program, educational programs for schools, conferences on wetlands and sludge, and certification programs for pesticide use).

Summary

As demonstrated in this chapter, numerous regulations address urban runoff pollution prevention and control at the federal, state, and local levels. In planning a program, all applicable regulations should be considered and integrated. For example, the planning process outlined in this handbook can be used to develop plans to address pollution from separated or combined systems, or where both systems exist. The process applies to BMP programs both for CSO problems and for separate storm water; in many instances, both sources exist within the same watershed. It can also be used in multijurisdictional planning efforts where storm water, CSO, drinking-water protection, or other elements are controlled by different levels of state, regional, or local government.

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

AWWA. 1990. American Water Works Association. Guidance manual for compliance with the filtration and disinfection requirements for public water systems using surface water sources. (NTIS PB90-148016). Washington, DC.

Federal Register. 1989. Fed. Reg. 54(173). September 8.

Margheim, G.A. 1990. Making nonpoint pollution control programs work, proceedings of a national conference, April 23-26, 1989. National Association of Conservation Districts. St. Louis, MO.

U.S. EPA. 1990a. U.S. Environmental Protection Agency. NPDES permit application requirements for storm water discharges. Final regulation: a summary. October 31.

U.S. EPA. 1990b. U.S. Environmental Protection Agency. Progress in the National Estuary Program, report to Congress. EPA/503/9-90/005. Office of Water, Washington, DC.

U.S. EPA. 1991. U.S. Environmental Protection Agency. Coastal Nonpoint Pollution Control Program: program development and approval guidance. Office of Water, Washington, DC.

U.S. EPA. 1993. U.S. Environmental Protection Agency. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. EPA/840/B-92/002. Office of Water, Washington, DC.

Chapter 3
The Planning Process

This chapter outlines the process for developing and initiating urban runoff pollution prevention and control plans. It also discusses the establishment and refinement of program goals. Each step in the planning process is discussed separately and in detail in subsequent chapters.

Description of the Planning Process

The planning process for urban runoff pollution prevention and control programs presented in this handbook is based on regulations that require such programs and on technical literature about planning approaches. Table 3-1 compares planning approaches required by various regulations. Despite the increasing complexities and uncertainties as one proceeds from left to right in the matrix (as was demonstrated in Table 1-1), the required planning approaches are similar. The process generally consists of the following major components:

- *Determining existing conditions:* Analyzing existing watershed and water resource data and collecting additional data to fill gaps in existing knowledge.
- *Quantifying pollution sources and effects:* Utilizing assessment tools and models to determine source flows and contaminant loads, extent of impacts, and level of control needed.
- *Assessing alternatives:* Determining the optimum mix of prevention and treatment practices to address the problems of concern.
- *Developing and implementing the recommended plan:* Defining the selected system of prevention and treatment practices for addressing the pollution problems of concern and developing a plan for implementing those practices.

Table 3-1. Planning Approaches Defined in Regulatory Programs

Project Type	Engineering Facilities	CSO Facilities	Storm Water Management	Nonpoint Source Control	Lake Restoration	Watershed Management
Regulatory basis	National Environmental Policy Act	National CSO Strategy (8/89)	Storm Water Permit Rule, 40 CFR 122	CWA, Section 319	CWA, Section 314	SDWA
Determining existing conditions	Describe existing system Develop planning criteria	Describe existing conditions	Describe existing conditions	Analyze existing conditions	Describe environmental conditions	Develop watershed description
Quantifying pollution sources and water resource impacts	Collect and analyze data	Collect and analyze data	Collect and analyze data	Collect and analyze data Identify and rank problems	Conduct diagnostic survey	Identify detrimental characteristics
Assessing alternatives	Develop alternatives Assess alternatives	Develop alternatives Assess alternatives	Developing alternatives Assess alternatives	Screen BMPs Select BMPs	Conduct feasibility study	Conduct risk assessment
Developing and implementing the recommended plan	Develop recommended plan Develop implementation plan	Develop recommended plan Develop implementation plan	Develop management plan Develop implementation plan	Develop recommended plan Develop implementation plan	Develop recommended plan Develop implementation plan	Develop detrimental activities control plan

Each regulatory program outlined in Table 3-1 addresses the same components of water quality planning but uses different language to describe the process of each component.

For example, as a result of the differing regulatory approaches, municipalities might independently conduct CSO and storm water planning. Yet since these sources of pollution often exist in the same watersheds and affect the same water resources, this fractured approach is not desirable. To address urban runoff pollution control effectively, communities must consider multiple pollution sources in planning using a watershed approach. Table 3-2 lists selected planning processes outlined in the literature, which tend to resemble those required by the regulations cited in Table 3-1. The planning process described in this handbook has been developed to be consistent with regulatory requirements as well as technical literature.

The planning approach used in this handbook (see Figure 3-1) is intended to offer municipal officials a systematic approach to developing an urban runoff pollution prevention and control plan. In general, the planning process proceeds as follows:

1. Initiate program (Chapter 3)
2. Determine existing conditions (Chapter 4)
3. Set site-specific goals

Table 3-2. Planning Approaches Defined in the Literature

Literature Reference	**Urban Surface Water Management (Walesh, 1989)**	**Developing the Watershed Plan (U.S. EPA, 1991a)**	**Developing Goals for Nonpoint Source Water Quality Projects (U.S. EPA, 1991b)**	**Santa Clara Valley Nonpoint Source Study—Volume II: NPS Control Program. (SCVWD, 1990)**	**State of California Storm Water Best Management Practice Handbooks (CDM, 1993)**	**Urban Stormwater Management and Technology: Update and Users' Guide (U.S. EPA, 1977)**
Determining existing conditions	Establish objectives and standards Conduct inventory	Identify problems and opportunities and determine objectives Develop resource data	Inventory resources and forecast conditions	Initiate public participation Define existing conditions Review regulatory problems Define goals and objectives	Define goals Assess existing conditions	Assess existing data Compare conditions vs. objectives Determine extent of runoff problem
Quantifying pollution sources and effects	Analyze data and prepare forecasts	Interpret, analyze, and evaluate data and forecasts	Identify problems Develop goals or objectives	Define and describe problems	Set priorities	Conduct selective field monitoring Refine problem estimates
Assessing alternatives	Formulate alternatives Compare alternatives and select recommended plan	Formulate and evaluate alternatives Evaluate and compare alternatives	Formulate alternatives Evaluate alternatives	Identify NPS control measures Evaluate control measures Develop evaluation criteria Examine and screen measures Select measures Reassessment of measures	Select near-term BMPs	Assess alternatives
Developing and implementing the recommended plan	Prepare plan implementation program Implement plan	Select alternative and record decision	Select best alternative and record decision	Recommend control measures and implementation program	Implement near-term program Assess program effectiveness	Determine attainable improvements

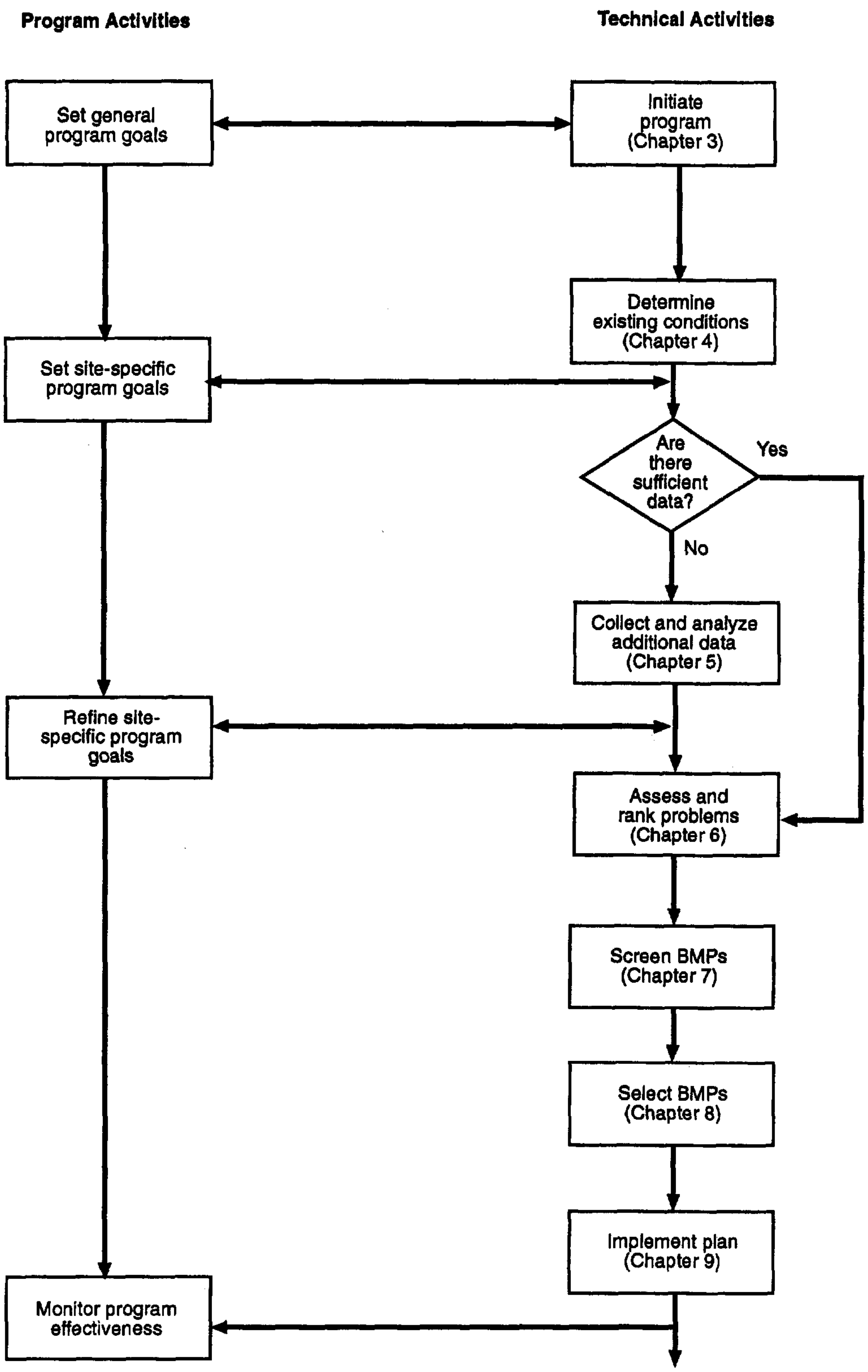

Figure 3-1. Urban runoff pollution prevention and control planning process.

4. Collect and analyze additional data (Chapter 5)
5. Refine site-specific goals
6. Assess and rank problems (Chapter 6)
7. Screen BMPs (Chapter 7)
8. Select BMPs (Chapter 8)
9. Implement plan (Chapter 9)

While the planning process generally is intended to be followed in sequence, the process can always be altered depending on the specific situation. For example, a municipality might already have begun planning to address certain sources (e.g., storm water or CSOs). In such cases, starting later in this planning process or integrating other sources into the ongoing planning might be more efficient.

Goal setting and refinement is more appropriately shown as a parallel process rather than a specific step. Only very general goals should be considered at the outset of a program. Existing data should be assessed before setting any site-specific goals. As new data are analyzed, new findings and issues are likely to emerge. Program goals therefore must be reevaluated as the planning process progresses. Monitoring the effectiveness of what has been implemented is very important. Since further planning typically will be required, the point of reentry in the planning process needs to be flexible.

The remainder of this chapter describes each step of the planning process in greater detail. The chapter ends with a case study showing the process of setting and refining program goals for Lewiston, Maine.

Initiate Program

As a first step in the planning process, municipal officials undertaking urban runoff pollution prevention and control planning should develop an overall program structure. Early considerations include organizing a program team; establishing communication, coordination, and control procedures for members of the planning team and other participants; identifying tasks and estimating the number and types of personnel and other resources for each task; and scheduling tasks (Walesh, 1989).

For local urban runoff pollution prevention and control programs, the program team should be made up of municipal personnel: public works personnel; conservation officials; engineering personnel; parks personnel; and planning and other officials who regularly deal with or control issues such as utilities, land use and zoning, development review, and environmental issues. The team should be multidisciplinary and able to address the engineering, land use, and environmental issues that will need to be resolved. It is important to involve all entities, including political officials and the public, who have a stake in the program outcome. To win support for the end result, a shared ownership of the process is necessary. Given that municipal boundaries typically do not coincide with watershed boundaries, individuals from all affected communities should be involved in the program. Depending on the size and complexity of the program, private consulting resources might also be necessary. In addition, involving officials of other agencies at the county, state, and federal levels is prudent, especially if one of these agencies is directly responsible for controlling sources within the watershed. Also, such agencies might have regulatory oversight and might be able to contribute funding or provide technical assistance. Based on their potential contribution to the program, their role could consist of participation on a technical or management advisory group. Further discussion on program team composition is provided in Chapter 9.

Initiating the program also includes establishing the program management tasks necessary for successful program execution. Methods of project management and control might already be in effect in the municipality or may be developed specifically for the program, particularly in the case of multiagency involvement. These tasks include estimating, forecasting, budgeting, and controlling costs; planning, estimating, and scheduling the program activities; developing and evaluating quality control practices; and developing and controlling the program scope. The program team also will have to develop a funding plan, as well as a public information, education, and outreach program.

Once the program team is assembled and the program is structured, the remaining portions of the planning process can be undertaken.

Goal Setting

Setting goals is a key aspect of the planning process, and refining goals is an ongoing consideration. Projects such as those discussed in this handbook, some of which deal with multiple point and nonpoint sources, require an integrated urban runoff management program, including flood, drainage, and pollution prevention and control. Successful implementation of these programs depends on establishing clear goals and objectives that are quantitative, measurable, and flexible (U.S. EPA, 1991c). Setting goals is a process that moves from less to more specificity as additional information on the watershed and water resources is obtained. Figure 3-1 shows the iterative nature of setting program goals as the planning process proceeds. As noted earlier, site-specific goals should not be set at least until existing conditions are assessed.

Types of Goals

The two main types of urban runoff goals are water resource- and technology-based goals. Water resource-based goals are based on receiving-water standards which consist of designated uses and criteria to protect these uses. For example, water resource-based goals may relate to uses, such as "opening half of the currently closed shellfish beds." They also may consist of more specific pollution reduction goals, such as lowering the Trophic State Index or reducing the number of oxygen-demanding substances in a lake. In addition, water resource-based goals can place numerical limits on the concentrations of specific pollutants. Further, examples of water resource-based goals include no degradation, no significant degradation, and meeting water quality standards. As a defining characteristic of water resource-based goals, the success in meeting such a goal is determined by the condition of the water resource. Applying water resource goals to urban runoff problems, however, might be difficult since water quality standards would need to be assigned to intermittent and variable events.

In contrast, technology-based goals require specific pollution prevention or control measures to address water resource problems. They can be very general, such as "implement the nine minimum technologies for CSO control," or very specific, such as "implementing runoff detention at 50 percent of the industrial sites in a watershed." A municipality might be able to determine the effectiveness of implementing these goals without conducting future water quality monitoring. With most technology-based goals, implementing the control measures is presumed to be adequate to protect water resources. Monitoring, however, is still essential after implementation to gauge the program's effectiveness and to see if the desired environmental results are being achieved.

The types of goals set by a municipality usually depend on the natural or political forces driving urban runoff control and the public's level of knowledge about the affected water body. If a community undertakes an urban runoff pollution prevention and control program because it has lost a resource (e.g., closed shellfish beds or loss of fishing or swimming areas), the community usually will set a water quality-based goal linked directly to recovering the resource. If a community expects to lose a resource from a known source (e.g., a farm located directly on a stream or frequent oil spills from an industrial plant), its goal can be specific and technology-based. On the other hand, communities that are not currently suffering from obvious problems with a water resource might launch urban runoff pollution prevention and control programs only to comply with regulations (see Chapter 2). These communities might not know or be aware of existing or potential water quality problems. Even under these conditions, however, setting general goals, such as "to meet the requirements of the regulations," is not only possible, but important. Even this general goal directs the program's focus, which then can be made more specific as more information is obtained. In these cases, the municipality typically has to rely on state-mandated goals for the specific water body of concern or general state mandates for the condition of all water bodies.

Although the water resource- and technology-based goals discussed above differ in specificity and complexity, they are all valid for an urban runoff pollution prevention and control plan. Goal-setting will focus the scope of work throughout a program.

Reassessing Goals

Far from static statements, water resource- or technology-based goals should be reassessed as appropriate in the planning process. Once early goals have been stated for a watershed or receiving water, all future actions affecting these resources can be considered against this backdrop and the goals can be reassessed. As more information is gathered, the goals can be maintained, made more specific, or changed completely. By the time the program is defined and ready to be implemented, however, fairly specific goals should exist so that program evaluators can determine whether or not goals have been met.

Determine Existing Conditions

After initiating the program, the planning team must develop a greater understanding of existing watershed characteristics and water resource conditions in order to:

- Define existing conditions pertinent to the urban runoff pollution prevention and control program.
- Identify data gaps.
- Maximize use of existing available information and data.
- Organize a diverse set of information in a useable way.

The required research is typically done by gathering existing available watershed information (e.g., environmental, infrastructure, municipal, and pollution source information), as well as receiving-water data (e.g., hydrologic, chemical, and biological data, and water quality standards and criteria). This information can be obtained from various data bases, mapping resources, and federal, state, and local agencies. The information can then be used to develop watershed maps; to determine water, sediment, and biological quality; and to establish the current status of streams, rivers, and other natural resources. Once these data are gathered, the program team can organize the information into a coherent description of existing conditions and determine gaps in knowledge. In this way, the existing conditions of the watershed and receiving waters can be defined. This step in the planning process is discussed in Chapter 4.

Collect and Analyze Additional Data

Even under the best circumstances, municipalities usually will not have all the required information to describe adequately a program area's existing conditions. The program team, therefore, might have to gather additional information through field investigation and data collection. With this additional information and existing data, the program team can evaluate more fully the existing conditions of the watersheds and water resources of concern. Given the cost and time involved in data gathering, the program team will have to weigh the benefits of additional data collection against using limited funds for plan development and implementation. If the additional data are required, a plan to gather these data must be developed. The plan should include an assessment of available staffing and analytical resources; identification of sampling stations, frequencies, and parameters for sampling and analysis; development of a plan to manage, analyze, and interpret the collected data; and analysis of available or needed financial resources. This step in the planning process is presented in Chapter 5.

Assess and Rank Problems

Once sufficient data have been collected and analyzed, the data can then be used to assess and rank the pollution problems. Based on data gathered in earlier steps, the team will need to develop a list of criteria to assess problems. These criteria are used in conjunction with water quality assessment methods and models to determine current impacts and future desired conditions.

Having determined the problems of concern, the project team can rank these problems to set priorities for the selection and implementation of pollution prevention and control measures. The emphasis on ranking of resources and problems is central to EPA's NPS strategy. This concept assumes that focusing resources on targeted areas or sources enhances water resource improvement. Further, it assumes that demonstrating water resource benefits increases public support of urban runoff pollution prevention and control programs as citizens become more closely attuned to overall water quality goals (U.S. EPA, 1987). The municipality, therefore, should investigate the sources of pollution affecting the high-priority water bodies to determine the order in which to address these problem sources. In many cases, an analysis at the sub-basin level is needed to determine which areas of a watershed contribute the greatest loadings. The data gathered in the previous step will be particularly useful in this assessment. Also, municipalities should investigate water resources within their region to develop priorities so that limited resources can be targeted to areas with greatest potential for improvement. Various levels of detail can be used in this assessment, ranging from simple unit load methods to complex computer models. This ranking procedure, one of the more subjective and difficult steps in the urban runoff planning process, is described in Chapter 6, along with problem assessment.

As additional data are collected and evaluated, the program team should refine the goals of the program and make them more specific. For example, at the beginning of the program, the municipality might have been aware of excessive algal blooms in a lake but might not know the cause. An initial goal of the pollution prevention and control program might have been simply to eliminate these algal blooms. After further investigation and water quality sampling, the municipality might discover that continuous high phosphorus loadings are directly contributing to the algal blooms. The goal could then be made more specific by focusing on reducing or eliminating phosphorus sources. The initial goal, rather than being abandoned in favor of another goal, is refined to focus future actions on the specific causes of the water resource impairment.

Screen Best Management Practices

Once the water resource problems have been prioritized, specific water resource problems and their sources can be addressed. The program team should compile a list of various pollution prevention and treatment practices and review them for their effectiveness in solving the prioritized problems. To assist the municipality in gathering information on various practices, Chapter 7 includes brief descriptions of various nonstructural and structural practices, and includes references for additional information. Also described is the initial BMP screening step, when potential practices are reviewed for their applicability to the watershed and water resource problems of concern. While the team initially faces a large number of potential practices, obviously inappropriate practices are eliminated in this step based on criteria such as the primary pollutants removed, drainage area served, soil conditions, land requirements, and institutional structure. Following this initial screening, the program team will have a list of potential practices to be evaluated further.

Select Best Management Practices

During this step, the program team investigates the list of potential pollution prevention and treatment practices developed from the previous step to determine which to include in the plan. More specific criteria should be used for analyzing these potential practices than during the initial screening. To make the final selection, the program team must use the analytical tools developed during the ranking and assessment of problems, as well as decision factors such as cost, program goals, environmental effects, and public acceptance. As with the initial screening step, these evaluation criteria depend on established priorities. Generally, the selection process yields a recommended system of various pollution prevention and treatment practices which together address the pollution sources of concern. Availability of required resources to implement the practices is a major consideration. If needs and resources don't match, the municipality might have to adjust its expectations to what realistically can be accomplished. Both structural and nonstructural practices might be required. This step in the planning process is discussed in Chapter 8.

Implement Plan

After choosing pollution prevention and treatment practices, the program team moves from planning to implementation, which often occurs through a phased approach. Inexpensive and well-developed practices can be implemented early in the program as pilot or demonstration studies; and these results might influence further implementation. Given the added requirements of implementation, operation, and maintenance, the original program team might expand to include members with more construction experience. Also, funding sources are needed for initial capital expenses and continuing operation and maintenance costs. Nonstructural practices must be implemented, and the team must arrange for the detailed design and construction of structural practices.

During this step, program responsibilities must be clearly delineated. All involved entities must be familiar with and accept their role in implementing and enforcing the plan. Continuing activities also should be clearly defined and monitoring schedules should be set to determine the program's effectiveness in meeting its goals. Maintenance programs should be developed so that structural practices continue to operate as intended. Finally, the municipality should be aware of available federal and state technical assistance that could help throughout implementation of the plan. This step in the planning process is discussed in Chapter 9.

Summary

This handbook is based on the process outlined in this chapter. The process includes setting goals, analyzing existing data, collecting and analyzing additional data, assessing and ranking problems, screening BMPs, selecting BMPs, and defining and implementing the plan. The process is founded on approaches described both in technical literature and in regulatory requirements. Each step should be followed to develop an effective and realistic urban runoff pollution prevention and control program.

Developing and implementing an urban runoff pollution prevention and control program at the municipal level is a multidisciplinary effort that requires a program team that has varied experience and is familiar with program requirements. The process presented in this handbook is designed to provide program teams with a step-by-step approach to conducting these types of planning programs.

Planning, however, is only the first phase in the protection of water resources. The program team should keep in mind the ultimate goals of the program. Since implementation and program assessment are important, the setting and refinement of program goals is key. By reaching an early consensus on program goals and reassessing goals during the process, the program team can increase the possibility of successful implementation. During the planning process, increasing knowledge about the area's water resources and characteristics of the watersheds should be emphasized. All these steps are important to the program's ultimate success.

The following case study outlines some of the initial steps in program development and initial goal setting for Lewiston, Maine.

Case Study:
City of Lewiston, Maine,
CSO, Storm Water, and Nonpoint Source Planning Program

Background

The city of Lewiston, situated on the Androscoggin River, is Maine's second largest city. Lewiston and its sister city, Auburn, serve as the industrial, commercial, and service center for Maine's southern, central, and western regions. With a population of about 40,000, Lewiston has a combination of residential, commercial, industrial, and parkland use with limited agricultural land. It has seven watersheds that will be described later.

In 1991, Lewiston launched a planning program to address issues such as CSO impacts, storm water management, and nonpoint source control. Known as the city's Clean Water Act master planning program, the effort was undertaken for a number of reasons: Maine required the city to develop a facilities plan for CSO abatement, and there was potential for development of new storm water and NPS requirements at the state and federal levels. Incorporating these considerations into an overall planning effort—a proactive approach—would meet requirements of existing regulations and prepare the city for future requirements. By undertaking a program consistent with watershed needs, Lewiston chose a comprehensive rather than fragmented approach based on different, and possibly conflicting and overlapping, regulatory requirements. The city also decided to set water resource-based goals that would be as consistent as possible despite the changing regulatory environment.

Program Initiation

The city's public works department assumed responsibility for the program and formed a team that would meet regularly and guide the planning process. The team included individuals from:

- Department of Public Works
- Planning Department
- Lewiston-Auburn Water Pollution Control Authority
- Highway Department
- General public

The public works department assigned a staff person who expended a significant amount of his time to support the effort. The department also secured funding (100% from city funds), developed a scope of services, and hired an engineering consultant to perform technical tasks and provide services which were beyond Lewiston's capability or available resources.

Regulatory Setting

One of the program team's first tasks was to compile information on current federal and state regulations that potentially pertained to the planning effort. A series of contacts were made, especially with state regulatory personnel, to determine the status of regulatory activities. Information on current regulatory setting was reviewed (as summarized in Table 3-3) and appropriate state regulatory personnel were identified. Changes were occurring in several areas, especially CSO and storm water, that needed to be monitored and incorporated into the program.

Set Initial Program Goals

Using available data, initial goals were developed along with assessment of existing conditions. This assessment is described in a companion case study at the end of Chapter 4. A basic goal was that the program should result in an understanding of and compliance with current and upcoming regulations related to CSO, storm water, and NPS control. Initial goals were also established for each major watershed. The watersheds are shown in Figure 3-2, and their characteristics are listed in Table 3-4.

Table 3-3. Federal and State Regulation of Urban Runoff

Regulation	Federal	State
Combined Sewer Overflows	National policy (currently under review)	State CSO policy (approved by EPA)
Storm Water NPDES Permits	CWA, Section 402 NPDES regulations	General permit (does not currently affect Lewiston) Future impacts Municipal permits Municipally owned industrial facilities
Pollution Prevention Act	National Pollution Prevention Strategy	Not applicable
Safe Drinking Water Act	Surface Water Treatment Rule	State allows variance; however, not applicable to Lewiston
Nonpoint Source Pollution Regulations	CWA, Section 319	General guidance from state NPS office
Coastal Zone Nonpoint Source Pollution Control	Coastal Zone Management Act, Section 6217(g)	Probably not applicable (coastal boundaries not yet determined)
Clean Lakes Program	CWA, Section 314	Limited funding for state program
National Estuary Program	CWA, Section 320	Lewiston and Auburn in upper reaches of Casco Bay watershed; CCMP being developed
Agricultural Nonpoint Source Programs	Funding and guidance provided at the state level through SCS	SCS assistance to farms; no significant farms in city
Comprehensive Planning/Growth Management	Not applicable	Growth management plans required; Lewiston obtained approval
Shoreland Zoning	Not applicable	Requires special zoning practices within 75 ft of streams and 250 ft of other water bodies; Lewiston obtained approval

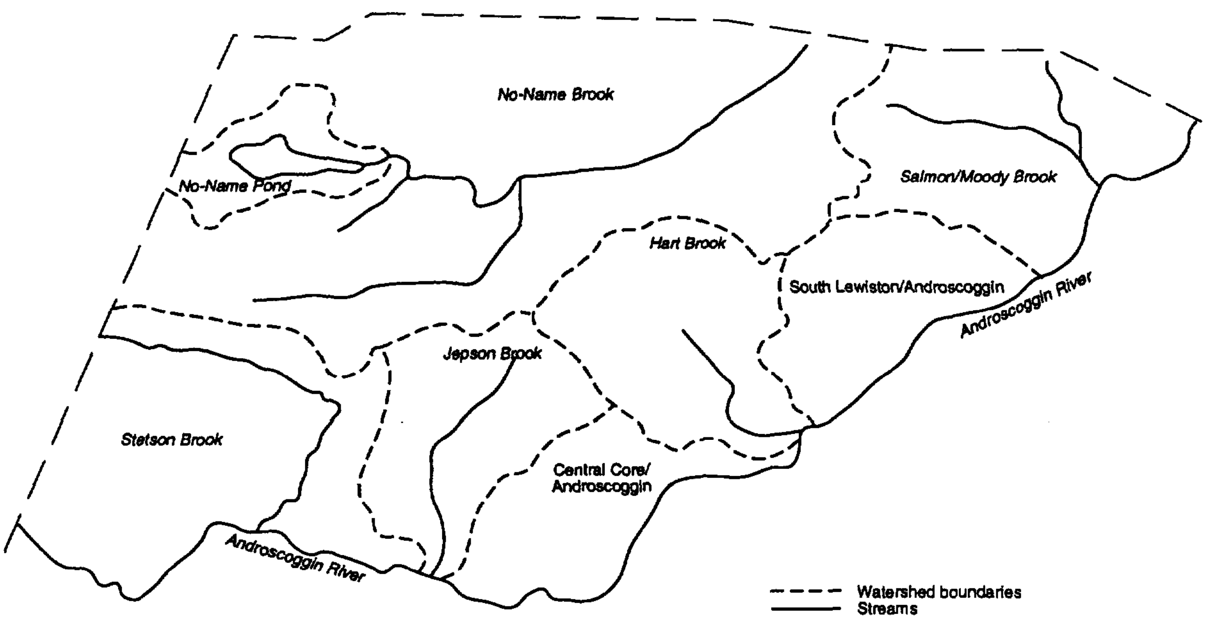

Figure 3-2. Watersheds in Lewiston, Maine.

Table 3-4. Land Use Near Major Watersheds in Lewiston, Maine

Watershed Name	Size, ac	Land Use Description
No-Name Pond	750	Rural/residential, shore line cottages
No-Name Brook	10,000	Mainly undeveloped, some residential
Stetson Brook	3,000	Rural, residential, and commercial/industrial
Hart/Goff Brooks	1,600	Residential, commercial, and industrial
Salmon/Moody Brooks	1,900	Primarily undeveloped, minor agriculture
Jepson Brook	1,500	Residential and institutional
Androscoggin River	2,300	Urban in central core, undeveloped or industrial in outlying area

The program team held a workshop to facilitate discussion and obtain input on the city's water resources and appropriate initial program goals. A form similar to that shown in Table 3-5 was used to compile the information. Each watershed was discussed, including its water quality classifications, current uses, known problems, desired uses, and goals. A qualitative assessment or ranking of the individual watersheds was included to indicate the relative importance of the water resources to the city. This procedure was done to assist later decision-making which could involve setting priorities for funding or phasing of activities.

Table 3-5. City of Lewiston Initial Water Resources Goals

Watershed Name	Water Quality Classification	Current Uses	Known Problems	Qualitative Assessment of Importance	Desired Uses	Goals
No-Name Pond	A	Aesthetics Recreation-fishing, boating	Algal blooms Septic tank discharges	Most important town water resource	Same	Maintain and protect existing uses
No-Name Brook	C	Aesthetics	Erosion (use of ATVs) Debris	Second most important town water resource	Same	Maintain and protect existing uses Upgrade to Class B
Stetson Brook	B	Aesthetics	Erosion CSOs (one)	Third most important town water resource	Same, plus fishing	Meet Class B standards
Hart and Goff Brooks	B	Aesthetics	Erosion Industrial areas Interceptor sewer surcharging	Fourth most important town water resource	Same	Meet Class B standards
Salmon/Moody Brook	B	Aesthetics	Agriculture	Small watercourses of minor importance	Same	Meet Class B standards
Jepson Brook	B	Drainage	CSOs (no visual/odor) Debris	Channelized drainage ditch	Same	Maintain current use
Androscoggin River	C	Aesthetics Recreation-fishing, boating	Point sources (paper mills) Erosion (gravel pits) CSOs	Large regional water resource	Same	Meet Class C standards
Ground water	GWA*	Drinking water supply (for town of Lisbon)	None known	Currently of limited importance to town	Same	Maintain and protect existing uses

* Ground-water classification A.

While the initial goals were recognized as expensive and potentially not attainable in the near future, the interactive process was desirable when feasible in terms of cost and effort. Moreover, the goals could be revised if unrealistic. Consideration was given to the existing regulatory requirements in the water quality standards (see Table 3-6). The main differences in water quality criteria for each classification are for dissolved oxygen and *E. coli* bacteria.

Table 3-6. Comparison of Maine Water Quality Standards

		Minimum Dissolved Oxygen		*E. coli* Bacteria	
Classification	**Designated Uses**	**mg/L**	**% Saturation**	**Geometric Mean No./100 mL**	**Single Sample No./100 mL**
AA	Drinking water (with disinfection); fishing; primary and secondary contact recreation; free-flowing and natural habitat for fish and other aquatic life	As naturally occurs	As naturally occurs	As naturally occurs	As naturally occurs
A	Drinking water (with disinfection); fishing; primary and secondary contact recreation; industrial process and cooling water; hydroelectric power generation; navigation; natural habitat for fish and other aquatic life	7.0	75	As naturally occurs	As naturally occurs
B	Drinking water (with treatment); fishing; primary and secondary contact recreation; industrial process and cooling water; hydroelectric power generation; navigation; unimpaired habitat for fish and other aquatic life	7.0[a]	75[a]	84[b]	427[b]
C	Drinking water (with treatment); fishing; primary and secondary contact recreation; industrial process and cooling water; hydroelectric power generation; navigation; habitat for fish and other aquatic life	5.0	60	142[b]	949[b]

[a] From October 1 to May 14, the 7-day mean dissolved oxygen is not less than 9.5 mg/L, the 1-day minimum is 8.0 mg/L.
[b] May 15 to September 30.

In some cases, where desired uses of the water resource were being met, maintaining and protecting these uses was set as an initial goal. For some brooks, aesthetics was the only use of concern; the initial goal of meeting Class B standards was set even though the Class B standard also allows fishing and swimming. For Jepson Brook, which is a channelized drainage ditch, meeting Class B standards was not a priority. For No-Name Brook, there was a desire to upgrade the standard to Class B from Class C. Thus, the variety of watersheds and water resources was reflected in the range of initial goals.

Assessment of Existing Data

An extensive effort was made to assess existing information and data, as described in a separate case study at the end of Chapter 4. The following conclusions pertaining to the program's initial goals were based on already available data:

- The city has an aggressive and extensive regulatory control system which addresses many NPS and storm water control issues; with minor improvements, this system could fulfill the goals of maintaining and protecting existing uses.
- Virtually no water quality data or information on any of the brooks in the city are available; more information is needed to assess the existing conditions and establish goals for these systems.
- Extensive data exist on the Androscoggin River, which does not meet Class C standards; much of the pollution appears to stem from upstream sources, but the contribution of CSOs needs to be defined better.

Future Activities

Several activities are planned for implementation. The data collection program (described in the separate case study at the end of Chapter 4) will be CSO-related and implemented in 1993. Additional data collection is being considered beyond that effort. After the initial planned data collection activities, the initial program goals are to be reviewed and refined as needed. The city is also considering changes in their current regulations to control urban runoff pollution better. Lewiston also plans to implement a cross-connection removal program. In the long term, Lewiston's Clean Water Act master planning effort plans to follow the overall planning approach outlined in this document, including data collection, refinement of program goals, data assessment and modeling, ranking of problems, and BMP screening and selection.

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

CDM. 1993. Camp Dresser & McKee. State of California storm water best management practice handbooks. California State Water Quality Control Board.

SCVWD. 1990. Santa Clara Valley Water District. Santa Clara Valley nonpoint source study—volume II: NPS control program. San Jose, CA.

U.S. EPA. 1977. U.S. Environmental Protection Agency. Urban stormwater management and technology: update and users' guide. EPA/600/8-77/014 (NTIS PB-275654).

U.S. EPA. 1987. U.S. Environmental Protection Agency. Setting priorities: the key to nonpoint source control. U.S. EPA Office of Water Regulations and Standards. Washington, DC.

U.S. EPA. 1991a. U.S. Environmental Protection Agency. Developing the watershed plan. Published in Seminar Publication: Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504). Cincinnati, OH.

U.S. EPA. 1991b. U.S. Environmental Protection Agency. Developing goals for nonpoint source water quality projects. Published in Seminar Publication: Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504). Cincinnati, OH.

U.S. EPA. 1991c. U.S. Environmental Protection Agency. Goals and objectives for nonpoint source control projects in an urban watershed. Published in Seminar Publication: Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504). Cincinnati, OH.

Walesh, Stuart G. 1989. Urban surface water management. New York: John Wiley & Sons, Inc.

Chapter 4
Determine Existing Conditions

Existing conditions must be investigated and described prior to data collection, problem assessment, and BMP evaluation. An investigation includes gathering, reviewing, analyzing, and summarizing mapping resources, hydrology, water quality and other environmental data, as well as municipal planning information for the subject region, county, municipality, or watershed. A description of existing conditions has two major components:

- Watershed description, which characterizes the sources of runoff and the "causes" of water resource problems.
- Receiving-water description, which characterizes the receptors of the watershed sources and their effects.

The watershed description defines the watershed area and its subwatersheds and further identifies pertinent geographic and environmental features (e.g., land use, geology, topography, and wetlands), infrastructure features (e.g., sewerage and drainage systems), municipal data (e.g., population, zoning, regulations, and ordinances), and potential pollution source data (e.g., in-stream sediments, landfills, underground tanks, and point source discharges). The receiving-water description provides water resource information for water bodies affected by the watershed, which can include any type of receiving water (e.g., rivers, streams, lakes, and estuaries) and its sediment and biota as well as ground water.

This chapter describes an approach and rationale for defining and assessing existing conditions. The objectives are to develop a convenient way to organize information, to develop a definition of existing conditions pertinent to urban runoff pollution prevention and control, to identify data gaps to be addressed under a field sampling program, and to maximize use of existing available information. Extensive applicable information usually is available from municipal government departments, state and federal agencies, and private vendors, as well as from files and data bases of maps and environmental data. The more persistent and thorough the investigator, the more information is obtained. These early efforts support future phases of planning by:

- Providing a basis for establishing and reassessing water resource protection and improvement objectives.
- Identifying pollutants of concern and related effects on water resources.
- Providing a base map for locating pollution sources and controls.
- Defining areas of concern where pollutant loadings pose a high environmental or public health risk and where source control efforts should be focused.
- Providing information for development of water quality models, if needed.
- Planning, designing, and implementing BMPs.
- Evaluating post-implementation improvements and beneficial use attainment.
- Identifying areas of good water quality and high value to focus protection efforts.

This chapter first discusses how to prepare a watershed description, including the types of information needed, sources of watershed mapping and data, and methods for organizing and presenting the information. For areas where watershed mapping does not exist or needs to be verified, techniques to develop mapping are discussed. Next, the chapter describes developing a receiving-water description including the types of water resource data useful in investigating pollution sources and assessing receiving water conditions, sources of data, and methods for organizing and evaluating the information.

Preparing a Watershed Description

The watershed is the entire surface area that drains into a particular water body. Runoff from precipitation falling on the watershed flows through systems of storm sewers, channels, gullies, and streams to the lowest elevation, usually to a river, lake, or estuary. Multiple watersheds often exist in a study area because many urban runoff pollution prevention and control programs are based upon political boundary areas, such as the limits of a municipality.

The first step in describing each watershed is to delineate the watershed and smaller watersheds or subwatersheds within it, some of which might be identified later in the planning process as significant contributors to water resource impacts. Once the areas are delineated, the municipalities and other entities with jurisdiction for actions within them should be identified.

In many states, watershed delineation mapping is available either on large base maps or through a digital mapping resource. If mapping is not readily available, however, watershed delineation can be done using topographical maps; watersheds can be delineated by connecting the points of highest elevation on land surrounding the subject water body. Watershed maps can be prepared using town or county topographic maps, which are typically available at scales suitable for use as a base map. These scales range from 1 in=200 ft for small watersheds, to 1 in=2,000 ft or higher for large watersheds. The watershed map will serve as the base map for additional data.

Types of Watershed Data

Table 4-1 outlines the types of mapping available for preparing a watershed description and the pertinent information in these sources. Land use data are especially important to obtain given the relationship between land use and urban runoff pollution (see Chapter 1). Land use information can be separated into either a few general categories or many specific categories; an appropriate level of detail should be selected before undertaking a mapping effort. Table 4-2 presents two options: 9 general categories of land use and 37 specific categories. In addition to these options, combinations of the two may also be considered. Classifications should be selected based on the diversity of land use types in the watershed and the level of detail of existing information. They can also be selected so that they are consistent with local zoning. At a minimum, however, classification should include major categories of land use, such as residential areas, commercial and industrial developments, agricultural operations, forested areas, open space and park land, and other significant land uses that could affect water resources.

Table 4-1. *Use of Mapping Resources for Urban Runoff Planning*

Types of Mapping	Use in Urban Runoff Planning
Drainage basins	Identify and delineate subwatersheds Identify and delineate pollution sources
Topographical	Delineate drainage areas, slopes, and patterns Calculate hydrologic model variables Identify areas prone to erosion
Land use	Qualitatively analyze runoff quantity and quality Identify land use trends Assess effects of land use on water quality Locate potential sites for installation of control structures
Soil/geology	Evaluate erosion potential Determine infiltration capacity for BMP design Determine depth to bedrock Identify depth to water table Determine treatability of soil column
Vegetation	Identify areas protected by wetland regulations Identify vegetative buffers Identify undeveloped areas (e.g., forested areas)
Zoning	Identify priority areas based on type of development Identify potential areas of future development Evaluate zoning changes and other regulatory controls
Infrastructure	Locate drainage system discharges Design drainage system modifications Identify opportunities for retrofit Design storm water sampling program Locate existing control practices Locate utilities for placement of controls
Assessor maps	Determine land ownership
Aerial photographs	Determine land use Identify resource areas Identify areas of erosion
Water bodies	Delineate potential problem areas Identify pollutant transport considerations

Once the watersheds are delineated on a base map and land use categories have been selected, additional features and data for each watershed are compiled. Pertinent information includes:

- Environment
  - topography,
  - land use,
  - recreational areas (e.g., beaches, boating areas),
  - soil and surface/bedrock geology,
  - vegetation,
  - natural resources (i.e., wetlands, wildlife resources, and shellfish beds),
  - temperature,
  - precipitation, and
  - hydrology.
- Infrastructure
  - roads and highways,
  - storm drainage systems,
  - sanitary sewer systems,
  - treatment facilities, and
  - other utilities (i.e., water, electric, gas).

Table 4-2. Land Use and Land Cover Classification System (Anderson, 1976)

Level I	Level II
1. Urban or developed land	11. Residential 12. Commercial and services 13. Industrial 14. Transportation, communications, and utilities 15. Industrial and commercial complexes 16. Mixed urban or developed land 17. Other urban or developed land
2. Agricultural land	21. Cropland and pasture 22. Orchards, groves, vineyards, nurseries, etc. 23. Confined feeding operations 24. Other agricultural land
3. Rangeland	31. Herbaceous rangeland 32. Shrub and brush rangeland 33. Mixed rangeland
4. Forest land	41. Deciduous forest land 42. Evergreen forest land 43. Mixed forest land
5. Water	51. Streams and canals 52. Lakes 53. Reservoirs 54. Bays and estuaries
6. Wetland	61. Forested wetlands 62. Nonforested wetlands
7. Barren land	71. Dry salt flats 72. Beaches 73. Sandy areas other than beaches 74. Bare exposed rock 75. Strip mines, quarries, and gravel pits 76. Transitional areas 77. Mixed barren land
8. Tundra	81. Shrub and brush tundra 82. Herbaceous tundra 83. Bare-ground tundra 84. Wet tundra 85. Mixed tundra
9. Perennial snow or ice	91. Perennial snowfields 92. Glaciers

- Municipality
  - population,
  - zoning,
  - land ownership,
  - regulations,
  - ordinances, and
  - municipal source control BMPs (e.g., street sweeping and catch basin cleaning).
- Potential pollution sources/existing structural BMPs
  - landfills,
  - waste handling areas,
  - salt storage facilities,
  - vehicle maintenance areas,
  - underground tanks,
  - NPDES discharges,
  - pollution control facilities,
  - retention/detention ponds, and
  - flood control structures.

Once these data are collected, some can be plotted on the watershed base map if useful.

Sources of Watershed Mapping and Data

Watershed data are site specific and can be obtained from municipal government departments, state and federal agencies, and private vendors, and by searching files and data bases of maps and environmental data. Much of this information is contained in reports and maps dealing with the watershed. At the federal and state levels, mapping is increasingly available in digital form that can be downloaded to a geographic information system (GIS)—a flexible and powerful computer-based tool that can store, display, and analyze geographical information. Digital data for use with a GIS are available from data bases maintained by many state and federal agencies, and the private sector. Two major sources of watershed data are U.S. Geological Survey (USGS) maps and aerial photographs. USGS maps depict many of the land attributes shown in Table 4-2, including urban, residential, forested, and wetland areas, as well as roads, buildings, and water bodies. Aerial photographs can provide a high level of detail on land use and also can be used later in the assessment and ranking of pollution sources. Aerial photographs are generally sold as 9 in by 9 in prints that cover about half a square mile; thus it may be necessary to overlap a number of photographs to map an entire study area. Satellite imagery is also available from several sources, but this tool is more useful for a regionwide analysis and might not provide the resolution required for analysis of smaller watersheds. The following paragraphs summarize sources of available watershed mapping and GIS data.

Local

Existing watershed mapping is most readily available from local municipal government departments that use mapping to track property ownership, plan for future development, maintain public utilities, and enforce environmental regulations. Potential local sources of mapping include the following municipal offices:

- *Assessor:* Maps of individual parcels, data on parcel size and property ownership.
- *Planner:* Land use maps, aerial photographs, zoning maps.
- *Engineer:* Storm sewer and other utility plans and structural information.
- *Public Works:* Utilities and maintenance activities.

- *Conservation:* Mapping of wetlands, soils, and other vegetation and natural resources.
- *Water:* Supply and distribution system utilities and ownership of protected areas.
- *Health:* Septic system locations and maintenance records, status of water resources with respect to public use and consumption.
- *Other:* Watersheds and other information also might be delineated on maps prepared for special drinking water districts and flood control districts.

State

Watershed mapping might also be available from state agencies responsible for conservation, water quality, and oversight of state programs implemented at the local level, such as wetland protection and health codes. These maps, however, might not be as site specific or as current as those available from local sources and might be less accessible because of the location or the structure of state government. One method of locating mapping at the state level is to obtain a directory of state departments and services and contact those departments that would likely maintain mapping. Generally the following types of information are available:

- *State environmental agency:* Water quality data, previous studies, existing controls, NPDES permits, and compliance data.
- *Conservation districts:* Farm locations and inventories, locations of existing agricultural BMPs, soil descriptions.
- *Water resources:* Watershed delineations, locations of potential pollution sources, status of water courses, locations of public drinking water supplies.
- *Wetlands and wildlife:* Locations of protected wetlands and other habitat areas.
- *State colleges and universities:* Mapping as part of research, government contracts, or graduate program studies at institutions with programs in environmental engineering or science, civil or agricultural engineering, or biology.

In addition, some states offer an extensive list of GIS data. Data typically available from state GIS agencies include: topography, state plane coordinates, community boundaries, hydrography, major roads, land use, major drainage basins and sub-basins, aquifers, public water supplies, EPA-designated sole source aquifers, surficial geology, census data, hypsography, and protected open space. Each data type exists as a separate "layer" of digital information. Many states publish descriptions of available data layers and user services.

Federal

The federal government collects and maintains environmental mapping and data through a number of programs and agencies. Readily available sources include USGS Earth Science Information Centers, EPA regions, and other agencies. Several federal sources of mapping are listed in Table 4-3; some are national offices of federal agencies that may direct inquiries to satellite offices with data for specific regions. The federal government also has an extensive amount of GIS data available for use. Some of the more important sources of these data are shown in Table 4-4. Additional sources are available from EPA.

Table 4-3. Federal Sources of Watershed-Related Data

Source	Type of Information
U.S. Geological Survey National Cartographic Information Center 507 National Center Reston, VA 22092	Mapping of topographic features, land use, land cover, and slopes; aerial photographs; and satellite imagery
U.S. Geological Survey EROS Data Center 507 National Center Reston, VA 22092	High altitude aerial photography
U.S. Department of Agriculture Soil Conservation Service (Contact the office of SCS State Conservationist or the State Agricultural Experiment Station)	Soil survey reports that include soil maps, soil descriptions, aerial photographs, and soil management information including erosion potential, suitability for septic tank adsorption fields, and flooding frequency
Hazardous Substance Sites National Technical Information Service Computer Product Support Group 5285 Port Royal Road Springfield, VA 22161	Topography, soil types, soil conditions, and substance storage data for specific studied sites
U.S. Fish and Wildlife Service (Contact: National Cartographic Information Center P.O. Box 6567 Fort Worth, TX 76115)	Wetland mapping on USGS topographical quadrangles

Private

Numerous private firms produce mapping, GIS data, aerial photographs, and land surveys, frequently for municipal clients. Local firms involved in mapping and GIS data are listed in the yellow pages or local business directory. An extensive list of private GIS data sources and services can be obtained from private sources, such as trade journals. In addition, private colleges and universities with programs in geology, engineering, or environmental protection can be valuable sources.

Table 4-4. Federal Sources of Geographic Information System Mapping Data

Source	Type of Information
U.S. Geological Survey Room 1C402 507 National Center Reston, VA 22092	Digital elevation models (DEMs)—digital terrain elevations at regularly spaced horizontal intervals
	Geographic names information system (GNIS)—proper names of places, features, and areas
	Planimetric data in digital line graph (DLG) form including boundaries of states, counties, and cities; transportation facilities including roads, trails; pipelines and transmission lines; hydrography including streams and water bodies; and topographical contours
	Land use and land cover (LULC) data on urban or developed land, agricultural land, rangeland, forested land, water, wetlands, barren land, tundra, and perennial snow and ice
U.S. Bureau of Census Data User Services Division Room 407 Washington Plaza Washington, DC 20233	Digital political and census data such as roads, rivers, political boundaries, address ranges, and zip codes
U.S. Fish & Wildlife Service National Wetlands Inventory 9720 Executive Center Drive St. Petersburg, FL 33702	Vegetated wetland and deep-water habitat mapping
U.S. Soil Conservation Service National Cartographic Center P.O. Box 6567 Fort Worth, TX 76115	Soils information (address shown is for the federal SCS office; soils information can also be obtained from individual state offices)

Analysis of Watershed Data

This section discusses several methods of analyzing watershed data to define existing conditions. These methods include development and use of watershed maps and analysis of existing regulatory and municipal practices and other existing BMPs.

Development of Watershed Maps

Maps are created to show watershed-related data, such as topography, land use, watersheds and subdrainage areas, soils, infrastructure, natural resources, recreational areas, special fish and wildlife habitat areas, and existing pollution control structures. All this information is important in urban runoff pollution prevention and control planning. If maps are generated from information that is several years old, field investigations might need to be conducted to verify and update the information. The most efficient way to verify this information is through a "windshield survey." In urban and suburban areas, most watershed areas are accessible by car. Field observations are compared with existing maps, and changes or additions are traced onto the base map.

When required information is not available from the sources discussed in the previous section, a more complete survey of the watershed will be required. In small watersheds of a few acres, these surveys are typically conducted by car and on foot. To conduct a survey of a large watershed, however, aerial photographs can supplement the site investigations and provide a more complete picture.

Another method of generating watershed maps is by computer. The data in a GIS are organized into thematic layers (such as land use, water bodies, watersheds, topography, or transportation) which can be overlaid and plotted in any combination. In addition, GIS systems are equipped with a data management system that can organize and store text and numerical descriptive information. This information can be very basic, such as whether a land use in a particular area is residential or industrial, or it can be very sophisticated, consisting of multiple tables of data, including land ownership information, discharge monitoring report information, soils information, or water quality information. Given the technical expertise required and the capital expenditures for computer hardware and software, the use of a GIS might not be feasible for some urban runoff pollution prevention and control program teams. A GIS requires an appropriate personal or mainframe computer and a graphics plotter.

Developing new mapping for an area, whether using GIS, aerial survey, or other means, can be expensive and time consuming. The urban runoff planning effort should not turn into a mapping and GIS effort. Since base mapping and GIS tools have numerous uses within a community, development of such a system should be considered as a separate program.

Use of Watershed Maps

Once watershed maps have been developed, additional data can be obtained by measuring the area of the watershed and its subwatersheds—useful information for calculating runoff flows and pollutant loads from the watershed. Available methods for measuring area range from manually measuring to using an electronic digitizer to using GIS software. In one method, a grid overlay is created on the watershed base map of known dimensions and the area is approximated by counting the grid squares in the watershed. Another similar method is to use a planimeter, a device designed to trace the watershed boundary. To use a digitizer, which functions as a computerized planimeter, the map is placed on a surface underlaid by an electronic grid system. The boundary of the watershed is traced with an electronic pointer which digitally records the coordinates, and the area is then calculated by computer. In addition, GIS software has algorithms that can be used to measure area.

Once the watersheds and subwatersheds are delineated and the existing conditions are indicated, the total area of each land use category for the entire watershed and each subwatershed can be calculated. This calculation is important because each type of land use tends to have its own pollutant loads and urban runoff pollution prevention and control issues. After the runoff from each type of land use is characterized, future changes in pollutant loading due to planned changes in land use can be estimated and used to assess potential future impacts and control scenarios. These data will be important to the problem assessment and ranking process described in Chapter 6.

Other land use analyses can be conducted by mapping and reviewing different watershed attributes. These analyses can be facilitated by creating overlays depicting individual watershed attributes or by displaying selected thematic layers on a GIS. For example, historical land use changes can be assessed by comparing historical mapping from USGS topographical maps, which are based on aerial photography and periodically updated, thus documenting land use changes over time. In many urban areas, the USGS maps exist from as early as the 1880s. Recent changes in land use can be used to focus source control efforts, to locate new sampling stations, or to modify land use regulations.

Analysis of Regulatory and Municipal Practices

Analyses of other types of watershed data generally consist of creating tabular summaries, plots and figures, or maps designed to describe the major characteristics of each data type and subtype. Public works, engineering, planning, and health department personnel can assist in developing a profile of existing regulations and practices. Table 4-5 is a simple format for presenting existing municipal practices; the information in this table is very general, indicating only whether or not certain practices are used. The comparison also can be more detailed as shown in Table 4-6, which describes the actual characteristics of each practice, such as the equipment used and frequency of actions.

In addition to these municipal practices, regulatory control practices affecting urban runoff pollution should be investigated and summarized. Table 4-7 outlines an example review of local subdivision regulations that could be used to prevent and reduce urban runoff pollution in four communities. The table analyzes the regulations' ability to provide runoff quantity control, solids control, and other pollution control. Such a review can be developed for all regulations (e.g., zoning, wetlands, earth removal, and special protection districts)

Table 4-5. Use of Nonstructural Practices In Study Area Watersheds (Adapted from Woodward-Clyde Consultants, 1989)

Control Practices	Watershed 1	Watershed 2	Watershed 3	Watershed 4
Street sweeping	Yes	Yes	No	Yes
Litter control	Yes	Yes	Yes	Yes
Public education	Yes	No	No	No
Pet waste removal	No	No	Yes	Yes
Local ordinances	Yes	No	Yes	Yes
Fertilizer control	No	Yes	Yes	Yes
Reduced sanding and salting	Yes	Yes	No	Yes
Catch basin cleaning	Yes	No	Yes	Yes
Hazardous waste collection days	Yes	Yes	No	No

Yes = Control measure exists
No = Control measure does not exist

that could affect urban runoff pollution. Generally, the municipality should investigate all aspects of current practices that could affect storm water runoff quality, including the practices and regulations shown in Tables 4-5, 4-6, and 4-7, as well as others: special requirements for stream corridor preservation, buffer zones, and open space preservation; septic system planning and testing requirements; and regulations pertaining to nontidal wetlands. These issues are discussed further in the regulatory control section of Chapter 7. An example analysis of both regulatory and municipal urban runoff practices is provided in two case studies at the end of this chapter.

Contents of a Watershed Description

Once the information on existing conditions has been gathered and the watershed maps have been developed, the watershed can be described. The watershed description is organized by data type (i.e., environmental, infrastructure, municipal, and potential sources/existing BMPs). Each data type has its own section with a narrative description of each data subtype supported by appropriate tables and/or maps. The maps and data developed in the previous steps provide the primary information in the description. While not all this information will be of immediate use to the program team at this stage, it could be important as planning continues.

Information gaps should be outlined and presented in the watershed description as a first step in developing a plan to gather additional information (see Chapter 5). A summary listing of information recommended for the

Table 4-6. Frequency and Types of Nonstructural Practices Used in Study Area Watersheds (U.S. EPA, 1992)

	Community 1	Community 2	Community 3	Community 4
Street Sweeping				
Frequency	Every other day on 30 major streets and once a week on others	Once a week downtown and once a year in other areas	Twice a year	Once a year, except Lake Cochichewick (three times a year) and downtown (twice a year)
Equipment (number)	Mechanical (3)	Mechanical (1) Vacuum (3)	Mechanical (1)	Mechanical (2)
Catch Basin Cleaning				
Frequency	Once a year	Once a year	Twice a year	Once a year
Equipment (number)	Mechanical (1): Clamp	Mechanical (1): Orange Peel	Mechanical (1)	Mechanical (1): Orange Peel
Solid Waste Management				
Residential	Once a week	Once a week	Once a week	Once a week
Commercial	Twice a week	Private collection	Twice a week	Once a week
Recycling program	Paper Fall leaves	Paper	None	Paper Leaves/grass
Roadway Sanding and Salting				
Sand:salt ratio	4:3	1:1	4:1	7:1
Salt used (tons/road mile)	11	12	3.5	6
Special reduced-use zones	None	None	None	None
Other Nonstructural Practices				
Fertilizer and pesticide usage	None used	Fertilizer used on town ball fields	None used	Granular fertilizer used for sodding
Animal waste removal	No program	No program	No program	No program
Illicit connection identification and removal	No program	No program	No program	No program

watershed description is provided later in this chapter, and two examples are given in the case studies at the end of the chapter.

Preparing a Receiving-Water Description

In addition to a watershed description, a receiving-water description should be prepared, which includes the types of water resource data that should be sought, sources of data, and methods to summarize and analyze existing receiving-water conditions. Many program areas have multiple receiving waters, such as tributaries, larger rivers or estuaries, or lakes; in many cases, adding ground water to this list could be useful. Effective identification and use of existing water resources data could reduce the program schedule and cost, most significantly by reducing additional sampling and analysis. In addition, review of historical water quality data provides a basis for:

- Establishing and reassessing goals.
- Documenting the type and extent of urban runoff-related water resource impacts.
- Identifying data gaps that should be addressed with a sampling program.
- Identifying priority areas and major nonpoint pollution sources.
- Quantifying pollutant loads.
- Documenting impairment or loss of beneficial uses and water quality standard violations.
- Documenting areas with good water quality that could be threatened or that should be protected.

Types of Receiving-Water Data

The types of water resources data that should be sought include:

- Source input data (flow and quality)
  - CSO data,
  - storm water data, and
  - other NPS data.
- Physical/hydrologic
  - physiographic and bathymetric data,

Table 4-7. Existing Regulatory Control Summary—Subdivision Control (U.S. EPA, 1992)

Subdivision Control	Community 1	Community 2	Community 3	Community 4
Scope of regulations	*All lots being subdivided come under Subdivision Regulations; lots on an accepted public way and with sufficient frontage are classified as "Approval Not Required"*	*All lots being subdivided come under Subdivision Regulations; lots on an accepted public way and with sufficient frontage are classified as "Approval Not Required"*	*All lots being subdivided come under Subdivision Regulations; lots on an accepted public way and with sufficient frontage are classified as "Approval Not Required"*	*All lots being subdivided come under Subdivision Regulations; lots on an accepted public way and with sufficient frontage are classified as "Approval Not Required"*
Runoff Quantity Control				
Open space	Requires due regard for maintaining natural features and open space	Requires that efforts be made to maintain natural features and open space	Requires that efforts be made to maintain natural features and open space	Requires that efforts be made to maintain natural features and open space
Postdevelopment flow control	None specified	Requires calculations showing no increase in peak flow during 100-year storm	None specified	Requires calculations showing pre- and postconstruction peak flows and total volumes for 2-, 10-, and 100-year storms
Runoff recharge	None specified	None specified	None specified	Requires that storm water be recharged rather than piped to surface waters to the maximum extent feasible
Additional Controls				
Solids control	None specified	Requires the development of a runoff control plan that minimizes erosion	None specified	Requires that an erosion control plan be developed for during and after construction
Other pollution control	None specified	None specified	None specified	None specified

- flow characteristics,
- tidal elevation in coastal areas, and
- sediment data.

- Chemical
  - water quality data and
  - sediment data.
- Biological
  - fisheries data,
  - benthos data,
  - plankton data, and
  - biomonitoring data.
- Water quality standards and criteria
  - federal criteria and
  - state standards.

These data should be gathered to help the program team develop a profile of the conditions in the water body of concern. Source discharge, water, sediment, and biological data typically will exist from past studies of the watershed. By gathering this information, a picture can be developed of existing conditions and data gaps can be identified.

Sources of Water Resources Data

A wide range of sources of existing water resources data can be found at the local, state, and federal levels. Each agency that has conducted water resource assessments in the study area should be contacted for its available data and asked about other potential sources. As this chain continues, fewer new sources are identified; diminishing returns indicate when most, if not all, available data have been obtained. The following paragraphs summarize potential, as well as established, sources of water resources data.

Local

Many municipal departments listed earlier as potential sources of mapping can also provide water resources data from previous studies, wetland or other permit applications, or routine water resources monitoring. For example, health departments typically conduct routine monitoring of water resources to protect the environment, to ensure the safety of recreational swimming areas, and to manage onsite sewage disposal systems or septic tanks. Municipal departments responsible for reviewing construction and wetlands permit applications can track local water quality conditions as part of local water resource regulations designed to prevent cumulative degradation of sensitive resources. Local permit applications can contain recent and historical water quality, source discharge, and hydrologic data to demonstrate compliance with local or state wetlands and water quality regulations. Receiving-water data also might be available from NPDES monitoring records, which often represent valuable information about the effects of a specific pollution source. Also data might be available for water bodies in special drinking-water or flood-control districts.

State

In most states, several agencies deal directly or indirectly with water quality issues, such as water resources, pollution control, clean lakes, transportation, fisheries, environmental review, wetlands, and coastal zone management. The agencies might also deal with water quality in terms of discharge permit applications, fisheries status reports, development review, wetlands impacts, and effects on coastal resources. Every 2 years, states prepare two reports—a Section 305(b) Water Quality Assessment Report, summarizing the status of the states' waterways, and a Section 319 Nonpoint Source Assessment Report, listing water bodies affected by nonpoint sources—that indicate sources of existing water data, programs that address NPS pollution, and sources of agency assistance. These reports are available from the state water pollution control agency or the EPA regional office. Information concerning water bodies in the Clean Lakes Program (CWA Section 314) also might be available from the state.

Federal

The federal government is an excellent source of hydrology and water resources data through agencies such as EPA, SCS, and the USGS. Table 4-8 outlines a number of major federal government sources of water resource data including water quality, hydrology, meteorology, biomonitoring, and sediment quality data. In some cases, information can be supplied through the mail; in other cases, such as the USGS National Water Data Exchange, the information can be accessed only by using a computer modem.

Table 4-8. Federal Sources of Water Resource and Hydrology Data

Source	Type of Information
U.S. Environmental Protection Agency	
Clean Lakes Program	Water quality and other diagnostic information for lakes monitored under the Clean Lakes Program
National Estuaries Program	Water quality and other diagnostic and research data for 21 coastal embayments
Mussel Watch Program	Monitoring of mussel tissue for heavy metals and other toxic and xenobiotic compounds in areas of wastewater discharges
Ocean Data Evaluation System	Pollution sources, effluent, water quality, biological and sediment pollution data
Permit Compliance System (PCS)	Point source discharge data from NPDES monitoring programs
STORET Data	Flow and water quality data in receiving waters
U.S. Geological Survey	
Water Resources Division	Flow and water quality data collected at USGS streamflow gaging stations for rivers and streams
Water Quality Branch	Receiving waterflow and water quality data, point source data from NPDES monitoring programs
U.S. Department of Commerce	
National Climatic Center	Precipitation data and statistics from weather-monitoring stations nationwide
U.S. Food and Drug Administration	
Shellfish Sanitation Branch	Sanitary survey reports for coastal areas with shellfish habitat. Reports include shoreline surveys for actual potential pollution sources and water sampling data for total and fecal coliform
U.S. Army Corps of Engineers	
Reservoir water	Quantity and quality data
Dredging Permit Application Program	Water and sediment quality data collected in support of Clean Water Act Section 404 dredge and fill permit applications
Other	
U.S. Department of Agriculture, Soil Conservation Service	Sediment data for specific structural controls
National Oceanic and Atmospheric Administration	Marine charts for coastal areas, tide tables, and tidal current tables
Federal Emergency Management Agency	100-year flood plain elevations

Analyzing Water Resources Data

Existing data collected by different local, state, and federal organizations likely were collected using different methods, at different times, and with different objectives. Each data set should, therefore, be reviewed to assess its quality and applicability to urban runoff pollution prevention and control program efforts. Although the criteria for this assessment should be site specific, basic considerations include sampling program design and quality assurance/quality control (QA/QC). Data that would be useful in the planning process can be entered into a data base to facilitate data organization, management, and analysis. One method is to enter the information into a personal computer-based standardized spreadsheet format that allows sorting and plotting of the data. Spreadsheets are extremely versatile and allow the user to:

- Organize data from multiple sources.
- Analyze data from individual sampling programs or of aggregate data.
- Sort data, such as by sampling station location, analytical parameter, or date of collection.
- Statistically analyze data.
- Create x-y plots of parameter concentration versus time or distance.
- Continuously update the data base.

Table 4-9 presents an example spreadsheet format with the results of example statistical calculations. Figure 4-1 illustrates an x-y plot of total suspended solids (TSS) concentrations over time at the monitoring station used in Table 4-9. More advanced applications of spreadsheets can be used for hydrologic calculations and for calculating pollutant loading based on runoff volumes and pollutant concentrations. Spreadsheets can also be used to create data input files for computer models that help evaluate pollutant concentrations in receiving waters and effects on water resources and beneficial uses.

In addition to simple spreadsheet programs for storing and organizing data, specialized database management programs can be utilized. These programs are designed specifically for organizing large amounts of data and manipulating the data to produce customized reports. These programs can often produce output for direct use in analysis programs, such as those discussed in Chapter 6. Also, since GIS applications generally use data bases to store and retrieve data for generating data layers, a GIS system could be used for analyzing the existing water resources data. In this way, the water resources information can be directly plotted on the base maps generated during the watershed description

Table 4-9. Example Water Resource Data Spreadsheet

Station[a]	Date[b]	Day[c]	Time[d]	Parameter[e]	Concentration,[f] mg/L	Flow,[g] ft^3/s	Agency[h]	Method[i]
45	031885	108	0800	TSS	50	2.1	USGS	1
45	032085	110	1310	TSS	30	2	EPA	1
45	040185	122	1010	TSS	800	10.5	EPA	1
45	042985	150	1300	TSS	330	4.1	USGS	1
45	050385	154	1230	TSS	200	2.6	EPA	1
45	051385	164	1410	TSS	20	2.3	EPA	1
45	051585	166	2010	TSS	50	1.9	EPA	1
45	052085	171	1800	TSS	100	3	USGS	1
45	052985	180	1330	TSS	40	2.7	EPA	1
45	062585	207	0810	TSS	400	2.9	USGS	1
45	071785	229	2040	TSS	324	4.3	EPA	1
45	072385	235	0850	TSS	930	6.1	EPA	1
45	072685	238	1330	TSS	160	2.5	USGS	1
45	072785	239	1620	TSS	120	2.9	EPA	1
45	073185	243	1150	TSS	450	3.7	USGS	1
				Avg	266.93			
				Dev	272.08			
				Max	930			
				Min	20			

[a] The station number assigned to the collection location during the study; the same physical location may have more than one station number for surveys conducted by different agencies.
[b] Date of the sample collection.
[c] Sequential numbering of days starting with the earliest date of data collection.
[d] Time of the sample collection (HHMM).
[e] Water quality parameter (TSS = total suspended solids).
[f] Mass of constituent per unit volume.
[g] Volume per unit time during sampling.
[h] Agency conducting the survey.
[i] Analytical method (1 = Standard Method 2540 D).

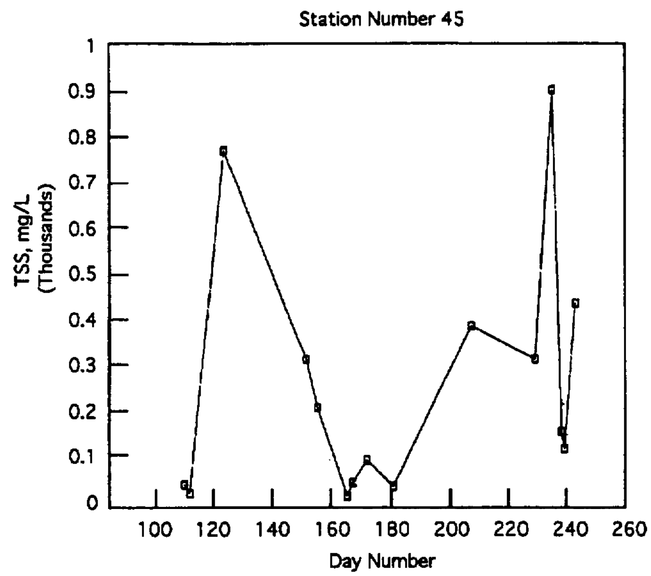

Figure 4-1. Total suspended solids (TSS) concentrations.

process, which allows the user to link watershed information, such as land use or soil conditions, directly with water resource data.

The Data Management and Analysis section of Chapter 5 discusses in more detail presenting and analyzing water resource data.

Contents of a Receiving-Water Description

After the water resource data have been gathered, a receiving-water description must be developed to describe the existing conditions of the water body being investigated. This description should include summaries of the data collected, organized by data type (i.e., physical/hydrologic, chemical, biological, and water quality standards and criteria). Each summary includes a narrative description outlining the information gathered for each data type. This information should be presented in a way that indicates existing data gaps and a priority for addressing those gaps.

Summary

This chapter discusses the collection of existing information to describe the planning area's watersheds and water resources. The information collected should concentrate on the delineation of watersheds; the description of land uses in the watersheds; and the identification of related environmental, infrastructure, municipal, and pollution source data. The water resource description should present data on physical, chemical, and biological conditions of the water body along with applicable standards and criteria. Based on the material presented in this chapter, a suggested outline for the existing conditions description is as follows:

- Project area
- Watershed data description
  - environmental data,
  - infrastructure data,
  - municipal data,
  - potential sources/existing BMP data,
  - miscellaneous data, and
  - data gaps.
- Receiving water data description
  - source input data,
  - physical/hydrologic data,
  - chemical data,
  - biological data,
  - water quality standards and criteria,
  - miscellaneous data, and
  - data gaps.
- Summary of data needs
- Refinement of goals

Expending resources at the beginning of the planning process to locate as much existing information as possible is cost effective in the long term, because it helps maximize use of existing information, minimize data collection costs, and avoid overlooking important data resources.

The information, having been gathered and analyzed, has to be examined to determine existing knowledge gaps. If necessary information is unavailable, the program team must collect additional data. The next chapter discusses obtaining and analyzing the water resource data required to describe existing conditions fully.

The program team can base site-specific program goals on the existing conditions information by examining the general initial goals and refining them. As discussed in Chapter 3, a knowledge of existing conditions is important to have before site-specific goals can be established.

The following case studies provide examples of existing conditions assessment for water bodies in Lewiston, Maine, and Pipers Creek in Seattle, Washington.

Case Study:
City of Lewiston, Maine,
CSO, Storm Water, and NPS Planning Program
Existing Conditions Assessment

Background

Lewiston, Maine, embarked on a planning program in 1991 to address CSO, storm water, and NPS pollution issues. Overall aspects of this planning program are described in a companion case study at the end of Chapter 3. This presentation focuses on the city's efforts to evaluate existing conditions.

The city invested significant time and energy in assembling and analyzing existing information in an effort to maximize the use of existing data and minimize the need for new data (and the potentially high cost of collecting it). The city also wanted a systematic way to sort and analyze information with respect to the critical pollution control issues. A set of "baseline information" was also desired from which to compare and assess future program needs and activities.

Existing conditions were assessed using a methodology similar to that described in Chapter 4. A watershed description, a receiving-water description, and a summary of data needs were prepared. Each of these components, including the approach and results, is described below.

Watershed Data

The program team, using the list of watershed data in Chapter 4, contacted and held meetings with individuals who might have pertinent data. The list of data compiled is shown in Table 4-10. Environmental data on the watersheds were generally available from a combination of local, state, and federal sources, as shown. Infrastructure data were available from the city, who already had accurate mapping of the major roadways, drainage system, and sewerage system. Municipal data, as well as data on potential pollution sources and BMPs, were available but required significant effort to compile.

Areas requiring a lot of work—potential pollution sources, nonstructural controls, municipal source controls, and existing structural controls—are described in the following paragraphs.

Potential Pollution Sources

While a number of possible pollution sources existed within the city's watersheds, they had never been mapped. The city compiled extensive information on underground and aboveground storage tanks, landfills, vehicle maintenance areas, salt storage and snow dumping areas, CSOs, and storm drain cross-connections. These were plotted on a base map, along with watershed boundaries, receiving waters, and other important features such as gaging stations, recreational areas, and flood control structures. The map contains information similar to that required in the NPDES storm water permit regulations. It provided a convenient way of reviewing watersheds and potential pollution sources within them, possible threats to receiving waters, and the underlying zoning districts.

Most of the potential pollution sources exist within the watershed areas of Jepson Brook, Hart Brook, and Androscoggin River—the most developed watersheds. Stetson Brook watershed has several potential sources, and Salmon/Moody Brook has almost none. No-Name Brook and Pond watersheds did not have many source areas. One area of medium-density residential development on Sabattus Street with a concentration of underground tanks was noted. Located at the brook's downstream portion near the pond, this area is of concern.

Nonstructural Controls

The city's land use and zoning code and other development guides were reviewed to determine the status of nonstructural controls. The city was determined to have a comprehensive set of nonstructural

Table 4-10. Lewiston Watershed Data

Description	Source
Environmental	
Topography	USGS topographical maps; city's 100- and 200-scale maps
Land use	Zoning Map Lewiston, Maine, revised 11/7/91; Comprehensive Land Use Plan (1987)
Recreational areas	Parks Department inventory
Soil and surface/bedrock geology	USDA Soil Conservation Service Soil Survey
Vegetation	USGS quadrangle sheets and Maine DOT aerial photos
Natural resources	Comprehensive Land Use Plan (1987)
Temperature	NOAA
Precipitation	National Climatic Data Center; four rainfall gauges owned and operated by Lewiston
Hydrology	FEMA flood mapping
Infrastructure	
Roads and highways	Various city maps exist
Storm drainage system	Record drawings provided by the city
Sanitary sewer (and combined sewer) system	Record drawings provided by the city
Treatment facilities	Record drawings provided by the city
Other utilities	Gas, New England Telephone maps
Municipal	
Population	U.S. Census data; Maine Dept. of Data Research and Vital Statistics; Comprehensive Land Use Plan (1987)
Zoning	Zoning regulations; city zoning map; Comprehensive Land Use Plan (1987)
Land ownership	City Assessor's maps
Regulations and ordinances	Draft development permit provided by the city; Comprehensive Land Use Plan (1987)
Municipal source control BMPs	Interviews with various city departments and staff
Potential Sources/BMPs	
Landfills	Locations developed by city
Waste handling areas	Locations developed by city
Salt storage facilities	Locations developed by city
Vehicle maintenance facilities	Locations developed by city
Underground tanks	ME DEP list supplemented by the city
NPDES discharges	Locations developed by city
Pollution control facilities	Lewiston Area Water Pollution Control Authority
Retention/detention ponds	Public Works Department inventory
Flood control structures	Public Works Department inventory

controls, which were analyzed and presented in a series of matrices—a convenient tool to assess the strengths and weaknesses of the regulations.

The major areas of existing regulatory authority include conservation districts, performance standards, and development review standards. Conservation districts (Table 4-11) are areas in the city that require special protection. Each district has requirements on the amount of open space or impervious surface area, on the size of buffer zones where applicable, and for solids control and pollution control.

Performance standards (Table 4-12) are designed to control impacts of certain activities (e.g., earth removal or timber harvesting) in specific areas (e.g., shoreline or flood plains). In each case, buffer or filter strips are required as appropriate. Controls also are specified in most cases for solids or other potential pollutants.

Development review standards (Table 4-13) apply to all new developments above certain specified sizes. The sizes are relatively small so that most new developments or redevelopments are covered. These standards contain a number of general review criteria for storm water management, erosion control, and other miscellaneous items.

Overall, the controls provide a more thorough and aggressive program than many communities of similar size have. The major area needing strengthening was the control of postdevelopment flows. Most requirements involved control of a 25-year storm which is oriented toward flood control. Because smaller storm events (i.e., 1-year return period or less) typically contribute most of the urban runoff pollutant

Table 4-11. Summary of Lewiston Nonstructural Controls—Conservation Districts

	Resource Conservation (RC)	Ground-Water Conservation (GC)	Lake Conservation (LC)
Scope of regulations	*Protects fragile ecosystems and areas of unique value as shown on city zoning map*	*Protects existing and potential ground-water supply areas*	*Protects water quality of No-Name Lake*
Runoff Quantity Control			
Open space	At least 90% open space Minimum 25-ft stream buffer Minimum 50-ft shoreline buffer	Maximum impervious surface ratio of 0.25	Maximum impervious surface ratio of 0.1 Minimum 50-ft shoreline buffer
Postdevelopment flow control	None specified	None specified	Increase of <20% for 25-yr/24-h storm
Runoff recharge	None specified	Specify measures to protect from loss of recharge	None specified
Additional Controls			
Solids control	Earth removal performance standards apply (see Table 4-12)	No earth removal below seasonal high ground-water table	Submit erosion and sediment control plan to minimize sediment discharge to pond
Other pollution control	Performance standards apply (see Table 4-12)	Prohibits solid waste disposal, petroleum storage, deicing chemical storage, snow dumping, hazardous waste storage, automotive repair shops, junkyards, cemeteries, and land application of sewage Ground-water protection plan required	Prohibits use of fertilizers within buffers, onsite sewage disposal within 250 ft Total lawn and garden area <30% of lot area No increase of phosphorus in pond >one part per billion for a development

Table 4-12. Summary of Lewiston Nonstructural Controls—Performance Standards

	Shoreline Area	Earth Removal	Timber Harvesting	Floodplain Management
Scope of regulations	*All areas within 250 ft of Androscoggin River and tributaries and all areas in Resource Conservation District (see Table 4-11)*	*New earth removal or expansion of existing activities*	*Limits activities depending on zoning district*	*Controls development within floodplains*
Runoff Quantity Control				
Open space	75-ft buffer around high-value wetlands Filter strip of varying width required between road and water body	Natural vegetative strip at least 50 ft wide must be maintained around activity (can be as high as 100 ft)	Minimum 50-ft stream buffer Buffer strip required depending on slope Limits on amount of vegetation removed depending on area	None specified
Postdevelopment flow control	Road culverts and bridges shall pass 25-yr storm	No net increase in runoff discharge	None specified	None specified
Runoff recharge	None specified	None specified	None specified	None specified
Additional Controls				
Solids control	No grading or filling on slopes >25% All listed activities must prevent erosion and sedimentation Filter strip required near tilled land	No slopes greater than 2:1 Erosion prevention plans including the use of ditches, sedimentation basins, or dikes must be used if the activities are within 250 ft of a water body	None specified	Structures must be protected from flood-waters (limits erosion)
Other pollution control	Subsurface disposal not allowed within 100 ft of water body Agriculture shall minimize bacteria and nutrient contamination	Operation may not cause harmful leachate Petroleum or hazardous waste storage prohibited	Prohibited in resource conservation district Limited in shoreline areas and lake conservation district	Locate sewerage system to minimize contamination of waters

loading on a long-term basis, control of such smaller storm events was recommended. Another area that could be strengthened is the onsite disposal of storm water. While noted in the development review standards, this plan could be made more specific. Finally, other parts of the development review standards could be made more specific with respect to runoff pollution control.

Municipal Source Controls

Interviews were conducted to summarize the current city "source control" activities (summarized in Table 4-14). Most activities conducted by the city appeared reasonable with respect to standard practices of similar sized municipalities. Areas that appear to need further consideration include cross-connection removal, road salting, and household hazardous waste pickup. The city has identified some cross-connections and plans to implement a removal program. Road-salting policy does not vary in sensitive areas such as No-Name Pond; such a policy could be beneficial in the sensitive receiving waters. Many communities are involved in household hazardous waste pickup programs. Such a program could prove beneficial and would be consistent with the city's other aggressive solid waste programs. Such programs, however, also can be expensive. Further evaluation of municipal BMP/source control activities is planned after collection of data and evaluation of various possible BMP programs.

Table 4-13. Summary of Lewiston Nonstructural Controls—Development Review Standards

	Storm Water Management	Erosion Control	Other
Scope of regulations	*Standards apply to all new subdivisions, residential developments with more than five units, nonresidential developments, and numerous other development categories.*		
Runoff Quantity Control			
Open space	Preserve natural drainage ways	Preserve natural vegetation	Landscaping plan required
		No fill storage within 50 ft of water body	Open space set-asides for larger developments
Postdevelopment flow control	Must handle 25-yr storm without surcharge	None specified	Storm water drainage plan required (25-yr/24-h storm)
Runoff recharge	Dispose of storm water on the property to the extent possible	None specified	None specified
Additional Controls			
Solids control	None specified	Earth material removal standards apply (see Table 4-12)	Erosion control plan required
		Permanent erosion control measures within 15 days after final grading, or use temporary measures	
		Use debris basins, silt traps, or other measures during construction	
Other pollution control	Cannot degrade biological and chemical properties of receiving waters; such controls as oil and grease traps, onsite vegetated waterways, and reductions of deicing and fertilizers may be required	None specified	Avoid extensive grading and filling
			No adverse impact on ground-water quantity or quality
			No undue water pollution
			No adverse impact on shoreland

Existing Structural Controls

The structural controls installed in the city within the last few years were inventoried. The information compiled is summarized in Table 4-15. Few structural controls exist largely because of the limited new development or redevelopment in recent years. Most of the projects used the 25-year storm required in current city regulations as the design criteria. As noted in the nonstructural control discussion, inclusion of smaller events is being considered as an additional requirement.

Most structural controls listed are detention ponds. In one case, subsurface infiltration is used. In another case, an inlet structure controls flow from the Garcelon bog wetland into Jepson Brook, and thus is not a development-related project. The summary indicates that there is currently no inspection or maintenance schedule for most of the facilities—a shortcoming for the flood-control use of the facilities as well as if the facilities were to be used to assist in urban runoff pollution control.

Receiving-Water Data

As shown in Table 4-16, data on receiving waters or on the major pollution sources to the receiving waters were limited. Data were available only for the Androscoggin and Little Androscoggin (which feeds into the Androscoggin River in Lewiston) rivers. The USGS maintains monitoring stations on both rivers, and published data are available on dissolved oxygen, temperature, pH, and conductivity. Maine Department of Environmental Protection (ME DEP) has collected grab samples on a weekly basis during summer, and data on dissolved oxygen, *E. coli* or fecal coliform bacteria, phosphorus, total Kjeldahl nitrogen (TKN), nitrate (NO_3), ammonia (NH_3), and conductivity are available for several years. The most

Table 4-14. Existing Source Controls/Municipal BMPs

Source Control/BMP	Description
Street Sweeping	
Frequency	All roads once a year; downtown, greater frequency
Equipment	City owns two mechanical and one vacuum sweeper, and leases one mechanical sweeper
Catch Basin Cleaning	
Frequency	2,750 catch basins exist; about 1,500 are cleaned each year, April through November
Equipment	City owns a Vac-All catch basin cleaner
Roadway Sanding and Salting	
Sand:Salt Ratio	6:1
Salt used (tons/road mile)	15,000 yd^3/yr sand; 3,000 tons/yr salt
Special reduced-use zones	None
Solid Waste Management	
Residential	By city; once a week; downtown areas twice a week; three fall leaf pickups
Commercial	By commercial haulers
Recycling program	Curbside once a week, newspapers/cans/clear glass; dropoff for all residential as well as commercial, scrap metals/office paper/magazines and other materials
Composting program	None; home composting is encouraged by the city
Other Existing Controls/BMPs	
Household hazardous waste	Waste oil dropoff for residents; no other program
Fertilizer and pesticide usage	None
Animal waste removal	Dead-animal pickup on roads only; no program to remove animal wastes
Illicit connection identification and removal	No removal program currently in place; some cross-connections have been identified
Storm drainage system maintenance	General maintenance activities use 25% of annual Highway Department staff labor hours

comprehensive set of data available was collected by International Paper Company relative to its wastewater discharge upstream of Lewiston. Although the available data do not cover the entire reach of the Androscoggin River in Lewiston, significant data on fisheries and sediment exist. None of the existing data were oriented towards definition of wet-weather impacts in the receiving water. Some of the ME DEP grab samples were taken during or after storm events, and the bacteria data indicate elevated bacteria levels during these periods.

Because of the limitations in available data, two major areas of data collection were decided upon. The first is data on CSO flows, loads, and impacts, required as part of CSO planning efforts by the state. The second is information on selected city water resources where no data currently exist. These programs are described in the following sections.

CSO Data Collection

The CSO data collection program, being conducted in 1993, encompasses two major elements: CSO and storm water discharges, and receiving waters. Flow and water quality data are being collected for several storm events for several of Lewiston's CSO discharges. These data will be used to calibrate a computer model of the sewer system. Data are also being collected on several separate urban storm drain discharges to identify the quality of storm water discharge to the receiving waters.

Dry- and wet-weather sampling is being conducted at four locations on the Androscoggin River, and at two along Jepson Brook, where many of the CSOs discharge. Sampling is being conducted over a 2-day period during and after several storm events. Sampling is also being conducted during dry weather to

Table 4-15. Lewiston Existing Structural Controls

	Kensington Terrace Phase II	Turnpike Industrial Park	Chalet Motel	Super Shop 'n Save	Sand Hill Estates	Andrews Pond	Jepson Brook Inlet Structure	Lewiston Recycling Facility
Structure type	Detention pond	Two detention ponds (P1 and P2)	Detention pond	Underground piping detention system	Detention pond	Small pond	Inlet control structure	Detention pond
Type of control	8-inch orifice 48-inch orifice stand pipe	P1: 12-inch orifice P2: 18-inch orifice	8-inch orifice	6-inch by 3-foot 4-inch orifice	10-inch orifice	48-inch orifice	Concrete weir	8-inch orifice 18-inch orifice
Location	Southerly side of Sherebrook Extension	P1: North of Cottage Road P2: South of Cottage Road	Southwest of Lisbon Street	Sabattus Street and Highland Spring Road	Southwest of Woodille Road	Bates College, behind Olin Arts Center	East of Farwell Street	West of recycling center
Ownership	City of Lewiston	City of Lewiston	Chalet Motel	Super Shop 'n Save	City of Lewiston	Bates College	City of Lewiston	City of Lewiston
Receiving water	Tributary to No-Name Brook	Drainage ditch to Hart Brook	Hart Brook	Tributary to Garcelon Bog/Jepson Brook	Intermittent stream to Jepson Brook	Jepson Brook	Jepson Brook	Tributary to Androscoggin River
Year constructed	1990	1990	1992	1988	1989	Unknown	1986	Scheduled for spring 1993
Design criteria	2-yr and 25-yr storms	25-yr storm	25-yr storm	25-yr storm	Volume = 0.52 acre-feet	Not available	Not available	25-yr storm
Land use	Neighborhood Conservation "A" and Res	Industrial	Highway business	Highway business	Neighborhood Conservation "A"	Institutional Office District	Neighborhood Conservation "A"	Industrial
Inspection schedule	None	None	None	None	None	Unknown	2-3 times/yr	N/A
Maintenance schedule	None	None	None	None	None	Unknown	None	N/A

Table 4-16. Lewiston Source Input and Receiving-Water Data

Description	Source
Source Inputs (Flow and Quality)	
CSO	None
Storm water	None
Other NPS	None
Receiving Water	
Physiographic and bathymetric data	Some available; see water quality data below
Flow characteristics	USGS flow data
Sediment data	International Paper—Androscoggin River
Water quality data*	ME DEP; USGS; CMP; Union Water Power Co.
Sediment data	International Paper—Androscoggin River
Fisheries data	International Paper—Androscoggin River
Benthos data	International Paper—Androscoggin River
Biomonitoring results	None
Federal standards and criteria	EPA
State standards and criteria	ME DEP

* Note: All water quality data in Androscoggin River only.

establish background conditions. Data are being analyzed for several parameters including *E. coli* bacteria, pH, dissolved oxygen, and temperature.

Water Resources Data Collection

Due to the absence of available data, collection of new data was recommended in the major watershed tributaries (except for Jepson Brook, which is being sampled as part of the CSO sampling effort) as well as in No-Name Pond. The details of the program will be developed after the CSO sampling effort is completed in 1993. In general, the program will consist of dry- and wet-weather data collection at various stations. Grab sampling is contemplated because the major purpose of this effort is to characterize the quality of each water resource.

Case Study: Pipers Creek Watershed Characterization and Water Quality Assessment

The Pipers Creek watershed borders Puget Sound in northern Seattle, Washington. Pipers Creek is an urban freshwater stream that drains a 3.5-square-mile watershed. Land use in the watershed is approximately 56 percent residential and 12 percent industrial and commercial, with the remaining 32 percent left as open space. Figure 4-2 shows the creek and its watershed.

As part of an overall effort to improve water quality in Puget Sound and its tributaries, an NPS pollution control plan was developed in 1989 and 1990 by the city of Seattle and the Washington Department of Ecology (WA DOE). The purpose of the plan was to develop a program of control measures to reduce or prevent NPS pollution to Pipers Creek. The plan was developed after Pipers Creek was selected by the WA DOE as one of the state's first early action watershed projects for NPS pollution control. The plan was funded by the WA DOE through a grant to Seattle.

An early step in action plan development was characterizing the natural and manmade environments in the Pipers Creek watershed to help determine the land use practices and physical conditions that contribute to NPS pollution in the watershed. Also, existing water resource conditions were determined by gathering and analyzing available water quality data for Pipers Creek. The results are summarized in the "Pipers Creek Watershed Action Plan for Nonpoint Source Pollution: Watershed Characterization and Water Quality Assessment" (WA DOE, 1990), which includes the data required to develop pollution prevention and control measures for the Pipers Creek watershed.

The types of watershed and water resources data collected and used in the Pipers Creek characterization, compared with the types of characterization data recommended for collection in this chapter, are shown in Tables 4-17 and 4-18. In general, the full range of relevant baseline information was gathered, except perhaps information that might have been available on certain potential pollution sources. While some existing watershed data were found to be available, existing water resource, sediment chemistry, and biological data were less complete. Water resource data came primarily from periodic sampling efforts carried out by the Seattle Engineering Department and the Metro Wastewater Treatment Plant. In general, samples were collected during dry weather and were collected for bacteria. Some wet-weather data were also available. The major sources of data were the monthly fecal coliform sampling conducted

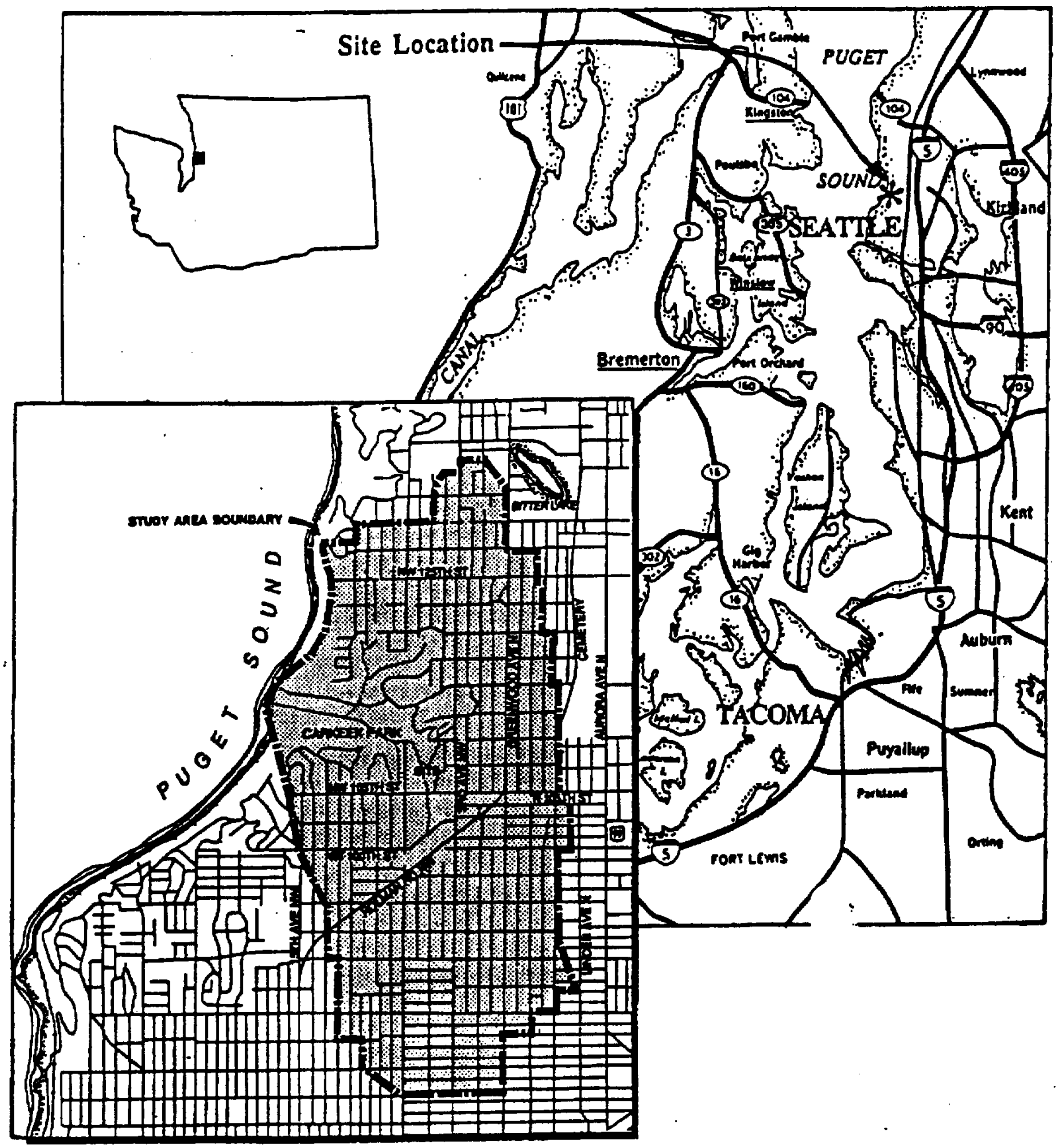

Figure 4-2. Pipers Creek watershed.

Table 4-17. Pipers Creek Watershed Characterization Data

Watershed Characteristics	Type of Information Included
Environmental Data	
Topography	Description of topography focusing on steep areas subject to erosion
Land use	Detailed discussion of current and projected land use with map showing residential, commercial, and recreational uses
Recreational areas	General discussion of recreational lands
Soil and surface bedrock	Description of soils and geology with emphasis on erosion potential
Vegetation	Detailed discussion of vegetative habitat with maps of watershed
Natural resources	Discussion of natural resources with maps of watershed
Temperature	General discussion indicating average, high, and low temperatures
Precipitation	Fifteen years of data to calculate rain event durations and intensities
Infrastructure Data	
Roads	Description of roadways in watershed
Storm drainage systems	Detailed discussion including map of major trunk drains
Sanitary sewer systems	General description of sewerage system
Treatment facilities	Discussion of size and location of treatment plant and outfall
Other utilities	Not addressed
Municipal Data	
Population	Detailed discussion including current and projected population data
Zoning	Description including watershed zoning map
Land ownership	Description of the amount and location of land publicly owned
Regulations	Detailed description of existing regulations and programs addressing potential NPS pollution
Ordinances	Detailed description of ordinances addressing NPS pollution
Municipal BMPs	General description of garbage disposal practices in the watershed
Potential Sources/Existing BMPs	
Landfills	Not addressed*
Waste handling areas	Brief description of existing facilities in the watershed
Salt storage facilities	Not addressed*
Vehicle maintenance areas	Not addressed*
Underground tanks	Description of underground tank program and potential extent of problems
NPDES discharges and pollution control facilities	Treatment plant discussed but not flows and loads
Retention/detention ponds	Not addressed*
Flood control structures	Not addressed*

* These sources may or may not exist in the watershed.

Table 4-18. Pipers Creek Water Quality Characterization Data

Receiving Water	Type of Information Included
Physical/Hydrologic Data	
Tidal elevation	No discussion of tidal influence on Pipers Creek
Flow characteristics	No available data on Pipers Creek flow characteristics
Physiographic/bathymetric	General discussion of physical characteristics
Sediment physical characteristics	No physical sediment data available
Chemical Data	
Water quality	Available water quality data from previous studies; data include sediments, metals, pathogens, nutrients, and organics
Sediment quality	Some available sediment heavy metal data from previous studies was discussed
Biological Data	
Fisheries	General description of fish populations in watershed
Benthos	No discussion of benthic data
General	Description of plant and animal life throughout the watershed
Other	
Quality standards and criteria	General description of federal and state water quality standards

by Metro at two stations in Pipers Creek since 1970 and a source tracing program conducted at 40 stations in Pipers Creek in 1987 and 1988. Some of these sites were sampled fewer than four times and others were sampled more than 25 times. Other parameters were analyzed only on a sporadic basis. Available data were summarized in text, tables, graphs, and maps to help develop a profile of existing watershed characteristics and water resources. Based on this information, the need for collecting additional water resource, sediment, and biological data was determined. The project team decided that no additional data collection was needed before developing the action plan (see Chapter 9 case study).

Once the existing conditions of the watershed were defined, the project team conducted an initial analysis of the NPS pollution problems using the available data. In this project, problems were defined as:

- Significant impairment of designated uses.
- Unfavorable conditions in comparison with similar watersheds.
- Relatively frequent exceedances of water resource standards.
- Lack of specific types of data that are necessary to quantify conclusions.
- Occurrences that contribute to NPS pollution.

Based on this qualitative assessment, the general problems identified included:

- Bacterial contamination
- Turbidity, sediments, and other solids caused by erosion
- Heavy metals
- Oxygen depletion

- Organics from pesticides and petroleum products
- Nutrients (e.g., phosphorus)

According to available wet-weather data, these problems worsened during rainy weather. The assessment concluded that urban runoff is the primary cause of pollution problems in Pipers Creek. More specific evaluations of NPS pollution could not be accomplished with the available data, and the project team proposed collecting additional data in conjunction with the implementation of preliminary pollution prevention measures. The areas requiring additional data collection are:

- Storm-related receiving water and storm runoff quality data.
- Periodic dry-weather sampling throughout a larger area of Pipers Creek.
- Flow and tidal data to help isolate specific sources.
- General biological sampling to determine the water body's overall health.

While the lack of such data prevented the project team from recommending specific structural BMPs to address identified pollution sources, the team determined that a general pollution prevention program focusing on municipal, regulatory, and public education approaches should be implemented as a first step. In addition to these measures, the program team incorporated additional water quality monitoring and implementation of structural demonstration projects to collect more data.

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

Anderson, J.R. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Service. Professional paper no. 964.

U.S. EPA. 1992. U.S. Environmental Protection Agency. Storm water quality control in the Merrimack River Basin. U.S. EPA Region 1. Boston, MA.

WA DOE. 1990. Washington Department of Ecology. Pipers Creek watershed action plan for nonpoint source pollution: watershed characterization and water quality assessment. Olympia, WA.

Woodward-Clyde Consultants. 1989. Santa Clara Valley Nonpoint Source Study Volume II: NPS Control Program. Santa Clara Valley Water District.

Chapter 5
Collect and Analyze Additional Data

Urban runoff pollution problems are rarely clear cut. While information from existing studies might be sufficient to understand certain issues, new data often must be collected before the assessment and ranking of problems or the screening and selection of BMPs.

Because of the diffuse and intermittent nature of urban runoff pollution, its characteristics are difficult to quantify. Nonetheless, documentation and quantification of pollutant characteristics and effects are critical in developing an urban runoff pollution prevention and control plan. Data collection activities are often the most expensive aspect of the urban runoff planning process. A common pitfall in urban runoff programs is expending extensive resources on collecting data that turns out to be of limited value to the overall planning. Data collection efforts therefore should be carefully planned with very specific objectives given the difficulty in characterizing urban runoff problems. In this way, only data that is necessary and valuable to the program are collected, saving scarce program resources for implementation of controls.

This chapter describes how to develop a data collection program that supports the urban runoff pollution prevention and control planning process. The chapter first outlines possible goals and objectives of data collection and the general types of data required depending on the program. Important factors in developing a data collection program are highlighted, including selection of parameters, selection of sampling stations, and frequency of data collection. Planning the data collection work is then discussed, including work plan development, sample analysis, and quality assurance/quality control. Executing the program is then discussed, including sampling techniques for water resource, hydrologic, and rainfall data collection. The chapter ends with a discussion of management and analysis of the collected data, including various methods for analyzing and presenting the data.

Objectives of Data Collection

The scope of a data collection program for urban runoff pollution investigations must be site specific. It should reflect the data needs determined during analysis of existing conditions in conjunction with initial program goals identified in the planning process. Data needs may focus on potential pollution sources; water resource problems; compliance with local, state, and federal regulations; or other issues. A discussion of typical data collection objectives at this stage of the program follows.

Assess Existing Conditions

If existing data are not sufficient to establish current dry- or wet-weather conditions, additional data are needed. Dry-weather sampling of water resources could include areas affected by urban runoff loading and areas upstream of, and therefore not influenced by, the urban runoff discharges in the watershed. It might also include sampling of dry-weather base flows entering the water resource through creeks, pipes, or ditches which could contain illicit connections. In addition to water sampling, sediment and biological sampling are particularly useful for determining a water resource's relative health, as discussed in the Chapter 6 case study. Also, sampling of habitats, wildlife, soils, and other components of the watershed might be required to establish existing conditions.

Wet-weather sampling can be used to determine runoff pollutant concentrations and to observe their downstream effects. Wet-weather sampling is critical in urban runoff pollution prevention and control planning because most of the source loadings occur in wet weather. Sampling of runoff and measurement of flow in both sources and receiving waters during a storm can be used to determine the variability of runoff volumes and pollutant loads and to assess receiving-water impacts for a particular storm. Results from sampling of receiving waters during storms can be used to evaluate the effects of storm water runoff on ambient water quality, violations of water quality standards, and the effects of storm water on beneficial uses. Other types of wet-weather observations could be useful to assess flow paths, ponding, areas of erosion, and other wet-weather conditions in the watershed.

Refine Problem Identification

Data collection programs might focus on collecting the additional information needed to identify problems clearly, such as pollutant sources and water resource impacts, that first were identified during the existing conditions assessment. These data can provide the basis for source identification, problem assessment, and BMP selection. Data collection for problem identification could again involve dry- or wet-weather sampling of sources, receiving waters, or watershed factors.

Calculate Pollutant Loads

Flow concentration data from sources of pollutants collected in dry or wet weather, as appropriate, can be used to estimate pollutant loadings and to identify priority pollution sources and watersheds. Pollutant loadings may be estimated using numerous methods ranging from simple to complex (see Chapter 6). These estimates can be used to evaluate event or annual pollutant loadings from the watershed, evaluate resource impacts, and select appropriate BMPs.

Provide Data for Computer Models

Computer models can be used as predictive tools to assess problems and the potential benefits of alternative pollution prevention and control strategies (see Chapter 6). Quantitative models that are calibrated and verified using data from site-specific sampling programs can be used to estimate impacts of future pollution loadings anticipated under potential control strategies. Models quantify pollutant loads as well as assess impacts on receiving waters or other ecosystem components. These models often require particular types of input data that might have to be collected. These typically involve dry- or wet-weather source flow and concentration data, but can also include other specialized parameters. For example, data on sediment oxygen demand in the receiving water might be needed if dissolved oxygen modeling is a primary concern, or physical and chemical characteristics of street surface solids might be tested if pollutant buildup and washoff is to be simulated.

Address Important Pollution Sources or Resource Areas

The monitoring program might need to focus on known or suspected major pollution sources, to supplement available data and confirm the existence of pollutant loading from a source. Pollution sources could be either point or nonpoint sources expected to be of particular importance to the program. The monitoring program also might need to focus on critical resource areas. Natural resources that could warrant special consideration for sampling include shellfish beds, wildlife sanctuaries and refuges, wetlands, coral reefs, spawning grounds, recreational fishing areas, bathing beaches, and drinking-water resources.

Fulfill Regulatory Requirements

Specific regulatory programs might require collection of certain data types. As discussed in Chapter 2, programs such as the NPDES storm water permit program have specific data collection requirements. As another example, flow and quality data at CSO outlets might have to be collected to satisfy state CSO planning requirements.

Each data collection program should be developed based on one or a combination of the above objectives, or other objectives as appropriate. Data should be collected only if a specific purpose relevant to the program is fulfilled.

Data Collection Programs

Developing a data collection program depends on numerous factors. The program should have clear objectives, as discussed in the previous section of this chapter. The program should also reflect the goal-setting process described in Chapter 3. Design of the data collection program also depends on factors such as the size and nature of the watersheds and receiving waters. The plan must take into account available funding, resources, and schedule constraints.

This section discusses how to implement urban runoff data collection programs. First, the major elements of designing a data collection program, including selection of parameters, sampling locations, and sampling frequency, are summarized. The selection of an analytical laboratory, laboratory methods and data quality assurance procedures are then discussed. Finally, the chapter discusses how to conduct the sampling program, including water sampling, sediment sampling, and hydrologic and rainfall monitoring. Some of the numerous, detailed technical references on monitoring that this handbook is not attempting to reproduce are included in Appendix A.

Designing the Data Collection Program

Since data collection programs are site specific and varied, providing detailed guidance on what should "typically" be done is not realistic. This chapter opens with an overview of the type of objectives often established. The major considerations in design of a data collection program—parameter selection, sampling station selection, and the frequency of data collection—are presented in this section.

Selection of Parameters

Parameters to be measured during the sampling program should be selected based on the review of existing conditions; the program's overall goals; the specific objectives of the data collection program; and the requirements of local, state, and federal regulations. For example, most state water quality standards have numeric limits for indicator bacteria levels in waters intended for swimming and boating. If local beaches are threatened by bacterial contamination from storm water or CSOs, bacteria sampling needs to be included in the program.

Given the long list of potentially important parameters, site-specific considerations drive the selection of parameters to be tested. The most common pollutant categories associated with urban runoff are solids, oxygen-demanding matter, nutrients, pathogens, and toxic substances as discussed in Chapter 1. The sampling plan may include analysis of specific parameters included in these or other pollutant categories (see Table 1-3). Table 5-1 lists the most commonly identified priority pollutants in the Nationwide Urban Runoff Program (NURP). Specific pollutant parameters are required for characterizing storm water as part of an NPDES permit application for a municipal storm sewer system discharge (Table 5-2).

Table 5-1. Priority Pollutants in at Least 10 Percent of Nationwide Urban Runoff Program Samples (U.S. EPA, 1983a)*

Metals and Inorganics	**Halogenated Aliphatics**
Antimony	Methane, dichloro
Arsenic (50%)	**Phenols and Cresols**
Beryllium	Phenol
Cadmium	Phenol, pentachloro
Chromium (60%)	Phenol, 4-nitro
Copper (90%)	**Phthalates Esters**
Cyanide	Phthalate, bis(2-ethylhexyl)
Lead (95%)	**Polycyclic Aromatic Hydrocarbons**
Nickel	Chrysene
Selenium	Fluoranthene
Zinc (95%)	Phenanthrene
Pesticides	Pyrene
Alpha-hexachlorocyclohexane	
Alpha-endosulfane	
Chlordane	
Lindane	

* Frequency of detection in parentheses when 50% or greater.

Table 5-2. Storm Water Sampling Parameters (U.S. EPA, 1991a)

Sediments/Solids	**Metals**
Total dissolved solids (TDS)	Antimony
Total suspended solids (TSS)	Arsenic
Bacteria	Beryllium
Total coliforms	Cadmium
Fecal coliforms	Chromium (total)
E. coli	Chromium (hexavalent)
Enterococci	Copper
Fecal streptococci	Lead
Nutrients	Mercury
Total phosphorus	Nickel
Dissolved phosphorus	Selenium
Total nitrogen	Silver
Total ammonia	Thallium
Organic nitrogen	Zinc
Other	**Organics**
pH	Volatile organic compounds (VOCs)
Cyanide	Base/neutral and acid extractable compounds (BNAs)
Biochemical oxygen demand (BOD)	Pesticides/PCBs
Chemical oxygen demand (COD)	Phenols
	Oil and grease

Table 5-3. Detection Frequencies of the Most Frequently Occurring Organic Compounds (U.S. EPA, 1990a)

Organic Compound	Frequency of Detection, %
1,3-Dichlorobenzene	23
Fluoranthene	23
Pyrene	19
Benzo(b)fluoranthene	17
Benzo(k)fluoranthene	17
Benzo(a)fluoranthene	17
Bis(2-chloroethyl)ether	14
Bis(chloroisopropyl)ether	14
Naphthalene	13
Chlordane	13
Benzo(a)anthracene	12
Benzyl butyl phthalate	12
Phenanthrene	10

Based on more recent data than NURP's, the most commonly detected organic compounds are shown in Table 5-3 (U.S. EPA, 1990a). In this same study, seven metals (aluminum, cadmium, chromium, copper, lead, nickel, and zinc) were tested for both filtered and unfiltered fractions from numerous source areas (i.e., roofs, parking areas, storage areas, streets, loading docks, vehicle service areas, landscaped areas, and urban creeks). Detection frequencies were very high for every metal tested in the unfiltered samples.

The information in Tables 5-1 through 5-3 can be used as a starting point and can be refined to reflect program-specific needs. Other conventional parameters such as temperature, dissolved oxygen, turbidity, and specific conductivity can be included as indicator parameters to support specific assessments of urban runoff pollution sources and receiving waters. It is also important to characterize particle settling velocities, particle diameters, and dissolved and nondissolved chemical fractions for use in evaluating runoff treatability and pollutant routing in the watershed and receiving waters.

In addition to the source and receiving-water quality parameters outlined above, sediment samples may be analyzed for physical and chemical parameters, such as grain size distribution, organic content, total organic carbon (TOC), nutrients, metals, petroleum products, polychlorinated biphenyls (PCBs), or other parameters. As pollutants are partitioned between the dissolved and particulate phase, sediment chemistry reflects the portion of the particulate-bound pollutants that settle. These pollutants can, through other physical and chemical mechanisms, be introduced into the water column. Sediment chemistry can indicate potential pollution problems caused by the sediments, such as the release of metals and other pollutants into the water column and the depletion of overlying dissolved oxygen (DO) as organic matter is broken down by microorganisms.

The sediment characteristics reflect the long-term effects of intermittent and variable urban runoff discharges. These long-term effects could be more significant than short-term water quality variations that occur in response to individual runoff events. In fact, it is easier and more cost effective to test sediments and plant and animal populations in the affected areas than to conduct sampling of the intermittent pollution sources and receiving-water responses. The existing substrate and communities integrate the cumulative effects and can be characterized rapidly since they do not vary extensively. Numerous runoff event samples are necessary to obtain reliable statistics, however, and such data gathering is expensive and time consuming.

Sampling of aquatic biota involves collecting biological species from the water column and sediments to determine the species diversity, dominance, and evenness. This process can include sampling for plankton, periphyton, macrophyton, macroinvertebrates, and fish and determining the number and density of populations in the water resource. In addition, physical habitat indicators, such as substrate and plant types and conditions, are useful indicators of pollution impacts. As with sediment, these habitats reflect the long-term effects of the intermittent urban runoff impacts. These effects might be subtle and take a long time to occur, depending on the nature of the transport mechanisms and receiving-water body.

Toxicity test sampling can be used to determine the relative toxicity of storm water runoff from a conduit, creek, or other flow stream that might be receiving contaminants. Toxicity testing, an integral part of the NPDES point source monitoring program, has been included in several states' storm water permitting programs. Toxicity test results also provide information on the relative degree of chronic and acute toxicity, which again reflect the period of exposure of organisms to toxic effects. A thorough discussion of toxicity testing can be found in the *Technical Support Document for Water Quality-Based Toxics Control* (U.S. EPA, 1991b).

Selection of Sampling Stations

Sampling stations should be selected strategically so that data collected from a limited number of stations satisfy multiple sampling objectives. The major types of sampling are watershed-based (urban runoff sampling) and water resource-based (receiving-water and aquatic ecosystem sampling).

Urban Runoff Sampling. Wet-weather generated discharges (e.g., storm water, CSO, and NPS) can contribute large pulses of pollutant load and could constitute a significant percentage of long-term pollutant loads from urban and suburban areas. Wet-weather sampling can be used to characterize runoff from these discharges, determine individual pollutant source and total watershed loadings, and assess the impact on receiving waters. Pollution sources, tributaries, or entire watersheds can be ranked by total pollutant load and prioritized for implementation of pollution prevention and control measures (see Chapter 6).

In selecting a site for urban runoff sampling during wet weather, the following criteria should be considered:

- *Discharge volume:* Select sites that constitute a significant portion of the flow from a watershed.
- *Pollutant concentrations:* Based either on historical information or on land use or population density, select sampling sites to quantify representative or varying pollutant load sources.
- *Geographic location:* Select sites that permit sampling of flows from major subwatersheds or tributaries to permit isolation of pollutant sources.
- *Accessibility:* Select sites that allow safe access and sample collection.
- *Hydraulic conditions:* Utilize existing flow measurement devices, such as weirs or gaging locations, or sample where hydraulic conditions are conducive to manual or automated flow measurements.

Sampling should also include dry-weather flows from storm drains or other structures to determine if they result from illicit connections, or from ground-water infiltration. The magnitude of these dry-weather discharges determines the need to identify and remove these illicit connections. Detailed procedures for this have been developed (U.S. EPA, 1993).

Water Resource Sampling. For the impact of urban runoff to be assessed, the water quality of receiving waters during normal dry-weather periods should be known. Water quality data collected during dry-weather conditions provide a basis of comparison to data collected during wet-weather conditions. These data are also needed to quantify dry-weather pollutant transport from tributaries and ground-water flows. If existing data are not sufficient to characterize current conditions, stations should provide good spatial coverage within the receiving waters. Based on initial sampling results, the number of stations potentially could be reduced. For example, if initial sampling results show that a particular stream within a watershed is of high quality, sampling coverage of this stream could be reduced. Additional stations could be added in response to expected changes in land use (such as high-density development projects), which might affect water quality. Critical stations, however, such as those that previously indicated water quality violations, need to be maintained. Also, use of existing stations from other programs should be maximized.

Wet-weather sampling stations should be located to assess impacts of significant urban runoff pollutants and major storm drain systems and CSO outfalls. Receiving water stations should include the dry-weather monitoring stations for comparison. Additional stations may be sampled within tributaries affected by storm water, CSO, or other discharges and land use types of particular concern.

Other general site selection criteria for receiving waters include:

- History of available data
- Easy accessibility
- Safety of personnel and equipment
- Entry points of incoming sources or tributaries
- Adequate mixing of sources or tributaries
- Straight reaches, rather than bends

Sediment Sampling. Sediments in receiving waters affected by urban runoff integrate the long-term effects of dry- and wet-weather discharges because of their relative immobility. Grab samples can be taken to indicate historical accumulation patterns. Sampling sites could be distributed spatially at points of impact, upstream (or downstream) reference sites, areas of future expected changes, or other areas of particular interest. Selection of specific locations is subject to accessibility, hydraulic conditions, or other aforementioned criteria.

Biological Sampling. Benthic or bottom-dwelling organisms are affected both by contaminants in the water column and through contact or ingestion of contaminated sediments. The type, abundance, and diversity of these benthic organisms thus can be used to investigate the presence, nature, and extent of pollution problems. Comparisons of areas upstream and downstream of a suspected pollution source require that sampling locations have similar bottom types, because physical characteristics affect both the chemical composition as well as the habitat requirements of organisms.

Regional data or indices might be available for comparisons with local site conditions to determine whether an ecosystem is stressed. An example of the use of ecoregional data and biotic indices is presented at the end of Chapter 6. Such data provide a reference for comparison and might suggest appropriate habitat types or areas to sample in determining the level of pollution impact.

Frequency of Data Collection

The frequency of data collection significantly affects program cost and should be determined judiciously based on the need for sufficient data to develop statistically valid conclusions. Information on determining valid sampling frequencies is available (U.S. EPA, 1983b). Wet-weather runoff sampling is often limited to several events and selected representative subwatersheds because of the large resource requirements and high costs. Data must then be extrapolated to other similar subwatershed areas and used to calculate storm-related pollutant loading for an entire watershed. Depending on the area's size and number of watersheds, and on financial resources, adequate characterization of storm water runoff from different watersheds might require a phased approach. Areas of most concern are sampled first, with subsequent sampling to characterize other areas based on a watershed priority sequence. Given the cost of such sampling, collection of sediment and ecosystem data that integrate the long-term effects of urban runoff may be fruitful since they are relatively stable and do not need to be characterized as frequently.

For water resources monitoring, the sampling schedule should account for seasonal climatic changes as well as seasonal land use activities, such as fertilizer application in spring, or road deicing activities in winter, that might influence water quality. In temperate areas with pronounced seasonal changes, monitoring stations are usually sampled at least seasonally. This is especially important for sampling of aquatic biota. For characterization of urban runoff sources, several sampling events are ordinarily scheduled during worst-case conditions: in spring during snowmelt and heavy rains when runoff and contaminant transport is significant, or during summer conditions when streamflow is low, receiving-water dilution is minimal, and contaminant concentrations are potentially highest. In addition, the relatively high temperatures in summer can affect aquatic biota, as well as reduce the capacity of water to maintain high DO levels and stimulate bacterial metabolism, placing additional demand on oxygen supplies in the water column. This scenario represents worst-case conditions in areas that experience organic and nutrient enrichment. In areas with fairly constant climate, less emphasis is placed on seasonality, with perhaps more attention placed on land use activities.

After the implementation of BMPs, additional data might be collected to assess their effectiveness. Data collection after BMP implementation is discussed in Chapter 9.

Planning the Data Collection Program

After the data collection program is designed, more detailed planning and preparation is necessary. This planning includes development of a data collection work plan, selection of analytical laboratories and methods, and organization of the necessary staff and equipment resources.

Quality Assurance/Quality Control

The sampling program should include a Quality Assurance Project Plan (QAPP) to ensure the collection of meaningful and cost-effective data. An EPA guidance manual, *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans* (U.S. EPA, 1983a) is designed to help EPA and its contractors prepare QAPPs. Another EPA document, entitled *Guidelines for Preparation of Combined Work/Quality Assurance Project Plans for Environmental Monitoring* (U.S. EPA, 1984), combines a work plan with revisions to the QAPP format and includes a generic plan. The elements of this plan, listed in Table 5-4, are discussed below.

Table 5-4. Typical Combined Work/Quality Assurance Project Plan (Adapted from U.S. EPA, 1984)

1. Title page
2. Table of contents
3. Project description
   A. Objective and scope statement
   B. Data usage
   C. Monitoring network design rationale
   D. Monitoring parameters and frequency of collection
   E. Parameter table
4. Project fiscal information (optional)
5. Schedule of tasks and products
6. Project organization and responsibilities
7. Data quality requirements and assessments
8. Sampling procedures
9. Sample custody procedure
10. Calibration procedures and preventive maintenance
11. Documentation, data reduction, and reporting
12. Data validation
13. Performance and system audits
14. Corrective action
15. Reports

Title pages of QAPPs should include places for signatures of personnel with approval authority. Municipal programs may use this format for approval by the project manager or other responsible individuals. Additional information could include project name, requestor, date of request, and date of initiation (U.S. EPA, 1984).

The project description is intended to define the goals or objectives of the project and how the plan will satisfy those objectives. A subsection on data usage identifies the recipients of the data and establishes their requirements, thus ensuring that the plan will produce usable and effective data. A description of the monitoring network includes sampling site locations and the rationale for their selection. A subsection on monitoring parameters and frequency includes a list of the types of samples to be taken at each site and how they will be collected. These parameters are then listed in a table that includes the number of samples, sample matrix (e.g., water and sediment), analytical method to be used by the laboratory, sample preservation method, and sample holding time.

Fiscal information as to projected costs for sampling labor, equipment and supplies, analyses, and requirements for outside support may be included to support a budgetary analysis of the project. This information will ensure that available resources are adequate and properly allocated to maximize the project's effectiveness.

One section details the schedule for the project from the conceptual stage through the completion of the final report. This schedule aids in assessing the availability of resources and arranging for outside support. A following section details the project organization and identifies individuals responsible for the various aspects of the project, as well as other outside support. An organizational chart is frequently included.

Data quality requirements (frequently subject to regulatory and budgetary constraints) are determined through input from data users, samplers, and analytical personnel and focus on the data needs of the program. Objectives should be established prior to development of a work plan. The objectives include the required level of detection, analytical precision (repeatability of a set of measurements), and accuracy (agreement of result with true value) obtained from analytical results. Accuracy and precision are identified through the use of performance standards, analytical spikes and surrogates, method blanks, and replicate samples. Many of these approaches are parameter-specific, as are the acceptance criteria. These considerations should be discussed with the analytical support personnel for the parameters to be sampled. Acceptable criteria for various analytical methods are listed in the federal regulations (40 CFR 136, Tables A and B).

Other quality assurance considerations include representativeness (whether the collection samples represent conditions and matrices that support the program's objectives), comparability (whether the analysis results can be compared with other data bases), and completeness (whether the valid data obtained satisfies the program's objectives). These considerations are basic to the development of the sampling plan, and are used to assess the success of sampling efforts.

Detailed sections follow in the combined Work Plan/QAPP that describe sampling procedures and documentation of sample custody, equipment calibration, and data handling. Sampling procedures can be generally described, citing method-specific references such as *Standard Methods* (APHA, 1992) for detailed sampling considerations. Sample documentation typically employs a chain-of-custody form that describes and follows the transfer of each sample bottle. Every time responsibility for the samples is transferred, signatures are used and copies retained to document the transaction. Equipment logbooks are maintained to document maintenance, calibration, and repairs. Data documentation includes provisions to meet the needs of legal or scientific challenges to the data, as well as quality control over data entry, transfers, and any calculations performed.

The remaining sections of the combined work/QAPP are used to document procedures to validate data, to record performance of laboratory personnel and equipment, to record steps for corrective action, and to note reporting requirements. Data validation consists of an objective review of the data base generated by the project against criteria established prior to sampling, including holding times, detection limits, and QA/QC results for accuracy and precision. Performance audits are done prior to making arrangements to ensure laboratory capabilities, as well as during the program to identify problems and institute corrective actions if required. Corrective action provisions define how to proceed in the event that QA/QC objectives are not met. Reporting requirements include interim progress reports to management personnel to document the status of the project, as well as a final report that presents the results and conclusions of the study, including a summary of QA/QC performance.

Analytical Laboratories

Before undertaking the data collection program, arrangements must be made to have the samples analyzed by a laboratory. If the laboratory analyses are not conducted inhouse, or if an appropriate laboratory is not already under contract to the municipality, a service contract can be developed with an outside laboratory that specifies the number of samples, the price per sample, the analytical methods to be used, and a QA/QC plan.

A laboratory should be selected based on a number of criteria, including price, analytical capability, past experience, reputation, and certification. In most instances, laboratories that are state certified for specific chemical analyses should be used. The laboratory should be familiar with the type of sampling program and the schedule. This familiarity facilitates development of a scope of services, which, in turn, helps ensure quality data and timely results. The laboratory should be asked to provide a list of past clients as references. The laboratory should have a strong QA/QC program and sufficient capacity to handle the volume and types of samples generated by a multifaceted sampling program. Because of the unpredictable nature of storms for wet-weather monitoring programs, the laboratory must be available to receive samples on short notice, including at night and on weekends, and to perform analyses within the required holding times.

Other important steps in selecting a laboratory include comparison of costs per analysis or per sample, and evaluation of savings through volume discounts for the large number of samples that might be generated, especially during wet-weather sampling. Turnaround time for data submittal and the form of deliverable offered are additional considerations. A turnaround time of 3 weeks is considered reasonable for typical analyses for nutrients, solids, and bacteria. Some laboratories can submit results in digital format so that it can be directly inputted to a database management system. Many laboratories can supply bottles and other equipment, such as coolers, for the preservation and transport of samples and courier service for sample pickup. Such details should be clearly communicated before finalizing the contract for analytical services.

Analytical Methods

Of the many analytical methods to determine the pollutant concentration in water and sediments, standard methods for water and wastewater, as published in the *Federal Register* and *Standard Methods for the Analysis of Water and Wastewater* (APHA, 1992), usually achieve the desired objectives of the program. The laboratory can modify these methods based on the type of sample and the level of detection required. For example, storm water pollutant concentrations might be significantly greater than those diluted by receiving water; therefore, methods for analysis of pollutants in storm water might require less sensitivity than methods used to analyze drinking water. Other particulars of the type of sample (e.g., salt water or fresh water) might dictate the analytical method or sample preparation requirements for certain parameters, such as metals. The desired detection limit, or the lowest concentration that can be reliably detected in a sample, should be determined in advance. As mentioned, the *Standard Methods* text provides complete documentation of applicable methods for physical, chemical, and biological analysis. Specific guidance on the analysis of pollutants as required under the NPDES program is provided in the federal regulations (40 CFR 136.3, Tables IA through IE). These guidelines establish standard analytical methods, detection limits for all parameters, and the volume of sample required.

Organization of Resources

Resources required for the data collection include personnel and equipment. Personnel should be familiar with their roles and responsibilities as defined in the work plan and the team leader and each crew chief should visit the sites in advance. A health and safety plan should be prepared which identifies the necessary emergency procedures and safety equipment. Special training might be required, particularly if potentially hazardous chemicals are involved, or if confined space entry (into manholes, for example) is required. The Occupational Safety and Health Administration (OSHA) sets forth requirements for worker safety and protection while conducting such work.

Equipment also must be prepared in advance: An inventory of all the necessary equipment should be taken; all equipment to be used in the effort, such as boats, motors, automobiles, and batteries, should be checked; field monitoring equipment should be properly calibrated and tested.

Specific sampling logistics vary with the objectives of the program. For example, dry-weather sampling can often be conducted during daytime work hours in an unhurried manner, though sampling must be scheduled appropriately to coincide with diurnal, tidal, or other variations of importance to the program. By contrast, investigations of wet-weather impacts in a large sampling program could require several teams who can mobilize with only a few hours notice to conduct concurrent sampling at several locations. Receiving-water sampling could frequently include sampling for several days after the rainfall event to assess the residual effects of urban runoff pollutant loads.

Wet-weather sampling requires thorough planning and rapid mobilization to implement an effective sampling program. It also requires specific and accurate weather information. Local offices of the American Meteorological Society can provide a list of Certified Consulting Meteorologists who provide forecasting services specific to the needs of a sampling program. Radar contact can also be established for real-time observation of conditions. If a sampling criterion requires a minimum of 0.5 inches of rainfall because of resulting CSO discharges, additional insight into the timeframe of heaviest rainfall can be developed. While incurring an additional cost, these efforts could result in significant savings in costs associated with false starts and unnecessary laboratory charges.

The rainfall, darkness, and cold temperatures that often occur when conducting wet-weather field investigations render even small tasks difficult. Contingency planning and extensive preparation, however, minimizes mishaps and helps ensure safety. Prior to field sampling, all equipment should be organized, sample containers should be assembled, and the bottle labels filled out to the extent possible. Labeling is best done by writing directly onto the sample bottle with permanent markers. If stick-on labels are used, they should be waterproof and secured with clear tape. The label should indicate the sampling event (e.g., storm #1), station location or number, sample number, preservative used, and the parameters for which the sample is to be analyzed. The sample number is the most important identifier, and should be unique to each sample.

Conducting the Data Collection Program

A comprehensive data collection program with both source and receiving-water sampling can consist of dry- and wet-weather monitoring including water quality, sediment, and sampling of aquatic biota; flow monitoring; and rainfall monitoring. This section describes the common types of sampling used for urban runoff programs.

Water Sampling

Sampling as part of an urban runoff control program primarily involves collecting water samples, preserving them, and transporting them to a laboratory with as little change in character as possible. Certain parameters, including temperature, pH, and dissolved oxygen, are measured in the field (in situ) because values for these parameters can change substantially if measured from a sample of water that has been disturbed or held for a long time. These parameters are usually measured using battery-powered instruments with probes placed directly in the water; results are taken from a digital or analog readout and values are recorded in a field notebook.

For samples undergoing laboratory analysis, the volume of sample required by the laboratory should be considered. In addition, accurate measurement of many pollutants requires specific sample container types, container cleaning or other preparations, or specialized collection techniques. After collection, sample bottles should be placed in a cooler with bagged ice or reusable ice packs. Glass bottles should be separated by plastic bottles or packing material to prevent breakage during transport to the laboratory. Documentation of analytical methods, volume requirements, containers, preservatives, and maximum holding times is provided in the federal regulations (40 CFR 136.3, Table II), and detailed in such documents as *Standard Methods* (APHA, 1992).

Sampling for water chemistry can involve a number of approaches. The following terminology is referred to:

- *Grab sample*: Samples collected manually and analyzed individually.
- *Discrete sample*: Individual samples collected at specific times collected manually or automatically, often combined to create a composite sample.
- *Composite sample*: Samples combined based on a predetermined formula involving flow weighting, time interval, or other approach.
- *Automatic sample*: Samples collected using an automated sampling device.

Grab samples usually are analyzed individually to characterize conditions at the time of sampling. Many parameters, such as nutrients and metals, may be composited, but attention must be paid to preservative requirements. If sampling protocols permit and program objectives are satisfied, composites represent a cost-effective approach to quantifying pollutant loads by reducing the number of samples submitted for analysis. Other analyses, including bacteria, oil and grease, and volatile organic compounds (VOCs), cannot be composited and individual grab samples must be used.

Urban Runoff Sampling. During wet-weather sampling, water samples may be taken manually or by automatic samplers installed at the sampling site before the rainfall. Automatic samplers may be installed in manholes to sample storm water or combined sewer systems, or placed in enclosures next to creeks or culverts to sample runoff. They can be controlled by flow-measurement devices, by stage height monitors, or by timers, permitting comprehensive sampling of flow quality with minimal labor.

Automatic samplers may be used to collect discrete samples into individual bottles at predetermined intervals of time or flow rate, or to collect discrete samples and automatically composite them directly into one container using a pre-set formula. The option of using discrete or composite sampling is dictated by the objectives of the program and the parameters to be measured. Automatic sampler units can be either purchased, leased, or furnished as part of a contractor's service.

Wet-weather sampling must be performed by two-person teams to reduce the time required to sample each station and for safety reasons. Typically, one team can sample at least two stations if the stations are in close proximity. Because of the typical rapidity of rainfall-runoff responses, however, the area that can be covered is limited. One team member typically fills sample bottles while the other performs flow measurements and records relevant information in a field book, including station number, time, date, weather conditions (e.g., rain intensity, wind intensity and direction), and other observations, such as oil sheens, odors, or the presence of foam.

Proper characterization of urban runoff, either by manual or automated sampling, requires periodic sampling of the flow stream. This sampling should begin with the pre-storm condition, if possible, followed by the "first flush," when rainfall first washes accumulated contaminants from the surface of the watershed and pollutant concentrations are highest, and should continue through the duration of the rainfall event. Storm water pollutant loadings can then be characterized using discrete samples taken over the course of the storm, or by creating a flow-weighted composite based on the relative flow rate (or other appropriate parameter) associated with each sample taken. Flow measurement methods and an example of flow-weight composited data are discussed later in this chapter.

Receiving-Water Sampling. Sampling of receiving waters to provide background water quality data and to assess impacts from urban runoff pollutants could range from manual collection of bacterial samples from a stream to a full-scale oceanographic investigation of a harbor using a sizable vessel and considerable logistics. The important considerations are to sample the parameters of concern using proper sampling techniques (i.e., USDI, 1984; U.S. EPA, 1982; Plumb, 1981; APHA, 1992). Further references are cited in Appendix A.

Other considerations for sampling are specific both to the program objectives as well as to the sampling station location characteristics. For example, while surface sampling of shallow, well-mixed systems, such as streams, is adequate to assess water quality, additional samples of a cross section of wider rivers might be necessary to meet study objectives. Deeper systems subject to stratification from salinity or thermal conditions should include some form of vertical sampling, which could entail samples taken separately from several depths analyzed individually or composited to yield one sample. Such a case requires the use of sampling devices such as Kemmerer or Nansen bottles which can be lowered to the desired depth and tripped by a weight dropped from the surface to produce a discrete sample. Instruments for in situ sampling of pH, temperature, dissolved oxygen, or salinity also can be lowered to specified depths, with measurements transmitted to the surface by cable and recorded.

Sediment Sampling

Analysis of sediment chemistry data can indicate the historic water quality. Water column contaminants are concentrated in the sediments through mechanisms such as sedimentation, adsorption, and organic complexation.

Chemical and physical sampling involve the collection of representative samples of sediments, with methodologies dictated by the physical character of the system (e.g., depth, substrate type) and the type of analysis being conducted. In most cases, shallow-water sediments can simply be collected by hand using a stainless steel spoon, spade, or push-corer. Deeper systems, such as lakes and estuaries, may require the use of vessel-deployed grab samplers or corers. These types of samplers are described in existing guidance (U.S. EPA, 1990b) and *Standard Methods* (APHA, 1992). The grab or core is then subsampled in a manner consistent with the requirements of individual analyses.

In most cases, the sample is placed in a plastic bag or other container and transported to the laboratory in iced coolers. While this approach is appropriate for physical analysis and certain chemical analyses (e.g., carbon and metals), some analyses require special containers or preservatives. Parameter-specific requirements, as well as the required volume of sample for various analyses, are listed in methodological references (Plumb, 1981).

Biological Sampling

Biological sampling of benthic organisms depends on the water body and the type of organism being sampled. Estuaries, lakes, and large rivers typically are sampled by a grab sampler of specified area and penetration depth. Samples then are screened through a sieve, and the organisms retained on the sieve are transferred to a sample bottle and preserved. Streams and small rivers can be sampled using a variety of samplers, again depending on depth, flow rate, substrate, and community type. In addition, artificial substrates can be employed which minimize the problem of locating similar substrates in all sampling areas. Comprehensive guidance exists for collecting biological samples using these devices (U.S. EPA, 1990b).

Flow Measurement

Flow measurement of streams, rivers, and runoff in and from drainage systems is needed to calculate pollutant loads and to design BMPs. Flow rate measurements can be made using a variety of methods: The velocity-area method (ISO, 1979; USGS, 1982; USDI, 1984) can be used to estimate flow rates in streams, rivers and other open channels. In this method, the channel's cross-sectional area, as computed from channel width and depth measurements, is multiplied by flow velocity readings. Flow measurements should be taken with a portable velocity meter at 20 and 80 percent of the depth, or at 60 percent of the depth at regular intervals across the channel (Chow, 1959).

Flow measurements can also be made by automatic devices installed in channels, storm drains, or CSO structures (U.S. EPA, 1975). These devices utilize a variety of sensor types, including pressure/depth sensors and acoustic measurements of stage height or Doppler effects from flow velocity. Data are stored in a computer chip that can be accessed and downloaded by portable computer. Data are processed based on the appropriate pipe, flume, or weir hydraulic equations. Field calibration of data using such equations is critical because these types of data might be influenced by surcharging, backwater, tidal flows, and other complex hydraulic conditions typical of urban runoff flows. Such devices can be purchased, leased, or furnished as a contract service.

Accurate flow measurements can also be made at hydraulic control structures, such as weirs or flumes, where the rate of flow is a function of the water elevation. If project finances allow, portable weirs or flumes can be purchased or leased and installed in storm drains, sewers, or channels for taking flow measurements during storms (USDI, 1984). Flow and elevation can also be taken at concrete weirs or staff gages owned by the U.S. Geological Survey. For weirs, flumes, and other standard structures, records of stage height taken at the time of flow measurements can be used to develop a stage discharge rating that can be used as a quick reference for future readings (USGS, 1982). Figure 5-1 provides an example of a stage discharge rating curve for a river. In general, flow measurement stations should have uniform channel

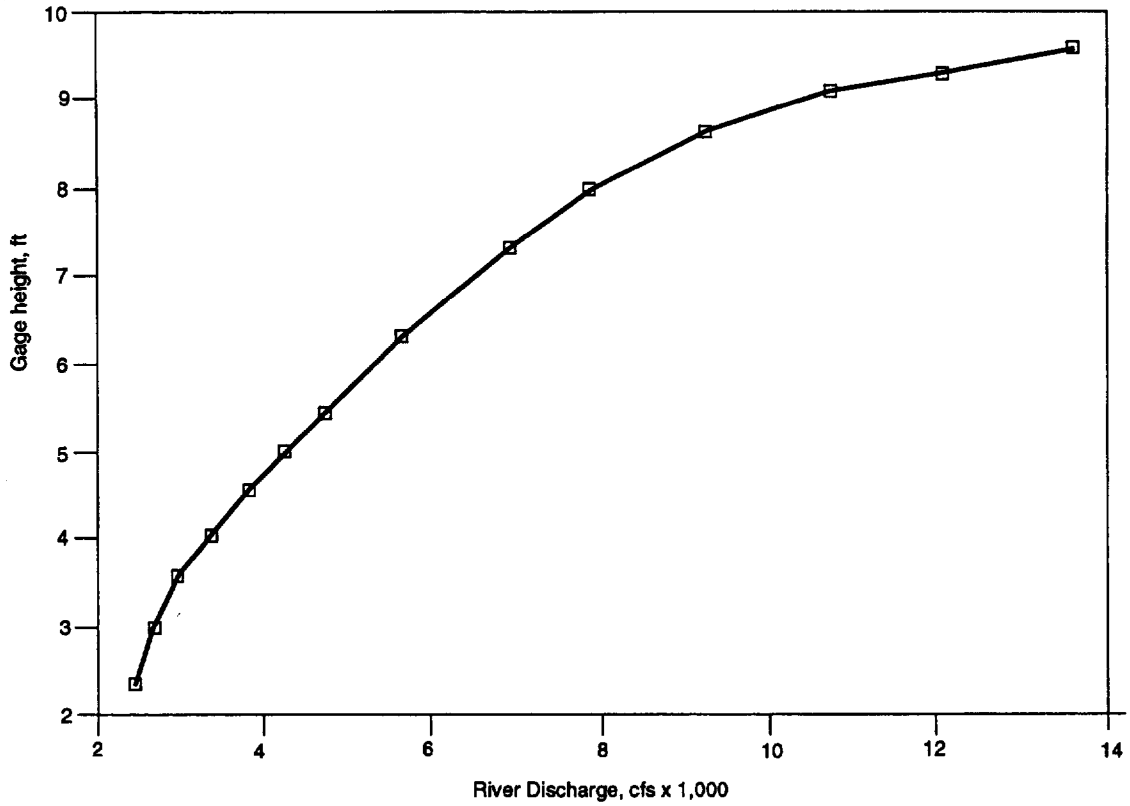

Figure 5-1. Example stage discharge rating curve.

conditions for six channel widths upstream to eliminate any turbulence, to avoid tidal or backwater effects that would interfere with flow patterns, and to allow adequate mixing of upstream flow from tributaries (U.S. EPA, 1991a).

Rainfall Monitoring

Rainfall data are necessary to estimate the amount of runoff generated during an event, which is then used to predict runoff volumes and predict responses to events of different magnitudes. Existing long-term rainfall data might be available near the area from the network of gages operated by the National Oceanic and Atmospheric Administration. Because of the variability in the possible distribution of rainfall over a relatively small area, a network of rain gages might be necessary to support these objectives. The number of gages required depends on the size of the program, the area, topography, season, and typical characteristics of local rainfall events. Available resources for rainfall monitoring should be concentrated in critical areas under investigation. Guidance in determining rain-gage network density is available (U.S. EPA, 1976).

Rainfall gages consist of two types: nonrecording gages, which measure total rainfall, and continuous-recording gages, which measure intensity over the duration of the event. The latter type is more desirable for most urban runoff programs because an understanding of the time-varying watershed hydrologic response to rainfall variations within a storm event can be gained from such data. One type of continuous-recording gage is the tipping-bucket gage, which records the number of times a calibrated bucket is filled and subsequently tipped and emptied into a larger reservoir. Other continuous gages utilize a weighing mechanism to record rainfall amounts.

Rainfall gages should be located in open spaces away from the immediate shielding effects of trees or buildings. Ground installations are preferable (if vandalism is not a significant problem). Roof installations are another option, and public buildings, such as police, fire, or public works buildings, are often used. The installation should be in an unobstructed area of the ground or roof.

Cost Estimating for Data Collection Programs

State and federal funding for urban runoff control programs typically is limited; the burden of financing these efforts therefore falls on a municipality. As the data collection program is being developed, the cost of the program should be considered. A cost estimate should be prepared for the entire program, including in-house and outside services from consultants and analytical laboratories. If funding levels are not adequate to complete the sampling program, the program should be redefined by scaling down the scope of sampling (i.e., number of sampling stations and/or sampling frequency) or by using a phased approach and completing critical components first and other components as funding becomes available.

Data collection for an entire municipal area with multiple watersheds can be very costly, and might use up limited resources that could be applied to actual implementation of controls. Sampling limited but representative areas and extrapolating this information to other unmonitored areas might be more cost effective. Although such extrapolation is risky and should be done with caution, it might be necessary given program budget constraints. As discussed earlier in this chapter, a focus on ecosystem components which integrate long-term effects (e.g., aquatic biota, habitats, sediments) could yield valuable data at a more reasonable cost.

Some large municipalities might have the in-house resources to undertake a comprehensive urban runoff sampling program, including staffing, equipment, analytical capabilities, and the technical expertise required for data interpretation. For smaller municipalities, or those without extensive technical resources, the sampling program should take full advantage of technical assistance offered by state and federal agencies; contracted laboratories can be used for necessary analytical services.

The major cost elements of the data collection program include the following:

- Personnel costs, in-house and/or contracted, for the field effort.
- Laboratory analysis costs.
- Monitoring equipment costs.
- Miscellaneous equipment costs.
- Data analysis and reporting costs.

Each item should be estimated in as much detail as possible. Labor costs should include direct salaries plus overhead and profit costs for contracted work. Laboratory analysis costs are often provided on a unit cost-per-sample basis. Other equipment costs are based on rental or purchase prices. Data analysis and reporting will include technical labor plus clerical time, and perhaps office supplies and computer costs.

Data collection cost estimates are highly site and circumstance specific and range from several thousand to millions of dollars. As stated earlier, it tends to be a major component, often the largest single element, of the planning program. Therefore, designing the program to respond to appropriate objectives requires the utmost care.

Data Management and Analysis

Since data collection programs generate large amounts of information, management and analysis of the data are critical to a successful program. Even small-scale programs, such as those involving only a few storm water and receiving-water monitoring stations, can generate hundreds of pages and thousands of data records. Monitoring these stations over time adds significantly to the amount of data. Thus, a key requirement is the ability to store large amounts of environmental data in an accessible format, allowing the data to be manipulated for a variety of analyses.

Methods to manage and analyze data are presented in this section: spreadsheets, graphical presentations, database management systems, and statistical analysis. Examples of how these methods can be used to assess a sample data set are given. These methods can also be used to analyze existing data (Chapter 4). More detailed methods of assessment, such as watershed and receiving water modeling, are presented in Chapter 6.

Spreadsheets

Selection of the most efficient method for data management depends on the scale of the program. For small-scale urban runoff programs, a computer spreadsheet program can be used. Entry of data into a computer format permits easy manipulations, such as calculations and graphics. Whether a computer is available or not, data records should be organized into tables by sampling station. An example of such a table is shown in Table 5-5. Parameters recorded during a survey can be entered into columns of data, with each row in the table representing a sampling event. For storm event monitoring, each row can consist of consecutive samples collected during the event. The sample ID number, which should be unique to every sample, can be used as the principal sample identifier should data be exported to a GIS or other computer applications.

Most spreadsheet programs can also be used to create graphs of the data and to perform calculations. Once a format has been developed for data entry, calculations such as contaminant load or percent oxygen saturation can be automatically performed as the data are entered. An example of a format used to calculate nitrogen loads (ammonia and total nitrogen) is presented in Table 5-6. Spreadsheet files can be combined as required to present selected information, perform investigations, or export data to other computer applications such as GIS (see Chapter 4) or urban runoff and receiving water models (see Chapter 6).

Table 5-5. Example Spreadsheet Format for Water Resource Data

Sample	Date: Month	Day	Hour	River Stage, ft	Temp., °C	pH	DO, mg/L	Conductivity, mS/cm	Fecal Coliforms, MPN/100 mL	TSS, mg/L	BOD_5, mg/L	Total Nitrogen, mg/L	Total Phosphorus, mg/L
6	7	18	2030	2.31	24.8	7.7	7.65	0.23	<20	<1	5.6	0.899	0.061
10	7	19	0920	2.34	21.2	7.7	8.14	0.23	20	1.2	4.4	0.897	0.033
23	7	20	1020	2.15	22.5	7.8	8.35	0.22	<20	<1	<4	0.853	0.030
38	9	4	1710	2.61	23.0	8.3	8.80	0.20	<20	1.8	<2	1.081	0.142
42	9	5	0656	2.59	21.8	7.8	8.20	0.20	<20	2.9	<2	*	0.113
47	9	5	1750	2.55	23.0	8.3	8.78	0.20	20	2.8	<2	0.775	0.122
51	9	6	0003	2.63	22.7	7.6	7.75	0.19	80	3.1	<2	0.832	0.153
61	10	17	1730	2.48	18.5	7.6	8.90	0.19	560	4.5	<2	0.914	0.059
65	10	18	0525	2.72	18.5	7.6	8.50	0.19	300	6.8	<2	0.905	0.049
69	10	18	1117	2.75	18.7	7.1	8.90	0.19	140	5.9	3.2	0.903	0.065
75	10	18	1714	2.57	18.5	7.3	8.20	0.19	140	5.8	<2	*	0.048

* Sample not analyzed.

Table 5-6. Spreadsheet to Calculate Nitrogen Loads

Sample	Date: Month	Day	Hour	Freshwater flows, ft^3/s	Total Nitrogen, mg/L	TN Load, kg/d	Ammonium, mg/L	Ammonia (NH_4) Load, kg/d
6	7	18	2030	19.4	0.899	42.6	0.015	0.7
10	7	19	0920	20.5	0.897	44.9	0.013	0.7
23	7	20	1020	12.1	0.853	25.3	0.011	0.3
38	9	4	1710	35.9	1.081	94.9	0.017	1.5
42	9	5	0656	35.3	*	*	0.021	1.8
47	9	5	1750	33.1	0.775	62.7	0.004	0.3
51	9	6	0003	37.1	0.832	75.4	0.010	0.9
61	10	17	1730	28.0	0.914	62.5	0.093	6.4
65	10	18	0525	45.3	0.905	100.4	0.098	10.9
69	10	18	1117	49.2	0.903	108.6	0.204	24.6
75	10	18	1714	33.9	*	*	0.180	14.9

* Sample not analyzed.

Graphical Presentation

Graphic displays enhance data analysis and interpretation. Plots translate large sets of data into easy summaries. Another effective use of graphics is the spatial presentation of environmental data, such as on a hand-drawn or GIS-simulated map (see Chapter 4). Whether using the capabilities of spreadsheet programs or a GIS, or plotting data on graph paper by hand, a trend analysis for a particular parameter, location, or sampling program can be developed from a data set. Figure 5-2 illustrates a simple line plot of routine monitoring data for fecal coliform data taken monthly over a 1-year period. Figure 5-3 depicts fecal coliform data at a receiving water station influenced by a storm sewer during a 24-hour period after a rainfall event. In both figures, the state water quality criterion for fecal coliform bacteria is indicated and quick, visual comparisons of the collected data to the criterion can be made.

Database Management Systems

A computer-based database management system is used to store collected data and to permit easy retrieval for subsequent calculations and analyses. Database design involves a knowledge of the database management system being used and the requirements of database manipulation and interaction with other software. The data base can be coordinated with, or be part of, a GIS. In addition, the data base can be used

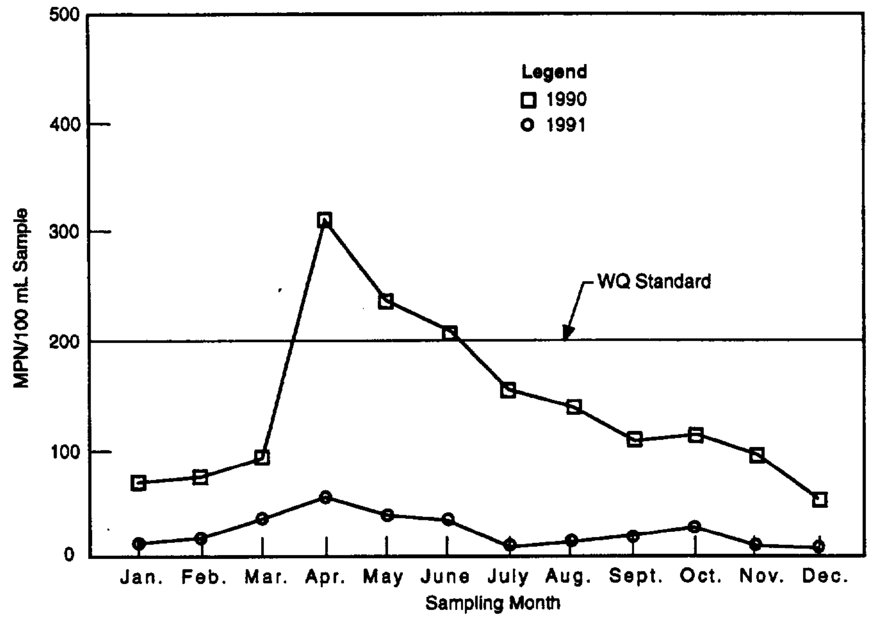

Figure 5-2. Fecal coliform densities at Station A.

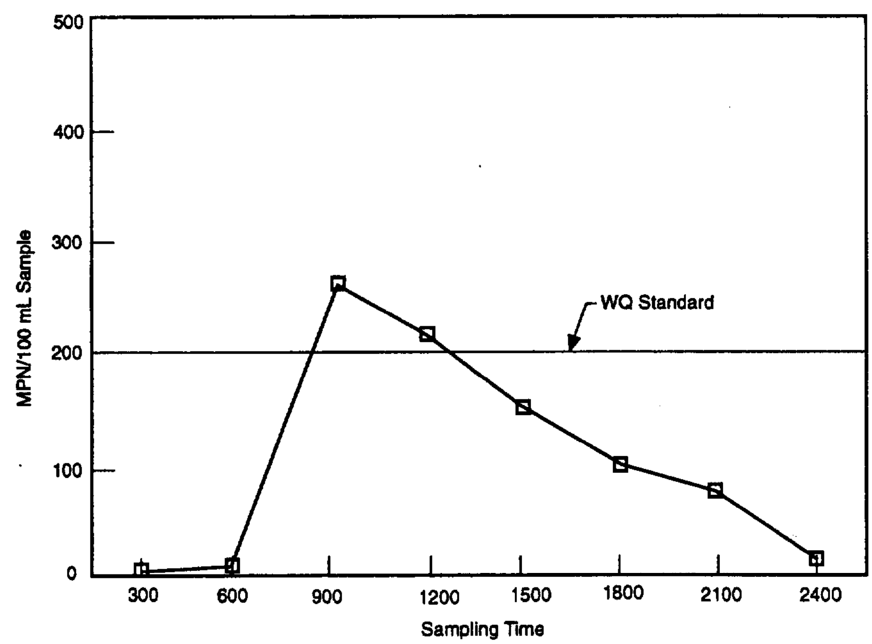

Figure 5-3. Fecal coliform densities at Station E.

as input to urban runoff and receiving water models (see Chapter 6).

Types of sampling information that could be included in the data base include: sample identification number, type of sample (e.g., rain water), sampling date and location, analyses performed, results of chemical analyses, detection limits, name of laboratory, name(s) of personnel collecting samples, climatic information, and comments regarding the sampling or analyses. Database queries can request information that focuses on specific attributes. For example, the user may select all dissolved oxygen concentration data for a specific sampling location, or the user may select all dissolved oxygen data below a certain concentration from all stations to determine compliance with water quality standards. More detailed information concerning data bases is available in the user manuals of database management software and in the literature (Date, 1985; Korth and Silberschatz, 1986; Maier, 1983; Hursch et al., 1988).

Statistical Analysis

Statistical analyses can be conducted to establish trends and comparisons of the collected data such as pollutant concentrations and loadings associated with specific sampling locations or storm events. Statistical interpretation provides information that can be used to determine characteristics of the data set such as whether a concentration is high or low compared to the others, the amount of variation among the data, and the way in which the data are distributed. Statistical methods can also be applied to results of biological sampling of receiving waters and sediments. These methods can be used to identify shifts in species abundance and community structure which might result from exposure to pollutants.

Commonly used statistical calculations are shown in Table 5-7 and discussed in the following sections. Table 5-8 presents results for TSS samples from a CSO monitoring program to illustrate the use of these statistical calculations. This CSO monitoring program included 10 sampling sites at combined sewer overflow locations for two storm events (November 3 and 22). Table 5-8 also includes estimates for flow-weighted composites for comparison with the statistical values. Flow-weighted composite data are frequently generated when discrete sampling is performed within a storm event, as discussed earlier in this chapter. Figure 5-4 depicts the results from one sampling site plotted against the overflow discharge rate and rainfall hyetograph to illustrate the relationship between flow and discrete samples upon which the flow-weighted composite value is based.

Measures of Location

Statistical measures of location describe the relationship between various values in a data set, including the mean, median, and frequency distribution. These statistical values can be used to determine average values and the most likely value of future sampling results.

Mean. The arithmetic mean, or average, is calculated by summing the observations and then dividing the sum by the number of observations (see Table 5-7). A mean value can be used as a benchmark for comparison to individual data points or to regulatory standards. In some cases, state water quality standards employ the use of the geometric mean (e.g., bacterial standards). In this case, the individual observations are multiplied, and the *n*th root (*n* = number of observations) is calculated. Arithmetic means for each station and an overall mean for the entire storm are provided in Table 5-8.

Median. To obtain the median or central point value of a data set, the observations must first be put into numerical order and then divided into two equal parts. If the number of observations is odd, the median is the single middle value. If the number is even, the median is obtained by calculating the mean of the two middle values of the ordered list. Median values for each station and an overall median for the entire storm are provided in Table 5-8.

Frequency Distribution. Frequency distributions are developed by dividing the range of data points or observations into evenly spaced intervals and then counting the number of observations that fall within each interval. A relative frequency distribution is obtained by dividing each number in the frequency column by the number of observations in the data set (Devore, 1987). A graphical representation of a frequency distribution can be obtained by plotting a histogram, or bar chart, of the intervals along the x-axis and the number of observations along the y-axis.

Many types of environmental data are either normally or lognormally distributed. Normally distributed data are symmetric about the mean (which in the case of normal distribution is equivalent to the median), with a histogram that resembles the shape of a bell curve. Lognormally distributed data could exhibit a curve which is skewed to the right or left, or could be flatter or more peaked than a normal curve. Storm water and CSO data are often lognormally distributed.

Many statistical tests (parametric statistics) to determine if mean values from two sets of data are significantly different require that data be normally

Table 5-7. Commonly Used Statistical Calculations

Statistical Parameter	Formula	Variable Definitions
Arithmetic mean	$\bar{x} = (x_1 + x_2 + ... + x_n)/n$	x_n = value of the n^{th} data point
Geometric mean	$\bar{x} = {}^{n}\sqrt{(x_1 \times x_2 \times \ldots \times x_n)}$	n = number of observations in a data set
Variance	$s^2 = [\Sigma(x_i - \bar{x})^2]/(n - 1)$	x_i, y_i = variables that are being correlated
	$s^2 = [\Sigma x_i 2 - (\Sigma x_i)^2/n]/(n - 1)$	
Correlation coefficient	$r = [\Sigma(x_i - \bar{x})(y_i - \bar{y})]/[(\Sigma(x_i - \bar{x})^2)^{1/2}(\Sigma(y_i - \bar{y})^2)^{1/2}]$	
	$= [n\Sigma(x_i)(y_i) - (\Sigma x_i)(\Sigma y_i)]/[((n\Sigma x_i 2) - (\Sigma x_i)^2)^{1/2}((n\Sigma y_i 2) - (\Sigma y_i)^2)^{1/2}$	

Table 5-8. CSO Sampling Results for Total Suspended Solids

Site	Date	Time	TSS, mg/L	Date	Time	TSS, mg/L
003	11/3	0525	35	11/22	1530	27
	11/3	0545	31	11/22	1545	33
	11/3	0615	38	11/22	2150	48
	11/3	0632	48	11/23	0215	16
	11/3	0632	46	11/23	0315	49
	11/3	0715	31	11/23	0535	22
	11/3	0815	42			
Mean value			37			32.5
Median value			38.5			30
Flow-weighted value			37			27
009	11/3	0705	160	11/23	0000	100
	11/3	0805	110	11/23	0015	110
	11/3	0905	63	11/23	0015	160
				11/23	0210	49
				11/23	0310	44
				11/23	0410	77
				11/23	0810	66
Mean value			111			78.5
Median value			110			71.5
Flow-weighted value			109			59
SMF	11/3	0745	400	11/23	0115	80
	11/3	0815	120	11/23	0130	140
	11/3	0845	73	11/23	0300	180
	11/3	0945	58	11/23	0300	190
	11/3	1045	29	11/23	0400	76
	11/3	1215	20	11/23	0510	30
	11/3	1215	18	11/23	0510	24
	11/3	1345	25	11/23	0800	31
Mean value			103			90
Median value			58			78
Flow-weighted value			105			45
023	11/3	1100	150	11/22	1820	38
	11/3	1115	91	11/22	1920	71
	11/3	1145	110	11/22	2020	33
	11/3	1215	55	11/22	2120	11
	11/3	1245	44	11/22	2120	12
	11/3	1315	46	11/22	2220	15
	11/3	1415	14	11/23	0020	13
	11/3	1515	26	11/23	0220	58
	11/3	1515	28	11/23	0520	160
Mean value			67			50
Median value			50.5			52
Flow-weighted value			58			83
080	11/3		No data	11/22	1605	110
				11/22	1620	140
				11/22	1650	49
				11/23	0105	45
				11/23	0205	74
				11/23	0405	21
				11/23	0605	30
				11/23	0905	33
Mean value						63
Median value						47
Flow-weighted value						42
012	11/3	0650	110	11/23	0130	68
	11/3	0705	63	11/23	0145	200
	11/3	0735	51	11/23	0215	170
	11/3	0835	35	11/23	0315	170
	11/3	0935	95	11/23	0415	60
				11/23	0615	21
				11/23	0615	22
				11/23	0805	23
Mean value			71			102
Median value			63			68
Flow-weighted value			59			82
003	11/3	0725	160	11/23	0015	44
	11/3	0740	39	11/23	0030	32
	11/3	0810	17	11/23	0200	22
	11/3	0910	47	11/23	0300	190
	11/3	0910	130			
	11/3	1010	230			
	11/3	1210	160			
Mean value			116			
Median value			124.5			
Flow-weighted value			160			
070	11/3	1025	42	11/23	0300	360
	11/3	1255	13	11/23	0330	110
	11/3	1325	18	11/23	0430	120
				11/23	0530	73
				11/23	0720	40
				11/23	0920	31
Mean value			24			122
Median value			18			91.5
Flow-weighted value			27			58
086	11/3	0840	27	11/22	1605	150
	11/3	0855	21	11/23	0025	140
	11/3	0925	17	11/23	0225	340
				11/23	0335	230
				11/23	0540	170
				11/23		67
Mean value			22			183
Median value			21			160
Flow-weighted value			23			266
088	11/3	0840	160	11/23	0205	780
	11/3	0940	91	11/23	0220	240
	11/3	1040	42	11/23	0250	150
	11/3	1140	25	11/23	0350	310
	11/3	1240	28	11/23	0450	230
	11/3	1240	24	11/23	0550	51
				11/23	0550	47
				11/23	0750	41
Mean value						257
Median value						230
Flow-weighted value						161
All Sites Combined						
Mean value			73			104
Median value			45			66

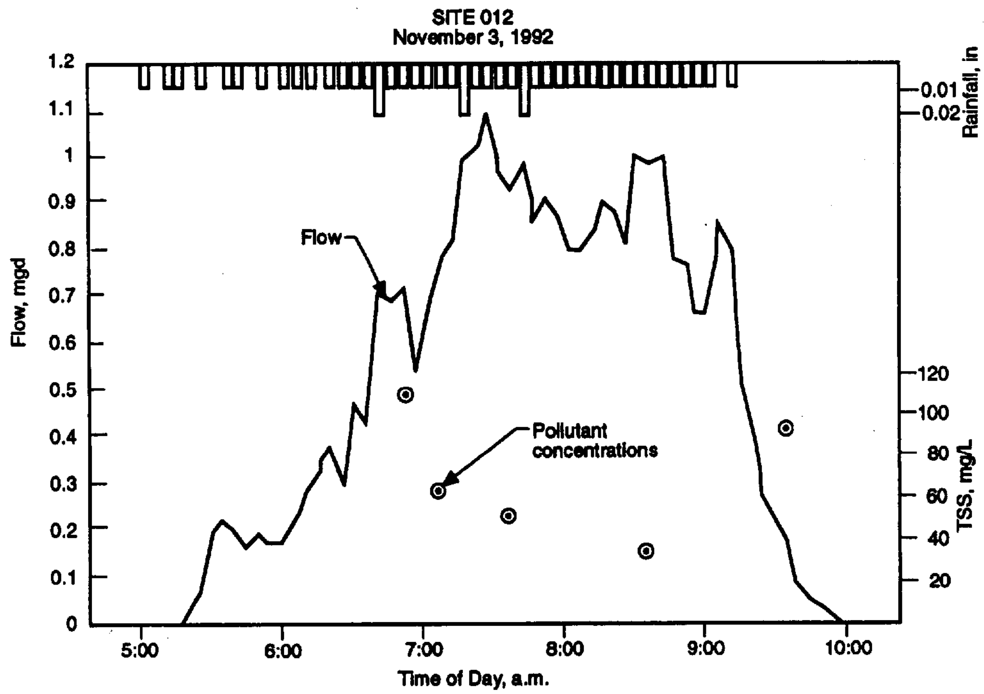

Figure 5-4. Relationship between flow and pollutant concentrations.

distributed. It is therefore necessary to determine whether a particular data set satisfies this assumption prior to employing parametric statistics. Tests for normality (e.g., Kolmogorov-Smirnov one-sample test, Sokal and Rohlf, 1969) are used to compare the data distribution with a normal one to determine if it is sufficiently similar.

Prior to comparisons with other data sets, such a test was performed on the pooled data for all measurements of TSS given in Table 5-8. A histogram of the pooled (untransformed) data was made first (Figure 5-5). A Kolmogorov-Smirnov one-sample test indicated the data were significantly different from a normal distribution (dotted line in histogram). A log transform was then applied (Figure 5-6), and the test for normality repeated. The transformed data were found to be normally distributed. The transformed data now met the assumptions for parametric statistical analysis. In the event that all attempts at data transformations prove to be ineffective, nonparametric statistics (e.g., Mann-Whitney U-test) can still be employed for comparison and assessment of data.

Many parametric and nonparametric tests can be found in statistical packages for personal computers. These statistical packages can easily access information from data bases, and greatly facilitate the evaluation of the data generated by a monitoring program.

Measures of Variability

Statistical measures of variability describe how closely the data set is grouped around the mean value. Statistical tests performed to determine significance between two means require as a basic assumption that the variance components of the two data sets are not significantly different. The two most frequently used measures of variability are variance and standard deviation.

Variance. Variance is a measurement of the dispersion of observations about the mean—the sum of the squares of the differences between each observation and the mean divided by the degrees of freedom in the data set (see Table 5-7). The term, degrees of freedom, equals the number of observations minus 1.

Standard Deviation. The standard deviation is the square root of the variance and is expressed in the same units as the mean. For a normal distribution, the data included in the range of 1 standard deviation from the mean represent 68.26 percent of the total data set. A range of 2 standard deviations from the mean represents 95.44 percent of the data set and a range of 3 standard deviations from the mean represents 99.74 percent of the data set. For example, the standard deviation in the pooled TSS data for all sites was 102 mg/L, indicating a high degree of variability when compared with an overall mean value of 91 mg/L.

Confidence Intervals

To determine whether an estimated parameter measurement such as a contaminant concentration measured in a laboratory or forecasted by a model represents the actual value of that parameter, the

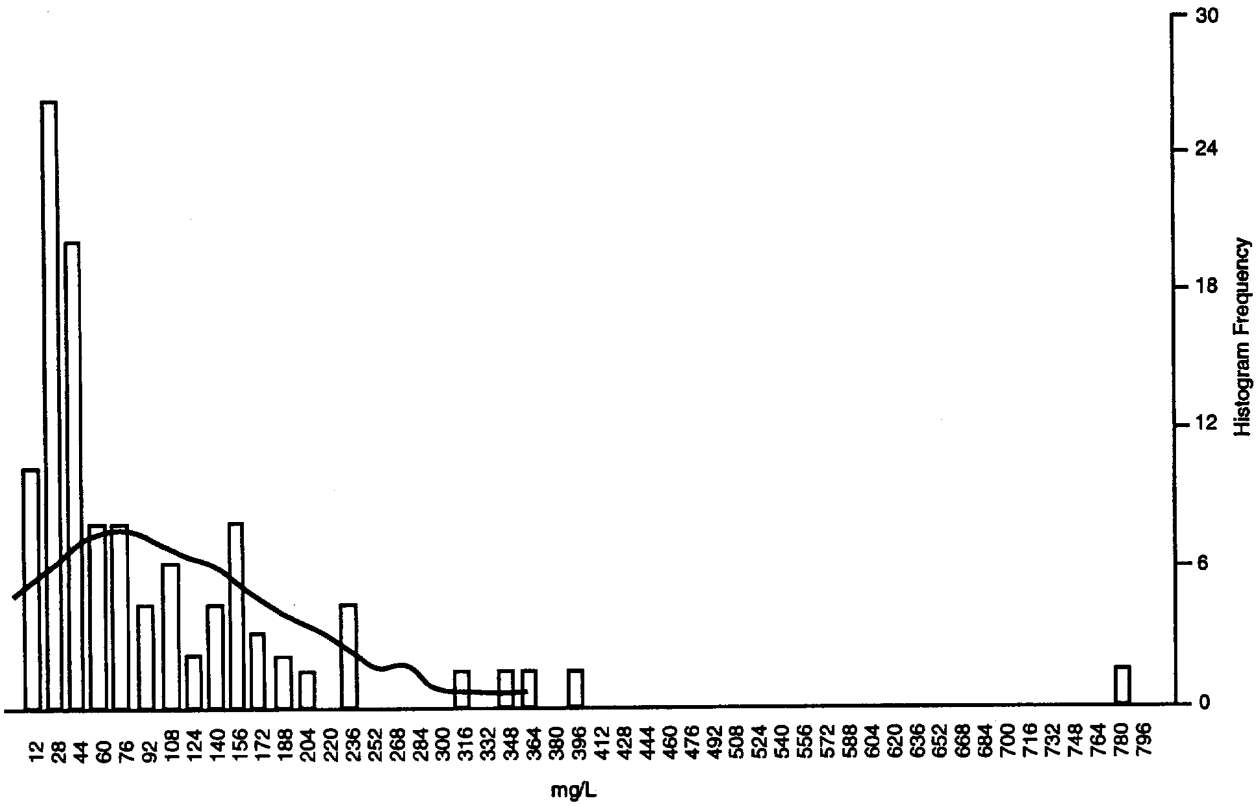

Figure 5-5. Untransformed total suspended solids (TSS) data.

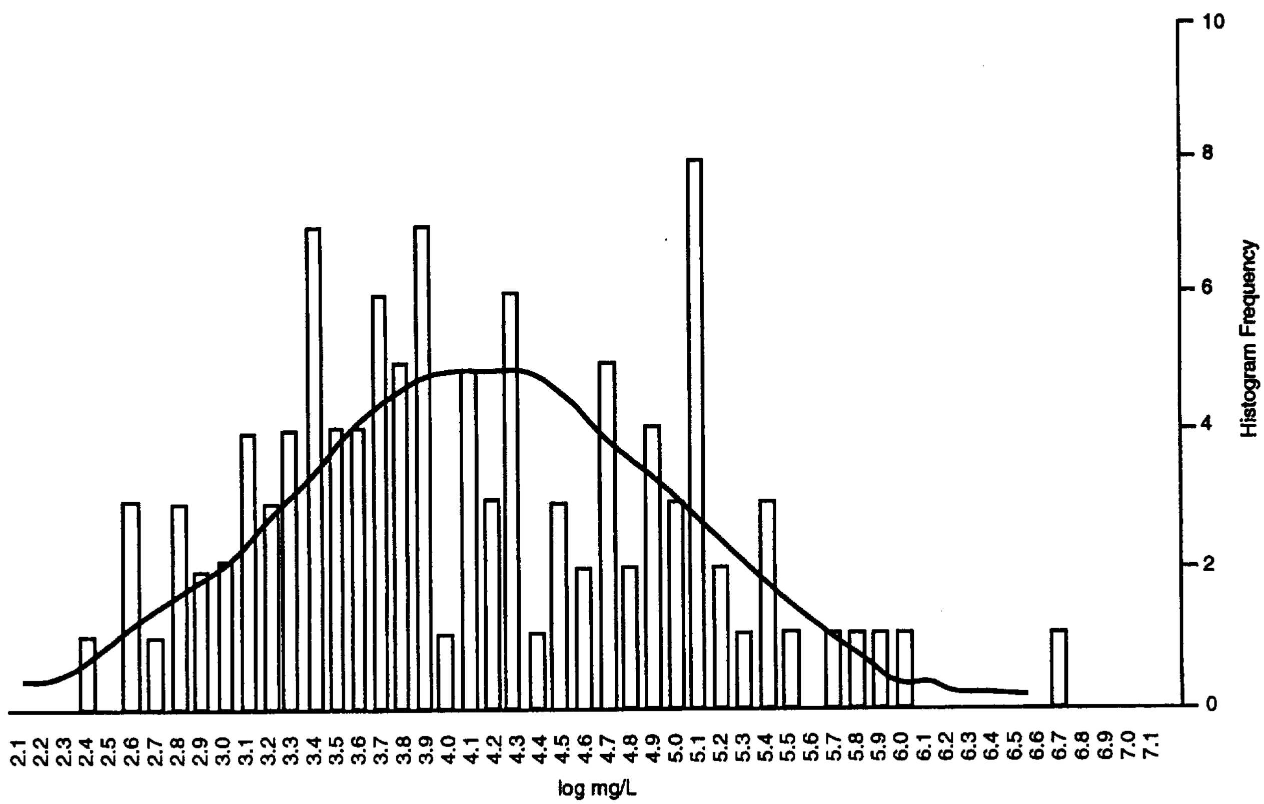

Figure 5-6. Log-transformed total suspended solids (TSS) data.

estimated value can be compared to a confidence interval. A confidence interval can be interpreted as the probability that an estimated value falls within the calculated limits of the interval. For example, a 95-percent confidence interval indicates a 95-percent probability that the estimated value falls within the specified limits of that confidence interval. Thus, only 5 percent of the estimated values would fall outside of this range. The technical details of deriving confidence intervals are beyond the scope of this document; however, there are numerous references that could be useful, including Devore (1987) and other textbooks on probability and statistics.

Correlation Coefficient. The correlation coefficient (r) provides useful information concerning the relationship between pairs of data, denoted as x and y. An example would be the relationship between TSS concentrations from a site and the area that contributes runoff to the site. The value of r does not depend on which of the two variables is labeled "x" and which is labeled "y," nor does it depend on the units of x and y. Generally, a correlation coefficient is considered weak if $0 \leq |r| \leq 0.5$, strong if $0.8 \leq |r| \leq 1.0$, and moderate otherwise (Devore, 1987).

Analysis of Biological Data

The evaluation of biological data could involve a number of statistical approaches, which include both qualitative and quantitative methods. Qualitative methods frequently include the use of indicator organisms whose presence or absence indicates the level of water quality. Quantitative methods include comparisons of biomass, organism densities, and community indices.

Qualitative Methods. Indicator species have been used for several community levels, including plankton, fish, and benthic macroinvertebrates. For example, phytoplankton species have been categorized as indicative of clean and polluted water, and responsible for taste and odor problems in reservoirs (APHA, 1992). Indicator species of organic enrichment and other pollutants in marine systems have been described by Pearson and Rosenberg (1978). In the case of freshwater benthic macroinvertebrates and fish, pollution-tolerant or -intolerant organisms have been assigned index values corresponding to their pollution tolerance (Hilsenhoff, 1977, 1987; U.S. EPA, 1989; summarized in U.S. EPA, 1990b). These index values typically utilize scales of 0 to 5, or 0 to 10, to indicate the level of tolerance to pollutants.

The use of benthic macroinvertebrate indicator species is illustrated in results from a stream survey to assess the relative impact of nutrients and other contaminants from an area affected by sewage leachate (Figure 5-7). In the survey, EPT taxa (*Ephemeroptera, Plecoptera, Trichoptera* = mayflies, stoneflies, and caddisflies) were used to represent species sensitive to pollution, while chironomid dipterans (blackflies), nonchironomid flies, and oligochaete worms were used to represent pollution-tolerant organisms.

The results reflected a fairly even distribution of the four groups of organisms at the upstream control site (Site A). Pollution-tolerant species, particularly the oligochaete worms which are good indicators of organic enrichment, were found in elevated numbers downstream of the impact area (Site B). Further downstream (sites C through E), the relative abundance of the four groups of organisms came to reflect conditions found at the upstream control site. In many urban environments, it might be difficult to find an upstream control site. This is common for feeder streams and creeks which originate within the urban area such that the entire reach is impacted. In such cases, it is necessary to consider reference sites in other areas which are not affected.

Quantitative Methods. Quantitative methods to analyze biological data utilize results for biomass, number of organisms, and species composition. Statistical methods described in earlier sections are used to interpret numeric data on biomass and densities. Community composition is analyzed through the use of diversity and similarity indices, which examine the number of organisms and taxa to determine if communities are stressed by pollutants. A number of these indices exist, which are described in the literature (Washington, 1984).

The most frequently used diversity indices describe species diversity, dominance, and evenness (Table 5-9), which provide the basis for comparisons of results from different sampling stations and study areas. Because of the influence of natural variability on the distribution of species, such comparisons are restricted to similar habitats such as fast-moving sections of a shallow stream (riffles), or deeper pooled areas. These indices have been employed in ecological studies for a number of years, permitting comparisons with historical data bases.

Calculation of these indices using the data in the stream survey (Table 5-10) mirrored the results for the

Table 5-9. Commonly Used Ecological Diversity Indices

Shannon-Wiener Diversity Index	$H' = \Sigma[n_i/n\ [\ln(n_i/n)]]$
Simpson's Dominance	$D = [\Sigma n_i(n_i - 1)/[n(n-1)]$
	where $i = 1 \ldots s$
Evenness	$E = H'/\ln(s)$

where:

n_i = number of individuals in a species i of a sample from a population

n = number of individuals in a sample from a population

s = number of species in a sample or population (also called richness)

Table 5-10. Diversity Indices for Sewage Leachate-Affected Stream Samples

Station	Total Taxa	Mean Number of Organisms per ft^2	Diversity	Dominance	Evenness
A	44	372.2	2.932	0.077	0.77
B	33	1261.9	1.196	0.536	0.34
C	31	1193.1	1.864	0.263	0.54
D	39	796	1.541	0.442	0.42
E	15	60	2.273	0.138	0.84

distribution of indicator organisms illustrated in Figure 5-7. Diversity and evenness values were both highest at the control Site A, and lowest at Site B, indicating the shift toward opportunistic, pollution-tolerant species which had a competitive advantage over less tolerant species. These results can also be plotted in a manner similar to the indicator species results. Statistical tests to determine the significance of the observed differences can be easily performed following the methods of Solow (1993).

Similarity indices permit comparisons of results to a reference station by calculation of similarity coefficients. These similarity coefficients can be subjected to cluster analysis, with the results illustrated through the use of dendrograms which graphically group similar communities together. Guidance exists using examples of the most widely used indices (U.S. EPA, 1990b), including examples of applying statistical methods described earlier to determine the level of significance associated with comparisons using these quantitative approaches.

A dendrogram for the Bray-Curtis coefficient calculated from the stream survey example (Figure 5-8) illustrates the similarities between sites influenced by the sewage leachate (Sites B through D). The upstream control site, A, and the most downstream site, E, clustered together, indicating a high degree of dissimilarity with the sites most influenced by the sewage leachate. Again, tests of significance can be applied to the results, and are typically included in statistical packages which are available to run cluster analyses.

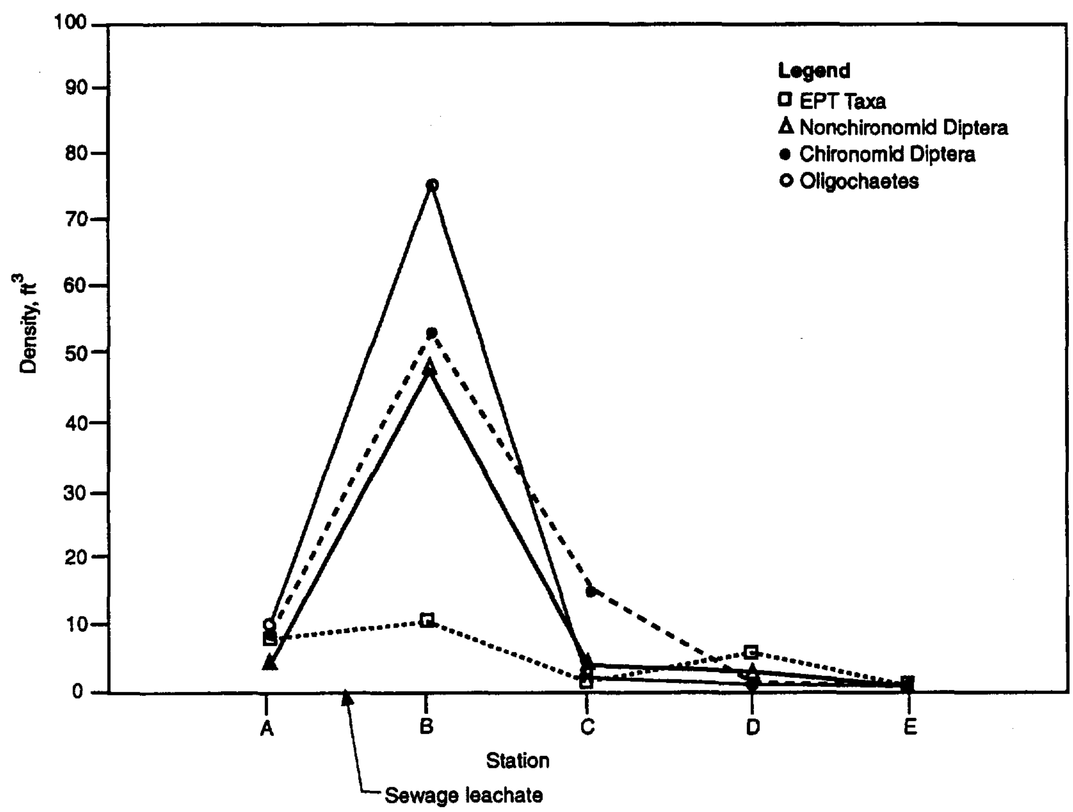

Figure 5-7. Distribution of macroinvertebrate indicator species along a sewage leachate-affected stream.

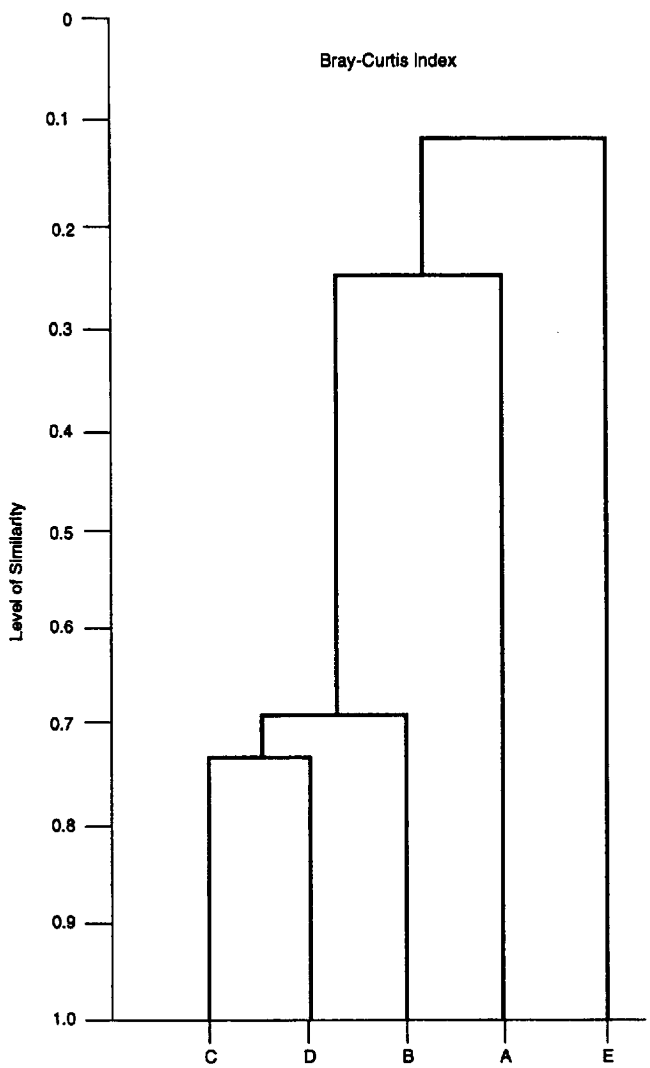

Figure 5-8. Cluster analysis dendrogram for sewage-affected stream survey results.

References

When an NTIS number is cited in a reference, that document is available from:

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APHA. 1992. American Public Health Association. Standard methods for the analysis of water and wastewater, 18th edition. Washington, DC.

Chow, V.T. 1959. Open-channel hydraulics. New York, NY: McGraw-Hill.

Date, C.J. 1985. An introduction to database systems. Menlo Park, CA: Addison Wesley.

Devore, J.L. 1987. Probability and statistics for engineering and the sciences, second edition. Monterey, CA: Brooks/Cole Publishing Company.

Hilsenhoff, W.L. 1977. The use of arthropods to evaluate water quality of streams. Dept. of Natural Resources, Madison, WI. Tech. Bull. No. 100.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomol. 20:31-39.

Hursch, C.J., and J.L. Hursch. 1988. SQL, the structured query language. Blue Ridge Summit, PA: TAB BOOKS, Inc.

ISO. 1979. International Organization for Standardization. Measurement of liquid flow in open channels. Case Postale 56-CH 1211, Geneva, Switzerland. ISO Standard 748-1979E.

Korth, H.F., and A. Silberschatz. 1986. Database system concepts. New York, NY: McGraw-Hill.

Maier, D. 1983. The theory of relational databases. Computer Science Press.

Pearson, T.H., and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanor. Mar. Biol. Ann. Rev. 16:229-311.

Plumb, R.H., Jr. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. U.S. Environmental Protection Agency/U.S. Army Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material. Vicksburg, MS: U.S. Army Waterways Exp. Station.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry—the principles and practice of statistics in biological research. San Francisco, CA: W.H. Freeman and Co. 776 pp.

Solow, A.R. 1993. A simple test for change in community structure. J. Animal Ecology 62:191-193.

USDI. 1984. U.S. Department of the Interior. Water measurement manual. Bureau of Reclamation Water Resources Technical Publication. Washington, DC: U.S. Govt. Printing Office.

U.S. EPA. 1975. U.S. Environmental Protection Agency. Sewer flow measurement; a state-of-the-art assessment. EPA/600/2-75/027 (NTIS PB-250371). Washington, DC.

U.S. EPA. 1976. U.S. Environmental Protection Agency. Methodology for the study of urban storm generated pollution and control. EPA/600/2-76/145 (NTIS PB-258743). U.S. EPA Office of Research and Development.

U.S. EPA. 1982. U.S. Environmental Protection Agency. Handbook for sampling and sample preservation of water and wastewater. EPA/600/4-82/029 (NTIS PB83-124503). Cincinnati, OH: U.S. EPA Office of Research and Development, Environmental Monitoring and Support Laboratory.

U.S. EPA. 1983a. U.S. Environmental Protection Agency. Interim guidelines and specifications for preparing quality assurance project plans. EPA/600/4-83/004 (NTIS PB83-170514). U.S. EPA Office of Research and Development.

U.S. EPA. 1983b. U.S. Environmental Protection Agency. Guidelines for the monitoring of urban runoff quality. EPA/600/2-83/124 (NTIS PB84-122902). U.S. EPA Office of Research and Development.

U.S. EPA. 1984. U.S. Environmental Protection Agency. Guidelines for preparation of combined work/quality assurance project plans for environmental monitoring. Office of Water Regulations and Standards, QA-1, May 1984. Washington, DC.

U.S. EPA. 1986. U.S. Environmental Protection Agency. Quality criteria for water, 1986. EPA/440/5-86/001. Washington, DC: U.S. EPA Office of Water, Regulations and Standards.

U.S. EPA. 1989. U.S. Environmental Protection Agency. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA/440/4-89/001.

U.S. EPA. 1990a. U.S. Environmental Protection Agency. Hazardous and toxic wastes associated with urban runoff. In: Remedial action, treatment, and disposal of hazardous wastes: proceedings of the 16th Annual Hazardous Waste Research Symposium. EPA/600/9-90/037 (NTIS PB91-148379). Washington, DC: U.S. EPA Office of Research and Development.

U.S. EPA. 1990b. U.S. Environmental Protection Agency. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. EPA/600/4-90/030 (NTIS PB91-171363). U.S. EPA Office of Research and Development.

U.S. EPA. 1991a. U.S. Environmental Protection Agency. Guidance manual for the preparation of part 1 of the NPDES permit applications for discharges from municipal separate storm sewer systems. EPA/505/8-91/003A. U.S. EPA Office of Water (EN-336).

U.S. EPA. 1991b. Technical support document for water quality-based toxics control. EPA/505/2-90/001. Washington, DC: U.S. EPA Office of Water.

U.S. EPA. 1993. U.S. Environmental Protection Agency. Investigation of inappropriate pollutant entries into storm drainage systems, a user's guide. EPA/600/R-92/238 (NTIS PB93-131472). Edison, NJ: U.S. EPA Office of Research and Development.

USGS. 1982. U.S. Geological Survey. Measurement and computation of streamflow: vol. 1—measurement of stage and discharge; vol. 2—computation of discharge. Water-Supply Paper 2175.

Washington, H.G. 1984. Diversity, biotic, and similarity indices: a review with special relevance to aquatic ecosystems. Water Res. 18(6)653-694.

Chapter 6
Assess and Rank Problems

This chapter presents methods for evaluating available or newly collected data in order to assess problems. Problem assessments, as defined in this chapter, are evaluations performed to determine the extent and severity of urban runoff-related problems. Problem assessments are used to determine the need for and appropriate level of pollution prevention and control measures for the program. It is important to consider both existing and potential problems, so that the program addresses resource protection, as well as problems that already exist.

The first step is defining problem assessment criteria, which are used to assess the extent or severity of an urban runoff-related problem. Following this definition, the most commonly used methods of problem assessment are presented, including pollutant source assessments, resource assessments, institutional assessments, and goals and objectives assessments. Finally, methods for ranking problems based on results of the assessments are included in this chapter because of the complexity of urban runoff problems and the frequent need to set priorities. Results of problem assessment and ranking presented in this chapter provide the basis for BMP screening and selection in subsequent steps of the planning process.

Problem Assessment Criteria

Problem assessments can address a wide range of issues, including:

- The types of urban runoff pollution in the watershed.
- The extent to which these pollution sources adversely affect resources.
- The institutional needs and constraints in addressing the problems.
- The goals established for the program area.

Criteria for the assessment can be developed to address these major issues, to determine the important issues, and to provide a basis for problem assessment. Only criteria considered most critical and helpful in distinguishing between problems should be selected. Assessment criteria, such as those listed in Table 6-1, can be evaluated qualitatively or quantitatively. These criteria are briefly described below and elaborated upon later in the chapter in the discussion of assessment methods.

Pollutant Source Criteria

Assessment criteria focusing on pollutant characteristics and the pollutant sources that affect a resource are among the most critical in determining which problems should be addressed. Pollutant source criteria, such as those listed in Table 6-1, describe the range of pollutant characteristics and sources and the size of each source. The distance between the source and the affected resource and the mode of pollutant transport are also useful assessment criteria. Pollutant loading during wet weather versus dry weather can also be considered. Tools useful in evaluating pollutant source criteria include GIS and urban runoff models (described later in this chapter).

Resource Criteria

Resource criteria assess effects on resources and aid in determining locations where preventive and corrective measures are needed. Water resources of various types (e.g., ground water, surface water, and drinking water) are often the driving force for such assessments, but many other types of resources, such as biological, wildlife, and infrastructure could be appropriate to consider. Examples of these assessment criteria, as listed in Table 6-1, describe the importance or value of a resource with respect to issues such as habitat, recreational use, and public water supplies. The current and desired uses of a resource may be included as resource criteria. The degree to which a resource is impaired and the type of impairment may also be considered. Tools such as receiving-water models and biotic indices (see the case study at the end of this chapter) and habitat evaluation procedures are used to assess the existing conditions and simulate responses of the resources to potential preventive and corrective measures. Information gathered during existing conditions assessment (Chapter 4) and data collection and analysis (Chapter 5) are useful in analyzing the resource criteria. The relative health of each resource

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Table 6-1. Criteria for the Assessment of Pollution Problems (Adapted from U.S. EPA, 1987a)

Pollutant Source
Type of pollutant
Pollutants typically associated with the source
Source magnitude/pollutant loading
Transport mechanisms to the resource (direct pipe, overland flow or ground water)
Wet-/dry-weather trends
Resource
Existing use of the affected resource (type, status, and level of use)
Designated or desired use of the affected resource
Type and severity of impairment
Relative value of resource affected
Institutional
Available resources and technologies
Understanding of problems and opportunities
Appraisal of potential for solving the identified problem
Implementability of controls
Applicable regulations
Multiagency responsibilities
Funding sources and limitations
Public perception
Goals and Objectives
Water resource goals (water use objectives)
Technology-based goals
Land use objectives
Objectives of planner and sponsor

in a community and the desire of the community to improve its quality helps determine the priorities for implementation.

Institutional Criteria

Urban runoff-related problems can also be assessed using criteria that focus on the institutional constraints on regulators, owners, and the public. Institutional criteria are based on applicable regulations, preferences of the local authorities and regulatory agencies, funding sources and limitations, multiagency responsibilities and overlaps, and public acceptance of the program. Interviews and meetings with interested parties, including agencies, environmental groups, advisory groups, and private citizens, can be conducted to help develop institutional criteria. Questionnaires can be prepared and distributed to help identify concerns. Complaints, either filed with local authorities or available through interviews with citizens, also provide useful input. Knowledge of problems gained through public interaction programs can help to ensure public support of urban runoff pollution prevention and control programs which are implemented later. Examples of institutional criteria are listed in Table 6-1.

Goals and Objectives Criteria

Urban runoff problems can be evaluated with respect to current and future goals. Using goals and objectives assessment criteria, presented in Table 6-1, allows the program team to focus on problems where preventive or corrective measures would provide the greatest benefit. One goal, for example, might be to increase the usage of public beaches by improving the conditions of degraded water bodies meant for swimming. Application of goals and objectives criteria could identify where corrective measures would provide the greatest benefit, perhaps at beaches only slightly degraded and needing only minimal cleanup before they are restored, or at beaches in heavily populated areas where many people could benefit from restoration of the water body. Goals and objectives can be set for restoration of affected resources, but protection of existing uses is as valid a goal as restoration.

Methods of problem assessment, presented in the following sections, use the criteria discussed in this section as a basis for comparison and evaluation.

Pollutant Source Assessments

Pollutant source assessments address the type, magnitude, and transport mode of pollution sources (existing or potential) in a watershed or program area. These assessments are frequently aimed at quantifying the source flows and pollutant loads under various conditions.

Source Determination and Data Evaluation

Urban runoff pollution sources can be defined using the watershed description (Chapter 4) and other information such as the type(s) of pollution affecting a water resource, the pollutant transport mechanisms, the characteristics of drainage patterns and drainage structures, and the land uses in the program area. Activities or land uses within a watershed that are, or potentially could be, causing pollution problems need to be identified. Pollutant types found in the watershed can provide clues regarding the source(s) of the problems. To isolate pollution sources, the watershed can be divided into smaller areas so that individual pollution sources can be tracked down. Depending on the size of the watershed, a drainage basin can first be divided into sub-basins, which can, if necessary, be divided into individual tributaries, pipe systems, or drainage channels. Pollutant types typically associated with certain activities or land uses are listed in Table 6-2.

Table 6-2. Types of Activities and Associated Pollutants (U.S. EPA, 1988a)

Categories and Subcategories	Nutrients	pH	Sediment	Organic Enrichment	Pathogens/ Indicator Bacteria	Toxic Organics	Toxic Metals	Oil and Grease	Salts (TDS)	Hydrologic Alterations	Thermal Alterations	Pesticides
Agriculture												
Cropland	X		X									X
Pastureland	X		X	X	X							
Animal holding areas	X		X	X	X							
Animal waste storage	X		X	X	X							
Hayland	X			X	X							
Wash and processing water	X	X	X	X	X			X				X
Waste application areas	X		X	X	X		X					
Construction												
Highways, bridges, roads			X		X	X		X	X	X	X	
Land development			X		X			X		X	X	
Urban Land												
Storm water sewers, combined sewers, surface runoff—pavement	X		X	X	X	X	X	X	X	X	X	
Surface runoff—turf areas	X				X			X				
Infiltration wells and basins	X				X	X		X	X			
Land Disposal												
Wastes, sludge, septage	X	X	X	X	X	X	X	X	X			
Landfills	X	X	X	X	X	X	X	X	X	X	X	X
In situ wastewater system	X											
Hazardous waste areas	X	X			X	X	X	X	X			X
Hydrologic Modification												
Earth fills, channelization			X							X		
Dam construction/reconstruction	X	X	X	X						X	X	
Other Sources												
Atmospheric deposition	X	X				X	X					
Underground storage tank leaks						X	X	X				X
Illegal disposals/dumping, release of contaminants from in-place deposits	X	X	X	X	X	X	X	X	X			X

Table 6-2. Types of Activities and Associated Pollutants (Continued)

Categories and Subcategories	Nutrients	pH	Sediment	Organic Enrichment	Pathogens/ Indicator Bacteria	Toxic Organics	Toxic Metals	Oil and Grease	Salts (TDS)	Hydrologic Alterations	Thermal Alterations	Pesticides
Highway/bridge maintenance			X			X	X	X	X			X
Auto salvage						X	X	X				
Washing and processing areas	X	X	X	X	X	X	X	X	X		X	X
Snow dumping areas	X		X	X	X	X	X	X	X			
Utility ROWs			X							X	X	X
Surface runoff from gasoline stations						X	X	X				
In-place sediments	X	X	X	X	X	X	X	X	X	X		
Sewer leaks, domestic/wild birds and mammals	X			X	X							
Natural vegetation (leaves, fallen trees)	X		X	X	X							
Marinas and boat moorings, boat maintenance and boat washing	X		X	X	X	X	X	X				

This information can be used to identify potential sources. Problem sources can also be identified based on resource conditions, such as eutrophication of a water body resulting from excessive nutrients, or closures of shellfish beds because of high levels of bacteria. In addition, sediments from aquatic systems and storm sewers can provide useful information for identifying potential sources (U.S. EPA, 1991a).

Pollutant Source Flow and Load Estimation

Computer modeling is valuable in quantifying the flows and loads of pollution sources needed for pollution source assessments. Models can be used to estimate source strengths as well as to evaluate the effectiveness of proposed corrective measures or BMPs. Models available for urban runoff assessments vary widely in complexity, ranging from simple estimation techniques to sophisticated and expensive computer models. The following discussion highlights a number of commonly used methods, focusing on models used to predict pollution characteristics in an urban environment. Information on urban and non-urban models is available from literature (U.S. EPA, 1987b,1991b; Nix, 1991; Walesh, 1989) and from agencies that sponsor the models. Methods of urban runoff modeling discussed in this section include the constant concentration or unit load estimates, preliminary screening procedure, statistical method, universal soil loss equation, rating-curve or regression approaches, and hydrologic and pollutant buildup-washoff models.

Constant Concentration or Unit Load Estimates

Constant concentrations or unit pollutant loads, which can be used to estimate pollutant source loads, can be obtained from available data or estimated based on the types and sizes of land uses in the watershed. Constant concentrations can be coupled with runoff volume estimates to calculate runoff loads or can be used in hydrologic models to calculate time variable flows and loads. The constant concentration or unit load method is easy to use, and can be helpful as a first-cut estimate to identify which areas within a watershed contribute the largest pollutant loads. Wet-weather and dry-weather conditions can also be evaluated separately, to determine the relative contributions of pollutants during these weather periods. This method can be facilitated using a GIS with information such as wet- and dry-weather pollutant concentrations from different sources, land use or source boundaries, and quantities of flow produced in each area. Constant concentrations or unit loads can also be estimated using a spreadsheet.

EPA's Nationwide Urban Runoff Program (NURP), conducted from 1978 to 1983, is one example of a comprehensive study of storm water runoff from residential, commercial, and light industrial areas throughout the United States. It contains a large data base of pollutant concentrations and loads measured during various storm events (U.S. EPA, 1983a). Other data bases of storm water pollutant concentrations and loads include Driver and Tasker (1990); Tasker and Driver (1988); and U.S. EPA, 1974, 1977,1982a, 1990. Such data bases, however, must be used cautiously. For example, since the NURP data are based largely on areas without sanitary waste or industrial waste influences, they might not be representative of the location being studied.

These types of data can be applied to source load estimation techniques such as the constant concentration or unit load method. For example, Table 6-3 presents median and mean values of event mean concentrations (EMCs) derived from urban runoff from EPA's NURP study (U.S. EPA, 1983a). Typical ranges of concentrations of various pollutants found in rainfall, storm water, combined wastewater, and wastewater effluent are presented in Table 6-4. With the aforementioned cautions, such values can be used as first-cut estimates of pollutant loadings. Because of the high variability of urban runoff data, however, site-specific data are required to ensure the accuracy of this or other methods.

Table 6-3. Water Quality Characteristics of Urban Runoff for the NURP Site (U.S. EPA, 1983a; Adapted from Novotny, 1992)

Constituents	Site Median Event Mean Concentration	Site Mean Event Mean Concentration
Total suspended solids, mg/L	100	141 to 224
Biochemical oxygen demand (5-day), mg/L	9	10 to 13
Chemical oxygen demand, mg/L	65	73 to 92
Total phosphorus, mg/L	0.33	0.37 to 0.47
Soluble phosphorus, mg/L	0.12	0.13 to 0.17
Total Kjeldahl nitrogen, mg/L	1.50	1.68 to 2.12
Nitrate and nitrite nitrogen, mg/L	0.68	0.76 to 0.96
Total copper, µg/L	34	38 to 48
Total lead, µg/L	144	161 to 204
Total zinc, µg/L	160	179 to 226

Table 6-5 shows an example of the constant concentration method used to estimate loadings of fecal coliform bacteria and nitrate-nitrogen and to prioritize nonpoint sources in a watershed. To estimate the loadings, mean concentrations for different land uses were multiplied by the estimated annual runoff volume.

Table 6-4. Characteristics of Rainfall, Storm Water, Combined Wastewater, and Treated Effluent (Adapted from various sources; see Metcalf & Eddy, Inc., 1991; Novotny, 1992)

Parameter	Rainfall	Storm Water	Combined Wastewater	Primary Effluent	Secondary Effluent
Suspended solids, mg/L	—	141 to 224	270 to 550	40 to 120	10 to 30
Biochemical oxygen demand (5-day), mg/L	1 to 13	10 to 13	60 to 220	70 to 200	15 to 45
Chemical oxygen demand, mg/L	9 to 16	73 to 92	260 to 480	165 to 600	25 to 80
Fecal coliform bacteria, MPN/100 mL	—	1,000 to 21,000	200,000 to 1,100,000	—	—
Total phosphorus, mg/L	0.02 to 0.15	0.37 to 0.47	1.2 to 2.8	7.5*	6*
Total nitrogen, mg/L	—	3 to 24	4 to 17	35*	30*
Total Kjeldahl nitrogen, mg/L	—	1.68 to 2.12	—	—	—
Nitrate nitrogen, mg/L	0.05 to 1.0	0 to 4.2	—	—	—
Total lead, μg/L	30 to 70	161 to 204	140 to 600	—	—

* Average value.

Table 6-5. Estimated Urban Runoff Loadings Using Constant Concentrations (U.S. EPA, 1992)

Source Area	Description and Location	Area, ac	% Impervious	Land Use	Runoff Coefficient	Annual Runoff Volume, Mgal	Annual Fecal Coliform Loading org x 10^{12} (rank)	Annual Nitrate Nitrogen Loading lb (rank)	Qualitative Ranking
A	Main St. and Freeport outlet stores	3.3	85	Commercial[a]	0.73	2.7	1.7 (12)	14 (11)	Low
B	Commercial development at I-95 interchange, Main and Pine streets	30.6	50	Commercial	0.45	15.7	9.8 (1)	82 (1)	High
C	A portion of Freeport Crossing outlets, Main St., Varney Rd., and Kar Klean	13.9	60	Commercial	0.61	9.7	6.0 (3)	51 (4)	High
D	Main St., Varney Rd., a portion of Linwood Rd., and adjacent residential development	21.0	10	Multifamily residential[b]	0.13	3.1	2.0 (10)	24 (8)	Low
E1	Southern L.L. Bean parking lot	6.5	85	Industrial[c]	0.73	5.4	2.8 (7)	28 (7)	Medium
E2	Northern L.L. Bean parking lot	5.5	80	Industrial	0.69	4.3	2.2 (8)	23 (9)	Medium
F	Independence Way, Eastland Shoe warehouse, Horsefeathers Restaurant, and Main St.	14.1	20	Commercial	0.21	3.4	2.1 (9)	18 (10)	Low
G	Somerset Condominiums, Summer St., Upper West St., and Freeport Place Condominiums	38.0	20	Single-[d] and multifamily residential	0.21	9.1	5.9 (4)	73 (3)	High
H	Municipal garage, Main St., and town office parking lot	15.0	60	Industrial Commercial	0.53	9.1	4.7 (5)	48 (5)	High
I	Downtown Village area along Main St. between Morse and West streets including Oak	19.2	75	Commercial	0.65	14.2	8.8 (2)	75 (2)	High

[a] Fecal coliform concentration = 16,000 org/100 mL, NO_3-N concentration = 0.63 mg/L
[b] Fecal coliform concentration = 17,000 org/100 mL, NO_3-N concentration = 0.96 mg/L
[c] Fecal coliform concentration = 14,000 org/100 mL, NO_3-N concentration = 0.63 mg/L
[d] Fecal coliform concentration = 37,000 org/100 mL, NO_3-N concentration = 0.96 mg/L

Runoff volumes were based on the size, imperviousness, and land use of each source area. Table 6-5 presents the estimated pollutant loadings for the watershed. Based on this analysis, 5 of the 10 areas (B, C, G, H, and I) of nonpoint source pollution were qualitatively assigned ratings of "high" based on their pollutant loadings. These areas contribute more than 75 percent of the total pollutant loading in the watershed.

Preliminary Screening Procedure

Simple equations can be used to estimate annual average loading contributions of urban runoff for 5-day biochemical oxygen demand (BOD_5), suspended solids, volatile solids, total phosphate phosphorus, and total nitrogen. The preliminary screening procedure is a sophisticated unit load method which can be used to calculate unit loads as a function of land use, population density, and frequency of street sweepings (U.S. EPA, 1982b). Pollutant loadings can be estimated based on the relative contribution of pollutants from each land use; however, the equations are not location specific and are useful only for screening purposes. Using the preliminary screening procedure, unit loads are calculated by the following equation developed by EPA (U.S. EPA, 1976a) as reported by Walesh (1989):

$$L = u(i,j) \times P \times PDF \times SWF$$

where:

- L = average annual amount of pollutant j generated per unit of land use i, lb/ac/yr
- u(i,j) = load of pollutant j generated per unit of runoff from land use i, in lb/acre-inch
- P = average annual precipitation, in
- PDF = population density factor, a dimensionless parameter with a value for residential areas of $0.142 + (0.218)(PD)^{0.54}$, where PD is a population density in persons per acre, equal to 1.0 for commercial and industrial areas, and 0.142 for institutional areas (e.g., parks, cemeteries, and schools)
- SWF = street-sweeping factor, a dimensionless parameter; SWF = 1.0 when streets are swept infrequently, with the average time between street sweepings being greater than 20 days; for more frequent street sweeping, SWF is less than 1.0 and could be estimated from site-specific data or literature values.

The unit pollutant loads (u) are obtained from measured or estimated concentrations or loadings from various land use or source areas.

Statistical Method

The statistical method of modeling urban runoff assumes that EMCs are distributed log-normally and characterizes EMCs by their median values and their coefficients of variation. EPA's statistical method (U.S. EPA, 1979) includes statistical properties of rainfall, area, runoff coefficients, median EMCs, and coefficients of variation of EMCs of various pollutants. The Federal Highway Administration (FHWA) has implemented EPA's statistical method for various locations in the United States (Driscoll et al., 1989; Woodward-Clyde Consultants, 1990a).

The runoff flow rate and volume from a mean event are computed by the FHWA model using the following equations:

$$MQR = Rv \times MIP \times ARW \times (3{,}630/3{,}600)$$

$$MVR = Rv \times MVP \times ARW \times 3{,}630$$

where:

- MQR = average runoff flow rate for mean storm events, ft^3/s
- Rv = runoff coefficient (ratio of runoff to rainfall), equal to $0.007 \times IMP + 0.10$, where IMP is equal to the impervious fraction of the drainage area, %
- MIP = rainfall intensity for mean storm event, in/hr
- ARW = drainage area of the highway segment, ac
- MVR = volume of runoff for mean storm event, ft^3
- MVP = rainfall volume for mean storm event, in

The numbers 3,630 and 3,600 are dimensional conversion factors.

The log-normally distributed EMCs are calculated by the equation:

$$MCR = TCR \sqrt{(1 + CVC^2)}$$

where:

- MCR = EMC for site, mg/L
- TCR = site median pollutant concentration, mg/L
- CVC = coefficient of variation of EMCs

and the mean event mass load is computed by:

$$M(MASS) = MCR \times MVR \times (62.45 \times 10^{-6})$$

where:

- M(MASS) = mean pollutant mass loading lb/event
- MCR = mean runoff concentration, mg/L
- MVR = mean storm event runoff volume, ft^3

Universal Soil Loss Equation

The Universal Soil Loss Equation is primarily applicable to agricultural areas and is used to estimate the soil loss and sediment yield from a homogeneous parcel of land (U.S. EPA, 1976b). The discussion in this handbook is general, and more detailed information can be obtained from referring to more specific sources (SCS, 1977). This method, relatively simple to use, considers such factors as rainfall, erosive forces of the rainfall, soil erodibility, slope, vegetative cover, and erosion control practices. Since this method is used primarily to estimate soil loss and, when modified, sediment yields from non-urban, agricultural areas, it is less applicable to the problems addressed in this handbook than other methods discussed.

The Universal Soil Loss Equation is:

$$E = A \times R \times K \times LS \times C \times P$$

where:

- E = soil loss by water erosion in rill and inter-rill areas, tons/yr
- A = area, ac
- R = rainfall factor, accounting for erosive forces of rainfall and runoff, erosion index units/yr
- K = soil erodibility factor reflecting the physical and chemical properties of a particular soil, tons/ac/erosion unit index
- LS = slope length or topographic factor reflecting the influence of vegetation and mulch, dimensionless
- C = cover and management factor reflecting the influence of vegetation and mulch, dimensionless
- P = erosion control practice factor that is similar to the cover-management factor, but accounts for practices on the land surface such as contouring, terracing, compacting, sedimentation basins and control structures, dimensionless

In order to estimate sediment yield (as opposed to soil loss), the equation is modified by adding a sediment delivery ratio (S_d) as follows:

$$Y(S)_E = A \times R \times K \times LS \times C \times P \times S_d$$

where:

- $Y(S)_E$ = sediment loading to stream, tons/yr
- S_d = sediment delivery ratio, dimensionless

The sediment delivery ratio is a function of the amount of attenuation of gross erosive soil loss in the watershed. This ratio depends on factors such as soil characteristics, slopes, lengths, and watershed area and is estimated using empirical data. Estimates for this and the other parameters should be made only after consulting more detailed references (i.e., SCS, 1977; U.S. EPA, 1976b).

Regression-Rating Curve Approaches

Rating curve or regression models, such as the 31 storm runoff load models developed by the USGS for metropolitan areas throughout the United States (Driver and Tasker, 1990; Tasker and Driver, 1988), use site-specific rainfall, runoff, and source concentration data, such as the data collected for NURP and similar studies, to relate concentrations and loads of pollutants to flow rates and volumes. The regression model for estimation of storm runoff loads and volumes is given by the equation (Driver and Tasker, 1990):

$$\hat{Y} = \beta_0 \times X_1^{(\beta 1)} \times X_2^{(\beta 2)} \ldots X_n^{(\beta n)} \times BCF$$

where:

- $\hat{Y}$ = estimated storm-runoff load or volume, response variable
- $\beta_0, \beta_1, \beta_2, \beta_n$ = regression coefficients, provided by Driver and Tasker, 1990
- X_0, X_1, X_2, X_3 = physical, land use, or climatic characteristics, explanatory variables
- BCF = bias-correction factor, calculated by Driver and Tasker, 1990

Hydrologic and Pollutant Buildup-Washoff Models

For larger and more complex programs, it may be desirable to use hydrologic and pollutant buildup-washoff models. These models address the accumulation of pollutants during dry-weather periods and the washing off of these pollutants during rainfall events. Of the many models available, some of the more widely used models that use a buildup-washoff mechanism include Hydrological Simulation Program—Fortran, HSPF (U.S. EPA, 1981); Storm Water Management Model, SWMM (U.S. EPA, 1988b); Storage, Treatment, Overflow, Runoff Model, STORM; and Source Loading and Management Model, SLAMM (Pitt, 1989). These models are described below. Table 6-6 compares these urban hydrologic and pollutant buildup-washoff models and the EPA statistical method as implemented by the FHWA. Many other models are available which are not described here.

HSPF, available from EPA, simulates movement and storage of water in the hydrologic budget of a watershed or drainage basin, from rainfall to streamflow to ground-water storage. HSPF is useful when large watersheds comprising multiple pollutants and land uses are to be modeled and/or when issues such as sediment erosion, pollutant interaction, and ground-water quality of the system are of concern. Input data requirements of this model are extensive and include time series inputs of hydrologic and meteorologic data, and input of characteristics describing pollutants, topography, storage, response, and evapotranspiration. HSPF can simulate receiving waters and pervious and

Table 6-6. Comparison of Urban Runoff Models (U.S. EPA, 1991c; Pitt, 1989)

Attribute	Storm Water Management Model (SWMM)	Hydrological Simulation Program—Fortran (HSPF)	Storage, Treatment, Overflow, Runoff Model (STORM)	Source Loading and Management Model (SLAMM)	Statistical
Sponsoring Agency	EPA	EPA	Hydrologic Engineering Center (HEC)	Pitt[a]	EPA
Type of Method					
Surface water—simple			X		
Surface water—refined	X	X		X	
Soil/ground water—simple	X				
Soil/ground water—refined		X			
Surface water—statistical					X
Simulation Type					
Continuous	X	X	X		N/A
Single event	X	X		X	N/A
Hydraulic/Hydrologic Features					
Rainfall/runoff analysis	X	X	X	X	[b]
Sewer system flow routing	X	X			
Full, dynamic flow routing	X[c]				
Surcharge	X[c]				
Regulators, overflow structures	X		X		
Storage analysis	X	X	X	X	X[d]
Predicted Pollutant Concentrations in:					
Runoff water	X	X	X	X	X
Surface water	X	X			
Ground water	X	X			
Predicted Pollutants					
Conventional	X	X	X	X	X
Organic	X	X			X
Metals	X			X	X
Number of pollutants	10	10	6	10	Any
Source/Release Types					
Continuous	X	X	X	X	
Intermittent	X	X			
Single	X	X			
Multiple	X	X			X
Diffuse	X	X	X	X	X
Unique Features					
Special solids routines	X	X		X	
Treatment analysis	X	X	X		X[c]
Degradation products	X	X			
Data base	X	X			
Uncertainty analysis	X		X		
Input/execution manager		X			
Level of Application					
Screening	X	X	X	X	X
Intermediate	X	X		X	
Detailed (suitable for design)	X	X		X	
Data and Personnel Requirements[e]	High	High	Low	High	Moderate
Overall Model Complexity[f]	High	High	Moderate	High	Moderate
Available on Microcomputer	X	X		X	X

[a] SLAMM is a proprietary model owned by R. Pitt, Ph.D., Department of Civil Engineering, University of Alabama.
[b] Runoff coefficient used to obtain runoff volumes.
[c] Full dynamic equations and surcharge calculations only in EXTRAN block of SWMM.
[d] Storage and treatment analyzed analytically.
[e] General interpretation based on requirements for model installation, familiarization, data requirements, etc.
[f] Reflection of model size and capabilities; complex models can be used to simulate simple systems with minimal data requirements.

impervious lands and soils. Although it is complicated, model documentation is available from EPA, including copies of the model, user assistance, and periodic training sessions (U.S. EPA, 1991d).

SWMM is a complex model using finite-difference approaches that can be used to simulate urban storm water runoff and combined sewer overflows. Input data requirements are extensive and involve information such as precipitation, air temperature, channel and pipe networks, land use patterns, and storage and treatment facilities (U.S EPA, 1991d). SWMM can be used during both the planning and design phases of a program. Its output consists of hydrographs, pollutographs, and control options and cost (U.S. EPA, 1991d). Model documentation is available from EPA.

While the use of SWMM and HSPF requires a high level of effort and expertise, the models also lend themselves to more simplified treatment and simplified versions are available. For example, in SWMM, the buildup-washoff method of estimating pollutant contribution to a system can be substituted with constant pollutant concentrations. SWMM can also be run in a long-term mode using variable time steps so both event-specific and seasonal/annual conditions can be analyzed.

STORM contains simplified hydrologic and water quality routines for urban runoff modeling. While data requirements of the model are minimal, the model is less flexible than other, more complex models. Output of STORM includes storm event summaries of runoff volume, concentrations and loads, storage and treatment utilization, and total overflow loads and concentrations (U.S. EPA, 1991d). Although the simplicity of STORM makes it an attractive model for screening purposes, it has not been updated by its agency sponsor, the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), since 1977. While the model has been updated and refined by private entities and many applications of STORM exist, use of STORM has declined in recent years (U.S. EPA, 1991d).

SLAMM is a proprietary model which can be used to evaluate the effects of pollution control measures and development characteristics on urban runoff quality and quantity. Model input requirements include rainfall duration, depth of rainfall, areas of each pollution source type, SCS soil types, building density, land use, pavement texture, traffic density, and roof pitch (Pitt, 1989). The SLAMM model user manual incorporates a discussion of the hydrology of small storm events and its relationship to more "standard" hydrologic models. Investigations have shown the need to represent the rainfall-runoff processes correctly for the more frequent, smaller size storms since they often account for a major part of the pollution loading (Pitt, 1989). Output of the SLAMM model includes, for each rain and land use, matrices describing source area and outfall flow volumes, particulate residue mass and concentrations, and relative contributions from each rainfall event (Pitt, 1989).

While many other models are also available, some receive little or no support from their sponsoring parties and/or have not been widely used. Other widely used models can simulate hydrology but not pollutant buildup and washoff. Such models include TR20 (SCS, 1969) and HEC1 (Hydrologic Engineering Center, 1990). These hydrologic models are not discussed in detail here; model documentation and references contain the specific hydrologic calculations used.

Hydrologic models, such as TR20 and HEC1, can be used to generate time-varying runoff flows for one or more storm events using rainfall and watershed characteristics as model inputs. To generate urban runoff pollutant loads, the hydrologic output (flow versus time) from the models could be combined with estimated urban runoff concentrations. For some applications, for example sizing of BMPs such as detention ponds, only a hydrologic model is needed.

Transport Characteristics Determination

In addition to the magnitude of a pollutant load, the location of a pollution source with respect to the affected resource, the mode of transport to the resource and degradation of the pollutant should also be considered. For example, sources with a clear path to a waterway, such as pipes, ditches and gulleys, are more likely to cause adverse effects in a receiving water than similar sources that must travel through natural filters such as forested or grassy areas before entering a surface water body. Changes in loads, from the initial source discharge to the point where they affect the receptor, occur because of such factors as travel time, dilution, soil infiltration, and decay. Fate and transport of pollutants can be modeled using hydrologic and pollutant buildup-washoff models which attempt to account for these factors deterministically. Since the simpler methods (i.e., unit load or statistical) can only empirically estimate these factors, the level of uncertainty and error is likely to be higher. The level of uncertainty is high even with the deterministic models, though. Site-specific data is thus important to validate any tool which is used.

Resource Assessments

Resource assessments address the impact of pollutant sources on the resources of interest—taking the results of the pollutant source assessments (described in the previous section of this chapter) and determining the effect of these pollutant sources on water resources. Assessments, however, can be conducted on other ecological aspects of a watershed, as well. Water resources can include water quality as well as aquatic life, sediment, and other characteristics of the water bodies. Methods to perform resource assessments can range from evaluation of water quality data and comparison with criteria, to mathematical modeling of receiving waters. These methods are described further in this section.

Basic Data Evaluation

Urban runoff problems can be identified by evaluating available and newly collected data. Evaluation of available data is conducted with numerous tools, including spreadsheets, database management systems, GIS, statistical analysis (described in Chapter 5), and mathematical models (described in this chapter). The data are compared to acceptable resource criteria to determine the existence and severity of problems.

A useful measure of the condition of a specific water resource is comparing its water quality, sediment, or biological data with state water quality standards or EPA water quality criteria. State water quality standards define the quality of water that supports a particular designated use. EPA publishes water quality criteria that consists of scientific information regarding the concentrations of specific chemicals in water that protect species against adverse acute (short-term) effects on sensitive aquatic organisms, chronic (long-term) effects on aquatic organisms, and effects on human health from drinking water and eating fish (U.S. EPA, 1986). These criteria, often based on results of toxicity testing of sensitive species, are intended to be protective of all species. Section 304(a)(1) of the Clean Water Act requires EPA to publish and periodically update these criteria.

The Safe Drinking Water Act of 1974, established to protect public drinking-water supplies, requires EPA to publish maximum contaminant level goals (MCLGs), which are non-enforceable levels at which there are no known or anticipated health effects, and maximum contaminant levels (MCLs), which are enforceable levels, based on best technology, treatment techniques, and other factors including cost. Updates to federal criteria are announced in *Federal Register* notices.

States have surface water standards that classify surface water bodies into use categories, establish instream levels necessary to support these uses, and define policies regarding the protection and enhancement of these water resources. EPA can establish water quality standards (40 CFR 131) for toxic pollutants in states and territories that have not fully adopted their own standards. In addition, many states have ground-water standards that designate uses for various ground waters, and water quality levels necessary to sustain these uses and protect ground-water quality.

The interpretation of sediment chemistry results is not straightforward. A number of approaches have been used to evaluate the degree of contamination in sediments (Maughan, 1993). Many of these approaches have been developed to determine impacts associated with dredging activities (U.S. EPA and U.S. ACOE, 1991). EPA is developing criteria for sediment similar to those for water quality for certain organic compounds (U.S. EPA, 1988c). An important factor affecting the development of these criteria is the bioavailability or toxicity risk to aquatic organisms due to a contaminant in undisturbed sediment. Since this bioavailability is influenced by the physical and chemical nature of the sediment, toxic effects which might be seen at low concentrations in some sediment types might not be evident in others.

To take the variability due to sediment characteristics into account, contaminant concentrations are normalized through equilibrium partitioning between particulate and liquid (pore water) phases, after which EPA water quality criteria are used to assess environmental or human health risks. Further development of sediment criteria for inorganics, such as metals, is anticipated. Until sediment criteria are finalized, much of the evaluation of sediment chemistry data is accomplished on a relative basis by comparing the results from upstream and downstream stations to determine if elevated levels of contaminants exist, or by comparing results to other areas where data are available.

Ecological effects can be assessed by examining the biological community structure. Specific parameters to consider include the relative abundance of pollution-tolerant and pollution-sensitive species as well as common indices including, but not limited to, Shannon-Weiner diversity, Simpson's dominance, and evenness (Pielou, 1975) as discussed in Chapter 5. Various types of biological criteria or indices are available from the literature and can be used for comparative purposes. An example of the use of biocriteria to evaluate data is the State of Ohio biotic index, which has been used to assess the condition of the biota of rivers and streams since 1978 (U.S. EPA, 1991e). Ohio's use of biocriteria is described in the case study at the end of this chapter.

Receiving-Water Modeling

Receiving-water models are used to assess existing conditions and to simulate future conditions of a water resource under various pollution prevention and control scenarios. They can also be used to assess the impact of alternative BMPs (Chapter 8). These models receive input from runoff model results, field-measured parameters, and values of parameters found in the literature. The level of complexity of the receiving-water model chosen should parallel that of the model used to assess urban runoff flows and loads. Some commonly used receiving water models include the Enhanced Stream Water Quality Model (QUAL2E), the Water Quality Analysis Simulation Program (WASP4), and the Exposure Analysis Modeling System II (EXAMSII), as summarized in Table 6-7 and described in more detail below. In addition, HSPF, discussed above, has a receiving-water model component. These models, along with the SWMM model, are available from EPA's Center for Exposure Assessment Modeling, Environmental Research Laboratory, in Athens, Georgia.

QUAL2E can be used either as a steady-state or quasi-dynamic model to simulate conditions of rivers with multiple headwaters, waste discharges, tributaries, withdrawals, dams, and incremental inflows and outflows. The model can simulate 15 water quality constituents, including dissolved oxygen, biochemical oxygen demand, temperature, nitrogen and phosphorus species, coliforms, arbitrary nonconservative constituents, and conservative constituents (U.S. EPA, 1987c). QUAL2E-UNCAS is an enhancement to QUAL2E which allows the user to perform uncertainty analysis on the effects of model sensitivities and uncertain input data on model forecasts (U.S. EPA, 1987c). Three types of uncertainty analyses are available: sensitivity analysis, first-order error analysis, and Monte Carlo simulation. Using this model, the user can determine input factors that contribute the most to the model's uncertainty and the level of risk associated with model predictions. Both QUAL2E and QUAL2E-UNCAS are supported by EPA and are well documented.

The modeling framework of WASP4 provides a flexible-compartment modeling approach, applicable in one, two, and three dimensions, which can be used to simulate contaminant fate in surface water. WASP4 is structured to allow the easy substitution of user-written subroutines into the model. Thus, a range of water quality problems can be simulated by WASP4 using either one of the model's kinetic subroutines or a subroutine written by the user. The model can be used to simulate biochemical oxygen demand, dissolved oxygen, nutrients and eutrophication, bacterial contamination, and toxic chemicals in the sediment bed and in the overlying waters. In addition, WASP4 can be linked to other models, such as DYNHYD5, a simple model that simulates variable tidal cycles, wind and unsteady flows, and the Food Chain Model, which predicts pollutant uptake and distribution throughout an aquatic food chain (U.S. EPA, undated).

EXAMSII performs evaluations and error analyses of the fate of synthetic organic chemicals based on user-specified properties of chemicals and ecosystems, such as descriptions of a system's external loadings, transport processes and transformation processes. Model predictions include chemical exposure, consisting of long-term chronic, 24-hour acute, and 96-hour acute concentrations; fate, consisting of the distribution of chemicals in the system and the relative dominance of each transport and transformation process; and persistence, the time required for effective purification of the system once the loading has ended (U.S. EPA, undated).

Model Selection

Selection of receiving water models for resource assessments (or of urban runoff models for pollutant source assessments) depends on considerations such as available input data, project requirements, budget constraints, and user preference and familiarity. It is sometimes useful to choose a simple or screening level model at first to identify major pollutant impacts or loads for which preliminary control measures could be implemented. A more complex model can then be selected if more detailed analyses of the impact of pollutants and the effect of alternative corrective measures are required. Since model simulations can help in selecting pollution prevention and treatment measures (and thus, in allocating of limited funding), the user should have experience with the model to ensure that the model predictions are correct. An understanding of the selected model and its capabilities and limitations is critical.

In 1976, EPA compiled a list of questions and factors that should be considered when selecting a model (U.S. EPA, 1976b). These considerations, which can be used to select either urban runoff or receiving water models, are presented below.

To determine whether a model is required or could be used, one could consider the following issues:

1. What is the problem to be solved?
2. What temporal resolution is required? Depending on the type of water quality problem and receiving-water, single-event, seasonal, or long-term multiple-year calculations might be appropriate.
3. Is a model needed? If so, what approach is necessary (e.g., computer program, hand calculations)? Would a gross assessment of relative loads and impacts on water quality suffice?
4. What input, calibration, and verification data are available? The model selected must be calibrated and verified, and adequate input data must be collected. If data are not available, or if adequate funds for data collection are not provided, the use of a complicated model could be ruled out.

Table 6-7. Comparison of Receiving-Water Models (U.S. EPA, 1983b, 1985a,b)

	Models			
Attribute	**Enhanced Stream Water Quality Model (QUAL2E)**	**Water Quality Analysis Simulation Program (WASP4)**	**Exposure Analysis Modeling Systems II (EXAMS II)**	**Hydrological Simulation Program—Fortran (HSPF)**
Application	River flow, well-mixed lakes	General—river flow, lakes, estuaries, oceans	Nontidal lakes	Unstratified lakes
Dimensionality	One-dimensional	Three-dimensional	Three-dimensional	One-dimensional
State	Steady-state Quasi-dynamic	Time-varying	Steady-state	Time-varying
Water column transport	Advective and dispersive	Advective and dispersive	Advective and dispersive	Advective
Sediment bed condition	Completely mixed	Completely mixed	Completely mixed Simplified exchange	Completely mixed, sedimentation
Sediment bed type	Stationary	Stationary	Stationary	Moving
Unique features	UNCAS—uncertainty analyses of input parameters on model forecasts	TOXIC—models dissolved and adsorbed chemical concentrations EUTRO4—models DO, CBOD, nutrients, phytoplankton DYNHYD5—models tidal cycles, wind, unsteady inflows Food Chain model—simulates uptake and distribution throughout a food chain	Contaminant transformation and transport processes	ARM—Agricultural runoff model NPS—Nonpoint source model

If a model is determined to be necessary, other factors to consider include the following:

1. Regardless of the method selected, personnel qualified in water quality analysis should be available. Any model, simple or complicated, requires a considerable amount of expert judgment in its application. Without this expertise, model application likely will fail.
2. The major costs in applying any computer-based model are related to becoming familiar with the model, collecting basic data for model application (most of these data remain the same, regardless of the number of times the model is used), and setting up the model on the local computer system. Thus, availability of models that previously have been calibrated and applied locally should be considered.

Once it has been determined that a model will be used, the following questions should be considered in determining whether the model is suitable for the problem being studied.

1. What, if any, water quality constituents are to be modeled and can the model accommodate them?
2. Is the problem steady state or dynamic (i.e., do sources or conditions change over time)?
3. What are the spatial considerations? For streams, a one-dimensional model is adequate if homogeneous mixing across the river cross-section is an adequate assumption. For an estuary, a two- or three-dimensional model might be required.
4. Has a model under consideration been used and tested? Is good, user-oriented documentation available?
5. If a proprietary model is considered, how will continuity in planning be accommodated? The planning process is ongoing, and models are most economical when used repeatedly.
6. What are the costs of model application? Computer costs are relatively insignificant; the major costs of model use are personnel costs.

Model Validation

The input data file for a model used either for resource assessment or pollutant source assessment is calibrated using values of parameters measured during field investigations of the pollution sources and/or receiving-water system, depending on the type of modeling. Parameters to be included as model input, but that were not measured during field sampling, are estimated and adjusted to provide a close fit of model predictions to measured data. Values for parameters not easily or regularly measured can be obtained from engineering and scientific publications. Often, typical values, or "default values," for these parameters are presented in the model's user manual and can be used in the initial phases of model calibration.

Model verification, the next step in the model validation process, often involves using a second data set to verify the accuracy of the calibrated model input. Measured parameters from the second data set are input to the model and simulated levels of parameters (such as dissolved oxygen concentration) are compared to actual values measured during the second field sampling survey. Verification may be conducted qualitatively, by visually comparing graphical representations of the model simulation and actual data. In addition, a quantitative verification can be conducted through the use of simple statistical comparisons. Calibrated parameters can be adjusted again, to ensure a good fit between model predictions and each data set. A detailed discussion of the model validation procedure was presented by U.S. EPA (1980).

Once the urban runoff or receiving-water model has been validated, it can be used to simulate various scenarios of storm events, pollutant loadings, and corrective measures. Graphical presentation of model results is an effective method for displaying model simulations during evaluation of results and in reports. While computer modeling is valuable for examining existing conditions and simulating impacts due to future changes, users should be aware that model predictions are only as accurate as the quality of the data used; some level of error is associated with even the best modeling techniques.

Institutional Assessments

Assessment of the institutional constraints of a program provides the managers with perspective concerning the nontechnical issues affecting the program. The institutional issues of a program are assessed by evaluating the program's potential and limitations and by reviewing the requirements of involved agencies and the public. One major institutional issue that must be addressed on an urban runoff program is determining the responsibilities of each involved party, especially for programs involving multiple agencies. Issues related to the control of the program (e.g., enforcement, maintenance, permitting, and funding) can affect the program's emphasis and the selection of its corrective measures. Another institutional issue involves the limitations of available technology. Implementability of controls can also be considered, particularly in areas involving limited access to private properties. The potential for eliminating or reducing an urban runoff problem or improving affected water resources can also be considered. Questions and concerns of the public might prove to be influential during the decision-making processes. Applicable regulations could force the sequencing of corrective measures so that those addressing compliance with the regulations are implemented first.

Goals and Objectives Assessments

The relative importance of an urban runoff problem can be assessed by comparing it to the program's resource and/or technology-based goals and the objectives of the program's sponsor, as discussed in Chapter 3. For example, one water resource goal might be to "provide improvements to water quality in areas where the most people will benefit." Comparison of the pollution problems to such a goal provides the program team with perspective on which problems to solve to achieve the goal. By comparing the pollution problems to the program's goals and objectives, the program team can identify and focus on problems that are compatible with these goals. The assessments conducted on pollutant sources, water resources, and institutional aspects provide input to these determinations.

Problem Ranking

Since funding to correct pollution problems is usually limited, the sources or impacts to be addressed should be prioritized to allow for targeting of limited resources. While ranking is a subjective process that requires the judgment of decision-makers, ranking systems can be used to help develop priorities. A ranking methodology can range from simple, descriptive methods (qualitative) to numerically complex (quantitative), depending on the urban runoff program objectives and funding constraints. Ranking methods can apply to a variety of geographic areas, ranging from counties or communities with multiple watersheds to individual water bodies or pollution sources. Criteria such as those presented in Table 6-1 can be used in problem ranking.

Ranking should be conducted following consultation with involved parties, including local, state, and federal agencies; local environmental groups; and concerned citizens. Public opinion can have a large influence on the ranking of pollution problems. For example, the public might give priority to controlling sources that discharge to a favorite pond used for swimming. Urban runoff control programs should consider public concerns and desires when prioritizing problems, no matter which type of ranking approach is employed.

Three types of ranking procedures, ranging from simple to complex, are discussed in this section.

Qualitative Ranking

The simplest ranking approach uses qualitative rankings (e.g., high, moderate, or low) to prioritize pollution problems such as in the example presented in Table 6-5. Other qualitative ranking methods use letters (e.g., A, B, C) or numbers (e.g., 1, 2, 3) to develop a relative scale for comparing problems. The qualitative rankings must then be interpreted to determine which problems should be of highest priority in developing controls. In the example in Table 6-5, the qualitative rank is based on estimated pollutant load. Other measures can also be used as a basis for qualitative rankings (e.g., level of public concern or the importance of the use to be protected).

Numerical Ranking

To perform numerical ranking, rating points are assigned to each ranking criterion for each problem. Each ranking criterion is assigned a weight based on its importance relative to the other criteria. The rating points are then multiplied by the relative weight. All of the products (i.e., criterion rating x relative weight) are summed for a given problem. This procedure is then repeated for all the problems being evaluated. The sums thus assigned are compared and the problems with the highest sums receive the highest priority during implementation of urban runoff controls.

In an example of a numerical ranking system for prioritizing pollution sources (Woodward-Clyde Consultants, 1990b), a hypothetical application of this weighted ranking methodology uses the following criteria: water body importance (as reflected by stream or lake size), type of use (ranging from urban drainage to recreational contact), status of use (impaired versus denied), level of use (low, moderate or high), pollutant loads (not actual loads but estimates for comparative purposes), and implementability of controls (based on institutional factors, existing ordinances, or technical considerations). These criteria are similar to some identified in Table 6-1. The relative importance of each criterion is designated by assigning a weight appropriate for the site-specific conditions of the watershed under consideration. The sum of all weights used to rank the problems equals 100. Next, for each problem, the criteria are ranked using a suggested range of 1 to 9, with a higher numerical ranking indicating a higher need for corrective action. This listing allows relative comparisons to be made among problems with respect to a single criterion.

A hypothetical urban watershed, consisting of three streams and several types of land use, illustrates this numerical ranking method for prioritizing pollution problems (Figure 6-1). Information describing the system is presented in Tables 6-8 and 6-9. Typical sources for these data include site-specific pollutant loading data, model results, and literature values from data bases such as those identified earlier in this chapter. There are four criteria of equal weight: stream size, beneficial use, pollutant load, and ability to implement (Table 6-10). The three "use" criteria are clustered together as subcriteria of the "beneficial use" criterion.

Ranking for "stream size" is determined based on the total drainage area of each of the three streams. Consistent with the goals for the hypothetical watershed, Stream C is ranked highest with respect to "type of use" because of its recreational uses in the city park; because it is used mainly as an urban drain, Stream B receives the lowest ranking; and Stream A is ranked between the other two streams because it is used to support aquatic life. With respect to "status of use," Stream A ranks highest because although somewhat impaired, it has the potential to be improved by control of pollution sources. Stream B receives a low ranking for use status because its water quality is poor and its function as part of an urban drainage system has long been accepted. Stream C also receives a low ranking for use status since the water is of high quality. Rankings for "level of use" reflect the number of people using or affected by each stream.

Mass pollutant loadings are calculated based on runoff coefficients (functions of the amount of impervious area), runoff concentrations of pollutants, and the amount of land use type in each stream's drainage area. Each stream is ranked based on the proportion of pollutant load from its watershed (in this example, total suspended solids is used). The watershed of Stream B is judged easiest to implement controls because it is predominantly industrial. Based on the method presented in this example, Stream C's watershed should receive priority during implementation of controls, followed by Stream A's and then Stream B's.

Quantitative Ranking

A fully quantitative ranking of urban runoff problems also could be performed using pollutant source assessment methods such as urban runoff models and resource assessment methods such as receiving-water models. Quantitative ranking requires the greatest amount of resources. For this approach, the models would be used to determine which pollution sources contribute the greatest impacts by testing various load reduction scenarios. Through such evaluations, critical problem sources or impacts could be prioritized. Chapter 8, which concerns selection of BMPs, discusses this type of approach further.

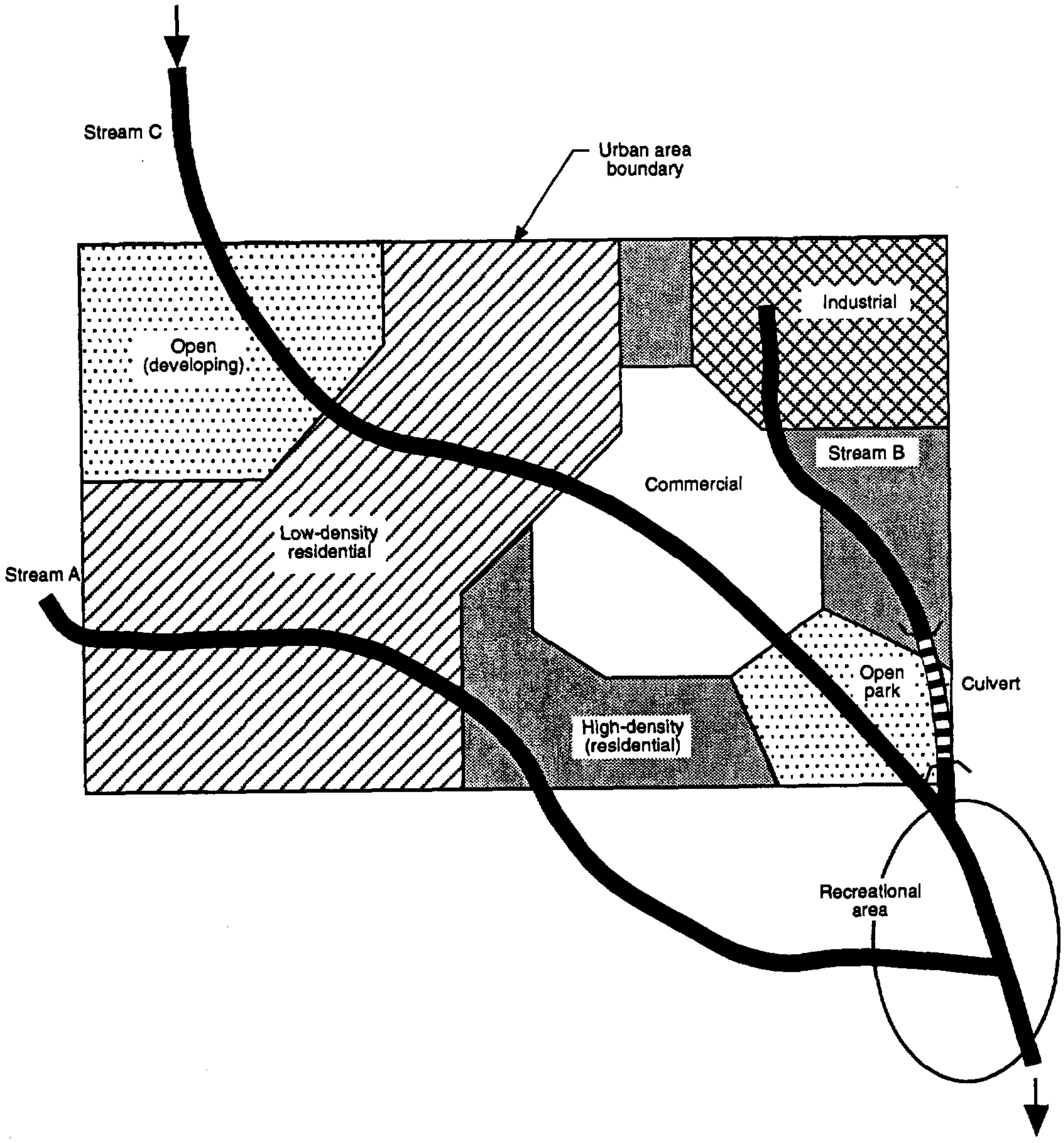

Figure 6-1. Schematic representation of watershed (Woodward-Clyde Consultants, 1990b).

Table 6-8. Characteristics of the Targeted Areas and Estimated Concentration Loads (Woodward-Clyde Consultants, 1990b)

Land Use Category	Runoff Coefficient	Average Concentration in Runoff, mg/L: Total Suspended Solids	Oil and Grease	Total Petroleum	Copper	Drainage Area, ac: Stream A	Stream B	Stream C	Urban Total
Industrial	0.6	120	20	0.20	0.05	0	150	0	150
Commercial	0.8	80	15	0.20	0.05	10	80	110	200
Residential (high density)	0.4	90	10	0.40	0.04	100	100	50	250
Residential (low density)	0.2	100	5	0.60	0.03	200	0	200	400
Open—developing	0.1	150	0	0.80	0.01	0	0	150	150
Open—urban park	0.1	50	0	0.80	0.01	0	0	50	50
Total urban area						310	330	560	1,200
Upstream drainage area						600	0	20,000	20,600
Total drainage area						910	330	20,560	21,800

Table 6-9. Estimated Total Suspended Solids Loads for Targeted Areas (Woodward-Clyde Consultants, 1990b)

Land Use Category	Total Suspended Solids, lb/in of rain: Stream A	Stream B	Stream C	Urban Total
Industrial	0	2,452	0	2,452
Commercial	145	1,162	1,598	2,906
Residential (high density)	817	817	409	2,043
Residential (low density)	908	0	908	1,816
Open—developing	0	0	511	511
Open—urban park	0	0	57	57
Watershed total	1,870	4,431	3,482	9,784
Watershed rank value	1.7	4.1	3.2	9.0

Table 6-10. Prioritization Analysis for Urban Area Targeting (Woodward-Clyde Consultants, 1990b)

Urban Watershed	Stream Size	Beneficial Use: Type	Status	Level	Pollutant Load (TSS)	Ability to Implement	Target Score*
Weights	25	10	10	5	25	25	100
Watershed A	4	5	7	4	1.7	5	4.08
Watershed B	2	2	2	1	4.1	7	3.73
Watershed C	8	8	2	6	3.2	3	4.85
Total urban watershed	8	8	5	8	9.0	2	6.45

* Target score = weighted average of rank points = sum (rank score x weight)/sum (weight)

Case Study:
Ohio Environmental Protection Agency
Biological Criteria for the Protection of Aquatic Life

Background

Since 1978, the Ohio Environmental Protection Agency (Ohio EPA) has been assessing the biota of rivers and streams as part of its basic monitoring strategy. This biomonitoring program was developed for Ohio's fishable waters in response to aquatic life goals of the Clean Water Act. Originally, biocriteria were used to assess the effects of wastewater treatment plant discharges on aquatic life throughout the state. Then, with the increased emphasis on addressing storm water runoff and NPS pollution sources, the Ohio EPA has begun using biomonitoring for these sources.

The use of biocriteria to assess a water body's overall health has several advantages over more common chemical analysis of receiving waters, including (Ohio EPA, 1987):

- The fish and macroinvertebrates sampled inhabit the receiving water continuously.
- The effects of past events (e.g., floods and droughts) are considered.
- Cumulative impacts can be seen.
- The species used have a long life span.
- The species allow a direct measure of CWA's biological goals.

The traditional approach of water chemistry analysis results in a snapshot of the receiving-water body at the time of sampling. For a more complete picture, numerous sampling events are required, which can be very costly. Biocriteria analysis, however, gives a cost-effective assessment, although somewhat qualitative, of the water body and its ability to support aquatic life.

Analysis Methods

In developing biocriteria, the state was divided into five different ecoregions with generally homogeneous characteristics. Within each ecoregion, water bodies were selected as "regional reference sites" to represent "least impacted" conditions. Rather than represent pristine conditions, these sites were selected based on the amount of stream channel modification, the condition of the vegetative riparian buffer, water volume, obvious color/odor problems, and general representativeness. Once these sites were selected, fish and macroinvertebrate sampling programs were implemented to determine water body characteristics and to obtain information required to develop quantifiable criteria to compare with the health of other water bodies. Three water body health indices were developed from the sampling data:

- Index of biotic integrity (IBI)
- Modified index of well being (MIwb)
- Invertebrate community index (ICI)

The IBI and MIwb are used to assess fish community health, and the ICI is used in the assessment of macroinvertebrate communities. Each index is developed by assessing a number of criteria for the water body of interest, as described below.

Index of Biotic Integrity

Used as a measure of the health of fish communities, the IBI consists of 12 criteria, or metrics, designed to give an overall assessment of the biota. The metrics are developed depending on the type of water resource being analyzed. The three types of sites include headwaters sites (drainage areas less than 20 square miles), wading sites (drainage areas greater than 20 square miles sampled by wading), and boat sites (drainage areas greater than 20 square miles sampled from a boat). Each of these types has its own set of metrics for use in determining the IBI, as shown in Table 6-11.

Table 6-11. Index of Biotic Integrity (IBI) Metrics

IBI Metric	Headwaters Sites	Wading Sites	Boat Sites
1. Total number of species	X	X	X
2. Number of darter species	X	X	
Round-bodied suckers, %			X
3. Number of sunfish species		X	X
Number of headwaters species	X		
4. Number of sucker species		X	X
Number of minnow species	X		
5. Number of intolerant species		X	X
Number of sensitive species	X		
6. Tolerant species, %	X	X	X
7. Omnivores, %	X	X	X
8. Insectivorous species, %	X	X	X
9. Top carnivores, %		X	X
Pioneering species, %	X		
10. Number of individuals	X	X	X
11. Simple lithophils, %		X	X
Number of simple lithophilic species	X		
12. Diseased individuals, %			
DELT anomalies, %	X	X	X

Data for each of these metrics were collected and plotted against drainage area for each of the "least affected reference sites" in each ecoregion. The plot showing the relationship between the metric and drainage area was then divided into three equal regions as shown in Figure 6-2. These plots form the basis for determining the IBI for the water body of concern. When determining the IBI, data for the water body are compared with the "least affected reference site" plots, and each metric is rated according to whether it approximates (5), deviates somewhat from (3), or strongly deviates (1) from the value expected at a reference site. For example, looking at the number of species example shown in Figure 6-2, a water body with a drainage area of 10 square miles and 10 species collected during a sampling run would be given a rating of 3 for that metric. Similar ratings are given for all 12 metrics making up the IBI. After all ratings for a water body are given, they are added up; the sum represents the water body's IBI. Because of the rating scales used, the IBI for a water body will range from 12 (very poor biotic integrity) to 60 (very good biotic integrity). Ranges of IBI values and their respective qualitative assessments are shown in Table 6-12.

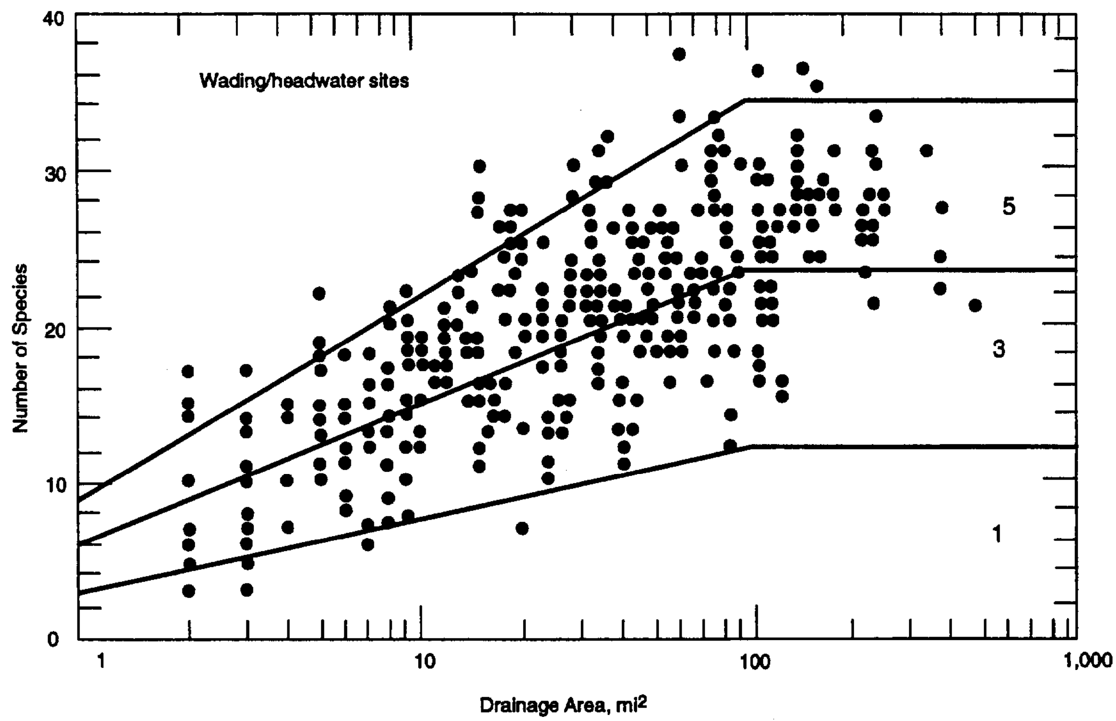

Figure 6-2. Number of species vs. drainage area for determining 5, 3, and 1 index of biotic integrity (IBI) scoring.

Table 6-12. Qualitative Assessment of Index of Biotic Integrity (IBI) Values

	Exceptional	Good	Fair	Poor	Very Poor
Wading sites	50-60	36-48	28-34	18-26	<18
Boat sites	50-60	36-48	26-34	16-24	<16
Headwaters sites	50-60	40-48	26-38	16-24	<16

Modified Index of Well Being

The MIwb is the second index used to describe the quality of fish populations in water bodies throughout the state. A more traditional index, the MIwb takes into consideration the fact that healthy systems support a larger variety and abundance of fish than stressed systems. This index incorporates four measures of fish community health:

- Numbers of individuals
- Total biomass
- Shannon diversity index based on numbers
- Shannon diversity index based on weight

The formulas used to calculate MIwb are:

$$MIwb = 0.5 \ln N + 0.5 \ln B + H(no.) + H(wt.)$$

where:

N = relative numbers of all species (excluding species designated highly tolerant)
B = relative weights of all species (excluding species designated highly tolerant)
H(no.) = Shannon diversity index based on numbers
H(wt.) = Shannon diversity index based on weight

The Shannon diversity index is defined by the following formula:

$$H = -\Sigma[(n_i/N) \times \ln(n_i/N)]$$

where:

n_i = relative numbers or weight of the i^{th} species
N = total number or weight of the sample

Ranges of MIwb values and their respective qualitative assessments are shown in Table 6-13.

Table 6-13. Qualitative Assessment of Modified Index of Well Being (MIwb) Values

	Exceptional	Good	Fair	Poor	Very Poor
Wading sites	≥9.4	8.0-9.3	5.9-7.9	4.5-5.9	≤4.5
Boat sites	≥9.5	8.3-9.4	6.4-8.7	5.0-6.4	≤5.0

Invertebrate Community Index

The ICI is used to measure the health of the invertebrate community. Invertebrates are useful as indicators of environmental quality because they (Ohio EPA, 1987):

- Form permanent and relatively immobile communities
- Can be easily collected in large numbers even in small water bodies
- Can be sampled at relatively low cost per sample
- React quickly to environmental change
- Occupy all stream habitats
- Inhabit the middle of the aquatic food web

The method used to determine the ICI is similar to that for the IBI. A number of "least affected reference sites" were identified and sampled to develop criteria. The ICI consists of 10 invertebrate community metrics each with four rating categories (0, 2, 4, and 6). The 10 metrics used to calculate the ICI are:

- Total number of taxa
- Total number of mayfly taxa
- Total number of caddisfly taxa
- Total number of dipteran taxa
- Percent mayfly composition
- Percent caddisfly composition

- Percent tribe tanytarsini midge composition
- Percent other dipteran and non-insect composition
- Percent tolerant organisms
- Total number of qualitative EPT taxa [EPT = *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies)]

The rating involves giving 6 points to sites of exceptional quality, 4 points for those representing typical good communities, 2 points for slightly affected communities, and 0 points for highly affected communities. As shown in Figure 6-3, plots have been developed to determine the range of values for each metric. For example, a stream sample that has a drainage area of 100 square miles and a total of 30 taxa would receive a rating of 4. A similar analysis is performed for each metric and the 10 values are summed to obtain the final ICI value. This value, which ranges from 0 to 60, represents the health of the water body with respect to the invertebrate community. Ranges of ICI values and their respective qualitative assessments are shown in Table 6-14.

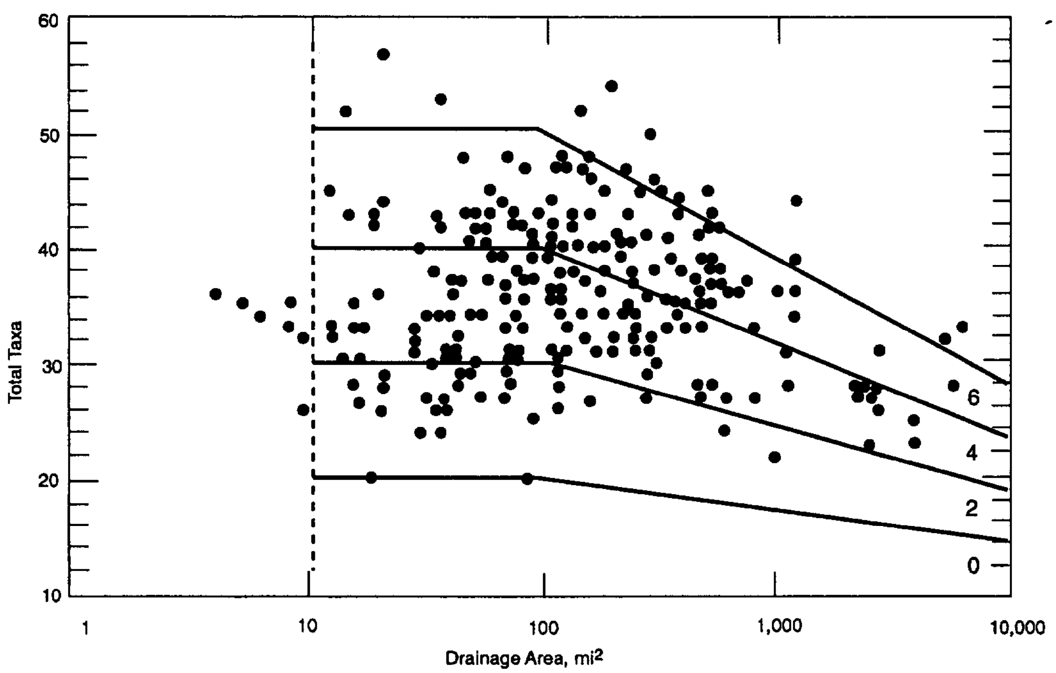

Figure 6-3. Total taxa vs. drainage area for determining 6, 4, 2, and 0 invertebrate community index (ICI) scoring.

Table 6-14. Qualitative Assessment of Invertebrate Community Index (ICI) Values

	Exceptional	Good	Fair	Poor	Very Poor
All sites	48-60	34-46	14-32	2-12	0

Example of Biocriteria Implementation

Taken from the upper Hocking River in Ohio, the calculation of IBI values for fish habitat at two different river headwater stations are shown in Table 6-15. In this example, the fish habitat at Station 2 is significantly better than at Station 1. As indicated by Table 6-12, the index for Station 1 (14) ranks it as very poor for fish habitat, while the rating for Station 2 (34) ranks it as fair for fish habitat. In order to compare these habitats effectively, strict controls had to be kept over the methods used to obtain the fish and analyze the results. To implement similar programs in other areas, the necessary background studies and tests must be conducted because of the site-specific nature of the criteria used to develop the IBI.

Table 6-15. Indices of Biotic Integrity for Two Headwater Stations in Hocking River, Ohio

	Station 1		Station 2	
	Value	Ranking	Value	Ranking
Numbers of				
Total species	5	1	14	3
Total individuals	12	1	130	1
Sunfish species	1	1	4	5
Sucker species	1	1	3	3
Intolerant species	0	1	0	1
Proportion of individuals, %				
Round-bodied suckers	0	1	34	3
Omnivores	67	1	38	1
Insectivores	19	1	50	3
Tolerant species	86	1	42	1
Top carnivores	7	3	10	3
Simple lithophils	7	1	57	5
Anomalies	0	1	0	5
Totals		14		34

References

When an NTIS number is cited in a reference, that document is available from:
National Technical Information Service
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Springfield, VA 22161
703-487-4650

Driscoll, E.D, P.E. Shelley, and E.W. Strecker. 1989. Pollutant loadings and impacts from highway storm water runoff. McLean, VA: Federal Highway Administration, Office of Engineering and Highway Operations Research and Development.

Driver, N.E., and G.D. Tasker. 1990. Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States. Denver, CO: U.S. Geological Survey. Open-File Report 88-191, Water Supply Paper #2363.

Hydrologic Engineering Center. 1990. HEC1, flood hydrograph package user's manual. U.S. Army Corps of Engineers.

Maughan, J.T. 1993. Ecological assessment of hazardous waste sites; chapter 7, evaluation of contaminants in sediments. New York, NY: Van Nostrand Reinhold.

Metcalf & Eddy, Inc. 1991. Wastewater engineering: treatment, disposal, and reuse, 3rd edition. New York, NY: McGraw-Hill.

Novotny, Vladimir. 1992. Unit pollutant loads. Water Environ. Tech. January.

Nix, Stephan. 1991. Applying urban runoff models. Water Environ. Tech. 3(6).

Ohio EPA. 1987. Ohio Environmental Protection Agency. Biological criteria for the protection of aquatic life. Division of Water Quality Monitoring and Assessment.

Pielou, E.C. 1975. Ecological diversity. New York, NY: John Wiley & Sons.

Pitt, Robert. 1989. SLAMM 5—source loading and management model: an urban nonpoint source water quality model, volume I: model development and summary. University of Alabama at Birmingham.

SCS. 1969. Soil Conservation Service. Project formulation program: hydrology. Tech. release no. 20. U.S. Department of Agriculture.

SCS. 1977. Soil Conservation Service. Procedure for computing sheet and rill erosion on project areas. Tech. release no. 51. U.S. Department of Agriculture.

Tasker, G.D., and N.E. Driver. 1988. Nationwide regression models for predicting urban runoff water quality at unmonitored sites. Water Res. Bull. 24(5):1091-1101.

U.S. EPA. 1974. U.S. Environmental Protection Agency. Urban stormwater management and technology: an assessment. EPA/670/2-74/040 (NTIS PB-240687). December.

U.S. EPA. 1976a. U.S. Environmental Protection Agency. Storm water management model: level I—preliminary screening procedures. EPA 600/2-76/275 (NTIS PB-259916). October.

U.S. EPA. 1976b. U.S. Environmental Protection Agency. Areawide assessment procedures manual, volumes I, II and III. EPA/600/9-76/014 (NTIS PB-271863). U.S. EPA Office of Research and Development. July.

U.S. EPA. 1977. U.S. Environmental Protection Agency. Urban stormwater management and technology: update and users' guide. EPA/600/8-77/014 (NTIS PB-275654). Washington, DC. September.

U.S. EPA. 1979. U.S. Environmental Protection Agency. A statistical method for the assessment of urban stormwater. EPA/440/3-79/023 (NTIS PB-299185/a).

U.S. EPA. 1980. U.S. Environmental Protection Agency. Measures of verification. Proc. Workshop on Verification of Water Quality Models. EPA/600/9-80/016 (NTIS PB80-186539). April.

U.S. EPA. 1981. U.S. Environmental Protection Agency. User's manual for hydrologic simulation program—Fortran (HSPF). Release 7.0. Washington, DC.

U.S. EPA. 1982a. U.S. Environmental Protection Agency. Urban rainfall-runoff-quality data base. EPA/600/S2-81/238. July.

U.S. EPA. 1982b. U.S. Environmental Protection Agency. Water quality assessment: a screening procedure for toxic and conventional pollutants, volumes I and II. EPA/600/6-82/004a (NTIS PB83-153122) and b (NTIS PB83-153130).

U.S. EPA. 1983a. U.S. Environmental Protection Agency. Results of the Nationwide Urban Runoff Program, volume 1. Final report. Washington, DC: U.S. EPA Water Planning Division. (NTIS PB84-185552.)

U.S. EPA. 1983b. U.S. Environmental Protection Agency. Technical support manual: waterbody surveys and assessments for conducting use attainability analyses, volumes I, II and III. Office of Water Regulations and Standards. Washington, DC. November.

U.S. EPA. 1985a. U.S. Environmental Protection Agency. Technical guidance manual for performing wasteload allocations. Washington, DC. May.

U.S. EPA. 1985b. U.S. Environmental Protection Agency. Rates, constants, and kinetics formulations in surface water quality modeling, 2nd ed. EPA/600/3-85/040 (NTIS PB85-245314). June.

U.S. EPA. 1986 as updated in 1987. U.S. Environmental Protection Agency. Quality criteria for water. EPA/440/5-86/001.

U.S. EPA. 1987a. U.S. Environmental Protection Agency. Setting priorities: the key to nonpoint source control. Office of Water Regulations and Standards. Washington, DC.

U.S. EPA. 1987b. U.S. Environmental Protection Agency. Guide to nonpoint source pollution control. Office of Water. Washington, DC.

U.S. EPA. 1987c. U.S. Environmental Protection Agency. The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: documentation and user model. EPA/600/3-87/007 (NTIS PB87-202156).

U.S. EPA. 1988a. U.S. Environmental Protection Agency. Ready reference guide to nonpoint source pollution; sources, pollutants, impairments; best management practices for the New England states. Detailed from U.S. Department of Agriculture, Soil Conservation Service. U.S. EPA Region I. Boston, MA.

U.S. EPA. 1988b. U.S. Environmental Protection Agency. Storm water management model, version 4.0: user's manual. Washington, DC.

U.S. EPA. 1988c. U.S. Environmental Protection Agency. Interim sediment criteria values of nonpolar hydrophobic organic contaminants. Washington, DC: U.S. EPA Office of Water Regulations and Standards, Criteria and Standards Division. SCD #17.

U.S. EPA. 1990. U.S. Environmental Protection Agency. Assessment of urban and industrial stormwater runoff toxicity and the evaluation/development of treatment for runoff toxicity abatement—phase I. Edison, NJ. U.S. EPA Office of Research and Development.

U.S. EPA. 1991a. U.S. Environmental Protection Agency. Water quality problem identification in urban watersheds. Seminar publication, Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504).

U.S. EPA. 1991b. U.S. Environmental Protection Agency. Guidance for water quality-based decisions: the TMDL process. EPA 440/4-91/001. April.

U.S. EPA. 1991c. U.S. Environmental Protection Agency. Evaluation of dredged material proposed for ocean disposal: testing manual. EPA/503/8-91/001.

U.S. EPA. 1991d. U.S. Environmental Protection Agency. Modeling of nonpoint source water quality in urban and non-urban areas. EPA/600/3-91/039 (NTIS PB92-109115). U.S. EPA Office of Research and Development.

U.S. EPA. 1991e. U.S. Environmental Protection Agency. The use of biocriteria in the assessment of nonpoint and habitat impacts in warmwater streams. Proc. Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504).

U.S. EPA. 1992. U.S. Environmental Protection Agency. Casco Bay storm water management project: Concord Gully, Frost Gully and Kelsey Brook watersheds. U.S. EPA Region I. Boston, MA. January.

U.S. EPA. Undated. U.S. Environmental Protection Agency. Description of the services and models available from the Center for Exposure Assessment Modeling (CEAM), Office of Research and Development, Environmental Research Laboratory. Athens, GA.

U.S. EPA and U.S. ACOE. 1991. U.S. Environmental Protection Agency and U.S. Army Corps of Engineers. Evaluation of dredged material proposed for ocean disposal: testing manual. EPA/503/8-91/001.

Walesh, S.G. 1989. Urban surface water management. New York, NY: John Wiley & Sons, Inc.

Woodward-Clyde Consultants. 1990a. Pollutant loading and impacts from highway stormwater runoff, volumes 1 through 4. McLean, VA: Federal Highway Administration.

Woodward-Clyde Consultants. 1990b. Urban targeting and BMP selection: an information and guidance manual for state NPS program staff engineers and managers. Final report.

Chapter 7
Screen Best Management Practices

Selecting BMPs for preventing and controlling urban runoff pollution is a two-step process. First, a comprehensive list of BMPs should be compiled and screened to eliminate those that are inappropriate for the area. Based on appropriate BMPs, alternatives are then developed and assessed. Finally, the BMPs to be implemented are selected.

This chapter addresses the first step in this process—initial screening. First, a general overview of the categories of BMPs addressed in this handbook is given. The chapter then describes methods of screening the list of potential BMPs. The remainder of the chapter defines BMPs used for urban runoff pollution prevention and control, along with a brief description of their characteristics and sources of additional information. This chapter's contents assist in compiling a list of BMPs for consideration in the screening process.

Best Management Practice Overview

Urban runoff pollution problems are more difficult to control than steady-state, dry-weather point source discharges because of the intermittent nature of rainfall and runoff, the number of diffuse discharge points, the large variety of pollutant source types, and the variable nature of the source loadings. Since the expense of constructing facilities to collect and treat urban runoff is often prohibitive, the emphasis of storm water pollution control should be on developing a least cost approach which includes nonstructural controls and low-cost structural controls.

Nonstructural controls include regulatory controls that prevent pollution problems by controlling land development and land use. They also include source controls that reduce pollutant buildup or lessen its availability for washoff during rainfall. A case study at the end of this chapter discusses the extensive nonstructural regulatory urban runoff controls used by Austin, Texas.

Low-cost structural controls include the use of facilities that encourage uptake of pollutants by vegetation, settling, or filtering. Because of the variability of pollutant removal, these controls can be used in series or in parallel combinations. The concept of implementing a "treatment train" might, for example, include initial pretreatment, primary pollutant removal, and final effluent polishing practices to be constructed in series.

All sources, both point and nonpoint, in a program area or watershed should be addressed. For urban areas, such sources often include urban runoff as well as CSOs. Practices for controlling both storm water and CSO pollution are described in this chapter. The practices discussed for urban runoff control are also applicable to storm water before it enters a combined sewer collection system. In addition, this chapter describes various types of storage and treatment facilities also commonly used to address CSOs.

Depending on the pollutant control mechanisms used, urban runoff pollution control practices can be divided into several categories:

- Regulatory controls
- Source controls
- Detention facilities
- Infiltration facilities
- Vegetative practices
- Filtration practices
- Water quality inlets

CSO-specific control practices are also divided into several categories:

- Source controls
- Collection system controls
- Storage
- Physical treatment
- Chemical precipitation
- Disinfection

While these lists do not include all urban runoff and CSO control practices, these categories are convenient ones for purposes of presentation and discussion.

Table 7-1 lists commonly used urban runoff and CSO BMPs based on the categories provided. The next section describes methods of BMP screening. The remainder of the chapter then gives a brief overview of some of the more important characteristics of these BMPs, including the types of pollutants controlled, the pollution removal mechanisms employed, limitations on their use, maintenance requirements, and general design considerations.

Best Management Practice Screening

The goal of BMP screening is to reduce the comprehensive list of BMPs to a more manageable list for final selection. Because this step is an initial screening, methods used are generally qualitative and require professional judgment. While extensive knowledge about specific design criteria is not necessary at this stage in the screening process, understanding the BMP's effectiveness and applicability to the program area's problems is crucial.

For this discussion, the BMPs are divided into two general categories: nonstructural and structural. Nonstructural BMPs—which include regulatory practices, such as those that limit impervious area or protect natural resources, and source controls, such as street sweeping or solid waste management—are typically implemented throughout an entire community, watershed, or special area. While structural BMPs, such as detention ponds or infiltration practices, may be designed to address specific pollutants from known sources, they also can be implemented throughout an area. In addition, structural BMPs can be required in new developments or redevelopments.

Comprehensive plans addressing urban runoff pollution prevention and control rely on both nonstructural and structural practices. While plans addressing specific

Table 7-1. Urban Runoff Pollution Control BMPs

Urban Runoff Controls	CSO Controls
Regulatory Controls	**Source Controls**
Land use regulations	Water conservation programs
Comprehensive runoff control regulations	Pretreatment programs
Land acquisition	**Collection System Controls**
Source Controls	Sewer separation
Cross-connection identification and removal	Infiltration control
Proper construction activities	Inflow control
Street sweeping	Regulator and system maintenance
Catch basin cleaning	Insystem modifications
Industrial/commercial runoff control	Sewer flushing
Solid waste management	**Storage**
Animal waste removal	Inline storage
Toxic and hazardous pollution prevention	Offline storage
Reduced fertilizer, pesticide, and herbicide use	Flow balance method
Reduced roadway sanding and salting	**Physical Treatment**
Detention Facilities	Bar racks and screens
Extended detention dry ponds	Swirl concentrators/vortex solids separators
Wet ponds	Dissolved air flotation
Constructed wetlands	Fine screens and microstrainers
Infiltration Facilities	Filtration
Infiltration basins	**Chemical Precipitation**
Infiltration trenches/dry wells	**Biological Treatment**
Porous pavement	**Disinfection**
Vegetative Practices	Chlorine treatment
Grassed swales	UV radiation
Filter strips	
Filtration Practices	
Filtration basins	
Sand filters	
Other	
Water quality inlets	

problems in small watersheds might tend to focus on structural practices, urban runoff pollution prevention and control programs should include implementation of nonstructural as well as structural control approaches. Methods for screening both nonstructural and structural practices are outlined below.

Nonstructural Practices

Since the number of potential nonstructural BMPs to be implemented is very large, initial screening is useful before the final selection process. The regulatory and source control BMP descriptions contained later in this chapter focus on the most commonly implemented practices; other, less commonly used practices, however, also could be considered. In addition, each practice (e.g., solid waste management) can be divided into numerous subpractices (e.g., management of leaf litter, rubbish, garbage, and lawn clippings). An urban runoff management plan for the Santa Clara Valley, for example, identified more than 100 separate potential nonstructural BMPs used throughout the country (Woodward-Clyde Consultants, 1989). Municipalities, therefore, have to screen regulatory and source control BMPs based on their particular watershed. The Santa Clara Valley program and the BMP screening and selection method are discussed in the case study at the end of Chapter 8.

One screening method involves applying screening criteria to each nonstructural practice to determine its applicability to the conditions in the watershed. The screening criteria, which are specific to the watershed and depend on the program goals, include:

- *Pollutant removal:* Since different regulations and source control practices are designed to address different pollutants, the program team should ensure that the screened list of controls includes practices designed to address the pollutants of primary concern. In addition, some practices might not provide sufficient pollutant removal.
- *Existing government structure:* Some practices implemented throughout the country require a specific government structure. For example, while a strong county government might be important for implementing a specific regulatory control, the role of county governments can vary from one section of the country to another. Practices requiring specific government structures that do not exist in the area of concern therefore could be eliminated from the list.
- *Legal authority:* For regulatory controls to be effective, the legal authority to implement and enforce the regulations must exist. If municipal boards and officials lack this authority, they could be required to obtain it through local action.
- *Public or municipal acceptance:* Implementing certain practices could be difficult because of resistance from the public or an involved municipal agency. These practices can be eliminated from the list.
- *Technical feasibility:* The municipal BMPs that require large expenditures and extensive efforts might not be suitable for small municipalities that lack the required resources.

Additional screening criteria may also be used, as shown in the Santa Clara Valley case study at the end of Chapter 8.

Another method of screening involves use of a comparative summary matrix. Figure 7-1 shows an example of such a matrix that can be used to screen nonstructural control practices. Though developed for screening nonstructural control practices in coastal areas, this matrix is at least in part applicable to inland areas as well. In this matrix, various regulatory and source control practices are listed and their abilities to meet various criteria are compared. The criteria listed include ability to remove specific pollutants, such as nutrients and sediments, maintenance requirements, longevity, community acceptance, secondary environmental impacts, costs, and site requirements. Other criteria are also listed, some of which are applicable only in coastal areas. For each practice and criterion, an assessment of effectiveness is indicated: solid circles indicate high effectiveness and open circles, low effectiveness. This type of matrix can provide a basis for an initial assessment of practices and their applicability to the program.

Structural Practices

Because structural practices generally are more site specific and have more restrictions on their use than nonstructural practices, the initial screening step for these practices can be more precise than for nonstructural practices. Table 7-2 outlines some of the more important criteria for the screening of structural BMPs, including their typical pollutant removal efficiencies, land requirements, the drainage area that each BMP can effectively treat, the desired soil conditions, and the desired ground-water elevation. By using these criteria and the information obtained during data collection and analysis and problem identification and ranking, the program team can narrow the list of BMPs to be further assessed in the BMP selection step.

The initial screening criteria for structural control practices include the following:

- *Pollutant removal:* The municipality should ensure that BMPs selected address the primary pollutants of concern to the level of removal desired.

	Nutrient Control	Shellfish	Estuarine Habitat Protection	Sedimentation	Sediment Toxics	Stormwater Control	Feasibility in Coastal Areas	Maintenance Burdens	Longevity	Community Acceptance	Secondary Environmental Impacts	Cost to Developers	Cost to Local Governments	Difficulty in Local Implementation	Site Data Required	Water-Dependent Use
Coastal Density Zones																
Intense zones	○	○	○	○	○	○	●	⊘	⊘	○	○	○	◍	○	◍	
Rural zones	○	◍	◍	◍	◍	◍	●	⊘	⊘	○	◍	◍	◍	○	◍	
Protection zones	◍	●	●	●	●	●	●	⊘	⊘	○	●	●	◍	◍	◍	
Overlay zones	◍	●	●	◍	◍	◍	●	⊘	⊘	○	◍	◍	◍	◍	○	
Performance zoning	◍	◍	◍	◍	◍	●	●	⊘	⊘	○	◍	◍	◍	◍	○	
Environmental Reserves																
Stream buffers	◍	◍	●	◍	○	○	●	●	●	●	●	◍	●	◍	●	○
Wetland buffers	◍	○	●	◍	○	○	●	●	●	●	●	○	●	●	●	●
Coastal buffers	◍	●	●	◍	○	○	●	●	●	●	●	○	◍	○	●	●
Expanded buffers	●	●	●	●	○	○	●	●	●	◍	●	◍	●	○	○	●
Floodplain limits	◍	○	●	○	○	◍	●	●	●	◍	●	◍	●	◍	◍	○
Steep soils limits	○	○	◍	●	○	◍	●	●	●	◍	●	◍	●	●	●	◍
Septic limits	◍	●	○	○	○	⊘	●	●	●	◍	●	○	◍	○	◍	◍
Wetland protection	●	◍	●	●	○	◍	●	●	●	●	●	◍	●	●	○	●
Forest protection	○	◍	◍	◍	○	○	●	●	●	●	●	○	●	◍	◍	●
Habitat protection	○	○	●	○	○	○	●	●	●	●	●	◍	●	◍	○	●
Open space protection	○	○	◍	○	○	○	●	●	●	●	●	○	●	◍	◍	●
	● 0 - 40% High level of control ◍ 30 - 40% Moderate level of control ○ 0 - 20% Low level of control ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Directly protects ◍ Indirectly protects ○ No protection ⊘ Not related	● 80% High ◍ 30 - 60% Moderate ○ 0 - 30% Low ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Widely applicable ◍ Applicable depending on site ○ Seldom applicable ⊘ Not applicable	● Low burden ◍ Moderate burden ○ High burden ⊘ Not applicable	● Long lived ◍ Long lived with maintenance ○ Short lived ⊘ Not applicable	● Positive ◍ Neutral ○ Negative ⊘ Mixed	● None or positive ◍ Slight negative impacts ○ Strong negative impacts at some sites ⊘ Prohibited	● Low ◍ Moderate ○ High ⊘ Very high	● Low ◍ Moderate ○ High ⊘ Very high	● Easy ◍ Moderate ○ Tough ⊘ Very tough	● Simple ◍ Moderate ○ Complex ⊘ None	● Can be used moderately in these areas ◍ Sometimes can be used ○ Seldom used ⊘ Not used

Figure 7-1. Sample nonstructural control screening matrix (U.S. EPA, 1991a).

	Nutrient Control	Shellfish	Estuarine Habitat Protection	Sedimentation	Sediment Toxics	Stormwater Control	Feasibility in Coastal Areas	Maintenance Burdens	Longevity	Community Acceptance	Secondary Environmental Impacts	Cost to Developers	Cost to Local Governments	Difficulty in Local Implementation	Site Data Required	Water-Dependent Use
Site Planning																
Cluster	○	◍	○	○	○	○	●	●	●	◍	●	●	●	○	◍	●
Performance criteria	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	●
Minimize imperviousness	○	○	○	○	○	◍	●									
Erosion & Sediment Control																
Time/area disturbance	◍	○	●	◍	⊘	○	●	●	●	●	●	●	◍	●	◍	●
Postdevelopment																
Urban housekeeping	○	◍	○	◍	◍	⊘	●	◍	○	◍	◍		●	●	●	●
Fertilizer control	◍	○	⊘	⊘	⊘	⊘	◍	○	○	◍	●		◍	◍	◍	◍
Septic maintenance	◍	●	○	⊘	⊘	⊘	●	○	◍	◍	◍		◍	◍	○	◍
Household hazardous waste	○	⊘	○	⊘	●	⊘	◍	○	○	◍	◍		◍	◍	○	◍
	● 0 - 40% High level of control ◍ 30 - 40% Moderate level of control ○ 0 - 20% Low level of control ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Directly protects ◍ Indirectly protects ○ No protection ⊘ Not related	● 80% High ◍ 30 - 60% Moderate ○ 0 - 30% Low ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Widely applicable ◍ Applicable depending on site ○ Seldom applicable ⊘ Not applicable	● Low burden ◍ Moderate burden ○ High burden ⊘ Not applicable	● Long lived ◍ Long lived with maintenance ○ Short lived ⊘ Not applicable	● Positive ◍ Neutral ○ Negative ⊘ Mixed	● None or positive ◍ Slight negative impacts ○ Strong negative impacts at some sites ⊘ Prohibited	● Low ◍ Moderate ○ High ⊘ Very high	● Low ◍ Moderate ○ High ⊘ Very high	● Easy ◍ Moderate ○ Tough ⊘ Very tough	● Simple ◍ Moderate ○ Complex ⊘ None	● Can be used moderately in these areas ◍ Sometimes can be used ○ Seldom used ⊘ Not used

Figure 7-1. Sample nonstructural control screening matrix (continued).

Table 7-2. Structural BMP Initial Screening Criteria

Structural BMPs	Typical Pollutant Removals[a]: Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals	Relative Land Require-ments	Drainage Area[b]	Desired Soil Conditions	Ground-Water Elevation
Detention Facilities									
Extended detention dry ponds	Medium	Low-medium	Low-medium	Low	Low-medium	Large	Medium-large	Permeable	Below facility
Wet ponds	Medium-high	Medium	Medium	Low	Medium-high	Large	Medium-large	Impermeable	Near surface
Constructed wetlands	Medium-high	Low	Low-medium	Low	Medium-high	Large	Large	Impermeable	Near surface
Infiltration Facilities									
Infiltration basins	Medium-high	Medium-high	Medium-high	High	Medium-high	Large	Small-medium	Permeable	Below facility
Infiltration trenches/dry wells	Medium-high	Medium-high	Low-medium	High	Medium-high	Small	Small	Permeable	Below facility
Porous pavement	High	High	Medium	High	High	N/A	Small-medium	Permeable	Below facility
Vegetative Practices									
Grassed swales	Medium	Low-medium	Low-medium	Low	Low-medium	Small	Small	Permeable	Below facility
Filter strips	Medium-high	Medium-high	Medium-high	Low	Medium	Varies	Small	Depends on type	Depends on type
Filtration Practices									
Filtration basins	Medium-high	Low	Medium-high	Low	Medium-high	Large	Medium-large	Permeable	Below facility
Sand filters	High	Low-medium	Low	Low	Medium-high	Varies	Low-medium	Depends on type	Depends on type
Other									
Water quality inlets	Low-medium	Low	Low	Low	Low	N/A	Small	N/A	N/A

[a] Low = <30%, Medium = 30-65%, High = 65-100%.
[b] Small = <10 acres, Medium = 10-40 acres, Large = >40 acres.

- *Land requirements:* Large land requirements for some of the aboveground structural BMPs can often restrict their use in highly developed urban areas. Land requirements vary depending on the BMP.
- *Drainage area:* The structural BMPs listed in Table 7-2 are used primarily to treat runoff from watersheds up to 50 or 60 acres, and the optimum drainage area to be served varies for each practice and according to the land use (connected impervious area, for example). Drainage areas above this size might have to be treated by locating BMPs in subwatersheds.
- *Soil characteristics:* Structural BMPs have differing requirements for soil conditions. Infiltration facilities generally require permeable soils, while detention BMPs generally require impermeable soils. The municipality must become familiar with soil conditions in the watershed.
- *Ground-water elevation:* The ground-water elevation in the watershed can be a limiting factor in siting and implementing structural BMPs. Generally, high ground-water elevation can restrict the use of infiltration facilities and filtration practices; but it is necessary for constructed wetlands and may be desirable for detention facilities.
- *Public acceptance:* Since a municipality could have difficulty implementing a structural BMP without public approval, public acceptance of the BMPs should be considered in the screening step.

Of the screening criteria listed, the pollutant removal, land requirements, and drainage area served are usually absolute restrictions. Soil condition and ground-water elevation, on the other hand, impose restrictions that could be overcome by such means as importing soil or constructing facilities with clay liners to restrict ground-water inflow. Such modifications, however, can add significantly to the BMP costs.

Best Management Practice Descriptions

This section provides a brief overview of the BMPs discussed, based on the categories presented in Table 7-1. Additional references should be consulted before selecting, designing, and implementing BMPs (see Appendix A). Appendix B lists widely available and helpful documents that provide more detailed information on designing, constructing, and maintaining urban runoff and CSO BMPs. There are a host of other BMPs that address specific pollution sources, such as landfills, industrial sites, salt storage facilities, marinas, and numerous others. As mentioned earlier, agricultural BMPs are not discussed in depth in this handbook.

Urban Runoff Control Practices

This section addresses regulatory controls, source controls, and several types of commonly used structural controls.

Regulatory Controls

Urbanization increases the amount of impervious land area, which in turn increases storm water runoff with its associated pollutants (see Chapter 1). Municipalities can prevent or reduce many of these pollution problems by implementing regulatory controls to limit the amount of impervious area and to protect valuable resources. These regulatory controls can prevent or limit the quantity of runoff as well as its pollution load. Regulatory controls typically implemented by municipalities include:

- Land use regulations, such as:
  - zoning ordinances,
  - subdivision regulations,
  - site plan review procedures, and
  - natural resource protection.
- Comprehensive runoff control regulations.
- Land acquisition.

Local government regulations can require storm runoff controls, reduce the level of impervious area, require the preservation of natural features, reduce erosion, or require other important practices. The major aspects of storm water prevention and control—including runoff quantity control, solids control, and other pollution control—are illustrated in the case study at the end of this chapter on the regulatory practices implemented by Austin, Texas.

Runoff Quantity Control. Regulations addressing runoff quantity control can be used to reduce the effects of land development on watershed hydrology. Hydrologic control in turn results in pollution control, and can be accomplished through requirements such as:

- *Open space:* By maintaining specified levels of open space on a development site, the total area of impervious surface is reduced and infiltration of precipitation is increased. This leads to decreases in total pollutant discharge and potential downstream erosion by reducing total and peak runoff flows.
- *Postdevelopment flow control:* Many development regulations require that peak runoff conditions from a site be calculated before and after construction. These requirements specify that conditions after construction must reflect conditions before construction. This control is typically accomplished through the use of detention facilities, which can reduce peak runoff discharge rates, thereby decreasing downstream erosion problems. These regulations specify the desired outcome; the approach for ensuring that outcome, however, is determined by the developer.
- *Runoff recharge:* Regulations may specify that storm water runoff be recharged on site. Such regulations can reduce the runoff leaving a site, thereby reducing development-induced hydrologic changes and pollutant transport. By directly promoting infiltration, peak and total runoff rates can be decreased and pollutant discharges and downstream erosion can be reduced. Such runoff recharge also might help maintain surficial aquifer levels.

Solids Control. Regulations addressing solids control could include requirements for control practices during and after construction, since such activity has been shown to be a major contributor of solids. Construction activities can greatly increase the level of suspended solids in storm water runoff by removing vegetation and exposing the topsoil to erosion during wet weather. Yet while communities have requirements for implementing erosion control practices on construction sites, fewer communities require erosion control after construction is complete. Since many other land uses can contribute solids loadings, regulatory requirements can cover various types of industrial and commercial activities.

Other Pollution Control. Land development increases the concentrations of nutrients, pathogens, oxygen demanding substances, toxic contaminants, and salt in storm water runoff. Development regulations, therefore, can be used to address some of these specific pollutants. These regulations can take the form of special requirements for limiting nutrient export in special protection districts or setting performance standards for known problem pollutants.

While many of the regulatory controls outlined in this section are used by municipalities, few communities have used these regulations systematically to prevent urban runoff pollution problems. The regulations, developed over a number of years, have had purposes largely unrelated to urban runoff pollution prevention and control. By reexamining and amending these regulations and ordinances to reflect water resource goals, however, communities can improve their ability to prevent and control urban runoff pollution.

Land Use Regulations. Land use regulations can include zoning ordinances, subdivision and site plan regulations and review requirements, and environmental resource regulations such as wetlands protection. These practices are used as tools to promote development patterns that are compatible with control of urban runoff discharges.

Zoning. Most communities have residential, commercial, industrial, and other zoning districts that specify the types of development allowed and dictate requirements, including:

- Specifying the density and type of development allowed in a given area, thereby maintaining pervious areas.
- Controlling acreage requirements for certain land uses and associated setback, buffer, and lot coverage requirements.
- Directly and indirectly affecting the types of materials that can be stored or used on sites.
- Not allowing potentially damaging uses (e.g., underground chemical storage or pesticide application) in sensitive watersheds.

Examples of types of zoning controls that can be used to protect water bodies include:

- *Cluster development:* Allowing structures in developments to be constructed close together to preserve open space.
- *Down-zoning:* Changing an established zone to a use that allows a lower level of density.
- *Phase-in zoning:* Changing the zoning of a specific area over time, usually as inappropriate sites reach the end of their useful life.
- *Large lot zoning:* Requiring greater minimum acreage for development in certain locations.
- *Conditional zoning:* Allowing certain activities only under specified conditions that protect water quality.
- *Overlay zoning:* Placing additional zoning requirements on an area that is already zoned for a specific activity or use.
- *Open space preservation:* Protecting open space and buffer zones in the community near water bodies.
- *Performance standards:* Permitting certain land uses, usually industrial activities, only if they meet specific performance criteria.

These practices can be used by communities to ensure that land uses in each area are appropriate for that area's water resources. Such controls are especially useful in sensitive areas, such as water supply watersheds, and can serve to reduce or control development.

Subdivision Regulations. Subdivision review deals with land that is divided into separately owned parcels for residential development. Municipalities have the authority to review the plans for such subdivisions and to restrict development options via requirements for drainage, grading, and erosion control, as well as provisions for buffer areas, open spaces, and maintenance. Through this review, municipalities can ensure that proper practices are designed into the development.

Site Plan Review. Site plan review ensures compliance with zoning, environmental, health, and safety requirements. Municipalities can require developers to consider how construction activities will affect drainage on site and to design plans for reducing urban runoff pollution problems. Developers usually are required to submit information to a municipality on the natural drainage characteristics of the site, plans for erosion control, retention and protection of wetlands and water resources, and disposal of construction-related wastes.

Natural Resource Protection. Municipalities can also protect water resources by protecting lands, such as floodplains, wetlands, stream buffers, steep slopes, and wellhead areas. By use of resource overlay zones that restrict high pollution activities in these areas, development can be controlled and the potential for urban runoff pollution can be reduced.

Comprehensive Runoff Control Regulations. In addition to strengthening and broadening existing local regulatory control practices, states and municipalities can implement runoff pollution control through comprehensive regulations. While still relatively rare, comprehensive plans to address urban runoff pollution exist in various states and communities. They are designed to fully address urban runoff pollution problems by identifying specific land use categories and water resources that deserve special attention, and outlining methods for implementing source control and structural BMPs. While the form that these comprehensive regulations take is very specific to the needs of a state or community, reviewing the regulatory approaches that have been tried by others is useful in developing options. Examples include (Pitt, 1989):

- *Austin, TX:* Comprehensive Watersheds Ordinance, 1986; Urban Watersheds Ordinance, 1991 (see the case study at the end of this chapter).
- *Birmingham, AL:* Proposed Watershed Protection Ordinance.
- *State of Maryland:* Model Stormwater Management Ordinance, 1988.
- *State of Wisconsin:* Model Construction Site Erosion Control Ordinance, 1987.

Land Acquisition. To protect valuable resources from the effects of development, municipalities can purchase land within the watershed to control land development. Municipalities can acquire land to convert to parks or to maintain as open space; this approach, however, can be very expensive.

Source Control Practices

Source controls include the nonstructural practices designed to reduce the availability of pollutants. Many of these practices tie directly into EPA's Pollution Prevention strategy discussed in Chapter 2, which focuses on preventing pollution sources from entering the system rather than on treatment. Some of the more common practices used by municipalities throughout the country include:

- Cross-connection identification and removal
- Proper construction activities
- Street sweeping and catch basin cleaning
- Industrial/commercial runoff control
- Solid waste management
- Animal waste removal
- Toxic and hazardous waste management
- Reduced fertilizer, pesticide, and herbicide use
- Reduced roadway sanding and salting

Cross-Connection Identification and Removal. Within the NPDES storm water regulations, EPA has specifically emphasized the importance of implementing a program to identify and remove inappropriate sanitary and industrial wastewater connections to municipal storm water drainage systems—a problem in many urban areas. For example, a study of the storm drainage system in the Humber River watershed in Toronto indicated that about 10 percent of the outfalls from the system had dry-weather flows considered to be significant pollutant sources. This study found that more than 50 percent of the annual discharges of water volume, total suspended solids, chlorides, and bacteria from the monitored industrial, residential and commercial areas were associated with dry-weather discharges from the storm drainage system (U.S. EPA, 1993a).

Dry-weather discharges, such as from illegal wastewater discharges to the storm drainage system, can cause serious water resource degradation. The addition of sanitary wastes increases the concentrations of organics, solids, nutrients, and bacteria in the storm water runoff. Industrial wastes can be highly variable but can substantially increase the concentrations of heavy metals and other related pollutants in runoff (U.S. EPA, 1993a).

Unauthorized and inappropriate connections to drainage systems can exist for many reasons. In the past, connector pipes between sanitary sewers and storm drains could have been installed to relieve surcharging of the sewer system and prevent backups of sewage into homes and businesses. Connections from residential sanitary sewers or commercial and industrial floor drains also exist.

Cross-connections are common in municipalities that have undergone sewer separation. During separation, a new pipe system is often constructed to act as a separate sanitary sewer, and the old combined system is converted to operate as a separate storm drain because of its large size and carrying capacity. To complete the separation, existing connections to the combined sewer must be plugged and reconnected to the new sanitary sewer. If sewer connections to the newly created storm drain continue to exist with no written record or are not located on plans, they can be missed during the reconnection. In addition, as new construction occurs, accidental connections to the storm drainage system can occur.

Because cross-connections typically are not documented, pollution from these connections can often be difficult to locate. Municipalities, however, can develop a program to locate and eliminate these connections. This program should be designed to identify dry-weather discharges and to determine the flow sources by developing updated drainage system maps, conducting dry-weather inspections, and sampling dry-weather discharges. In some instances, discharge results from ground-water infiltration to the drainage system and might not be a pollution concern. If the analyses conducted on dry-weather flows indicate the presence of pollutants, however, the system should be traced to locate the source of the pollutants.

Locating cross-connections to storm drainage systems is similar to conducting the infiltration and inflow (I/I) and sanitary sewer evaluation survey (SSES) investigations that many municipalities regularly conduct. These investigations can be done through successive visual inspections, dye testing, or TV investigations. Once located, cross-connections must be removed so that industrial and sanitary wastes are discharged to a municipal sewerage system. Routine drainage system inspections should continue in order to avoid problems from inadvertent cross-connections from new development.

Detailed information is available in an EPA guidance document entitled *Investigation of Inappropriate Pollution Entries into Storm Drainage Systems* (U.S. EPA, 1993a).

Proper Construction Activities. Construction activities have been cited in numerous water quality assessments as a major source of sediment to surface waters. During construction, natural vegetation is removed from a site, exposing the topsoil. If the soil remains bare and exposed for extended periods, rainfall can cause erosion and transport the soil to nearby water bodies. After the soil enters a water body, decreases in water velocity cause the suspended solids to settle out of the water column and accumulate as sediment on the bottom of the water body. This sediment can smother benthic organisms and carry pollutants, such as petroleum products and metals. Construction-induced erosion therefore should be minimized. This section addresses some of the planning practices and controls that can be used at construction sites to reduce erosion and subsequent soil transport.

While the practices discussed in this section are general and can be applied at construction sites throughout the country, most state environmental offices have developed soil and erosion control handbooks tailored to the specific needs of the state. These documents provide more detailed guidance for developing and implementing programs to address construction site pollution problems. In addition, some municipalities, such as Birmingham, Alabama (Pitt, 1989), have developed ordinances to address construction-site erosion controls.

On construction sites, areas to be maintained in their preconstruction condition should remain undisturbed during construction; existing vegetation to be incorporated into the final site should be maintained. The planned roads and parking areas should be used for construction traffic and other construction-related activities; these areas can be treated with crushed stone during construction and paved after construction has been completed. Planned open areas at a site should be seeded immediately after clearing, and open areas not in use for construction should be covered with crushed stone or seeded with a temporary cover crop.

The planning, sequencing, and timing of construction activities are also important to reduce soil transport. Phasing and limiting of clearing activities so that one area of a site is complete and stabilized before beginning work on other areas can also reduce the potential for erosion.

On large construction sites with extensive grading and vegetation removal, structural erosion control practices are required. During construction activities, temporary berms or weirs can divert runoff away from disturbed areas of the site. Runoff diversion or slope modifications should be incorporated into the final site design; during construction, these diversion structures should be protected by crushed stone or blankets to reduce erosion.

Since construction site runoff contains high levels of suspended solids, temporary structures that filter out or settle out solids should be incorporated into the site. Straw bales, silt fences, dewatering filters, and sedimentation basins are often used to control erosion. Straw bales can be placed across a sloped area to intercept runoff from the slope and trap sediment. They can also be used around storm water inlets and catch basins to reduce the transport of sediment to nearby drainage systems. In addition, straw bales can be placed at intervals along long slopes to reduce runoff velocity to control erosion. Straw bales need to be replaced every few months; the old bales can be broken up and used for ground cover if properly installed and maintained. Silt fences can be used for many of the same functions as straw bales and usually have a longer life.

In addition to these temporary, inexpensive erosion-control devices, storm water runoff from larger construction sites should be directed to sedimentation basins, designed to intercept runoff and hold it for an extended period to allow suspended solids to settle out. Sedimentation basins, which require periodic cleaning, already might be incorporated into the final site design as permanent storm water attenuation/treatment controls. When construction is completed, they should be cleaned out and the bottoms regraded.

To ensure that construction site erosion control practices are properly implemented and that regulations are followed, plans must be reviewed prior to construction activities and inspections must be conducted. Municipalities or responsible agencies must provide for erosion control plan review, site review, and enforcement.

Street Sweeping and Catch Basin Cleaning. Frequent street sweeping can limit the accumulation of dirt, debris, and associated pollutants, and the subsequent deposition of these pollutants in storm drains and waterways. Regular cleaning of catch basins can also remove accumulated sediment and debris that ultimately could be discharged from storm drains and combined sewers. In most municipalities, these tasks are conducted at scheduled intervals and have been shown to result in significant pollutant reductions only if an intensive schedule is followed. A study performed in San Jose, California, showed that

50 percent of the total solids and heavy metals could be removed from urban runoff when city streets were cleaned once or twice a day. When the streets were cleaned only once or twice a month, the removal rate dropped to less than 5 percent (U.S. EPA, 1979). Increased frequency also could result in increased fugitive air emissions. Regular street sweeping and catch basin cleaning can, in any case, remove some of the large floatable litter that is unsightly in urban surface waters. Street sweeping twice a week and catch basin cleaning once or twice a year have been found effective in removing these large floatable pollutants (U.S. EPA, 1983). Determining the effectiveness of street sweeping programs, however, is difficult because of variations in pollutant buildup and storm events. In addition, studies have shown that the choice of sweeping equipment can significantly affect the effectiveness of cleaning programs (Pitt, 1989).

Commercial/Industrial Runoff Control. Certain commercial and industrial sites can be responsible for disproportionate contributions of some pollutants (e.g., grit, oils, grease, and toxic materials) to the drainage system. Typical sources of potential concern include gasoline stations, railroad yards, freight loading areas, and parking lots. In specific cases where significant pollutant loadings to the system are contributed by well-defined locations of limited area, pretreatment of the runoff from these areas could be a practical and effective control measure. Pretreatment measures can be required as part of a community's regulations. Examples of pretreatment measures include oil/water separators for gasoline stations, or the use of modified catch basin designs to enhance the retention of oil and grease or solids. Procedures for the detection and location of illicit connections to separate storm drains by testing for specific chemical tracers could be applied to identify commercial or industrial sources contributing substantial levels of problem pollutants.

Solid Waste Management. Most communities have programs to collect and dispose of solid waste in an effort to maintain clean streets and provide a service for local residents and businesses. Some communities provide added services during times of particularly high waste generation. For example, some municipalities in the northern United States provide extra collection services during the fall to collect leaves—an added service that helps keep leaves from blowing into surface waters. A study of storm water runoff into Minneapolis lakes found that phosphorus levels were reduced by 30 to 40 percent when street gutters were kept free of leaves and lawn clippings (MPCA, 1989). Actual reductions of pollutant loads, however, are difficult to predict. In general, any solid waste that is picked up and disposed of in a controlled manner will be less likely to enter a drainage system.

Animal Waste Removal. Domesticated and wild animal wastes represent a source of bacteria and other pollutants that can be washed into surface waters by urban runoff. These pollutants can be reduced by reducing the animal waste on paved surfaces. Municipalities often enact and enforce leash laws and pet waste cleanup ordinances. The effectiveness of these programs in reducing pollutant loads is unknown, however, and usually depends on voluntary actions by private citizens.

Toxic and Hazardous Waste Management. Improper dumping of household and automotive toxic and hazardous wastes into municipal storm inlets, catch basins, and other storm drainage system entry points can result in significant discharges of pollutants to surface waters during rainstorms. This dumping can be a particular problem in urban areas where individuals change the oil or antifreeze in their cars and dispose of the wastes in nearby catch basins. In addition, homeowners and small businesses sometimes dispose of products such as waste paints and solvents in storm water inlets and catch basins. To address the problem, municipalities can educate residents on the consequences of dumping these wastes into storm drainage system entry points. In addition, communities can develop hazardous- and toxic-waste collection days to dispose of or recycle these wastes properly. Also, storm drain systems can be labeled with warnings about the pollution problems associated with dumping wastes. The effectiveness of such programs, however, cannot be determined in advance because of the voluntary nature of compliance. For business and industry, an inspection, testing, and enforcement program (similar to an industrial pretreatment program) can be developed.

Reduced Fertilizer, Pesticide, and Herbicide Use. Fertilizers, pesticides, and herbicides washed off the ground during storms can contribute to water pollution. Agricultural, park land, and other land uses can be sources of these pollutants. Many communities use these chemicals on park lands, and homeowners utilize them on their lawns. Controlling the use of these chemicals on municipal lands and educating the public can help reduce nutrient and toxic pollutant concentrations in urban runoff.

Reduced Roadway Sanding and Salting. In areas of the United States with freezing road conditions, sand and salt are used in the winter to improve driving conditions. Salt and sand can be washed off roadways, however, and pollute receiving waters. The problem is exacerbated during spring snowmelt and early spring rainstorms when most of these pollutants are available for transport. These problems can be reduced by minimizing the use of chemicals for snow and ice control to the minimum necessary for public safety and by utilizing proper equipment. In addition, salt storage sites have been shown to be persistent and frequent sources of contamination, especially during rainfall (U.S. EPA, 1973); sand and salt piles therefore should be covered. Also, deicing alternatives, such as calcium magnesium acetate (CMA), can be used in some cases (U.S. EPA, 1974a,b).

Detention Facilities

One of the most common structural methods for controlling urban runoff and reducing pollution loading is through the construction of ponds or wetlands to collect runoff, detain it, and release it to receiving waters in a controlled manner. Pollution reduction during the period of temporary runoff storage results primarily from settling of solids. Detention facilities, therefore, are most effective at reducing the concentrations of solids and the pollutants that typically adhere to solids, and less effective at removing dissolved pollutants.

Currently, the three types of detention facilities commonly used to remove pollutants from storm water runoff are extended detention dry ponds, wet ponds, and constructed wetlands; each is discussed below. For more detailed design information, the references listed in Appendix B should be consulted.

Extended Detention Dry Ponds. Most municipalities are familiar with the concept of constructing dry ponds to control peak runoff. When used as water quality BMPs, dry ponds are designed with orifices or other structures that restrict the velocity and volume of the discharges (see Figure 7-2). Dry ponds thereby detain the runoff before discharging it to surface waters.

Pollutant Removal. During the storage period, heavier particles settle out of the runoff, removing suspended solids and pollutants, such as metals, that attach to the particles or precipitate out. Some dry ponds also include vegetated areas that can provide pollutant removal through filtering and vegetative uptake. Dry ponds are, therefore, most effective at removing suspended solids and some nutrients and metals, and less effective at removing dissolved pollutants and microorganisms. Overall, the pollutant removal effectiveness of dry ponds has been shown to be less than for wet ponds and constructed wetlands (see Table 7-2).

Design Considerations. Retrofitting existing dry ponds with new outlet structures can sometimes enhance a municipal flood-control structure to increase its pollution control effectiveness. Care must be taken, however, to ensure that the overflow capacity of the pond is maintained, so that it continues to fulfill its original flood-control function. Study of the hydraulic characteristics of the dry pond will be necessary before retrofitting. Temporary storage also can be provided for runoff from smaller storms by building a small berm around an existing outlet structure.

For water quality dry ponds, important design criteria include the desired detention time and the volume of runoff to be detained. These factors dictate the pond's size and affect the pollutant removal efficiency of the structures. Most dry-pond sizing criteria specify a

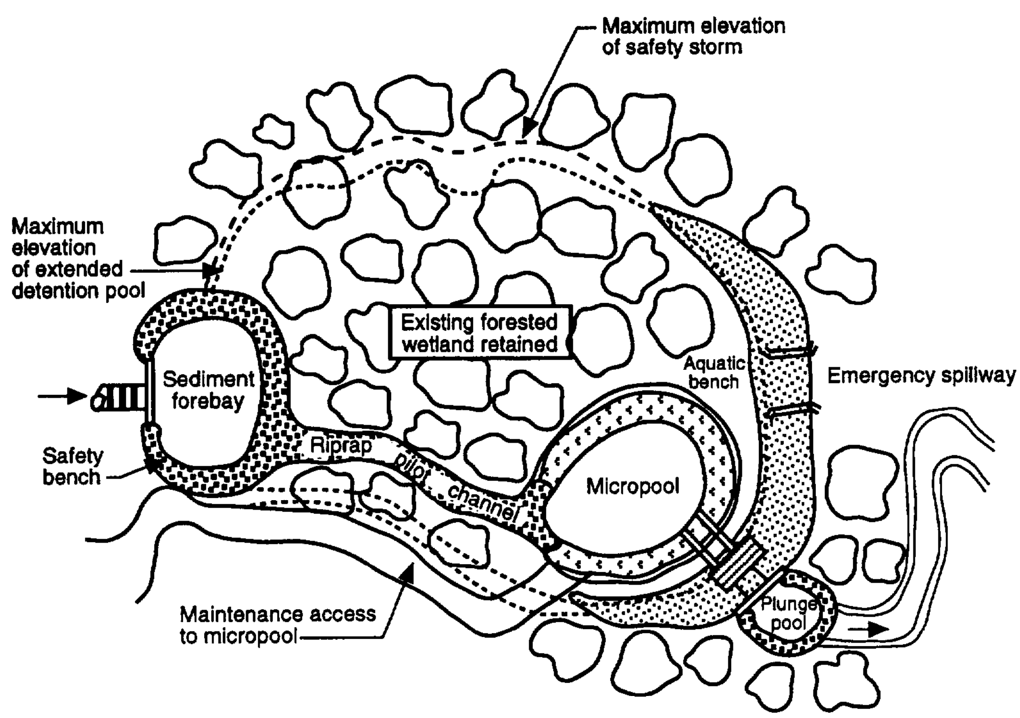

Figure 7-2. Extended detention pond (U.S. EPA, 1991a).

certain detention time for a given design storm. For example, the Maryland Water Resources Authority specifies that water quality dry ponds must be large enough to accommodate the runoff volume generated by the 1-year, 24-hour storm to be released over a minimum of 24 hours (Schueler, 1987). In contrast, the Washington State Department of Ecology (WA DOE) specifies that dry ponds must be large enough to accommodate the runoff volume generated by the 2-year, 24-hour storm and release it over a period of 40 hours (WA DOE, 1991).

Dry ponds should also include some form of low-flow channel designed to reduce erosion; vegetation on the bottom of the pond to promote filtering, sedimentation, and uptake of pollutants; and an outlet structure designed to remove pollutants and withstand clogging. In addition, dry pond designs typically include upstream structures to remove coarse sediments and reduce sedimentation and clogging of the outlet. Also, outlets might be connected to grassed swales (biofilters) to provide additional pollutant removal (WA DOE, 1991). Each of these components of a dry pond design either enhances pollutant removal or reduces operation and maintenance costs for the structure.

Maintenance Requirements. Maintenance of water quality dry ponds is important. Regular mowing, inspection, erosion control, and debris and litter removal, are necessary to prevent significant sediment buildup and vegetative overgrowth (Schueler, 1987). Also, periodic nuisance and pest control could be required. Dry-pond design should recognize these maintenance requirements. The pond slopes should allow for mowing, and access roads should be provided.

Limitations on Use. Like other storm water treatment structures used in large watersheds, a primary physical constraint on the construction of water quality dry ponds is their large land requirements. For this reason, locating dry ponds in new developments is usually more practical than constructing them in already developed areas. Other physical constraints include the topography and the depth to bedrock.

Wet Ponds. The design of wet ponds is similar to that of dry ponds and constructed wetlands. In wet ponds, storm water runoff is directed into an constructed pond or enhanced natural pond, in which a permanent pool of water is maintained until being replaced with runoff as shown in Figure 7-3. Once the capacity of a wet pond is exceeded, collected runoff is discharged through an outlet structure or an emergency spillway.

Pollutant Removal. The primary pollutant removal mechanism in wet ponds is settling. The ponds are designed to collect storm water runoff during rainfall and to detain it until additional storm water enters the pond and displaces it. While the runoff is detained, settling of particulates and associated pollutants takes place in the pond.

Wet ponds can also remove pollutants from runoff through vegetative uptake. Wet ponds should be vegetated with native emergent aquatic plant species, which can remove dissolved pollutants such as nutrients from the runoff before it is discharged to the receiving water.

Design Considerations. Wet ponds typically are designed with a number of different water levels. One level of the pond has a permanent pool of water. The next level periodically is inundated with water during storms; this area should be vegetated and relatively flat to promote settling and filtering of sediments and vegetative uptake of nutrients. The highest level will be inundated only during extremely heavy rainfall; this area also should be vegetated to prevent soil erosion. At least 30 percent of the surface area of a wet pond should be a vegetated zone (Livingston et al., 1988). Typically, this vegetation is concentrated at the outlet as a final "polishing" biofilter.

The sizing of wet ponds is similar to that of dry ponds in that a number of different "sizing rules" provide varying levels of pollution control. Generally, these rules specify the volume of runoff to be detained in the wet pond during a storm. For example, the Maryland Water Resources Authority specifies that the permanent pool of a wet pond should be large enough to contain one-half inch of runoff distributed over the impervious portion of the contributing watershed (MD WRA, 1986). In Florida, storage volume for 1 inch of runoff above the normal pool elevation is recommended. This volume must be released at a slow rate; no more than half should be discharged within 60 hours after the event, and all the volume must be released after 120 hours. A hydraulic retention time of 14 days for the permanent pool volume is recommended (Livingston et al., 1988).

The design of water quality wet ponds must also take into consideration the possibility of large storms. Emergency spillways should be included in the design to prevent flooding difficulties. In addition, the pond's inlet and outlet structures should be separated and constructed at either end of the pond to maximize full mixing when large flows occur and avoid short-circuiting. By separating the inlet from the outlet, the detention time of the pond can also be increased. A forebay or other system for pretreatment also might be advisable. Further design guidelines for wet ponds can be found in the references in Appendix B.

Maintenance Requirements. Like many other BMPs, wet ponds require routine maintenance to be effective. Wet ponds are designed to allow for settling of suspended solids; therefore, periodic removal of the accumulated sediment must be performed (perhaps

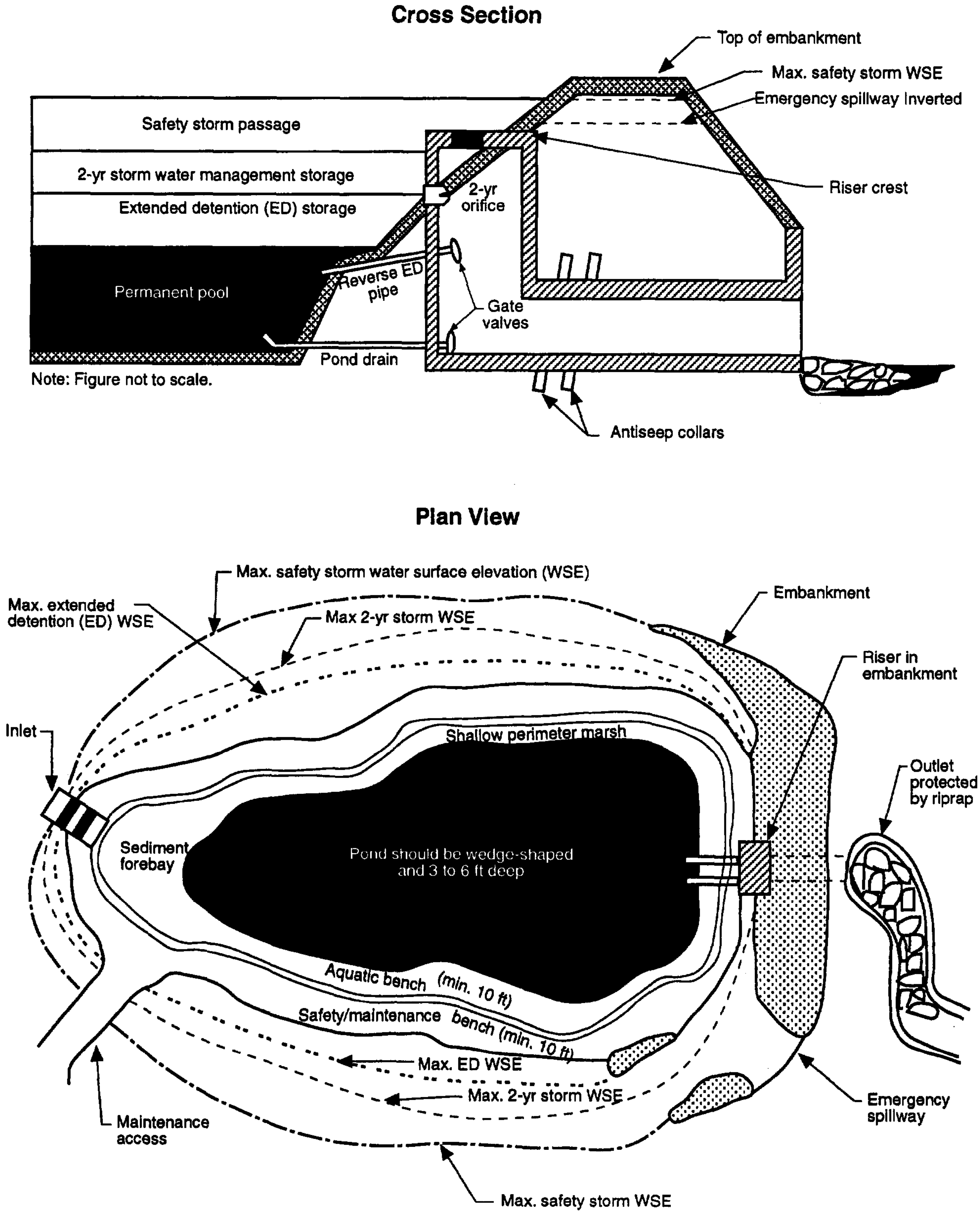

Figure 7-3. Wet detention system (Roesner et al., 1988).

every 10 to 20 years). Removed sediment must be disposed of in accordance with appropriate regulations, which could include testing and special handling requirements for contaminated material. In addition, the pond slopes should be regularly mowed to make the sediment removal process easier and to enhance the aesthetic qualities of the area. Inlet and outlet structures should be inspected periodically for damage and accumulated litter, and the pond bottom should be inspected for potential erosion. Erosion of the pond bottom from high velocity flows can result in increased sediment transport and overall reduction in the pollutant removal capabilities of the pond.

Limitations on Use. Water quality wet ponds have large land requirements and usually are more suited to new development projects where they can be designed into the site. In addition, wet ponds are not suitable for use in areas with porous soils or low ground-water levels because a pool of water in the bottom is key to their design. Wet ponds should be built into the ground water with their control elevation set above the level of seasonal high water tables. Synthetic impermeable materials or clay can be used to prevent seepage. Wet ponds also have physical limitations related to the site topography; since locating wet ponds in areas with extreme slopes is often difficult, relatively flat locations are preferable.

Constructed Wetlands. Constructed wetlands are effective in removing many urban storm water pollutants. Two prevalent types of systems are shallow-constructed wetlands (Figure 7-4) and wet detention systems (Figure 7-5). The wet detention system is a wet pond with extensive shoreline shallow wetland areas. Wetland systems combine the pollutant removal capabilities of structural storm water controls with the flood attenuation provided by natural wetlands. Proper design of constructed wetlands—including their configuration, proper use of pretreatment techniques to remove sediments and petroleum products, and choice of vegetation—is crucial to the functioning of the system.

Pollutant Removal. Constructed wetland systems perform a series of pollutant removal mechanisms including sedimentation, filtration, adsorption, microbial

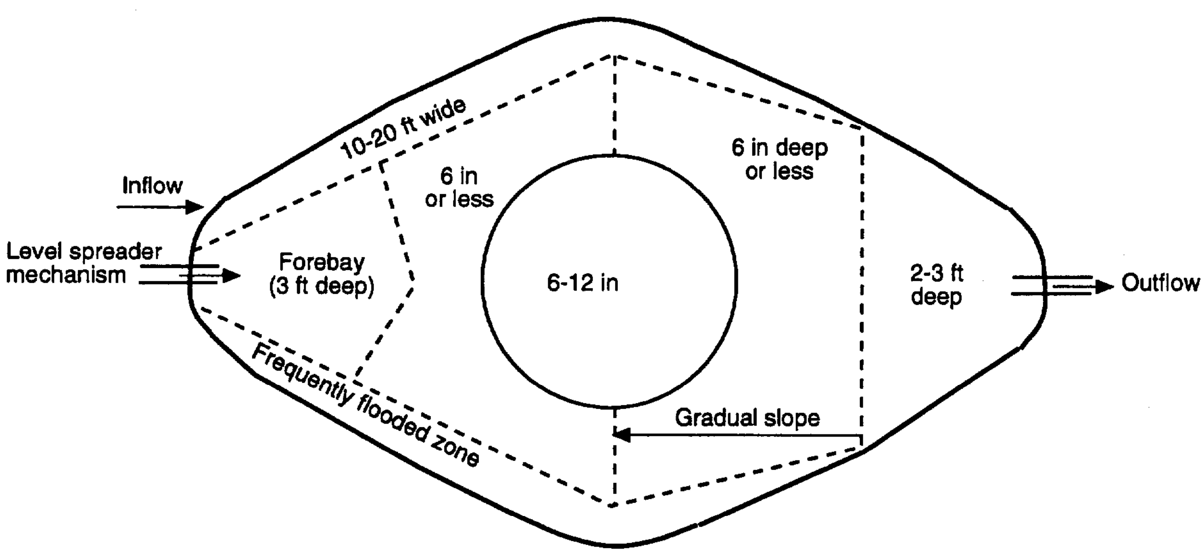

Figure 7-4. Example shallow-constructed wetland system design for storm water treatment (Maryland DNR, 1987).

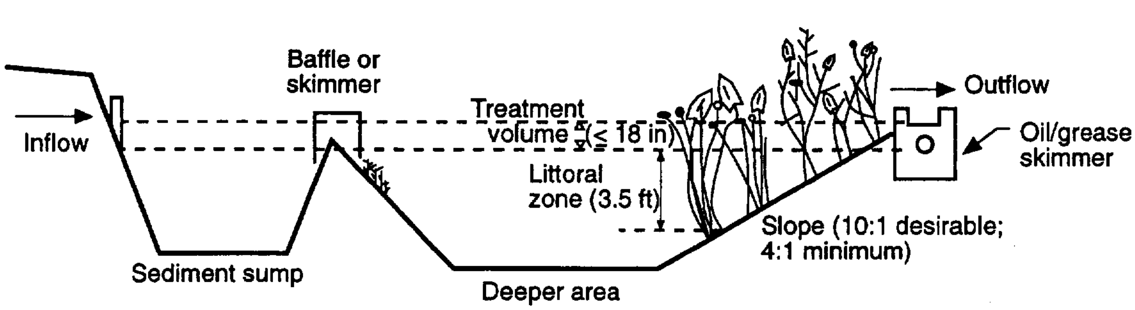

Figure 7-5. Example wet detention system design for storm water treatment (Livingston et al., 1988).

Table 6-1. Criteria for the Assessment of Pollution Problems (Adapted from U.S. EPA, 1987a)

Pollutant Source
Type of pollutant
Pollutants typically associated with the source
Source magnitude/pollutant loading
Transport mechanisms to the resource (direct pipe, overland flow or ground water)
Wet-/dry-weather trends
Resource
Existing use of the affected resource (type, status, and level of use)
Designated or desired use of the affected resource
Type and severity of impairment
Relative value of resource affected
Institutional
Available resources and technologies
Understanding of problems and opportunities
Appraisal of potential for solving the identified problem
Implementability of controls
Applicable regulations
Multiagency responsibilities
Funding sources and limitations
Public perception
Goals and Objectives
Water resource goals (water use objectives)
Technology-based goals
Land use objectives
Objectives of planner and sponsor

in a community and the desire of the community to improve its quality helps determine the priorities for implementation.

Institutional Criteria

Urban runoff-related problems can also be assessed using criteria that focus on the institutional constraints on regulators, owners, and the public. Institutional criteria are based on applicable regulations, preferences of the local authorities and regulatory agencies, funding sources and limitations, multiagency responsibilities and overlaps, and public acceptance of the program. Interviews and meetings with interested parties, including agencies, environmental groups, advisory groups, and private citizens, can be conducted to help develop institutional criteria. Questionnaires can be prepared and distributed to help identify concerns. Complaints, either filed with local authorities or available through interviews with citizens, also provide useful input. Knowledge of problems gained through public interaction programs can help to ensure public support of urban runoff pollution prevention and control programs which are implemented later. Examples of institutional criteria are listed in Table 6-1.

Goals and Objectives Criteria

Urban runoff problems can be evaluated with respect to current and future goals. Using goals and objectives assessment criteria, presented in Table 6-1, allows the program team to focus on problems where preventive or corrective measures would provide the greatest benefit. One goal, for example, might be to increase the usage of public beaches by improving the conditions of degraded water bodies meant for swimming. Application of goals and objectives criteria could identify where corrective measures would provide the greatest benefit, perhaps at beaches only slightly degraded and needing only minimal cleanup before they are restored, or at beaches in heavily populated areas where many people could benefit from restoration of the water body. Goals and objectives can be set for restoration of affected resources, but protection of existing uses is as valid a goal as restoration.

Methods of problem assessment, presented in the following sections, use the criteria discussed in this section as a basis for comparison and evaluation.

Pollutant Source Assessments

Pollutant source assessments address the type, magnitude, and transport mode of pollution sources (existing or potential) in a watershed or program area. These assessments are frequently aimed at quantifying the source flows and pollutant loads under various conditions.

Source Determination and Data Evaluation

Urban runoff pollution sources can be defined using the watershed description (Chapter 4) and other information such as the type(s) of pollution affecting a water resource, the pollutant transport mechanisms, the characteristics of drainage patterns and drainage structures, and the land uses in the program area. Activities or land uses within a watershed that are, or potentially could be, causing pollution problems need to be identified. Pollutant types found in the watershed can provide clues regarding the source(s) of the problems. To isolate pollution sources, the watershed can be divided into smaller areas so that individual pollution sources can be tracked down. Depending on the size of the watershed, a drainage basin can first be divided into sub-basins, which can, if necessary, be divided into individual tributaries, pipe systems, or drainage channels. Pollutant types typically associated with certain activities or land uses are listed in Table 6-2.

Table 6-2. Types of Activities and Associated Pollutants (U.S. EPA, 1988a)

Categories and Subcategories	Nutrients	pH	Sediment	Organic Enrichment	Pathogens/ Indicator Bacteria	Toxic Organics	Toxic Metals	Oil and Grease	Salts (TDS)	Hydrologic Alterations	Thermal Alterations	Pesticides
Agriculture												
Cropland	X		X									X
Pastureland	X		X	X	X							
Animal holding areas	X		X	X	X							
Animal waste storage	X		X	X	X							
Hayland	X			X	X							
Wash and processing water	X	X	X	X	X			X				X
Waste application areas	X		X	X	X		X					
Construction												
Highways, bridges, roads			X		X	X		X	X	X	X	
Land development			X		X			X		X	X	
Urban Land												
Storm water sewers, combined sewers, surface runoff—pavement	X		X	X	X	X	X	X	X	X	X	
Surface runoff—turf areas	X				X			X				
Infiltration wells and basins	X				X	X		X	X			
Land Disposal												
Wastes, sludge, septage	X	X	X	X	X	X	X	X	X			
Landfills	X	X	X	X	X	X	X	X	X	X	X	X
In situ wastewater system	X											
Hazardous waste areas	X	X			X	X	X	X	X			X
Hydrologic Modification												
Earth fills, channelization			X							X		
Dam construction/reconstruction	X	X	X	X						X	X	
Other Sources												
Atmospheric deposition	X	X				X	X					
Underground storage tank leaks						X	X	X				X
Illegal disposals/dumping, release of contaminants from in-place deposits	X	X	X	X	X	X	X	X	X			X

Table 6-2. Types of Activities and Associated Pollutants (Continued)

Categories and Subcategories	Nutrients	pH	Sediment	Organic Enrichment	Pathogens/ Indicator Bacteria	Toxic Organics	Toxic Metals	Oil and Grease	Salts (TDS)	Hydrologic Alterations	Thermal Alterations	Pesticides
Highway/bridge maintenance			X			X	X	X	X			X
Auto salvage						X	X	X				
Washing and processing areas	X	X	X	X	X	X	X	X	X		X	X
Snow dumping areas	X		X	X	X	X	X	X	X			
Utility ROWs			X							X	X	X
Surface runoff from gasoline stations						X	X	X				
In-place sediments	X	X	X	X	X	X	X	X	X	X		
Sewer leaks, domestic/wild birds and mammals	X			X	X							
Natural vegetation (leaves, fallen trees)	X		X	X	X							
Marinas and boat moorings, boat maintenance and boat washing	X		X	X	X	X	X	X				

This information can be used to identify potential sources. Problem sources can also be identified based on resource conditions, such as eutrophication of a water body resulting from excessive nutrients, or closures of shellfish beds because of high levels of bacteria. In addition, sediments from aquatic systems and storm sewers can provide useful information for identifying potential sources (U.S. EPA, 1991a).

Pollutant Source Flow and Load Estimation

Computer modeling is valuable in quantifying the flows and loads of pollution sources needed for pollution source assessments. Models can be used to estimate source strengths as well as to evaluate the effectiveness of proposed corrective measures or BMPs. Models available for urban runoff assessments vary widely in complexity, ranging from simple estimation techniques to sophisticated and expensive computer models. The following discussion highlights a number of commonly used methods, focusing on models used to predict pollution characteristics in an urban environment. Information on urban and non-urban models is available from literature (U.S. EPA, 1987b,1991b; Nix, 1991; Walesh, 1989) and from agencies that sponsor the models. Methods of urban runoff modeling discussed in this section include the constant concentration or unit load estimates, preliminary screening procedure, statistical method, universal soil loss equation, rating-curve or regression approaches, and hydrologic and pollutant buildup-washoff models.

Constant Concentration or Unit Load Estimates

Constant concentrations or unit pollutant loads, which can be used to estimate pollutant source loads, can be obtained from available data or estimated based on the types and sizes of land uses in the watershed. Constant concentrations can be coupled with runoff volume estimates to calculate runoff loads or can be used in hydrologic models to calculate time variable flows and loads. The constant concentration or unit load method is easy to use, and can be helpful as a first-cut estimate to identify which areas within a watershed contribute the largest pollutant loads. Wet-weather and dry-weather conditions can also be evaluated separately, to determine the relative contributions of pollutants during these weather periods. This method can be facilitated using a GIS with information such as wet- and dry-weather pollutant concentrations from different sources, land use or source boundaries, and quantities of flow produced in each area. Constant concentrations or unit loads can also be estimated using a spreadsheet.

EPA's Nationwide Urban Runoff Program (NURP), conducted from 1978 to 1983, is one example of a comprehensive study of storm water runoff from residential, commercial, and light industrial areas throughout the United States. It contains a large data base of pollutant concentrations and loads measured during various storm events (U.S. EPA, 1983a). Other data bases of storm water pollutant concentrations and loads include Driver and Tasker (1990); Tasker and Driver (1988); and U.S. EPA, 1974, 1977,1982a, 1990. Such data bases, however, must be used cautiously. For example, since the NURP data are based largely on areas without sanitary waste or industrial waste influences, they might not be representative of the location being studied.

These types of data can be applied to source load estimation techniques such as the constant concentration or unit load method. For example, Table 6-3 presents median and mean values of event mean concentrations (EMCs) derived from urban runoff from EPA's NURP study (U.S. EPA, 1983a). Typical ranges of concentrations of various pollutants found in rainfall, storm water, combined wastewater, and wastewater effluent are presented in Table 6-4. With the aforementioned cautions, such values can be used as first-cut estimates of pollutant loadings. Because of the high variability of urban runoff data, however, site-specific data are required to ensure the accuracy of this or other methods.

Table 6-3. Water Quality Characteristics of Urban Runoff for the NURP Site (U.S. EPA, 1983a; Adapted from Novotny, 1992)

Constituents	Site Median Event Mean Concentration	Site Mean Event Mean Concentration
Total suspended solids, mg/L	100	141 to 224
Biochemical oxygen demand (5-day), mg/L	9	10 to 13
Chemical oxygen demand, mg/L	65	73 to 92
Total phosphorus, mg/L	0.33	0.37 to 0.47
Soluble phosphorus, mg/L	0.12	0.13 to 0.17
Total Kjeldahl nitrogen, mg/L	1.50	1.68 to 2.12
Nitrate and nitrite nitrogen, mg/L	0.68	0.76 to 0.96
Total copper, µg/L	34	38 to 48
Total lead, µg/L	144	161 to 204
Total zinc, µg/L	160	179 to 226

Table 6-5 shows an example of the constant concentration method used to estimate loadings of fecal coliform bacteria and nitrate-nitrogen and to prioritize nonpoint sources in a watershed. To estimate the loadings, mean concentrations for different land uses were multiplied by the estimated annual runoff volume.

Table 6-4. Characteristics of Rainfall, Storm Water, Combined Wastewater, and Treated Effluent (Adapted from various sources; see Metcalf & Eddy, Inc., 1991; Novotny, 1992)

Parameter	Rainfall	Storm Water	Combined Wastewater	Primary Effluent	Secondary Effluent
Suspended solids, mg/L	—	141 to 224	270 to 550	40 to 120	10 to 30
Biochemical oxygen demand (5-day), mg/L	1 to 13	10 to 13	60 to 220	70 to 200	15 to 45
Chemical oxygen demand, mg/L	9 to 16	73 to 92	260 to 480	165 to 600	25 to 80
Fecal coliform bacteria, MPN/100 mL	—	1,000 to 21,000	200,000 to 1,100,000	—	—
Total phosphorus, mg/L	0.02 to 0.15	0.37 to 0.47	1.2 to 2.8	7.5*	6*
Total nitrogen, mg/L	—	3 to 24	4 to 17	35*	30*
Total Kjeldahl nitrogen, mg/L	—	1.68 to 2.12	—	—	—
Nitrate nitrogen, mg/L	0.05 to 1.0	0 to 4.2	—	—	—
Total lead, µg/L	30 to 70	161 to 204	140 to 600	—	—

* Average value.

Table 6-5. Estimated Urban Runoff Loadings Using Constant Concentrations (U.S. EPA, 1992)

Source Area	Description and Location	Area, ac	% Impervious	Land Use	Runoff Coefficient	Annual Runoff Volume, Mgal	Annual Fecal Coliform Loading org x 10^{12} (rank)	Annual Nitrate Nitrogen Loading lb (rank)	Qualitative Ranking
A	Main St. and Freeport outlet stores	3.3	85	Commercial[a]	0.73	2.7	1.7 (12)	14 (11)	Low
B	Commercial development at I-95 interchange, Main and Pine streets	30.6	50	Commercial	0.45	15.7	9.8 (1)	82 (1)	High
C	A portion of Freeport Crossing outlets, Main St., Varney Rd., and Kar Klean	13.9	60	Commercial	0.61	9.7	6.0 (3)	51 (4)	High
D	Main St., Varney Rd., a portion of Linwood Rd., and adjacent residential development	21.0	10	Multifamily residential[b]	0.13	3.1	2.0 (10)	24 (8)	Low
E1	Southern L.L. Bean parking lot	6.5	85	Industrial[c]	0.73	5.4	2.8 (7)	28 (7)	Medium
E2	Northern L.L. Bean parking lot	5.5	80	Industrial	0.69	4.3	2.2 (8)	23 (9)	Medium
F	Independence Way, Eastland Shoe warehouse, Horsefeathers Restaurant, and Main St.	14.1	20	Commercial	0.21	3.4	2.1 (9)	18 (10)	Low
G	Somerset Condominiums, Summer St., Upper West St., and Freeport Place Condominiums	38.0	20	Single-[d] and multifamily residential	0.21	9.1	5.9 (4)	73 (3)	High
H	Municipal garage, Main St., and town office parking lot	15.0	60	Industrial Commercial	0.53	9.1	4.7 (5)	48 (5)	High
I	Downtown Village area along Main St. between Morse and West streets including Oak	19.2	75	Commercial	0.65	14.2	8.8 (2)	75 (2)	High

[a] Fecal coliform concentration = 16,000 org/100 mL, NO_3-N concentration = 0.63 mg/L
[b] Fecal coliform concentration = 17,000 org/100 mL, NO_3-N concentration = 0.96 mg/L
[c] Fecal coliform concentration = 14,000 org/100 mL, NO_3-N concentration = 0.63 mg/L
[d] Fecal coliform concentration = 37,000 org/100 mL, NO_3-N concentration = 0.96 mg/L

Runoff volumes were based on the size, imperviousness, and land use of each source area. Table 6-5 presents the estimated pollutant loadings for the watershed. Based on this analysis, 5 of the 10 areas (B, C, G, H, and I) of nonpoint source pollution were qualitatively assigned ratings of "high" based on their pollutant loadings. These areas contribute more than 75 percent of the total pollutant loading in the watershed.

Preliminary Screening Procedure

Simple equations can be used to estimate annual average loading contributions of urban runoff for 5-day biochemical oxygen demand (BOD_5), suspended solids, volatile solids, total phosphate phosphorus, and total nitrogen. The preliminary screening procedure is a sophisticated unit load method which can be used to calculate unit loads as a function of land use, population density, and frequency of street sweepings (U.S. EPA, 1982b). Pollutant loadings can be estimated based on the relative contribution of pollutants from each land use; however, the equations are not location specific and are useful only for screening purposes. Using the preliminary screening procedure, unit loads are calculated by the following equation developed by EPA (U.S. EPA, 1976a) as reported by Walesh (1989):

$$L = u(i,j) \times P \times PDF \times SWF$$

where:

- L = average annual amount of pollutant j generated per unit of land use i, lb/ac/yr
- u(i,j) = load of pollutant j generated per unit of runoff from land use i, in lb/acre-inch
- P = average annual precipitation, in
- PDF = population density factor, a dimensionless parameter with a value for residential areas of $0.142 + (0.218)(PD)^{0.54}$, where PD is a population density in persons per acre, equal to 1.0 for commercial and industrial areas, and 0.142 for institutional areas (e.g., parks, cemeteries, and schools)
- SWF = street-sweeping factor, a dimensionless parameter; SWF = 1.0 when streets are swept infrequently, with the average time between street sweepings being greater than 20 days; for more frequent street sweeping, SWF is less than 1.0 and could be estimated from site-specific data or literature values.

The unit pollutant loads (u) are obtained from measured or estimated concentrations or loadings from various land use or source areas.

Statistical Method

The statistical method of modeling urban runoff assumes that EMCs are distributed log-normally and characterizes EMCs by their median values and their coefficients of variation. EPA's statistical method (U.S. EPA, 1979) includes statistical properties of rainfall, area, runoff coefficients, median EMCs, and coefficients of variation of EMCs of various pollutants. The Federal Highway Administration (FHWA) has implemented EPA's statistical method for various locations in the United States (Driscoll et al., 1989; Woodward-Clyde Consultants, 1990a).

The runoff flow rate and volume from a mean event are computed by the FHWA model using the following equations:

$$MQR = Rv \times MIP \times ARW \times (3{,}630/3{,}600)$$

$$MVR = Rv \times MVP \times ARW \times 3{,}630$$

where:

- MQR = average runoff flow rate for mean storm events, ft^3/s
- Rv = runoff coefficient (ratio of runoff to rainfall), equal to 0.007 × IMP + 0.10, where IMP is equal to the impervious fraction of the drainage area, %
- MIP = rainfall intensity for mean storm event, in/hr
- ARW = drainage area of the highway segment, ac
- MVR = volume of runoff for mean storm event, ft^3
- MVP = rainfall volume for mean storm event, in

The numbers 3,630 and 3,600 are dimensional conversion factors.

The log-normally distributed EMCs are calculated by the equation:

$$MCR = TCR \sqrt{(1 + CVC^2)}$$

where:

- MCR = EMC for site, mg/L
- TCR = site median pollutant concentration, mg/L
- CVC = coefficient of variation of EMCs

and the mean event mass load is computed by:

$$M(MASS) = MCR \times MVR \times (62.45 \times 10^{-6})$$

where:

- M(MASS) = mean pollutant mass loading lb/event
- MCR = mean runoff concentration, mg/L
- MVR = mean storm event runoff volume, ft^3

Universal Soil Loss Equation

The Universal Soil Loss Equation is primarily applicable to agricultural areas and is used to estimate the soil loss and sediment yield from a homogeneous parcel of land (U.S. EPA, 1976b). The discussion in this handbook is general, and more detailed information can be obtained from referring to more specific sources (SCS, 1977). This method, relatively simple to use, considers such factors as rainfall, erosive forces of the rainfall, soil erodibility, slope, vegetative cover, and erosion control practices. Since this method is used primarily to estimate soil loss and, when modified, sediment yields from non-urban, agricultural areas, it is less applicable to the problems addressed in this handbook than other methods discussed.

The Universal Soil Loss Equation is:

$$E = A \times R \times K \times LS \times C \times P$$

where:

- E = soil loss by water erosion in rill and inter-rill areas, tons/yr
- A = area, ac
- R = rainfall factor, accounting for erosive forces of rainfall and runoff, erosion index units/yr
- K = soil erodibility factor reflecting the physical and chemical properties of a particular soil, tons/ac/erosion unit index
- LS = slope length or topographic factor reflecting the influence of vegetation and mulch, dimensionless
- C = cover and management factor reflecting the influence of vegetation and mulch, dimensionless
- P = erosion control practice factor that is similar to the cover-management factor, but accounts for practices on the land surface such as contouring, terracing, compacting, sedimentation basins and control structures, dimensionless

In order to estimate sediment yield (as opposed to soil loss), the equation is modified by adding a sediment delivery ratio (S_d) as follows:

$$Y(S)_E = A \times R \times K \times LS \times C \times P \times S_d$$

where:

- $Y(S)_E$ = sediment loading to stream, tons/yr
- S_d = sediment delivery ratio, dimensionless

The sediment delivery ratio is a function of the amount of attenuation of gross erosive soil loss in the watershed. This ratio depends on factors such as soil characteristics, slopes, lengths, and watershed area and is estimated using empirical data. Estimates for this and the other parameters should be made only after consulting more detailed references (i.e., SCS, 1977; U.S. EPA, 1976b).

Regression-Rating Curve Approaches

Rating curve or regression models, such as the 31 storm runoff load models developed by the USGS for metropolitan areas throughout the United States (Driver and Tasker, 1990; Tasker and Driver, 1988), use site-specific rainfall, runoff, and source concentration data, such as the data collected for NURP and similar studies, to relate concentrations and loads of pollutants to flow rates and volumes. The regression model for estimation of storm runoff loads and volumes is given by the equation (Driver and Tasker, 1990):

$$\hat{Y} = \beta_0 \times X_1^{(\beta 1)} \times X_2^{(\beta 2)} \ldots X_n^{(\beta n)} \times BCF$$

where:

- $\hat{Y}$ = estimated storm-runoff load or volume, response variable
- $\beta_0, \beta_1, \beta_2, \beta_n$ = regression coefficients, provided by Driver and Tasker, 1990
- X_0, X_1, X_2, X_3 = physical, land use, or climatic characteristics, explanatory variables
- BCF = bias-correction factor, calculated by Driver and Tasker, 1990

Hydrologic and Pollutant Buildup-Washoff Models

For larger and more complex programs, it may be desirable to use hydrologic and pollutant buildup-washoff models. These models address the accumulation of pollutants during dry-weather periods and the washing off of these pollutants during rainfall events. Of the many models available, some of the more widely used models that use a buildup-washoff mechanism include Hydrological Simulation Program—Fortran, HSPF (U.S. EPA, 1981); Storm Water Management Model, SWMM (U.S. EPA, 1988b); Storage, Treatment, Overflow, Runoff Model, STORM; and Source Loading and Management Model, SLAMM (Pitt, 1989). These models are described below. Table 6-6 compares these urban hydrologic and pollutant buildup-washoff models and the EPA statistical method as implemented by the FHWA. Many other models are available which are not described here.

HSPF, available from EPA, simulates movement and storage of water in the hydrologic budget of a watershed or drainage basin, from rainfall to streamflow to ground-water storage. HSPF is useful when large watersheds comprising multiple pollutants and land uses are to be modeled and/or when issues such as sediment erosion, pollutant interaction, and ground-water quality of the system are of concern. Input data requirements of this model are extensive and include time series inputs of hydrologic and meteorologic data, and input of characteristics describing pollutants, topography, storage, response, and evapotranspiration. HSPF can simulate receiving waters and pervious and

Table 6-6. Comparison of Urban Runoff Models (U.S. EPA, 1991c; Pitt, 1989)

Attribute	Model: Storm Water Management Model (SWMM)	Hydrological Simulation Program—Fortran (HSPF)	Storage, Treatment, Overflow, Runoff Model (STORM)	Source Loading and Management Model (SLAMM)	Statistical
Sponsoring Agency	EPA	EPA	Hydrologic Engineering Center (HEC)	Pitt[a]	EPA
Type of Method					
Surface water—simple			X		
Surface water—refined	X	X		X	
Soil/ground water—simple	X				
Soil/ground water—refined		X			
Surface water—statistical					X
Simulation Type					
Continuous	X	X	X		N/A
Single event	X	X		X	N/A
Hydraulic/Hydrologic Features					
Rainfall/runoff analysis	X	X	X	X	[b]
Sewer system flow routing	X	X			
Full, dynamic flow routing	X[c]				
Surcharge	X[c]				
Regulators, overflow structures	X		X		
Storage analysis	X	X	X	X	X[d]
Predicted Pollutant Concentrations in:					
Runoff water	X	X	X	X	X
Surface water	X	X			
Ground water	X	X			
Predicted Pollutants					
Conventional	X	X	X	X	X
Organic	X	X			X
Metals	X			X	X
Number of pollutants	10	10	6	10	Any
Source/Release Types					
Continuous	X	X	X	X	
Intermittent	X	X			
Single	X	X			
Multiple	X	X			X
Diffuse	X	X	X	X	X
Unique Features					
Special solids routines	X	X		X	
Treatment analysis	X	X	X		X[c]
Degradation products	X	X			
Data base	X	X			
Uncertainty analysis	X		X		
Input/execution manager		X			
Level of Application					
Screening	X	X	X	X	X
Intermediate	X	X		X	
Detailed (suitable for design)	X	X		X	
Data and Personnel Requirements[e]	High	High	Low	High	Moderate
Overall Model Complexity[f]	High	High	Moderate	High	Moderate
Available on Microcomputer	X	X		X	X

[a] SLAMM is a proprietary model owned by R. Pitt, Ph.D., Department of Civil Engineering, University of Alabama.
[b] Runoff coefficient used to obtain runoff volumes.
[c] Full dynamic equations and surcharge calculations only in EXTRAN block of SWMM.
[d] Storage and treatment analyzed analytically.
[e] General interpretation based on requirements for model installation, familiarization, data requirements, etc.
[f] Reflection of model size and capabilities; complex models can be used to simulate simple systems with minimal data requirements.

impervious lands and soils. Although it is complicated, model documentation is available from EPA, including copies of the model, user assistance, and periodic training sessions (U.S. EPA, 1991d).

SWMM is a complex model using finite-difference approaches that can be used to simulate urban storm water runoff and combined sewer overflows. Input data requirements are extensive and involve information such as precipitation, air temperature, channel and pipe networks, land use patterns, and storage and treatment facilities (U.S EPA, 1991d). SWMM can be used during both the planning and design phases of a program. Its output consists of hydrographs, pollutographs, and control options and cost (U.S. EPA, 1991d). Model documentation is available from EPA.

While the use of SWMM and HSPF requires a high level of effort and expertise, the models also lend themselves to more simplified treatment and simplified versions are available. For example, in SWMM, the buildup-washoff method of estimating pollutant contribution to a system can be substituted with constant pollutant concentrations. SWMM can also be run in a long-term mode using variable time steps so both event-specific and seasonal/annual conditions can be analyzed.

STORM contains simplified hydrologic and water quality routines for urban runoff modeling. While data requirements of the model are minimal, the model is less flexible than other, more complex models. Output of STORM includes storm event summaries of runoff volume, concentrations and loads, storage and treatment utilization, and total overflow loads and concentrations (U.S. EPA, 1991d). Although the simplicity of STORM makes it an attractive model for screening purposes, it has not been updated by its agency sponsor, the U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), since 1977. While the model has been updated and refined by private entities and many applications of STORM exist, use of STORM has declined in recent years (U.S. EPA, 1991d).

SLAMM is a proprietary model which can be used to evaluate the effects of pollution control measures and development characteristics on urban runoff quality and quantity. Model input requirements include rainfall duration, depth of rainfall, areas of each pollution source type, SCS soil types, building density, land use, pavement texture, traffic density, and roof pitch (Pitt, 1989). The SLAMM model user manual incorporates a discussion of the hydrology of small storm events and its relationship to more "standard" hydrologic models. Investigations have shown the need to represent the rainfall-runoff processes correctly for the more frequent, smaller size storms since they often account for a major part of the pollution loading (Pitt, 1989). Output of the SLAMM model includes, for each rain and land use, matrices describing source area and outfall flow volumes, particulate residue mass and concentrations, and relative contributions from each rainfall event (Pitt, 1989).

While many other models are also available, some receive little or no support from their sponsoring parties and/or have not been widely used. Other widely used models can simulate hydrology but not pollutant buildup and washoff. Such models include TR20 (SCS, 1969) and HEC1 (Hydrologic Engineering Center, 1990). These hydrologic models are not discussed in detail here; model documentation and references contain the specific hydrologic calculations used.

Hydrologic models, such as TR20 and HEC1, can be used to generate time-varying runoff flows for one or more storm events using rainfall and watershed characteristics as model inputs. To generate urban runoff pollutant loads, the hydrologic output (flow versus time) from the models could be combined with estimated urban runoff concentrations. For some applications, for example sizing of BMPs such as detention ponds, only a hydrologic model is needed.

Transport Characteristics Determination

In addition to the magnitude of a pollutant load, the location of a pollution source with respect to the affected resource, the mode of transport to the resource and degradation of the pollutant should also be considered. For example, sources with a clear path to a waterway, such as pipes, ditches and gulleys, are more likely to cause adverse effects in a receiving water than similar sources that must travel through natural filters such as forested or grassy areas before entering a surface water body. Changes in loads, from the initial source discharge to the point where they affect the receptor, occur because of such factors as travel time, dilution, soil infiltration, and decay. Fate and transport of pollutants can be modeled using hydrologic and pollutant buildup-washoff models which attempt to account for these factors deterministically. Since the simpler methods (i.e., unit load or statistical) can only empirically estimate these factors, the level of uncertainty and error is likely to be higher. The level of uncertainty is high even with the deterministic models, though. Site-specific data is thus important to validate any tool which is used.

Resource Assessments

Resource assessments address the impact of pollutant sources on the resources of interest—taking the results of the pollutant source assessments (described in the previous section of this chapter) and determining the effect of these pollutant sources on water resources. Assessments, however, can be conducted on other ecological aspects of a watershed, as well. Water resources can include water quality as well as aquatic life, sediment, and other characteristics of the water bodies. Methods to perform resource assessments can range from evaluation of water quality data and comparison with criteria, to mathematical modeling of receiving waters. These methods are described further in this section.

Basic Data Evaluation

Urban runoff problems can be identified by evaluating available and newly collected data. Evaluation of available data is conducted with numerous tools, including spreadsheets, database management systems, GIS, statistical analysis (described in Chapter 5), and mathematical models (described in this chapter). The data are compared to acceptable resource criteria to determine the existence and severity of problems.

A useful measure of the condition of a specific water resource is comparing its water quality, sediment, or biological data with state water quality standards or EPA water quality criteria. State water quality standards define the quality of water that supports a particular designated use. EPA publishes water quality criteria that consists of scientific information regarding the concentrations of specific chemicals in water that protect species against adverse acute (short-term) effects on sensitive aquatic organisms, chronic (long-term) effects on aquatic organisms, and effects on human health from drinking water and eating fish (U.S. EPA, 1986). These criteria, often based on results of toxicity testing of sensitive species, are intended to be protective of all species. Section 304(a)(1) of the Clean Water Act requires EPA to publish and periodically update these criteria.

The Safe Drinking Water Act of 1974, established to protect public drinking-water supplies, requires EPA to publish maximum contaminant level goals (MCLGs), which are non-enforceable levels at which there are no known or anticipated health effects, and maximum contaminant levels (MCLs), which are enforceable levels, based on best technology, treatment techniques, and other factors including cost. Updates to federal criteria are announced in *Federal Register* notices.

States have surface water standards that classify surface water bodies into use categories, establish instream levels necessary to support these uses, and define policies regarding the protection and enhancement of these water resources. EPA can establish water quality standards (40 CFR 131) for toxic pollutants in states and territories that have not fully adopted their own standards. In addition, many states have ground-water standards that designate uses for various ground waters, and water quality levels necessary to sustain these uses and protect ground-water quality.

The interpretation of sediment chemistry results is not straightforward. A number of approaches have been used to evaluate the degree of contamination in sediments (Maughan, 1993). Many of these approaches have been developed to determine impacts associated with dredging activities (U.S. EPA and U.S. ACOE, 1991). EPA is developing criteria for sediment similar to those for water quality for certain organic compounds (U.S. EPA, 1988c). An important factor affecting the development of these criteria is the bioavailability or toxicity risk to aquatic organisms due to a contaminant in undisturbed sediment. Since this bioavailability is influenced by the physical and chemical nature of the sediment, toxic effects which might be seen at low concentrations in some sediment types might not be evident in others.

To take the variability due to sediment characteristics into account, contaminant concentrations are normalized through equilibrium partitioning between particulate and liquid (pore water) phases, after which EPA water quality criteria are used to assess environmental or human health risks. Further development of sediment criteria for inorganics, such as metals, is anticipated. Until sediment criteria are finalized, much of the evaluation of sediment chemistry data is accomplished on a relative basis by comparing the results from upstream and downstream stations to determine if elevated levels of contaminants exist, or by comparing results to other areas where data are available.

Ecological effects can be assessed by examining the biological community structure. Specific parameters to consider include the relative abundance of pollution-tolerant and pollution-sensitive species as well as common indices including, but not limited to, Shannon-Weiner diversity, Simpson's dominance, and evenness (Pielou, 1975) as discussed in Chapter 5. Various types of biological criteria or indices are available from the literature and can be used for comparative purposes. An example of the use of biocriteria to evaluate data is the State of Ohio biotic index, which has been used to assess the condition of the biota of rivers and streams since 1978 (U.S. EPA, 1991e). Ohio's use of biocriteria is described in the case study at the end of this chapter.

Receiving-Water Modeling

Receiving-water models are used to assess existing conditions and to simulate future conditions of a water resource under various pollution prevention and control scenarios. They can also be used to assess the impact of alternative BMPs (Chapter 8). These models receive input from runoff model results, field-measured parameters, and values of parameters found in the literature. The level of complexity of the receiving-water model chosen should parallel that of the model used to assess urban runoff flows and loads. Some commonly used receiving water models include the Enhanced Stream Water Quality Model (QUAL2E), the Water Quality Analysis Simulation Program (WASP4), and the Exposure Analysis Modeling System II (EXAMSII), as summarized in Table 6-7 and described in more detail below. In addition, HSPF, discussed above, has a receiving-water model component. These models, along with the SWMM model, are available from EPA's Center for Exposure Assessment Modeling, Environmental Research Laboratory, in Athens, Georgia.

QUAL2E can be used either as a steady-state or quasi-dynamic model to simulate conditions of rivers with multiple headwaters, waste discharges, tributaries, withdrawals, dams, and incremental inflows and outflows. The model can simulate 15 water quality constituents, including dissolved oxygen, biochemical oxygen demand, temperature, nitrogen and phosphorus species, coliforms, arbitrary nonconservative constituents, and conservative constituents (U.S. EPA, 1987c). QUAL2E-UNCAS is an enhancement to QUAL2E which allows the user to perform uncertainty analysis on the effects of model sensitivities and uncertain input data on model forecasts (U.S. EPA, 1987c). Three types of uncertainty analyses are available: sensitivity analysis, first-order error analysis, and Monte Carlo simulation. Using this model, the user can determine input factors that contribute the most to the model's uncertainty and the level of risk associated with model predictions. Both QUAL2E and QUAL2E-UNCAS are supported by EPA and are well documented.

The modeling framework of WASP4 provides a flexible-compartment modeling approach, applicable in one, two, and three dimensions, which can be used to simulate contaminant fate in surface water. WASP4 is structured to allow the easy substitution of user-written subroutines into the model. Thus, a range of water quality problems can be simulated by WASP4 using either one of the model's kinetic subroutines or a subroutine written by the user. The model can be used to simulate biochemical oxygen demand, dissolved oxygen, nutrients and eutrophication, bacterial contamination, and toxic chemicals in the sediment bed and in the overlying waters. In addition, WASP4 can be linked to other models, such as DYNHYD5, a simple model that simulates variable tidal cycles, wind and unsteady flows, and the Food Chain Model, which predicts pollutant uptake and distribution throughout an aquatic food chain (U.S. EPA, undated).

EXAMSII performs evaluations and error analyses of the fate of synthetic organic chemicals based on user-specified properties of chemicals and ecosystems, such as descriptions of a system's external loadings, transport processes and transformation processes. Model predictions include chemical exposure, consisting of long-term chronic, 24-hour acute, and 96-hour acute concentrations; fate, consisting of the distribution of chemicals in the system and the relative dominance of each transport and transformation process; and persistence, the time required for effective purification of the system once the loading has ended (U.S. EPA, undated).

Model Selection

Selection of receiving water models for resource assessments (or of urban runoff models for pollutant source assessments) depends on considerations such as available input data, project requirements, budget constraints, and user preference and familiarity. It is sometimes useful to choose a simple or screening level model at first to identify major pollutant impacts or loads for which preliminary control measures could be implemented. A more complex model can then be selected if more detailed analyses of the impact of pollutants and the effect of alternative corrective measures are required. Since model simulations can help in selecting pollution prevention and treatment measures (and thus, in allocating of limited funding), the user should have experience with the model to ensure that the model predictions are correct. An understanding of the selected model and its capabilities and limitations is critical.

In 1976, EPA compiled a list of questions and factors that should be considered when selecting a model (U.S. EPA, 1976b). These considerations, which can be used to select either urban runoff or receiving water models, are presented below.

To determine whether a model is required or could be used, one could consider the following issues:

1. What is the problem to be solved?
2. What temporal resolution is required? Depending on the type of water quality problem and receiving-water, single-event, seasonal, or long-term multiple-year calculations might be appropriate.
3. Is a model needed? If so, what approach is necessary (e.g., computer program, hand calculations)? Would a gross assessment of relative loads and impacts on water quality suffice?
4. What input, calibration, and verification data are available? The model selected must be calibrated and verified, and adequate input data must be collected. If data are not available, or if adequate funds for data collection are not provided, the use of a complicated model could be ruled out.

Table 6-7. Comparison of Receiving-Water Models (U.S. EPA, 1983b, 1985a,b)

Attribute	Models: Enhanced Stream Water Quality Model (QUAL2E)	Water Quality Analysis Simulation Program (WASP4)	Exposure Analysis Modeling Systems II (EXAMS II)	Hydrological Simulation Program—Fortran (HSPF)
Application	River flow, well-mixed lakes	General—river flow, lakes, estuaries, oceans	Nontidal lakes	Unstratified lakes
Dimensionality	One-dimensional	Three-dimensional	Three-dimensional	One-dimensional
State	Steady-state Quasi-dynamic	Time-varying	Steady-state	Time-varying
Water column transport	Advective and dispersive	Advective and dispersive	Advective and dispersive	Advective
Sediment bed condition	Completely mixed	Completely mixed	Completely mixed Simplified exchange	Completely mixed, sedimentation
Sediment bed type	Stationary	Stationary	Stationary	Moving
Unique features	UNCAS—uncertainty analyses of input parameters on model forecasts	TOXIC—models dissolved and adsorbed chemical concentrations EUTRO4—models DO, CBOD, nutrients, phytoplankton DYNHYD5—models tidal cycles, wind, unsteady inflows Food Chain model—simulates uptake and distribution throughout a food chain	Contaminant transformation and transport processes	ARM—Agricultural runoff model NPS—Nonpoint source model

If a model is determined to be necessary, other factors to consider include the following:

1. Regardless of the method selected, personnel qualified in water quality analysis should be available. Any model, simple or complicated, requires a considerable amount of expert judgment in its application. Without this expertise, model application likely will fail.
2. The major costs in applying any computer-based model are related to becoming familiar with the model, collecting basic data for model application (most of these data remain the same, regardless of the number of times the model is used), and setting up the model on the local computer system. Thus, availability of models that previously have been calibrated and applied locally should be considered.

Once it has been determined that a model will be used, the following questions should be considered in determining whether the model is suitable for the problem being studied.

1. What, if any, water quality constituents are to be modeled and can the model accommodate them?
2. Is the problem steady state or dynamic (i.e., do sources or conditions change over time)?
3. What are the spatial considerations? For streams, a one-dimensional model is adequate if homogeneous mixing across the river cross-section is an adequate assumption. For an estuary, a two- or three-dimensional model might be required.
4. Has a model under consideration been used and tested? Is good, user-oriented documentation available?
5. If a proprietary model is considered, how will continuity in planning be accommodated? The planning process is ongoing, and models are most economical when used repeatedly.
6. What are the costs of model application? Computer costs are relatively insignificant; the major costs of model use are personnel costs.

Model Validation

The input data file for a model used either for resource assessment or pollutant source assessment is calibrated using values of parameters measured during field investigations of the pollution sources and/or receiving-water system, depending on the type of modeling. Parameters to be included as model input, but that were not measured during field sampling, are estimated and adjusted to provide a close fit of model predictions to measured data. Values for parameters not easily or regularly measured can be obtained from engineering and scientific publications. Often, typical values, or "default values," for these parameters are presented in the model's user manual and can be used in the initial phases of model calibration.

Model verification, the next step in the model validation process, often involves using a second data set to verify the accuracy of the calibrated model input. Measured parameters from the second data set are input to the model and simulated levels of parameters (such as dissolved oxygen concentration) are compared to actual values measured during the second field sampling survey. Verification may be conducted qualitatively, by visually comparing graphical representations of the model simulation and actual data. In addition, a quantitative verification can be conducted through the use of simple statistical comparisons. Calibrated parameters can be adjusted again, to ensure a good fit between model predictions and each data set. A detailed discussion of the model validation procedure was presented by U.S. EPA (1980).

Once the urban runoff or receiving-water model has been validated, it can be used to simulate various scenarios of storm events, pollutant loadings, and corrective measures. Graphical presentation of model results is an effective method for displaying model simulations during evaluation of results and in reports. While computer modeling is valuable for examining existing conditions and simulating impacts due to future changes, users should be aware that model predictions are only as accurate as the quality of the data used; some level of error is associated with even the best modeling techniques.

Institutional Assessments

Assessment of the institutional constraints of a program provides the managers with perspective concerning the nontechnical issues affecting the program. The institutional issues of a program are assessed by evaluating the program's potential and limitations and by reviewing the requirements of involved agencies and the public. One major institutional issue that must be addressed on an urban runoff program is determining the responsibilities of each involved party, especially for programs involving multiple agencies. Issues related to the control of the program (e.g., enforcement, maintenance, permitting, and funding) can affect the program's emphasis and the selection of its corrective measures. Another institutional issue involves the limitations of available technology. Implementability of controls can also be considered, particularly in areas involving limited access to private properties. The potential for eliminating or reducing an urban runoff problem or improving affected water resources can also be considered. Questions and concerns of the public might prove to be influential during the decision-making processes. Applicable regulations could force the sequencing of corrective measures so that those addressing compliance with the regulations are implemented first.

Goals and Objectives Assessments

The relative importance of an urban runoff problem can be assessed by comparing it to the program's resource and/or technology-based goals and the objectives of the program's sponsor, as discussed in Chapter 3. For example, one water resource goal might be to "provide improvements to water quality in areas where the most people will benefit." Comparison of the pollution problems to such a goal provides the program team with perspective on which problems to solve to achieve the goal. By comparing the pollution problems to the program's goals and objectives, the program team can identify and focus on problems that are compatible with these goals. The assessments conducted on pollutant sources, water resources, and institutional aspects provide input to these determinations.

Problem Ranking

Since funding to correct pollution problems is usually limited, the sources or impacts to be addressed should be prioritized to allow for targeting of limited resources. While ranking is a subjective process that requires the judgment of decision-makers, ranking systems can be used to help develop priorities. A ranking methodology can range from simple, descriptive methods (qualitative) to numerically complex (quantitative), depending on the urban runoff program objectives and funding constraints. Ranking methods can apply to a variety of geographic areas, ranging from counties or communities with multiple watersheds to individual water bodies or pollution sources. Criteria such as those presented in Table 6-1 can be used in problem ranking.

Ranking should be conducted following consultation with involved parties, including local, state, and federal agencies; local environmental groups; and concerned citizens. Public opinion can have a large influence on the ranking of pollution problems. For example, the public might give priority to controlling sources that discharge to a favorite pond used for swimming. Urban runoff control programs should consider public concerns and desires when prioritizing problems, no matter which type of ranking approach is employed.

Three types of ranking procedures, ranging from simple to complex, are discussed in this section.

Qualitative Ranking

The simplest ranking approach uses qualitative rankings (e.g., high, moderate, or low) to prioritize pollution problems such as in the example presented in Table 6-5. Other qualitative ranking methods use letters (e.g., A, B, C) or numbers (e.g., 1, 2, 3) to develop a relative scale for comparing problems. The qualitative rankings must then be interpreted to determine which problems should be of highest priority in developing controls. In the example in Table 6-5, the qualitative rank is based on estimated pollutant load. Other measures can also be used as a basis for qualitative rankings (e.g., level of public concern or the importance of the use to be protected).

Numerical Ranking

To perform numerical ranking, rating points are assigned to each ranking criterion for each problem. Each ranking criterion is assigned a weight based on its importance relative to the other criteria. The rating points are then multiplied by the relative weight. All of the products (i.e., criterion rating x relative weight) are summed for a given problem. This procedure is then repeated for all the problems being evaluated. The sums thus assigned are compared and the problems with the highest sums receive the highest priority during implementation of urban runoff controls.

In an example of a numerical ranking system for prioritizing pollution sources (Woodward-Clyde Consultants, 1990b), a hypothetical application of this weighted ranking methodology uses the following criteria: water body importance (as reflected by stream or lake size), type of use (ranging from urban drainage to recreational contact), status of use (impaired versus denied), level of use (low, moderate or high), pollutant loads (not actual loads but estimates for comparative purposes), and implementability of controls (based on institutional factors, existing ordinances, or technical considerations). These criteria are similar to some identified in Table 6-1. The relative importance of each criterion is designated by assigning a weight appropriate for the site-specific conditions of the watershed under consideration. The sum of all weights used to rank the problems equals 100. Next, for each problem, the criteria are ranked using a suggested range of 1 to 9, with a higher numerical ranking indicating a higher need for corrective action. This listing allows relative comparisons to be made among problems with respect to a single criterion.

A hypothetical urban watershed, consisting of three streams and several types of land use, illustrates this numerical ranking method for prioritizing pollution problems (Figure 6-1). Information describing the system is presented in Tables 6-8 and 6-9. Typical sources for these data include site-specific pollutant loading data, model results, and literature values from data bases such as those identified earlier in this chapter. There are four criteria of equal weight: stream size, beneficial use, pollutant load, and ability to implement (Table 6-10). The three "use" criteria are clustered together as subcriteria of the "beneficial use" criterion.

Ranking for "stream size" is determined based on the total drainage area of each of the three streams. Consistent with the goals for the hypothetical watershed, Stream C is ranked highest with respect to "type of use" because of its recreational uses in the city park; because it is used mainly as an urban drain, Stream B receives the lowest ranking; and Stream A is ranked between the other two streams because it is used to support aquatic life. With respect to "status of use," Stream A ranks highest because although somewhat impaired, it has the potential to be improved by control of pollution sources. Stream B receives a low ranking for use status because its water quality is poor and its function as part of an urban drainage system has long been accepted. Stream C also receives a low ranking for use status since the water is of high quality. Rankings for "level of use" reflect the number of people using or affected by each stream.

Mass pollutant loadings are calculated based on runoff coefficients (functions of the amount of impervious area), runoff concentrations of pollutants, and the amount of land use type in each stream's drainage area. Each stream is ranked based on the proportion of pollutant load from its watershed (in this example, total suspended solids is used). The watershed of Stream B is judged easiest to implement controls because it is predominantly industrial. Based on the method presented in this example, Stream C's watershed should receive priority during implementation of controls, followed by Stream A's and then Stream B's.

Quantitative Ranking

A fully quantitative ranking of urban runoff problems also could be performed using pollutant source assessment methods such as urban runoff models and resource assessment methods such as receiving-water models. Quantitative ranking requires the greatest amount of resources. For this approach, the models would be used to determine which pollution sources contribute the greatest impacts by testing various load reduction scenarios. Through such evaluations, critical problem sources or impacts could be prioritized. Chapter 8, which concerns selection of BMPs, discusses this type of approach further.

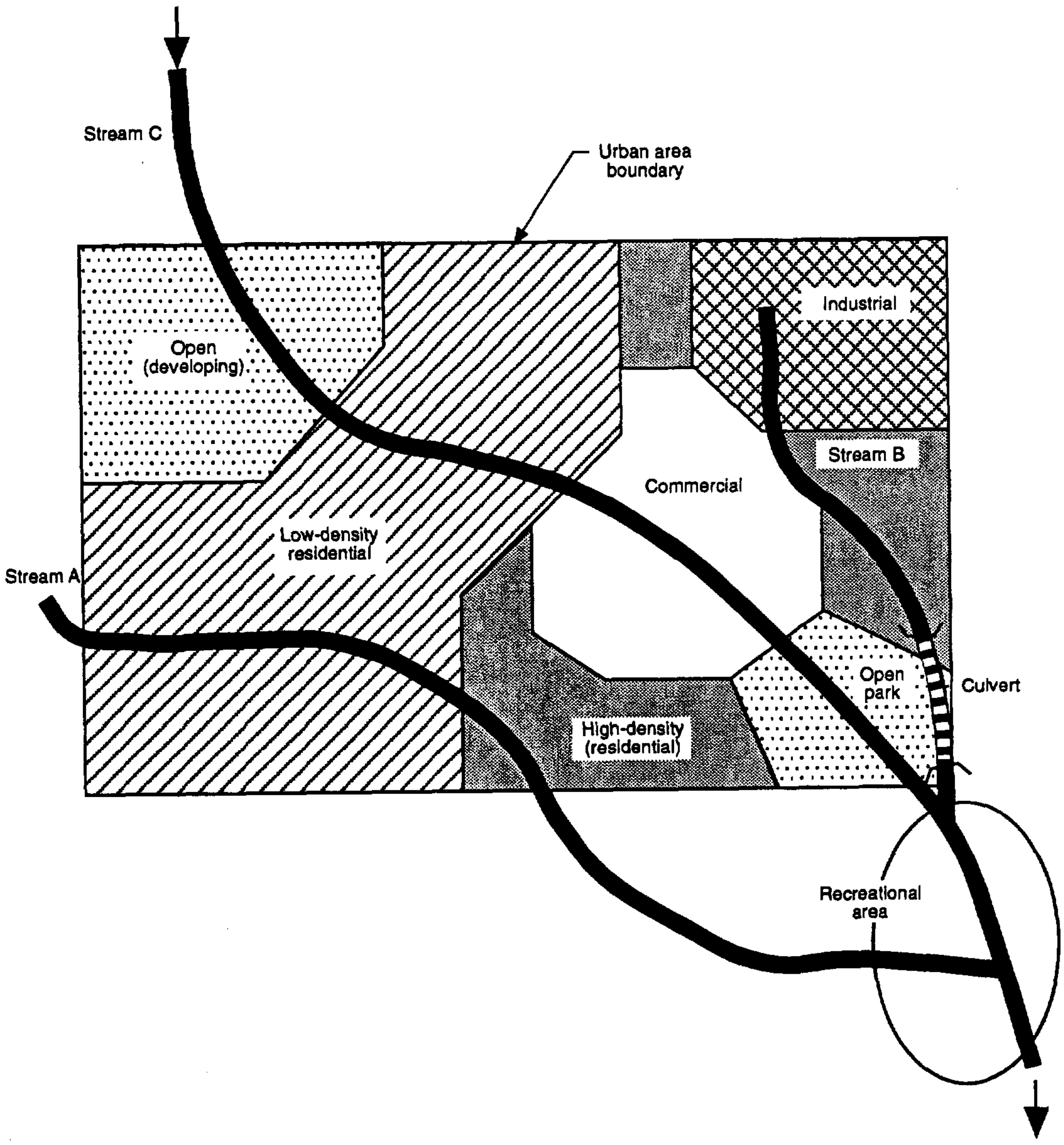

Figure 6-1. Schematic representation of watershed (Woodward-Clyde Consultants, 1990b).

Table 6-8. Characteristics of the Targeted Areas and Estimated Concentration Loads (Woodward-Clyde Consultants, 1990b)

		Average Concentration in Runoff, mg/L				Drainage Area, ac			
Land Use Category	Runoff Coefficient	Total Suspended Solids	Oil and Grease	Total Petroleum	Copper	Stream A	Stream B	Stream C	Urban Total
Industrial	0.6	120	20	0.20	0.05	0	150	0	150
Commercial	0.8	80	15	0.20	0.05	10	80	110	200
Residential (high density)	0.4	90	10	0.40	0.04	100	100	50	250
Residential (low density)	0.2	100	5	0.60	0.03	200	0	200	400
Open—developing	0.1	150	0	0.80	0.01	0	0	150	150
Open—urban park	0.1	50	0	0.80	0.01	0	0	50	50
Total urban area						310	330	560	1,200
Upstream drainage area						600	0	20,000	20,600
Total drainage area						910	330	20,560	21,800

Table 6-9. Estimated Total Suspended Solids Loads for Targeted Areas (Woodward-Clyde Consultants, 1990b)

	Total Suspended Solids, lb/in of rain			
Land Use Category	Stream A	Stream B	Stream C	Urban Total
Industrial	0	2,452	0	2,452
Commercial	145	1,162	1,598	2,906
Residential (high density)	817	817	409	2,043
Residential (low density)	908	0	908	1,816
Open—developing	0	0	511	511
Open—urban park	0	0	57	57
Watershed total	1,870	4,431	3,482	9,784
Watershed rank value	1.7	4.1	3.2	9.0

Table 6-10. Prioritization Analysis for Urban Area Targeting (Woodward-Clyde Consultants, 1990b)

		Beneficial Use					
Urban Watershed	Stream Size	Type	Status	Level	Pollutant Load (TSS)	Ability to Implement	Target Score*
Weights	25	10	10	5	25	25	100
Watershed A	4	5	7	4	1.7	5	4.08
Watershed B	2	2	2	1	4.1	7	3.73
Watershed C	8	8	2	6	3.2	3	4.85
Total urban watershed	8	8	5	8	9.0	2	6.45

* Target score = weighted average of rank points = sum (rank score x weight)/sum (weight)

Case Study:
Ohio Environmental Protection Agency
Biological Criteria for the Protection of Aquatic Life

Background

Since 1978, the Ohio Environmental Protection Agency (Ohio EPA) has been assessing the biota of rivers and streams as part of its basic monitoring strategy. This biomonitoring program was developed for Ohio's fishable waters in response to aquatic life goals of the Clean Water Act. Originally, biocriteria were used to assess the effects of wastewater treatment plant discharges on aquatic life throughout the state. Then, with the increased emphasis on addressing storm water runoff and NPS pollution sources, the Ohio EPA has begun using biomonitoring for these sources.

The use of biocriteria to assess a water body's overall health has several advantages over more common chemical analysis of receiving waters, including (Ohio EPA, 1987):

- The fish and macroinvertebrates sampled inhabit the receiving water continuously.
- The effects of past events (e.g., floods and droughts) are considered.
- Cumulative impacts can be seen.
- The species used have a long life span.
- The species allow a direct measure of CWA's biological goals.

The traditional approach of water chemistry analysis results in a snapshot of the receiving-water body at the time of sampling. For a more complete picture, numerous sampling events are required, which can be very costly. Biocriteria analysis, however, gives a cost-effective assessment, although somewhat qualitative, of the water body and its ability to support aquatic life.

Analysis Methods

In developing biocriteria, the state was divided into five different ecoregions with generally homogeneous characteristics. Within each ecoregion, water bodies were selected as "regional reference sites" to represent "least impacted" conditions. Rather than represent pristine conditions, these sites were selected based on the amount of stream channel modification, the condition of the vegetative riparian buffer, water volume, obvious color/odor problems, and general representativeness. Once these sites were selected, fish and macroinvertebrate sampling programs were implemented to determine water body characteristics and to obtain information required to develop quantifiable criteria to compare with the health of other water bodies. Three water body health indices were developed from the sampling data:

- Index of biotic integrity (IBI)
- Modified index of well being (MIwb)
- Invertebrate community index (ICI)

The IBI and MIwb are used to assess fish community health, and the ICI is used in the assessment of macroinvertebrate communities. Each index is developed by assessing a number of criteria for the water body of interest, as described below.

Index of Biotic Integrity

Used as a measure of the health of fish communities, the IBI consists of 12 criteria, or metrics, designed to give an overall assessment of the biota. The metrics are developed depending on the type of water resource being analyzed. The three types of sites include headwaters sites (drainage areas less than 20 square miles), wading sites (drainage areas greater than 20 square miles sampled by wading), and boat sites (drainage areas greater than 20 square miles sampled from a boat). Each of these types has its own set of metrics for use in determining the IBI, as shown in Table 6-11.

Table 6-11. Index of Biotic Integrity (IBI) Metrics

IBI Metric	Headwaters Sites	Wading Sites	Boat Sites
1. Total number of species	X	X	X
2. Number of darter species	X	X	
Round-bodied suckers, %			X
3. Number of sunfish species		X	X
Number of headwaters species	X		
4. Number of sucker species		X	X
Number of minnow species	X		
5. Number of intolerant species		X	X
Number of sensitive species	X		
6. Tolerant species, %	X	X	X
7. Omnivores, %	X	X	X
8. Insectivorous species, %	X	X	X
9. Top carnivores, %		X	X
Pioneering species, %	X		
10. Number of individuals	X	X	X
11. Simple lithophils, %		X	X
Number of simple lithophilic species	X		
12. Diseased individuals, %			
DELT anomalies, %	X	X	X

Data for each of these metrics were collected and plotted against drainage area for each of the "least affected reference sites" in each ecoregion. The plot showing the relationship between the metric and drainage area was then divided into three equal regions as shown in Figure 6-2. These plots form the basis for determining the IBI for the water body of concern. When determining the IBI, data for the water body are compared with the "least affected reference site" plots, and each metric is rated according to whether it approximates (5), deviates somewhat from (3), or strongly deviates (1) from the value expected at a reference site. For example, looking at the number of species example shown in Figure 6-2, a water body with a drainage area of 10 square miles and 10 species collected during a sampling run would be given a rating of 3 for that metric. Similar ratings are given for all 12 metrics making up the IBI. After all ratings for a water body are given, they are added up; the sum represents the water body's IBI. Because of the rating scales used, the IBI for a water body will range from 12 (very poor biotic integrity) to 60 (very good biotic integrity). Ranges of IBI values and their respective qualitative assessments are shown in Table 6-12.

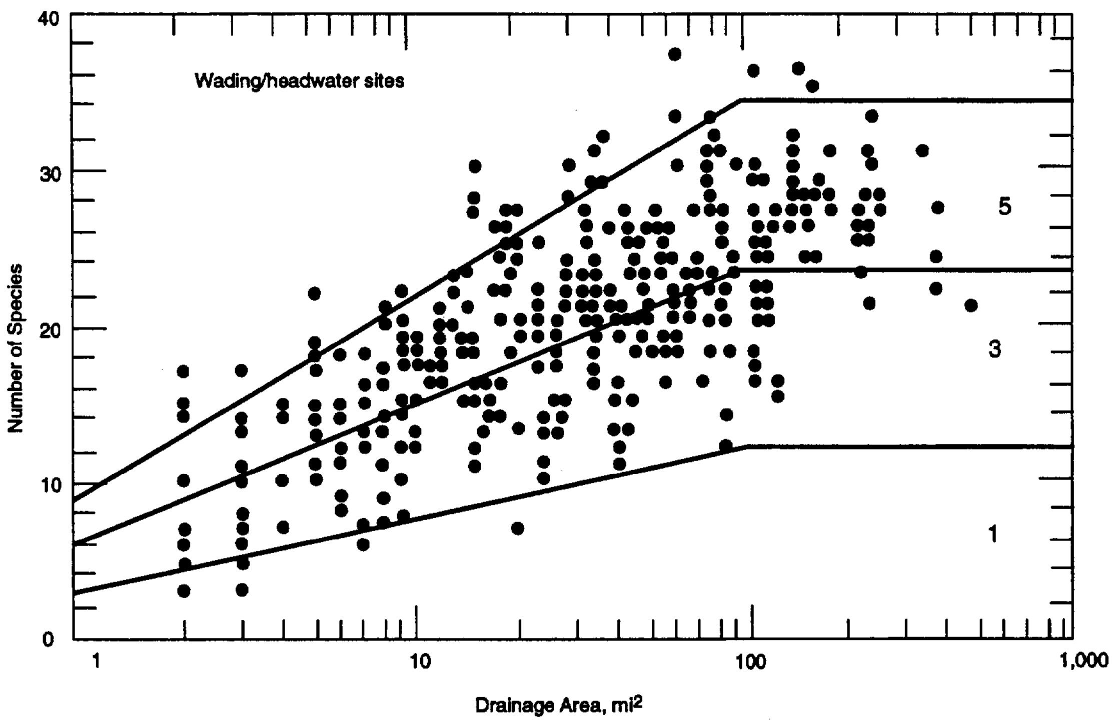

Figure 6-2. Number of species vs. drainage area for determining 5, 3, and 1 index of biotic integrity (IBI) scoring.

Table 6-12. Qualitative Assessment of Index of Biotic Integrity (IBI) Values

	Exceptional	Good	Fair	Poor	Very Poor
Wading sites	50-60	36-48	28-34	18-26	<18
Boat sites	50-60	36-48	26-34	16-24	<16
Headwaters sites	50-60	40-48	26-38	16-24	<16

Modified Index of Well Being

The MIwb is the second index used to describe the quality of fish populations in water bodies throughout the state. A more traditional index, the MIwb takes into consideration the fact that healthy systems support a larger variety and abundance of fish than stressed systems. This index incorporates four measures of fish community health:

- Numbers of individuals
- Total biomass
- Shannon diversity index based on numbers
- Shannon diversity index based on weight

The formulas used to calculate MIwb are:

$$MIwb = 0.5 \ln N + 0.5 \ln B + H(no.) + H(wt.)$$

where:

N = relative numbers of all species (excluding species designated highly tolerant)
B = relative weights of all species (excluding species designated highly tolerant)
H(no.) = Shannon diversity index based on numbers
H(wt.) = Shannon diversity index based on weight

The Shannon diversity index is defined by the following formula:

$$H = -\Sigma[(n_i/N) \times \ln(n_i/N)]$$

where:

n_i = relative numbers or weight of the i^{th} species
N = total number or weight of the sample

Ranges of MIwb values and their respective qualitative assessments are shown in Table 6-13.

Table 6-13. Qualitative Assessment of Modified Index of Well Being (MIwb) Values

	Exceptional	Good	Fair	Poor	Very Poor
Wading sites	≥9.4	8.0-9.3	5.9-7.9	4.5-5.9	≤4.5
Boat sites	≥9.5	8.3-9.4	6.4-8.7	5.0-6.4	≤5.0

Invertebrate Community Index

The ICI is used to measure the health of the invertebrate community. Invertebrates are useful as indicators of environmental quality because they (Ohio EPA, 1987):

- Form permanent and relatively immobile communities
- Can be easily collected in large numbers even in small water bodies
- Can be sampled at relatively low cost per sample
- React quickly to environmental change
- Occupy all stream habitats
- Inhabit the middle of the aquatic food web

The method used to determine the ICI is similar to that for the IBI. A number of "least affected reference sites" were identified and sampled to develop criteria. The ICI consists of 10 invertebrate community metrics each with four rating categories (0, 2, 4, and 6). The 10 metrics used to calculate the ICI are:

- Total number of taxa
- Total number of mayfly taxa
- Total number of caddisfly taxa
- Total number of dipteran taxa
- Percent mayfly composition
- Percent caddisfly composition

- Percent tribe tanytarsini midge composition
- Percent other dipteran and non-insect composition
- Percent tolerant organisms
- Total number of qualitative EPT taxa [EPT = *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies)]

The rating involves giving 6 points to sites of exceptional quality, 4 points for those representing typical good communities, 2 points for slightly affected communities, and 0 points for highly affected communities. As shown in Figure 6-3, plots have been developed to determine the range of values for each metric. For example, a stream sample that has a drainage area of 100 square miles and a total of 30 taxa would receive a rating of 4. A similar analysis is performed for each metric and the 10 values are summed to obtain the final ICI value. This value, which ranges from 0 to 60, represents the health of the water body with respect to the invertebrate community. Ranges of ICI values and their respective qualitative assessments are shown in Table 6-14.

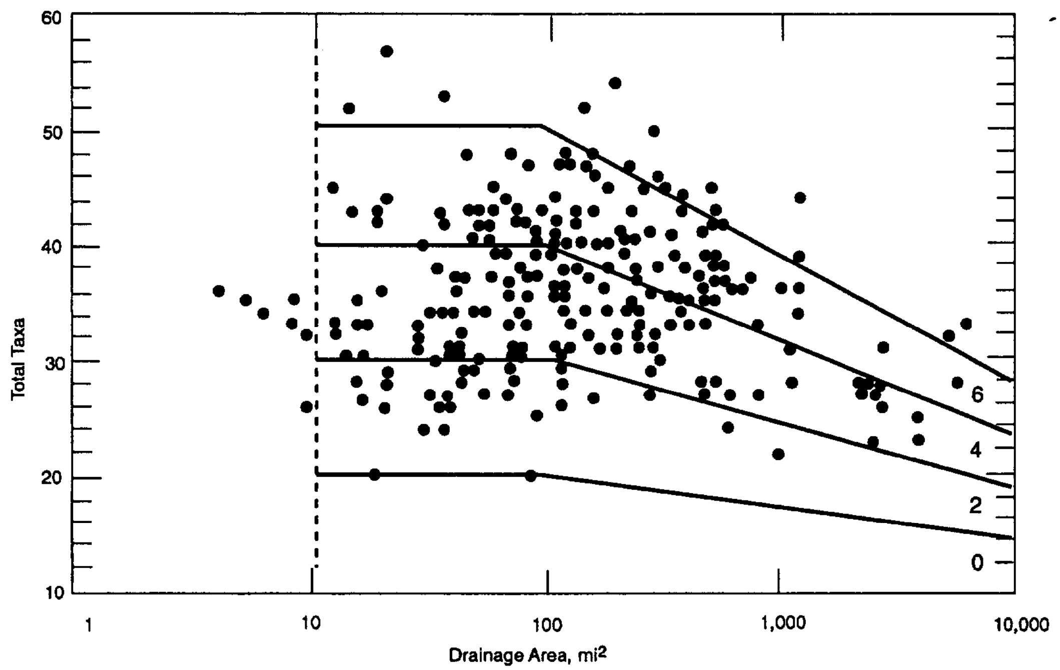

Figure 6-3. Total taxa vs. drainage area for determining 6, 4, 2, and 0 invertebrate community index (ICI) scoring.

Table 6-14. Qualitative Assessment of Invertebrate Community Index (ICI) Values

	Exceptional	Good	Fair	Poor	Very Poor
All sites	48-60	34-46	14-32	2-12	0

Example of Biocriteria Implementation

Taken from the upper Hocking River in Ohio, the calculation of IBI values for fish habitat at two different river headwater stations are shown in Table 6-15. In this example, the fish habitat at Station 2 is significantly better than at Station 1. As indicated by Table 6-12, the index for Station 1 (14) ranks it as very poor for fish habitat, while the rating for Station 2 (34) ranks it as fair for fish habitat. In order to compare these habitats effectively, strict controls had to be kept over the methods used to obtain the fish and analyze the results. To implement similar programs in other areas, the necessary background studies and tests must be conducted because of the site-specific nature of the criteria used to develop the IBI.

Table 6-15. Indices of Biotic Integrity for Two Headwater Stations in Hocking River, Ohio

	Station 1		Station 2	
	Value	Ranking	Value	Ranking
Numbers of				
Total species	5	1	14	3
Total individuals	12	1	130	1
Sunfish species	1	1	4	5
Sucker species	1	1	3	3
Intolerant species	0	1	0	1
Proportion of individuals, %				
Round-bodied suckers	0	1	34	3
Omnivores	67	1	38	1
Insectivores	19	1	50	3
Tolerant species	86	1	42	1
Top carnivores	7	3	10	3
Simple lithophils	7	1	57	5
Anomalies	0	1	0	5
Totals		14		34

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
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Springfield, VA 22161
703-487-4650

Driscoll, E.D, P.E. Shelley, and E.W. Strecker. 1989. Pollutant loadings and impacts from highway storm water runoff. McLean, VA: Federal Highway Administration, Office of Engineering and Highway Operations Research and Development.

Driver, N.E., and G.D. Tasker. 1990. Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States. Denver, CO: U.S. Geological Survey. Open-File Report 88-191, Water Supply Paper #2363.

Hydrologic Engineering Center. 1990. HEC1, flood hydrograph package user's manual. U.S. Army Corps of Engineers.

Maughan, J.T. 1993. Ecological assessment of hazardous waste sites; chapter 7, evaluation of contaminants in sediments. New York, NY: Van Nostrand Reinhold.

Metcalf & Eddy, Inc. 1991. Wastewater engineering: treatment, disposal, and reuse, 3rd edition. New York, NY: McGraw-Hill.

Novotny, Vladimir. 1992. Unit pollutant loads. Water Environ. Tech. January.

Nix, Stephan. 1991. Applying urban runoff models. Water Environ. Tech. 3(6).

Ohio EPA. 1987. Ohio Environmental Protection Agency. Biological criteria for the protection of aquatic life. Division of Water Quality Monitoring and Assessment.

Pielou, E.C. 1975. Ecological diversity. New York, NY: John Wiley & Sons.

Pitt, Robert. 1989. SLAMM 5—source loading and management model: an urban nonpoint source water quality model, volume I: model development and summary. University of Alabama at Birmingham.

SCS. 1969. Soil Conservation Service. Project formulation program: hydrology. Tech. release no. 20. U.S. Department of Agriculture.

SCS. 1977. Soil Conservation Service. Procedure for computing sheet and rill erosion on project areas. Tech. release no. 51. U.S. Department of Agriculture.

Tasker, G.D., and N.E. Driver. 1988. Nationwide regression models for predicting urban runoff water quality at unmonitored sites. Water Res. Bull. 24(5):1091-1101.

U.S. EPA. 1974. U.S. Environmental Protection Agency. Urban stormwater management and technology: an assessment. EPA/670/2-74/040 (NTIS PB-240687). December.

U.S. EPA. 1976a. U.S. Environmental Protection Agency. Storm water management model: level I—preliminary screening procedures. EPA 600/2-76/275 (NTIS PB-259916). October.

U.S. EPA. 1976b. U.S. Environmental Protection Agency. Areawide assessment procedures manual, volumes I, II and III. EPA/600/9-76/014 (NTIS PB-271863). U.S. EPA Office of Research and Development. July.

U.S. EPA. 1977. U.S. Environmental Protection Agency. Urban stormwater management and technology: update and users' guide. EPA/600/8-77/014 (NTIS PB-275654). Washington, DC. September.

U.S. EPA. 1979. U.S. Environmental Protection Agency. A statistical method for the assessment of urban stormwater. EPA/440/3-79/023 (NTIS PB-299185/a).

U.S. EPA. 1980. U.S. Environmental Protection Agency. Measures of verification. Proc. Workshop on Verification of Water Quality Models. EPA/600/9-80/016 (NTIS PB80-186539). April.

U.S. EPA. 1981. U.S. Environmental Protection Agency. User's manual for hydrologic simulation program—Fortran (HSPF). Release 7.0. Washington, DC.

U.S. EPA. 1982a. U.S. Environmental Protection Agency. Urban rainfall-runoff-quality data base. EPA/600/S2-81/238. July.

U.S. EPA. 1982b. U.S. Environmental Protection Agency. Water quality assessment: a screening procedure for toxic and conventional pollutants, volumes I and II. EPA/600/6-82/004a (NTIS PB83-153122) and b (NTIS PB83-153130).

U.S. EPA. 1983a. U.S. Environmental Protection Agency. Results of the Nationwide Urban Runoff Program, volume 1. Final report. Washington, DC: U.S. EPA Water Planning Division. (NTIS PB84-185552.)

U.S. EPA. 1983b. U.S. Environmental Protection Agency. Technical support manual: waterbody surveys and assessments for conducting use attainability analyses, volumes I, II and III. Office of Water Regulations and Standards. Washington, DC. November.

U.S. EPA. 1985a. U.S. Environmental Protection Agency. Technical guidance manual for performing wasteload allocations. Washington, DC. May.

U.S. EPA. 1985b. U.S. Environmental Protection Agency. Rates, constants, and kinetics formulations in surface water quality modeling, 2nd ed. EPA/600/3-85/040 (NTIS PB85-245314). June.

U.S. EPA. 1986 as updated in 1987. U.S. Environmental Protection Agency. Quality criteria for water. EPA/440/5-86/001.

U.S. EPA. 1987a. U.S. Environmental Protection Agency. Setting priorities: the key to nonpoint source control. Office of Water Regulations and Standards. Washington, DC.

U.S. EPA. 1987b. U.S. Environmental Protection Agency. Guide to nonpoint source pollution control. Office of Water. Washington, DC.

U.S. EPA. 1987c. U.S. Environmental Protection Agency. The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS: documentation and user model. EPA/600/3-87/007 (NTIS PB87-202156).

U.S. EPA. 1988a. U.S. Environmental Protection Agency. Ready reference guide to nonpoint source pollution; sources, pollutants, impairments; best management practices for the New England states. Detailed from U.S. Department of Agriculture, Soil Conservation Service. U.S. EPA Region I. Boston, MA.

U.S. EPA. 1988b. U.S. Environmental Protection Agency. Storm water management model, version 4.0: user's manual. Washington, DC.

U.S. EPA. 1988c. U.S. Environmental Protection Agency. Interim sediment criteria values of nonpolar hydrophobic organic contaminants. Washington, DC: U.S. EPA Office of Water Regulations and Standards, Criteria and Standards Division. SCD #17.

U.S. EPA. 1990. U.S. Environmental Protection Agency. Assessment of urban and industrial stormwater runoff toxicity and the evaluation/development of treatment for runoff toxicity abatement—phase I. Edison, NJ. U.S. EPA Office of Research and Development.

U.S. EPA. 1991a. U.S. Environmental Protection Agency. Water quality problem identification in urban watersheds. Seminar publication, Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504).

U.S. EPA. 1991b. U.S. Environmental Protection Agency. Guidance for water quality-based decisions: the TMDL process. EPA 440/4-91/001. April.

U.S. EPA. 1991c. U.S. Environmental Protection Agency. Evaluation of dredged material proposed for ocean disposal: testing manual. EPA/503/8-91/001.

U.S. EPA. 1991d. U.S. Environmental Protection Agency. Modeling of nonpoint source water quality in urban and non-urban areas. EPA/600/3-91/039 (NTIS PB92-109115). U.S. EPA Office of Research and Development.

U.S. EPA. 1991e. U.S. Environmental Protection Agency. The use of biocriteria in the assessment of nonpoint and habitat impacts in warmwater streams. Proc. Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504).

U.S. EPA. 1992. U.S. Environmental Protection Agency. Casco Bay storm water management project: Concord Gully, Frost Gully and Kelsey Brook watersheds. U.S. EPA Region I. Boston, MA. January.

U.S. EPA. Undated. U.S. Environmental Protection Agency. Description of the services and models available from the Center for Exposure Assessment Modeling (CEAM), Office of Research and Development, Environmental Research Laboratory. Athens, GA.

U.S. EPA and U.S. ACOE. 1991. U.S. Environmental Protection Agency and U.S. Army Corps of Engineers. Evaluation of dredged material proposed for ocean disposal: testing manual. EPA/503/8-91/001.

Walesh, S.G. 1989. Urban surface water management. New York, NY: John Wiley & Sons, Inc.

Woodward-Clyde Consultants. 1990a. Pollutant loading and impacts from highway stormwater runoff, volumes 1 through 4. McLean, VA: Federal Highway Administration.

Woodward-Clyde Consultants. 1990b. Urban targeting and BMP selection: an information and guidance manual for state NPS program staff engineers and managers. Final report.

Chapter 7
Screen Best Management Practices

Selecting BMPs for preventing and controlling urban runoff pollution is a two-step process. First, a comprehensive list of BMPs should be compiled and screened to eliminate those that are inappropriate for the area. Based on appropriate BMPs, alternatives are then developed and assessed. Finally, the BMPs to be implemented are selected.

This chapter addresses the first step in this process—initial screening. First, a general overview of the categories of BMPs addressed in this handbook is given. The chapter then describes methods of screening the list of potential BMPs. The remainder of the chapter defines BMPs used for urban runoff pollution prevention and control, along with a brief description of their characteristics and sources of additional information. This chapter's contents assist in compiling a list of BMPs for consideration in the screening process.

Best Management Practice Overview

Urban runoff pollution problems are more difficult to control than steady-state, dry-weather point source discharges because of the intermittent nature of rainfall and runoff, the number of diffuse discharge points, the large variety of pollutant source types, and the variable nature of the source loadings. Since the expense of constructing facilities to collect and treat urban runoff is often prohibitive, the emphasis of storm water pollution control should be on developing a least cost approach which includes nonstructural controls and low-cost structural controls.

Nonstructural controls include regulatory controls that prevent pollution problems by controlling land development and land use. They also include source controls that reduce pollutant buildup or lessen its availability for washoff during rainfall. A case study at the end of this chapter discusses the extensive nonstructural regulatory urban runoff controls used by Austin, Texas.

Low-cost structural controls include the use of facilities that encourage uptake of pollutants by vegetation, settling, or filtering. Because of the variability of pollutant removal, these controls can be used in series or in parallel combinations. The concept of implementing a "treatment train" might, for example, include initial pretreatment, primary pollutant removal, and final effluent polishing practices to be constructed in series.

All sources, both point and nonpoint, in a program area or watershed should be addressed. For urban areas, such sources often include urban runoff as well as CSOs. Practices for controlling both storm water and CSO pollution are described in this chapter. The practices discussed for urban runoff control are also applicable to storm water before it enters a combined sewer collection system. In addition, this chapter describes various types of storage and treatment facilities also commonly used to address CSOs.

Depending on the pollutant control mechanisms used, urban runoff pollution control practices can be divided into several categories:

- Regulatory controls
- Source controls
- Detention facilities
- Infiltration facilities
- Vegetative practices
- Filtration practices
- Water quality inlets

CSO-specific control practices are also divided into several categories:

- Source controls
- Collection system controls
- Storage
- Physical treatment
- Chemical precipitation
- Disinfection

While these lists do not include all urban runoff and CSO control practices, these categories are convenient ones for purposes of presentation and discussion.

Table 7-1 lists commonly used urban runoff and CSO BMPs based on the categories provided. The next section describes methods of BMP screening. The remainder of the chapter then gives a brief overview of some of the more important characteristics of these BMPs, including the types of pollutants controlled, the pollution removal mechanisms employed, limitations on their use, maintenance requirements, and general design considerations.

Best Management Practice Screening

The goal of BMP screening is to reduce the comprehensive list of BMPs to a more manageable list for final selection. Because this step is an initial screening, methods used are generally qualitative and require professional judgment. While extensive knowledge about specific design criteria is not necessary at this stage in the screening process, understanding the BMP's effectiveness and applicability to the program area's problems is crucial.

For this discussion, the BMPs are divided into two general categories: nonstructural and structural. Nonstructural BMPs—which include regulatory practices, such as those that limit impervious area or protect natural resources, and source controls, such as street sweeping or solid waste management—are typically implemented throughout an entire community, watershed, or special area. While structural BMPs, such as detention ponds or infiltration practices, may be designed to address specific pollutants from known sources, they also can be implemented throughout an area. In addition, structural BMPs can be required in new developments or redevelopments.

Comprehensive plans addressing urban runoff pollution prevention and control rely on both nonstructural and structural practices. While plans addressing specific

Table 7-1. Urban Runoff Pollution Control BMPs

Urban Runoff Controls	CSO Controls
Regulatory Controls	**Source Controls**
Land use regulations	Water conservation programs
Comprehensive runoff control regulations	Pretreatment programs
Land acquisition	**Collection System Controls**
Source Controls	Sewer separation
Cross-connection identification and removal	Infiltration control
Proper construction activities	Inflow control
Street sweeping	Regulator and system maintenance
Catch basin cleaning	Insystem modifications
Industrial/commercial runoff control	Sewer flushing
Solid waste management	**Storage**
Animal waste removal	Inline storage
Toxic and hazardous pollution prevention	Offline storage
Reduced fertilizer, pesticide, and herbicide use	Flow balance method
Reduced roadway sanding and salting	**Physical Treatment**
Detention Facilities	Bar racks and screens
Extended detention dry ponds	Swirl concentrators/vortex solids separators
Wet ponds	Dissolved air flotation
Constructed wetlands	Fine screens and microstrainers
Infiltration Facilities	Filtration
Infiltration basins	**Chemical Precipitation**
Infiltration trenches/dry wells	**Biological Treatment**
Porous pavement	**Disinfection**
Vegetative Practices	Chlorine treatment
Grassed swales	UV radiation
Filter strips	
Filtration Practices	
Filtration basins	
Sand filters	
Other	
Water quality inlets	

problems in small watersheds might tend to focus on structural practices, urban runoff pollution prevention and control programs should include implementation of nonstructural as well as structural control approaches. Methods for screening both nonstructural and structural practices are outlined below.

Nonstructural Practices

Since the number of potential nonstructural BMPs to be implemented is very large, initial screening is useful before the final selection process. The regulatory and source control BMP descriptions contained later in this chapter focus on the most commonly implemented practices; other, less commonly used practices, however, also could be considered. In addition, each practice (e.g., solid waste management) can be divided into numerous subpractices (e.g., management of leaf litter, rubbish, garbage, and lawn clippings). An urban runoff management plan for the Santa Clara Valley, for example, identified more than 100 separate potential nonstructural BMPs used throughout the country (Woodward-Clyde Consultants, 1989). Municipalities, therefore, have to screen regulatory and source control BMPs based on their particular watershed. The Santa Clara Valley program and the BMP screening and selection method are discussed in the case study at the end of Chapter 8.

One screening method involves applying screening criteria to each nonstructural practice to determine its applicability to the conditions in the watershed. The screening criteria, which are specific to the watershed and depend on the program goals, include:

- *Pollutant removal:* Since different regulations and source control practices are designed to address different pollutants, the program team should ensure that the screened list of controls includes practices designed to address the pollutants of primary concern. In addition, some practices might not provide sufficient pollutant removal.
- *Existing government structure:* Some practices implemented throughout the country require a specific government structure. For example, while a strong county government might be important for implementing a specific regulatory control, the role of county governments can vary from one section of the country to another. Practices requiring specific government structures that do not exist in the area of concern therefore could be eliminated from the list.
- *Legal authority:* For regulatory controls to be effective, the legal authority to implement and enforce the regulations must exist. If municipal boards and officials lack this authority, they could be required to obtain it through local action.
- *Public or municipal acceptance:* Implementing certain practices could be difficult because of resistance from the public or an involved municipal agency. These practices can be eliminated from the list.
- *Technical feasibility:* The municipal BMPs that require large expenditures and extensive efforts might not be suitable for small municipalities that lack the required resources.

Additional screening criteria may also be used, as shown in the Santa Clara Valley case study at the end of Chapter 8.

Another method of screening involves use of a comparative summary matrix. Figure 7-1 shows an example of such a matrix that can be used to screen nonstructural control practices. Though developed for screening nonstructural control practices in coastal areas, this matrix is at least in part applicable to inland areas as well. In this matrix, various regulatory and source control practices are listed and their abilities to meet various criteria are compared. The criteria listed include ability to remove specific pollutants, such as nutrients and sediments, maintenance requirements, longevity, community acceptance, secondary environmental impacts, costs, and site requirements. Other criteria are also listed, some of which are applicable only in coastal areas. For each practice and criterion, an assessment of effectiveness is indicated: solid circles indicate high effectiveness and open circles, low effectiveness. This type of matrix can provide a basis for an initial assessment of practices and their applicability to the program.

Structural Practices

Because structural practices generally are more site specific and have more restrictions on their use than nonstructural practices, the initial screening step for these practices can be more precise than for nonstructural practices. Table 7-2 outlines some of the more important criteria for the screening of structural BMPs, including their typical pollutant removal efficiencies, land requirements, the drainage area that each BMP can effectively treat, the desired soil conditions, and the desired ground-water elevation. By using these criteria and the information obtained during data collection and analysis and problem identification and ranking, the program team can narrow the list of BMPs to be further assessed in the BMP selection step.

The initial screening criteria for structural control practices include the following:

- *Pollutant removal:* The municipality should ensure that BMPs selected address the primary pollutants of concern to the level of removal desired.

	Nutrient Control	Shellfish	Estuarine Habitat Protection	Sedimentation	Sediment Toxics	Stormwater Control	Feasibility in Coastal Areas	Maintenance Burdens	Longevity	Community Acceptance	Secondary Environmental Impacts	Cost to Developers	Cost to Local Governments	Difficulty in Local Implementation	Site Data Required	Water-Dependent Use
Coastal Density Zones																
Intense zones	○	○	○	○	○	○	●	⊘	⊘	○	○	○	◍	○	◍	
Rural zones	○	◍	◍	◍	◍	◍	●	⊘	⊘	○	◍	◍	◍	○	◍	
Protection zones	◍	●	●	●	●	●	●	⊘	⊘	○	●	●	◍	◍	◍	
Overlay zones	◍	●	●	◍	◍	◍	●	⊘	⊘	○	◍	◍	◍	◍	○	
Performance zoning	◍	◍	◍	◍	◍	●	●	⊘	⊘	○	◍	◍	◍	◍	○	
Environmental Reserves																
Stream buffers	◍	◍	●	◍	○	○	●	●	●	●	●	◍	●	◍	●	○
Wetland buffers	◍	○	●	◍	○	○	●	●	●	●	●	○	●	●	●	●
Coastal buffers	◍	●	●	◍	○	○	●	●	●	●	●	○	◍	○	●	●
Expanded buffers	●	●	●	●	○	○	●	●	●	◍	●	◍	●	○	○	●
Floodplain limits	◍	○	●	○	○	◍	●	●	●	◍	●	◍	●	◍	◍	○
Steep soils limits	○	○	◍	●	○	◍	●	●	●	◍	●	◍	●	●	●	◍
Septic limits	◍	●	○	○	○	⊘	●	●	●	◍	●	○	◍	○	◍	◍
Wetland protection	●	◍	●	●	○	◍	●	●	●	●	●	◍	●	●	○	●
Forest protection	○	◍	◍	◍	○	○	●	●	●	●	●	○	●	◍	◍	●
Habitat protection	○	○	●	○	○	○	●	●	●	●	●	◍	●	◍	○	●
Open space protection	○	○	◍	○	○	○	●	●	●	●	●	○	●	◍	◍	●
	● 0 - 40% High level of control ◍ 30 - 40% Moderate level of control ○ 0 - 20% Low level of control ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Directly protects ◍ Indirectly protects ○ No protection ⊘ Not related	● 80% High ◍ 30 - 60% Moderate ○ 0 - 30% Low ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Widely applicable ◍ Applicable depending on site ○ Seldom applicable ⊘ Not applicable	● Low burden ◍ Moderate burden ○ High burden ⊘ Not applicable	● Long lived ◍ Long lived with maintenance ○ Short lived ⊘ Not applicable	● Positive ◍ Neutral ○ Negative ⊘ Mixed	● None or positive ◍ Slight negative impacts ○ Strong negative impacts at some sites ⊘ Prohibited	● Low ◍ Moderate ○ High ⊘ Very high	● Low ◍ Moderate ○ High ⊘ Very high	● Easy ◍ Moderate ○ Tough ⊘ Very tough	● Simple ◍ Moderate ○ Complex ⊘ None	● Can be used moderately in these areas ◍ Sometimes can be used ○ Seldom used ⊘ Not used

Figure 7-1. Sample nonstructural control screening matrix (U.S. EPA, 1991a).

	Nutrient Control	Shellfish	Estuarine Habitat Protection	Sedimentation	Sediment Toxics	Stormwater Control	Feasibility in Coastal Areas	Maintenance Burdens	Longevity	Community Acceptance	Secondary Environmental Impacts	Cost to Developers	Cost to Local Governments	Difficulty in Local Implementation	Site Data Required	Water-Dependent Use
Site Planning																
Cluster	○	◍	○	○	○	○	●	●	●	◍	●	●	●	○	◍	●
Performance criteria	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	●
Minimize imperviousness	○	○	○	○	○	◍	●									
Erosion & Sediment Control																
Time/area disturbance	◍	○	●	◍	⊘	○	●	●	●	●	●	●	◍	●	◍	●
Postdevelopment																
Urban housekeeping	○	◍	○	◍	◍	⊘	●	◍	○	◍	◍		●	●	●	●
Fertilizer control	◍	○	⊘	⊘	⊘	⊘	◍	○	○	◍	●		◍	◍	◍	◍
Septic maintenance	◍	●	○	⊘	⊘	⊘	●	○	◍	◍	◍		◍	◍	○	◍
Household hazardous waste	○	⊘	○	⊘	●	⊘	◍	○	○	◍	◍		◍	◍	○	◍
	● 0 - 40% High level of control ◍ 30 - 40% Moderate level of control ○ 0 - 20% Low level of control ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Directly protects ◍ Indirectly protects ○ No protection ⊘ Not related	● 80% High ◍ 30 - 60% Moderate ○ 0 - 30% Low ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Highly effective ◍ Moderately effective ○ Low effectiveness ⊘ Ineffective	● Widely applicable ◍ Applicable depending on site ○ Seldom applicable ⊘ Not applicable	● Low burden ◍ Moderate burden ○ High burden ⊘ Not applicable	● Long lived ◍ Long lived with maintenance ○ Short lived ⊘ Not applicable	● Positive ◍ Neutral ○ Negative ⊘ Mixed	● None or positive ◍ Slight negative impacts ○ Strong negative impacts at some sites ⊘ Prohibited	● Low ◍ Moderate ○ High ⊘ Very high	● Low ◍ Moderate ○ High ⊘ Very high	● Easy ◍ Moderate ○ Tough ⊘ Very tough	● Simple ◍ Moderate ○ Complex ⊘ None	● Can be used moderately in these areas ◍ Sometimes can be used ○ Seldom used ⊘ Not used

Figure 7-1. Sample nonstructural control screening matrix (continued).

Table 7-2. Structural BMP Initial Screening Criteria

Structural BMPs	Typical Pollutant Removals[a]: Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals	Relative Land Require-ments	Drainage Area[b]	Desired Soil Conditions	Ground-Water Elevation
Detention Facilities									
Extended detention dry ponds	Medium	Low-medium	Low-medium	Low	Low-medium	Large	Medium-large	Permeable	Below facility
Wet ponds	Medium-high	Medium	Medium	Low	Medium-high	Large	Medium-large	Impermeable	Near surface
Constructed wetlands	Medium-high	Low	Low-medium	Low	Medium-high	Large	Large	Impermeable	Near surface
Infiltration Facilities									
Infiltration basins	Medium-high	Medium-high	Medium-high	High	Medium-high	Large	Small-medium	Permeable	Below facility
Infiltration trenches/dry wells	Medium-high	Medium-high	Low-medium	High	Medium-high	Small	Small	Permeable	Below facility
Porous pavement	High	High	Medium	High	High	N/A	Small-medium	Permeable	Below facility
Vegetative Practices									
Grassed swales	Medium	Low-medium	Low-medium	Low	Low-medium	Small	Small	Permeable	Below facility
Filter strips	Medium-high	Medium-high	Medium-high	Low	Medium	Varies	Small	Depends on type	Depends on type
Filtration Practices									
Filtration basins	Medium-high	Low	Medium-high	Low	Medium-high	Large	Medium-large	Permeable	Below facility
Sand filters	High	Low-medium	Low	Low	Medium-high	Varies	Low-medium	Depends on type	Depends on type
Other									
Water quality inlets	Low-medium	Low	Low	Low	Low	N/A	Small	N/A	N/A

[a] Low = <30%, Medium = 30-65%, High = 65-100%.
[b] Small = <10 acres, Medium = 10-40 acres, Large = >40 acres.

- *Land requirements:* Large land requirements for some of the aboveground structural BMPs can often restrict their use in highly developed urban areas. Land requirements vary depending on the BMP.
- *Drainage area:* The structural BMPs listed in Table 7-2 are used primarily to treat runoff from watersheds up to 50 or 60 acres, and the optimum drainage area to be served varies for each practice and according to the land use (connected impervious area, for example). Drainage areas above this size might have to be treated by locating BMPs in subwatersheds.
- *Soil characteristics:* Structural BMPs have differing requirements for soil conditions. Infiltration facilities generally require permeable soils, while detention BMPs generally require impermeable soils. The municipality must become familiar with soil conditions in the watershed.
- *Ground-water elevation:* The ground-water elevation in the watershed can be a limiting factor in siting and implementing structural BMPs. Generally, high ground-water elevation can restrict the use of infiltration facilities and filtration practices; but it is necessary for constructed wetlands and may be desirable for detention facilities.
- *Public acceptance:* Since a municipality could have difficulty implementing a structural BMP without public approval, public acceptance of the BMPs should be considered in the screening step.

Of the screening criteria listed, the pollutant removal, land requirements, and drainage area served are usually absolute restrictions. Soil condition and ground-water elevation, on the other hand, impose restrictions that could be overcome by such means as importing soil or constructing facilities with clay liners to restrict ground-water inflow. Such modifications, however, can add significantly to the BMP costs.

Best Management Practice Descriptions

This section provides a brief overview of the BMPs discussed, based on the categories presented in Table 7-1. Additional references should be consulted before selecting, designing, and implementing BMPs (see Appendix A). Appendix B lists widely available and helpful documents that provide more detailed information on designing, constructing, and maintaining urban runoff and CSO BMPs. There are a host of other BMPs that address specific pollution sources, such as landfills, industrial sites, salt storage facilities, marinas, and numerous others. As mentioned earlier, agricultural BMPs are not discussed in depth in this handbook.

Urban Runoff Control Practices

This section addresses regulatory controls, source controls, and several types of commonly used structural controls.

Regulatory Controls

Urbanization increases the amount of impervious land area, which in turn increases storm water runoff with its associated pollutants (see Chapter 1). Municipalities can prevent or reduce many of these pollution problems by implementing regulatory controls to limit the amount of impervious area and to protect valuable resources. These regulatory controls can prevent or limit the quantity of runoff as well as its pollution load. Regulatory controls typically implemented by municipalities include:

- Land use regulations, such as:
  - zoning ordinances,
  - subdivision regulations,
  - site plan review procedures, and
  - natural resource protection.
- Comprehensive runoff control regulations.
- Land acquisition.

Local government regulations can require storm runoff controls, reduce the level of impervious area, require the preservation of natural features, reduce erosion, or require other important practices. The major aspects of storm water prevention and control—including runoff quantity control, solids control, and other pollution control—are illustrated in the case study at the end of this chapter on the regulatory practices implemented by Austin, Texas.

Runoff Quantity Control. Regulations addressing runoff quantity control can be used to reduce the effects of land development on watershed hydrology. Hydrologic control in turn results in pollution control, and can be accomplished through requirements such as:

- *Open space:* By maintaining specified levels of open space on a development site, the total area of impervious surface is reduced and infiltration of precipitation is increased. This leads to decreases in total pollutant discharge and potential downstream erosion by reducing total and peak runoff flows.
- *Postdevelopment flow control:* Many development regulations require that peak runoff conditions from a site be calculated before and after construction. These requirements specify that conditions after construction must reflect conditions before construction. This control is typically accomplished through the use of detention facilities, which can reduce peak runoff discharge rates, thereby decreasing downstream erosion problems. These regulations specify the desired outcome; the approach for ensuring that outcome, however, is determined by the developer.
- *Runoff recharge:* Regulations may specify that storm water runoff be recharged on site. Such regulations can reduce the runoff leaving a site, thereby reducing development-induced hydrologic changes and pollutant transport. By directly promoting infiltration, peak and total runoff rates can be decreased and pollutant discharges and downstream erosion can be reduced. Such runoff recharge also might help maintain surficial aquifer levels.

Solids Control. Regulations addressing solids control could include requirements for control practices during and after construction, since such activity has been shown to be a major contributor of solids. Construction activities can greatly increase the level of suspended solids in storm water runoff by removing vegetation and exposing the topsoil to erosion during wet weather. Yet while communities have requirements for implementing erosion control practices on construction sites, fewer communities require erosion control after construction is complete. Since many other land uses can contribute solids loadings, regulatory requirements can cover various types of industrial and commercial activities.

Other Pollution Control. Land development increases the concentrations of nutrients, pathogens, oxygen demanding substances, toxic contaminants, and salt in storm water runoff. Development regulations, therefore, can be used to address some of these specific pollutants. These regulations can take the form of special requirements for limiting nutrient export in special protection districts or setting performance standards for known problem pollutants.

While many of the regulatory controls outlined in this section are used by municipalities, few communities have used these regulations systematically to prevent urban runoff pollution problems. The regulations, developed over a number of years, have had purposes largely unrelated to urban runoff pollution prevention and control. By reexamining and amending these regulations and ordinances to reflect water resource goals, however, communities can improve their ability to prevent and control urban runoff pollution.

Land Use Regulations. Land use regulations can include zoning ordinances, subdivision and site plan regulations and review requirements, and environmental resource regulations such as wetlands protection. These practices are used as tools to promote development patterns that are compatible with control of urban runoff discharges.

Zoning. Most communities have residential, commercial, industrial, and other zoning districts that specify the types of development allowed and dictate requirements, including:

- Specifying the density and type of development allowed in a given area, thereby maintaining pervious areas.
- Controlling acreage requirements for certain land uses and associated setback, buffer, and lot coverage requirements.
- Directly and indirectly affecting the types of materials that can be stored or used on sites.
- Not allowing potentially damaging uses (e.g., underground chemical storage or pesticide application) in sensitive watersheds.

Examples of types of zoning controls that can be used to protect water bodies include:

- *Cluster development:* Allowing structures in developments to be constructed close together to preserve open space.
- *Down-zoning:* Changing an established zone to a use that allows a lower level of density.
- *Phase-in zoning:* Changing the zoning of a specific area over time, usually as inappropriate sites reach the end of their useful life.
- *Large lot zoning:* Requiring greater minimum acreage for development in certain locations.
- *Conditional zoning:* Allowing certain activities only under specified conditions that protect water quality.
- *Overlay zoning:* Placing additional zoning requirements on an area that is already zoned for a specific activity or use.
- *Open space preservation:* Protecting open space and buffer zones in the community near water bodies.
- *Performance standards:* Permitting certain land uses, usually industrial activities, only if they meet specific performance criteria.

These practices can be used by communities to ensure that land uses in each area are appropriate for that area's water resources. Such controls are especially useful in sensitive areas, such as water supply watersheds, and can serve to reduce or control development.

Subdivision Regulations. Subdivision review deals with land that is divided into separately owned parcels for residential development. Municipalities have the authority to review the plans for such subdivisions and to restrict development options via requirements for drainage, grading, and erosion control, as well as provisions for buffer areas, open spaces, and maintenance. Through this review, municipalities can ensure that proper practices are designed into the development.

Site Plan Review. Site plan review ensures compliance with zoning, environmental, health, and safety requirements. Municipalities can require developers to consider how construction activities will affect drainage on site and to design plans for reducing urban runoff pollution problems. Developers usually are required to submit information to a municipality on the natural drainage characteristics of the site, plans for erosion control, retention and protection of wetlands and water resources, and disposal of construction-related wastes.

Natural Resource Protection. Municipalities can also protect water resources by protecting lands, such as floodplains, wetlands, stream buffers, steep slopes, and wellhead areas. By use of resource overlay zones that restrict high pollution activities in these areas, development can be controlled and the potential for urban runoff pollution can be reduced.

Comprehensive Runoff Control Regulations. In addition to strengthening and broadening existing local regulatory control practices, states and municipalities can implement runoff pollution control through comprehensive regulations. While still relatively rare, comprehensive plans to address urban runoff pollution exist in various states and communities. They are designed to fully address urban runoff pollution problems by identifying specific land use categories and water resources that deserve special attention, and outlining methods for implementing source control and structural BMPs. While the form that these comprehensive regulations take is very specific to the needs of a state or community, reviewing the regulatory approaches that have been tried by others is useful in developing options. Examples include (Pitt, 1989):

- *Austin, TX:* Comprehensive Watersheds Ordinance, 1986; Urban Watersheds Ordinance, 1991 (see the case study at the end of this chapter).
- *Birmingham, AL:* Proposed Watershed Protection Ordinance.
- *State of Maryland:* Model Stormwater Management Ordinance, 1988.
- *State of Wisconsin:* Model Construction Site Erosion Control Ordinance, 1987.

Land Acquisition. To protect valuable resources from the effects of development, municipalities can purchase land within the watershed to control land development. Municipalities can acquire land to convert to parks or to maintain as open space; this approach, however, can be very expensive.

Source Control Practices

Source controls include the nonstructural practices designed to reduce the availability of pollutants. Many of these practices tie directly into EPA's Pollution Prevention strategy discussed in Chapter 2, which focuses on preventing pollution sources from entering the system rather than on treatment. Some of the more common practices used by municipalities throughout the country include:

- Cross-connection identification and removal
- Proper construction activities
- Street sweeping and catch basin cleaning
- Industrial/commercial runoff control
- Solid waste management
- Animal waste removal
- Toxic and hazardous waste management
- Reduced fertilizer, pesticide, and herbicide use
- Reduced roadway sanding and salting

Cross-Connection Identification and Removal. Within the NPDES storm water regulations, EPA has specifically emphasized the importance of implementing a program to identify and remove inappropriate sanitary and industrial wastewater connections to municipal storm water drainage systems—a problem in many urban areas. For example, a study of the storm drainage system in the Humber River watershed in Toronto indicated that about 10 percent of the outfalls from the system had dry-weather flows considered to be significant pollutant sources. This study found that more than 50 percent of the annual discharges of water volume, total suspended solids, chlorides, and bacteria from the monitored industrial, residential and commercial areas were associated with dry-weather discharges from the storm drainage system (U.S. EPA, 1993a).

Dry-weather discharges, such as from illegal wastewater discharges to the storm drainage system, can cause serious water resource degradation. The addition of sanitary wastes increases the concentrations of organics, solids, nutrients, and bacteria in the storm water runoff. Industrial wastes can be highly variable but can substantially increase the concentrations of heavy metals and other related pollutants in runoff (U.S. EPA, 1993a).

Unauthorized and inappropriate connections to drainage systems can exist for many reasons. In the past, connector pipes between sanitary sewers and storm drains could have been installed to relieve surcharging of the sewer system and prevent backups of sewage into homes and businesses. Connections from residential sanitary sewers or commercial and industrial floor drains also exist.

Cross-connections are common in municipalities that have undergone sewer separation. During separation, a new pipe system is often constructed to act as a separate sanitary sewer, and the old combined system is converted to operate as a separate storm drain because of its large size and carrying capacity. To complete the separation, existing connections to the combined sewer must be plugged and reconnected to the new sanitary sewer. If sewer connections to the newly created storm drain continue to exist with no written record or are not located on plans, they can be missed during the reconnection. In addition, as new construction occurs, accidental connections to the storm drainage system can occur.

Because cross-connections typically are not documented, pollution from these connections can often be difficult to locate. Municipalities, however, can develop a program to locate and eliminate these connections. This program should be designed to identify dry-weather discharges and to determine the flow sources by developing updated drainage system maps, conducting dry-weather inspections, and sampling dry-weather discharges. In some instances, discharge results from ground-water infiltration to the drainage system and might not be a pollution concern. If the analyses conducted on dry-weather flows indicate the presence of pollutants, however, the system should be traced to locate the source of the pollutants.

Locating cross-connections to storm drainage systems is similar to conducting the infiltration and inflow (I/I) and sanitary sewer evaluation survey (SSES) investigations that many municipalities regularly conduct. These investigations can be done through successive visual inspections, dye testing, or TV investigations. Once located, cross-connections must be removed so that industrial and sanitary wastes are discharged to a municipal sewerage system. Routine drainage system inspections should continue in order to avoid problems from inadvertent cross-connections from new development.

Detailed information is available in an EPA guidance document entitled *Investigation of Inappropriate Pollution Entries into Storm Drainage Systems* (U.S. EPA, 1993a).

Proper Construction Activities. Construction activities have been cited in numerous water quality assessments as a major source of sediment to surface waters. During construction, natural vegetation is removed from a site, exposing the topsoil. If the soil remains bare and exposed for extended periods, rainfall can cause erosion and transport the soil to nearby water bodies. After the soil enters a water body, decreases in water velocity cause the suspended solids to settle out of the water column and accumulate as sediment on the bottom of the water body. This sediment can smother benthic organisms and carry pollutants, such as petroleum products and metals. Construction-induced erosion therefore should be minimized. This section addresses some of the planning practices and controls that can be used at construction sites to reduce erosion and subsequent soil transport.

While the practices discussed in this section are general and can be applied at construction sites throughout the country, most state environmental offices have developed soil and erosion control handbooks tailored to the specific needs of the state. These documents provide more detailed guidance for developing and implementing programs to address construction site pollution problems. In addition, some municipalities, such as Birmingham, Alabama (Pitt, 1989), have developed ordinances to address construction-site erosion controls.

On construction sites, areas to be maintained in their preconstruction condition should remain undisturbed during construction; existing vegetation to be incorporated into the final site should be maintained. The planned roads and parking areas should be used for construction traffic and other construction-related activities; these areas can be treated with crushed stone during construction and paved after construction has been completed. Planned open areas at a site should be seeded immediately after clearing, and open areas not in use for construction should be covered with crushed stone or seeded with a temporary cover crop.

The planning, sequencing, and timing of construction activities are also important to reduce soil transport. Phasing and limiting of clearing activities so that one area of a site is complete and stabilized before beginning work on other areas can also reduce the potential for erosion.

On large construction sites with extensive grading and vegetation removal, structural erosion control practices are required. During construction activities, temporary berms or weirs can divert runoff away from disturbed areas of the site. Runoff diversion or slope modifications should be incorporated into the final site design; during construction, these diversion structures should be protected by crushed stone or blankets to reduce erosion.

Since construction site runoff contains high levels of suspended solids, temporary structures that filter out or settle out solids should be incorporated into the site. Straw bales, silt fences, dewatering filters, and sedimentation basins are often used to control erosion. Straw bales can be placed across a sloped area to intercept runoff from the slope and trap sediment. They can also be used around storm water inlets and catch basins to reduce the transport of sediment to nearby drainage systems. In addition, straw bales can be placed at intervals along long slopes to reduce runoff velocity to control erosion. Straw bales need to be replaced every few months; the old bales can be broken up and used for ground cover if properly installed and maintained. Silt fences can be used for many of the same functions as straw bales and usually have a longer life.

In addition to these temporary, inexpensive erosion-control devices, storm water runoff from larger construction sites should be directed to sedimentation basins, designed to intercept runoff and hold it for an extended period to allow suspended solids to settle out. Sedimentation basins, which require periodic cleaning, already might be incorporated into the final site design as permanent storm water attenuation/treatment controls. When construction is completed, they should be cleaned out and the bottoms regraded.

To ensure that construction site erosion control practices are properly implemented and that regulations are followed, plans must be reviewed prior to construction activities and inspections must be conducted. Municipalities or responsible agencies must provide for erosion control plan review, site review, and enforcement.

Street Sweeping and Catch Basin Cleaning. Frequent street sweeping can limit the accumulation of dirt, debris, and associated pollutants, and the subsequent deposition of these pollutants in storm drains and waterways. Regular cleaning of catch basins can also remove accumulated sediment and debris that ultimately could be discharged from storm drains and combined sewers. In most municipalities, these tasks are conducted at scheduled intervals and have been shown to result in significant pollutant reductions only if an intensive schedule is followed. A study performed in San Jose, California, showed that

50 percent of the total solids and heavy metals could be removed from urban runoff when city streets were cleaned once or twice a day. When the streets were cleaned only once or twice a month, the removal rate dropped to less than 5 percent (U.S. EPA, 1979). Increased frequency also could result in increased fugitive air emissions. Regular street sweeping and catch basin cleaning can, in any case, remove some of the large floatable litter that is unsightly in urban surface waters. Street sweeping twice a week and catch basin cleaning once or twice a year have been found effective in removing these large floatable pollutants (U.S. EPA, 1983). Determining the effectiveness of street sweeping programs, however, is difficult because of variations in pollutant buildup and storm events. In addition, studies have shown that the choice of sweeping equipment can significantly affect the effectiveness of cleaning programs (Pitt, 1989).

Commercial/Industrial Runoff Control. Certain commercial and industrial sites can be responsible for disproportionate contributions of some pollutants (e.g., grit, oils, grease, and toxic materials) to the drainage system. Typical sources of potential concern include gasoline stations, railroad yards, freight loading areas, and parking lots. In specific cases where significant pollutant loadings to the system are contributed by well-defined locations of limited area, pretreatment of the runoff from these areas could be a practical and effective control measure. Pretreatment measures can be required as part of a community's regulations. Examples of pretreatment measures include oil/water separators for gasoline stations, or the use of modified catch basin designs to enhance the retention of oil and grease or solids. Procedures for the detection and location of illicit connections to separate storm drains by testing for specific chemical tracers could be applied to identify commercial or industrial sources contributing substantial levels of problem pollutants.

Solid Waste Management. Most communities have programs to collect and dispose of solid waste in an effort to maintain clean streets and provide a service for local residents and businesses. Some communities provide added services during times of particularly high waste generation. For example, some municipalities in the northern United States provide extra collection services during the fall to collect leaves—an added service that helps keep leaves from blowing into surface waters. A study of storm water runoff into Minneapolis lakes found that phosphorus levels were reduced by 30 to 40 percent when street gutters were kept free of leaves and lawn clippings (MPCA, 1989). Actual reductions of pollutant loads, however, are difficult to predict. In general, any solid waste that is picked up and disposed of in a controlled manner will be less likely to enter a drainage system.

Animal Waste Removal. Domesticated and wild animal wastes represent a source of bacteria and other pollutants that can be washed into surface waters by urban runoff. These pollutants can be reduced by reducing the animal waste on paved surfaces. Municipalities often enact and enforce leash laws and pet waste cleanup ordinances. The effectiveness of these programs in reducing pollutant loads is unknown, however, and usually depends on voluntary actions by private citizens.

Toxic and Hazardous Waste Management. Improper dumping of household and automotive toxic and hazardous wastes into municipal storm inlets, catch basins, and other storm drainage system entry points can result in significant discharges of pollutants to surface waters during rainstorms. This dumping can be a particular problem in urban areas where individuals change the oil or antifreeze in their cars and dispose of the wastes in nearby catch basins. In addition, homeowners and small businesses sometimes dispose of products such as waste paints and solvents in storm water inlets and catch basins. To address the problem, municipalities can educate residents on the consequences of dumping these wastes into storm drainage system entry points. In addition, communities can develop hazardous- and toxic-waste collection days to dispose of or recycle these wastes properly. Also, storm drain systems can be labeled with warnings about the pollution problems associated with dumping wastes. The effectiveness of such programs, however, cannot be determined in advance because of the voluntary nature of compliance. For business and industry, an inspection, testing, and enforcement program (similar to an industrial pretreatment program) can be developed.

Reduced Fertilizer, Pesticide, and Herbicide Use. Fertilizers, pesticides, and herbicides washed off the ground during storms can contribute to water pollution. Agricultural, park land, and other land uses can be sources of these pollutants. Many communities use these chemicals on park lands, and homeowners utilize them on their lawns. Controlling the use of these chemicals on municipal lands and educating the public can help reduce nutrient and toxic pollutant concentrations in urban runoff.

Reduced Roadway Sanding and Salting. In areas of the United States with freezing road conditions, sand and salt are used in the winter to improve driving conditions. Salt and sand can be washed off roadways, however, and pollute receiving waters. The problem is exacerbated during spring snowmelt and early spring rainstorms when most of these pollutants are available for transport. These problems can be reduced by minimizing the use of chemicals for snow and ice control to the minimum necessary for public safety and by utilizing proper equipment. In addition, salt storage sites have been shown to be persistent and frequent sources of contamination, especially during rainfall (U.S. EPA, 1973); sand and salt piles therefore should be covered. Also, deicing alternatives, such as calcium magnesium acetate (CMA), can be used in some cases (U.S. EPA, 1974a,b).

Detention Facilities

One of the most common structural methods for controlling urban runoff and reducing pollution loading is through the construction of ponds or wetlands to collect runoff, detain it, and release it to receiving waters in a controlled manner. Pollution reduction during the period of temporary runoff storage results primarily from settling of solids. Detention facilities, therefore, are most effective at reducing the concentrations of solids and the pollutants that typically adhere to solids, and less effective at removing dissolved pollutants.

Currently, the three types of detention facilities commonly used to remove pollutants from storm water runoff are extended detention dry ponds, wet ponds, and constructed wetlands; each is discussed below. For more detailed design information, the references listed in Appendix B should be consulted.

Extended Detention Dry Ponds. Most municipalities are familiar with the concept of constructing dry ponds to control peak runoff. When used as water quality BMPs, dry ponds are designed with orifices or other structures that restrict the velocity and volume of the discharges (see Figure 7-2). Dry ponds thereby detain the runoff before discharging it to surface waters.

Pollutant Removal. During the storage period, heavier particles settle out of the runoff, removing suspended solids and pollutants, such as metals, that attach to the particles or precipitate out. Some dry ponds also include vegetated areas that can provide pollutant removal through filtering and vegetative uptake. Dry ponds are, therefore, most effective at removing suspended solids and some nutrients and metals, and less effective at removing dissolved pollutants and microorganisms. Overall, the pollutant removal effectiveness of dry ponds has been shown to be less than for wet ponds and constructed wetlands (see Table 7-2).

Design Considerations. Retrofitting existing dry ponds with new outlet structures can sometimes enhance a municipal flood-control structure to increase its pollution control effectiveness. Care must be taken, however, to ensure that the overflow capacity of the pond is maintained, so that it continues to fulfill its original flood-control function. Study of the hydraulic characteristics of the dry pond will be necessary before retrofitting. Temporary storage also can be provided for runoff from smaller storms by building a small berm around an existing outlet structure.

For water quality dry ponds, important design criteria include the desired detention time and the volume of runoff to be detained. These factors dictate the pond's size and affect the pollutant removal efficiency of the structures. Most dry-pond sizing criteria specify a

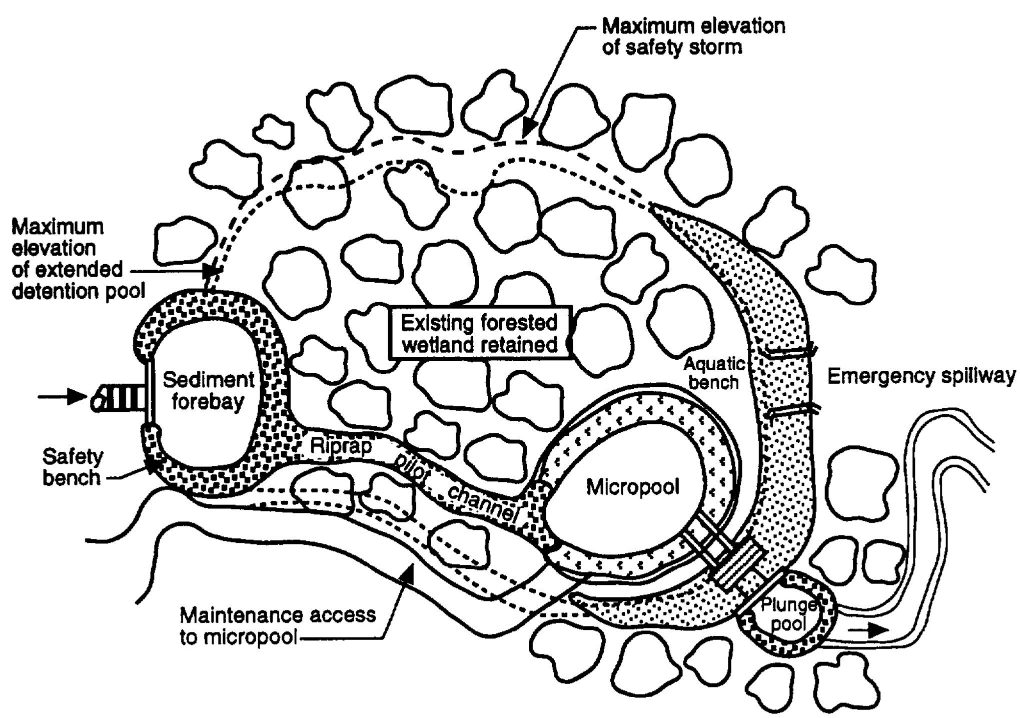


Figure 7-2. Extended detention pond (U.S. EPA, 1991a).

certain detention time for a given design storm. For example, the Maryland Water Resources Authority specifies that water quality dry ponds must be large enough to accommodate the runoff volume generated by the 1-year, 24-hour storm to be released over a minimum of 24 hours (Schueler, 1987). In contrast, the Washington State Department of Ecology (WA DOE) specifies that dry ponds must be large enough to accommodate the runoff volume generated by the 2-year, 24-hour storm and release it over a period of 40 hours (WA DOE, 1991).

Dry ponds should also include some form of low-flow channel designed to reduce erosion; vegetation on the bottom of the pond to promote filtering, sedimentation, and uptake of pollutants; and an outlet structure designed to remove pollutants and withstand clogging. In addition, dry pond designs typically include upstream structures to remove coarse sediments and reduce sedimentation and clogging of the outlet. Also, outlets might be connected to grassed swales (biofilters) to provide additional pollutant removal (WA DOE, 1991). Each of these components of a dry pond design either enhances pollutant removal or reduces operation and maintenance costs for the structure.

Maintenance Requirements. Maintenance of water quality dry ponds is important. Regular mowing, inspection, erosion control, and debris and litter removal, are necessary to prevent significant sediment buildup and vegetative overgrowth (Schueler, 1987). Also, periodic nuisance and pest control could be required. Dry-pond design should recognize these maintenance requirements. The pond slopes should allow for mowing, and access roads should be provided.

Limitations on Use. Like other storm water treatment structures used in large watersheds, a primary physical constraint on the construction of water quality dry ponds is their large land requirements. For this reason, locating dry ponds in new developments is usually more practical than constructing them in already developed areas. Other physical constraints include the topography and the depth to bedrock.

Wet Ponds. The design of wet ponds is similar to that of dry ponds and constructed wetlands. In wet ponds, storm water runoff is directed into an constructed pond or enhanced natural pond, in which a permanent pool of water is maintained until being replaced with runoff as shown in Figure 7-3. Once the capacity of a wet pond is exceeded, collected runoff is discharged through an outlet structure or an emergency spillway.

Pollutant Removal. The primary pollutant removal mechanism in wet ponds is settling. The ponds are designed to collect storm water runoff during rainfall and to detain it until additional storm water enters the pond and displaces it. While the runoff is detained, settling of particulates and associated pollutants takes place in the pond.

Wet ponds can also remove pollutants from runoff through vegetative uptake. Wet ponds should be vegetated with native emergent aquatic plant species, which can remove dissolved pollutants such as nutrients from the runoff before it is discharged to the receiving water.

Design Considerations. Wet ponds typically are designed with a number of different water levels. One level of the pond has a permanent pool of water. The next level periodically is inundated with water during storms; this area should be vegetated and relatively flat to promote settling and filtering of sediments and vegetative uptake of nutrients. The highest level will be inundated only during extremely heavy rainfall; this area also should be vegetated to prevent soil erosion. At least 30 percent of the surface area of a wet pond should be a vegetated zone (Livingston et al., 1988). Typically, this vegetation is concentrated at the outlet as a final "polishing" biofilter.

The sizing of wet ponds is similar to that of dry ponds in that a number of different "sizing rules" provide varying levels of pollution control. Generally, these rules specify the volume of runoff to be detained in the wet pond during a storm. For example, the Maryland Water Resources Authority specifies that the permanent pool of a wet pond should be large enough to contain one-half inch of runoff distributed over the impervious portion of the contributing watershed (MD WRA, 1986). In Florida, storage volume for 1 inch of runoff above the normal pool elevation is recommended. This volume must be released at a slow rate; no more than half should be discharged within 60 hours after the event, and all the volume must be released after 120 hours. A hydraulic retention time of 14 days for the permanent pool volume is recommended (Livingston et al., 1988).

The design of water quality wet ponds must also take into consideration the possibility of large storms. Emergency spillways should be included in the design to prevent flooding difficulties. In addition, the pond's inlet and outlet structures should be separated and constructed at either end of the pond to maximize full mixing when large flows occur and avoid short-circuiting. By separating the inlet from the outlet, the detention time of the pond can also be increased. A forebay or other system for pretreatment also might be advisable. Further design guidelines for wet ponds can be found in the references in Appendix B.

Maintenance Requirements. Like many other BMPs, wet ponds require routine maintenance to be effective. Wet ponds are designed to allow for settling of suspended solids; therefore, periodic removal of the accumulated sediment must be performed (perhaps

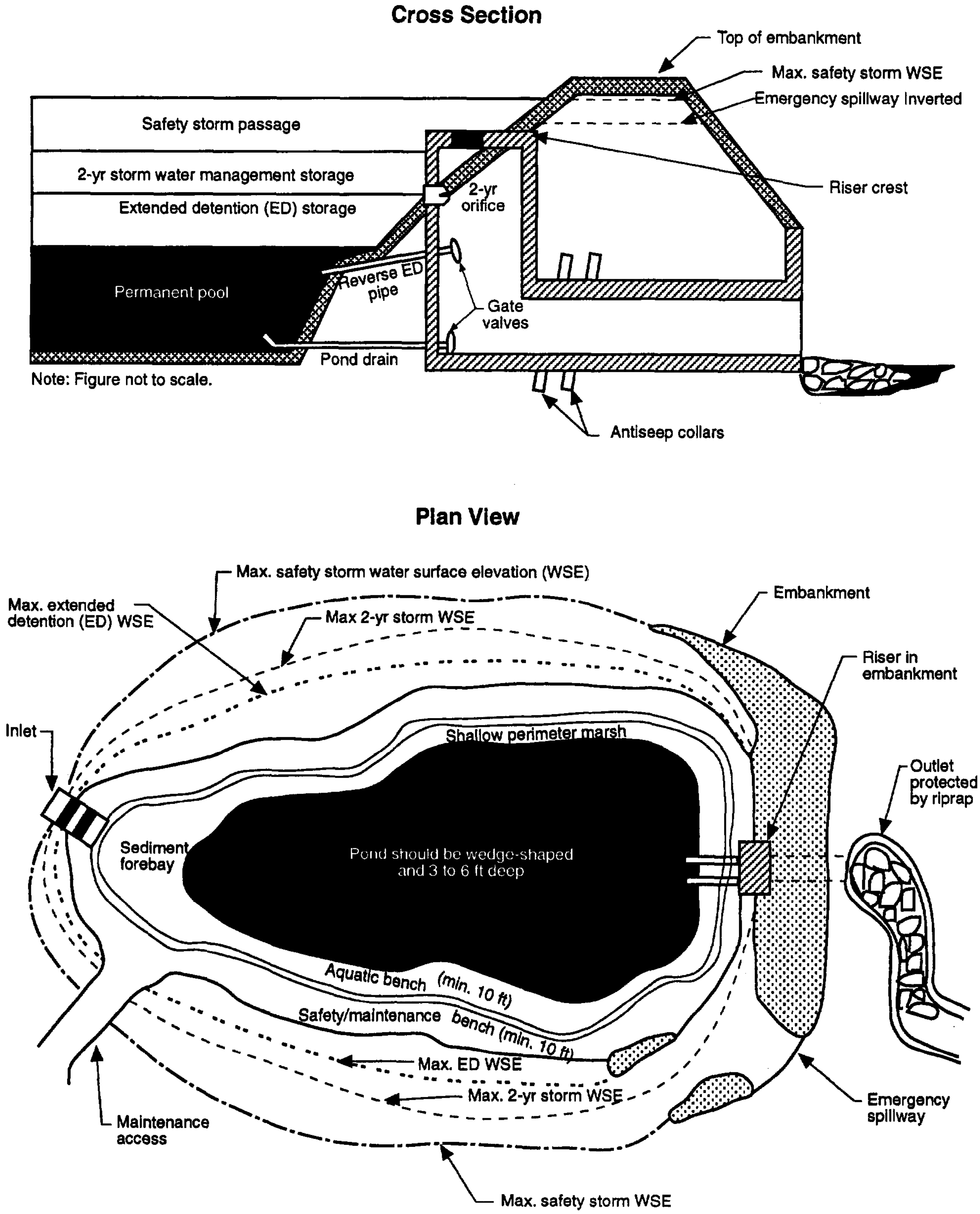


Figure 7-3. Wet detention system (Roesner et al., 1988).

every 10 to 20 years). Removed sediment must be disposed of in accordance with appropriate regulations, which could include testing and special handling requirements for contaminated material. In addition, the pond slopes should be regularly mowed to make the sediment removal process easier and to enhance the aesthetic qualities of the area. Inlet and outlet structures should be inspected periodically for damage and accumulated litter, and the pond bottom should be inspected for potential erosion. Erosion of the pond bottom from high velocity flows can result in increased sediment transport and overall reduction in the pollutant removal capabilities of the pond.

Limitations on Use. Water quality wet ponds have large land requirements and usually are more suited to new development projects where they can be designed into the site. In addition, wet ponds are not suitable for use in areas with porous soils or low ground-water levels because a pool of water in the bottom is key to their design. Wet ponds should be built into the ground water with their control elevation set above the level of seasonal high water tables. Synthetic impermeable materials or clay can be used to prevent seepage. Wet ponds also have physical limitations related to the site topography; since locating wet ponds in areas with extreme slopes is often difficult, relatively flat locations are preferable.

Constructed Wetlands. Constructed wetlands are effective in removing many urban storm water pollutants. Two prevalent types of systems are shallow-constructed wetlands (Figure 7-4) and wet detention systems (Figure 7-5). The wet detention system is a wet pond with extensive shoreline shallow wetland areas. Wetland systems combine the pollutant removal capabilities of structural storm water controls with the flood attenuation provided by natural wetlands. Proper design of constructed wetlands—including their configuration, proper use of pretreatment techniques to remove sediments and petroleum products, and choice of vegetation—is crucial to the functioning of the system.

Pollutant Removal. Constructed wetland systems perform a series of pollutant removal mechanisms including sedimentation, filtration, adsorption, microbial

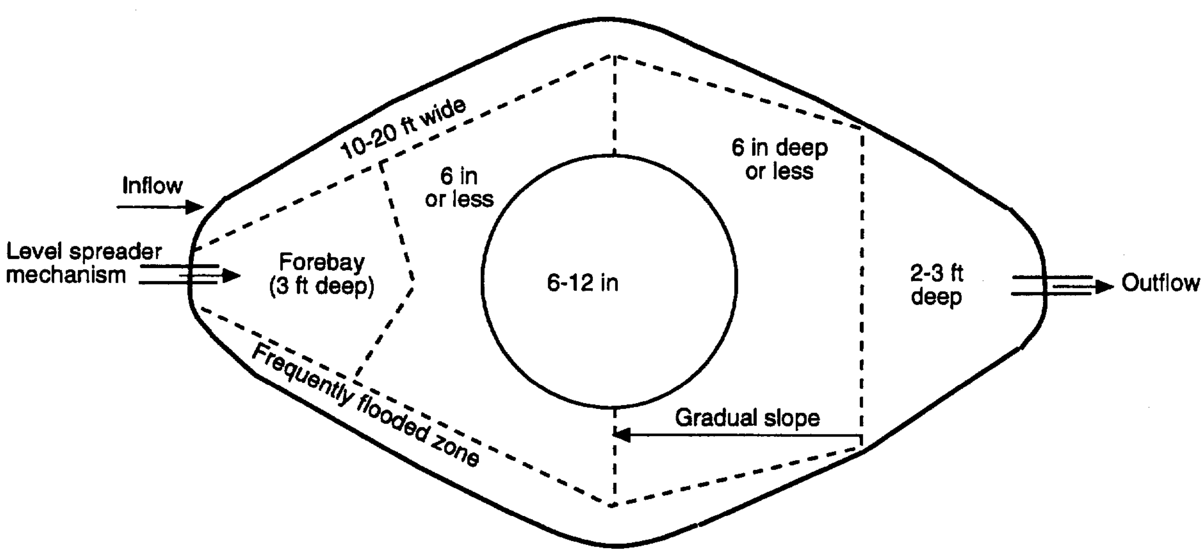


Figure 7-4. Example shallow-constructed wetland system design for storm water treatment (Maryland DNR, 1987).

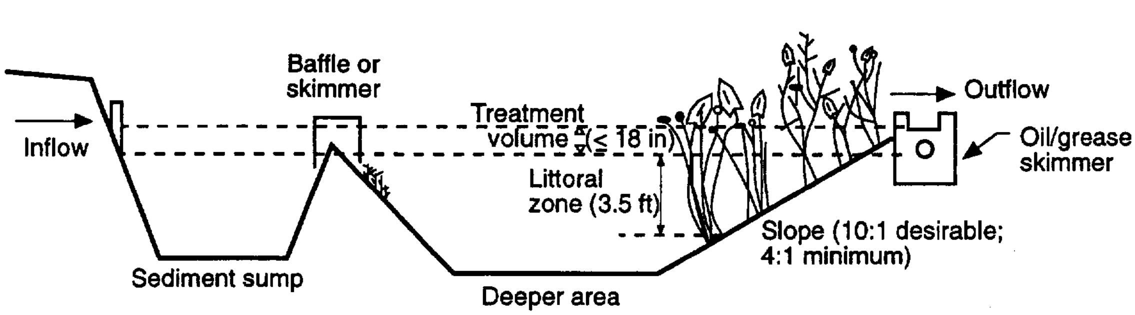


Figure 7-5. Example wet detention system design for storm water treatment (Livingston et al., 1988).

decomposition, and vegetative uptake to remove sediment, nutrients, oil and grease, bacteria, and metals. Wetland systems reduce runoff velocity, thereby promoting settling of suspended solids. Plant uptake accounts for removal of dissolved constituents. In addition, plant material can serve as an effective filter medium, and denitrification in the wetland can remove nitrogen. A review of pollutant removal effectiveness data for 15 constructed wetlands and 11 natural wetland systems designed to treat storm water found high removals of total suspended solids and lead and only fair removal of ammonia, total phosphorus, and zinc (U.S. EPA, 1992a). In addition, constructed wetlands were found to have higher average removal rates and less variability than natural systems (U.S. EPA, 1992a). Specific wetland vegetation species remove specific pollutants from storm water runoff (RIDEM, 1989). Some of the most commonly used wetland vegetation includes cattails, bulrushes, and canary grass.

Design Considerations. Because the use of wetland systems for storm water runoff control is a relatively new technology, generally accepted design criteria do not exist. Some general guidelines, however, are recognized as important in the design of wetland systems. These guidelines include maximizing the detention time of runoff in the wetland system, maximizing the distance between the inlet and outlet, and providing some form of pretreatment for sediment removal.

Maximizing the travel time of runoff through a wetland system allows for greater opportunity for sediments to settle out of the water and for wetland plants to take up nutrients and other pollutants. Travel time can be increased in a wetland by reducing the gradient over which the flow travels or by making the flow travel over a greater distance before being discharged. In either case, some designers recommend a 24-hour detention time during the 1-year, 24-hour storm (RIDEM, 1989). If the distance separating the inlet from the outlet in a wetland system is not sufficient, flow might enter the wetland system and not become fully mixed during large rainstorms (see also the wet pond discussion). This phenomenon, known as short-circuiting, can greatly reduce the wetland system's level of treatment. Short-circuiting can be reduced by careful design of the wetland system. Wetland design should also take into account that sediment accumulation in wetland systems can greatly shorten their effective life and that some suspended solids should be removed from the runoff before it enters the wetland system. The design should include sloped sides to allow easy removal of accumulated sediments and harvesting of plants. Recommendations for constructed wetland systems are expected to evolve as more research is conducted.

Maintenance Requirements. Like most storm water quality controls, constructed wetlands require regular maintenance. In addition to regularly scheduled sediment removal, wetland systems should be periodically cleared of dead vegetation. Harvesting of plants in the wetland might be appropriate for pollutant removal purposes; if so, disposal of removed material must be planned.

Limitations on Use. While constructed wetland systems can treat storm water runoff effectively, they do require large areas of undeveloped land, which can make siting of wetland systems difficult especially in urban areas. For this reason, incorporating wetland systems into new development is usually more feasible than retrofitting them into existing developments. Existing wetlands occasionally can be retrofitted for pollutant removal if not prohibited by local or state regulations. Achieving proper soil conditions and ground-water levels can also present difficulties. To maintain a wetland environment, soils must be resistant to infiltration (i.e., have low permeability) and a water supply must be constant. In general, soils in the system must be saturated throughout the growing season so the desired vegetation will survive. Since natural wetlands are protected resources, diverting storm water to them for treatment will likely be prohibited. Finally, created wetlands become a resource area that may be subject to protection under federal, state, and local laws.

Infiltration Facilities

Unlike detention facilities that capture and eventually release storm water runoff to a surface water body, infiltration facilities permanently capture runoff so that it soaks into the ground water. Because they do not release the runoff to a surface water, infiltration facilities are sometimes called retention facilities. Pollutant removal in these BMPs occurs primarily through infiltration, which eliminates the runoff volume or lowers it by the capacity of the facility. Since the infiltrated flow can travel through the ground water and still be released to surface waters, dissolved pollutants such as some nutrients and metals could be reintroduced to the surface water with minimal pollutant removal. Currently, the three different types of facilities commonly used to promote infiltration and remove pollutants from storm water runoff are infiltration basins, infiltration trenches/dry wells, and porous pavement (grassed swales, which also promote infiltration, are addressed later under vegetative practices). Each of these BMPs is discussed in this section. For detailed design information, the references listed in Appendix B should be consulted.

Infiltration Basins. Infiltration basins are similar to dry ponds, except that infiltration basins have only an emergency spillway and no standard outlet structure.

All flow entering an infiltration basin (up to the capacity of the basin) is, therefore, retained and allowed to infiltrate into the soil (see Figure 7-6).

Pollutant Removal. Infiltration is the major pollutant removal mechanism. Infiltration basins, like dry and wet ponds, receive storm water runoff from drainage systems and provide storage up to a designed volume. Unlike dry detention ponds which eventually release stored runoff through a drainage system, or wet ponds which maintain a permanent pool of water, infiltration basins release stored runoff through the basin's underlying soil. Infiltration basins provide storm water pollutant removal through volume reduction and filtration and settling. Infiltration basins are particularly effective in removing bacteria, suspended solids, insoluble nutrients, oil and grease, and floating wastes. They are less effective in removing dissolved nutrients, some toxic pollutants, and chlorides. Therefore infiltration basins should not be used when the ground-water quality itself is a concern or when these pollutants can be reintroduced through ground-water flow to surface waters.

Design Considerations. The most important consideration in the design of infiltration basins is calculating the basin's size for the drainage area and the soil type involved. Some designers recommend off-line basins to capture and infiltrate the first one-half inch of rainfall from the contributing drainage area (MD WRA, 1986). The appropriate amount of flow must be diverted to the system, and soil tests need to be performed to estimate the infiltration rates and appropriately size the basin. Also related to the proper size of infiltration basins is the amount of time necessary for the basin bottom to dry between rainstorms. Designers generally specify that infiltration basins should be designed to be dry for at least 3 days between storms (Schueler, 1987). This interval allows the soil to dry, thereby increasing its pollutant removal capacity. Basin shape is also important. It should have gently sloping sides to allow for easy access to mow the bottom vegetation. An emergency spillway must also be incorporated into the basin design. Finally, some form of pretreatment is recommended to remove suspended sediments from runoff before it is discharged to the basin. This pretreatment will reduce the need for periodic removal of accumulated sediment which can clog the soil pores and reduce the level of infiltration.

Maintenance Requirements. Infiltration basins require moderate to high levels of periodic maintenance. Most are designed with vegetated bottoms to provide stabilization and promote some vegetative uptake of nutrients. Periodically, the bottom of the basin must be mowed and accumulated sediments must be removed to maintain desired infiltration rates.

Limitations on Use. Infiltration basins often have relatively large land requirements and are better suited for location in developing areas than in already developed areas. Infiltration basins also require suitable soil to be effective. Accumulating runoff must be able to infiltrate the soil in the bottom of the basin. Typically, sand and loam, with infiltration rates greater than or equal to 0.27 in/hr (WA DOE, 1991), are the preferred soils for infiltration systems. The use of infiltration basins can be restricted by high ground-water elevations. For infiltration to occur, ground-water levels should be located at least 2 to 4 feet below the bottom of the basin.

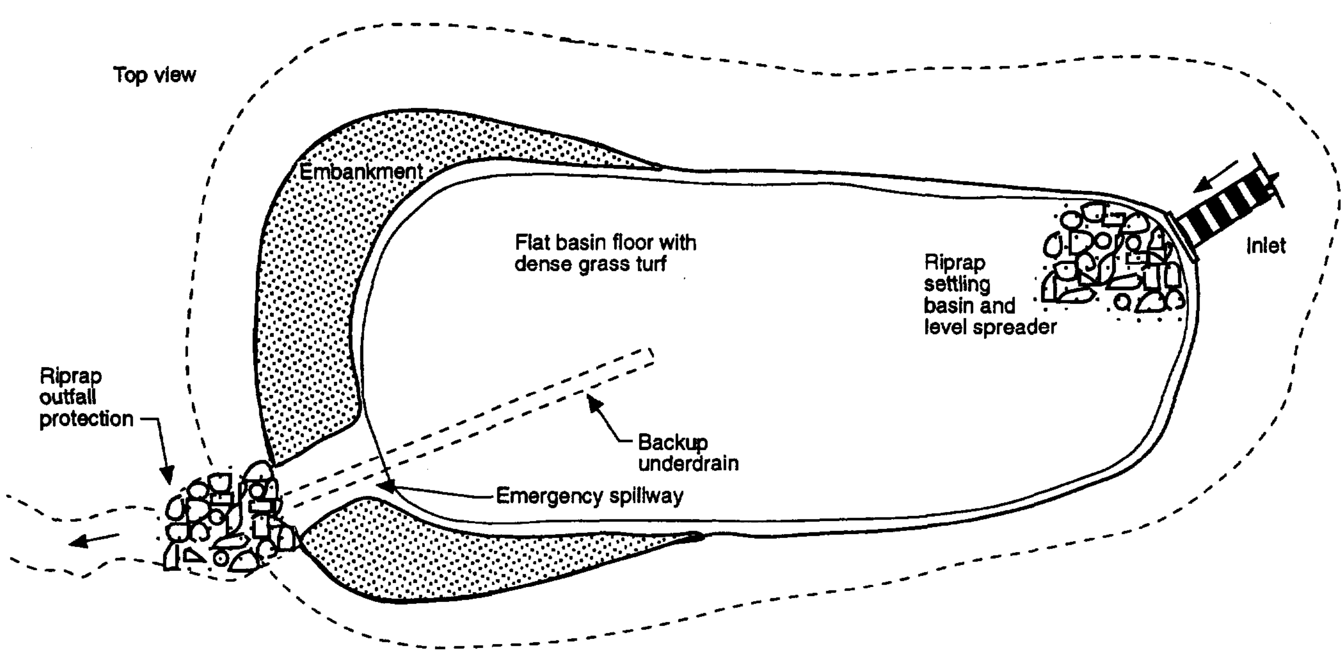


Figure 7-6. Sample infiltration basin.

Infiltration Trenches/Dry Wells. Subsurface infiltration practices, such as infiltration trenches or dry wells, force runoff into the soil to recharge ground water and remove pollutants. These infiltration structures are located below ground and usually must be built "off line" because of their limited storage area (see Figure 7-7). Subsurface infiltration systems generally consist of precast concrete structures with holes in the sides and bottom surrounded by 2 to 4 feet of washed stone. Storm water runoff is directed into these structures and infiltration takes place.

Pollutant Removal. The structural controls described in this section use filtration as the primary pollutant removal mechanism, much like onsite wastewater treatment systems commonly used in many small communities. These controls effectively remove suspended sediments and floating debris, as well as bacteria which are difficult to remove without disinfection. Infiltration practices are generally less effective at removing dissolved nutrients, such as nitrogen or other soluble contaminants, which can travel through ground water and be discharged to the receiving water.

Design Considerations. The soil infiltration rate is probably the most important consideration in the design of infiltration structures. The soils underlying the structure must be tested to determine their suitability for infiltration. Some authorities specify the types of soils acceptable for infiltration as noted above for infiltration basins. Structure size is another primary consideration. The structures must be large enough to handle the desired design storms. Also, the structures must be designed to allow larger storms to bypass them. Because subsurface infiltration structures do not have outlets, they usually have to be designed off line of the regular drainage system. Runoff can then enter the infiltration structure until it is full; additional runoff is directed away from the structure. A diversion structure upstream of the infiltration structure is normally part of the design. The flow entering this structure (which could be a simple manhole) is directed to the subsurface infiltration structure until it is full; then additional flow is directed away from the structure and along the drainage system. A typical sizing rule for subsurface infiltration structures is they should store the runoff from the first one-half inch of rainfall on the site (Livingston et al., 1988).

Infiltration structures must also be designed to empty in a reasonable length of time. The underlying soils, to remove pollutants from runoff effectively, must be allowed to dry between rainstorms. Most experts specify that infiltration structures should contain a reservoir of runoff for no more than 3 days after rainfall (Shaver, 1986).

Maintenance Requirements. Infiltration structures require periodic cleaning to remove accumulated sediment and petroleum products. Often the need for this maintenance can be reduced by incorporating into the design a pretreatment structure that removes sediments and petroleum products from the runoff. These pretreatment

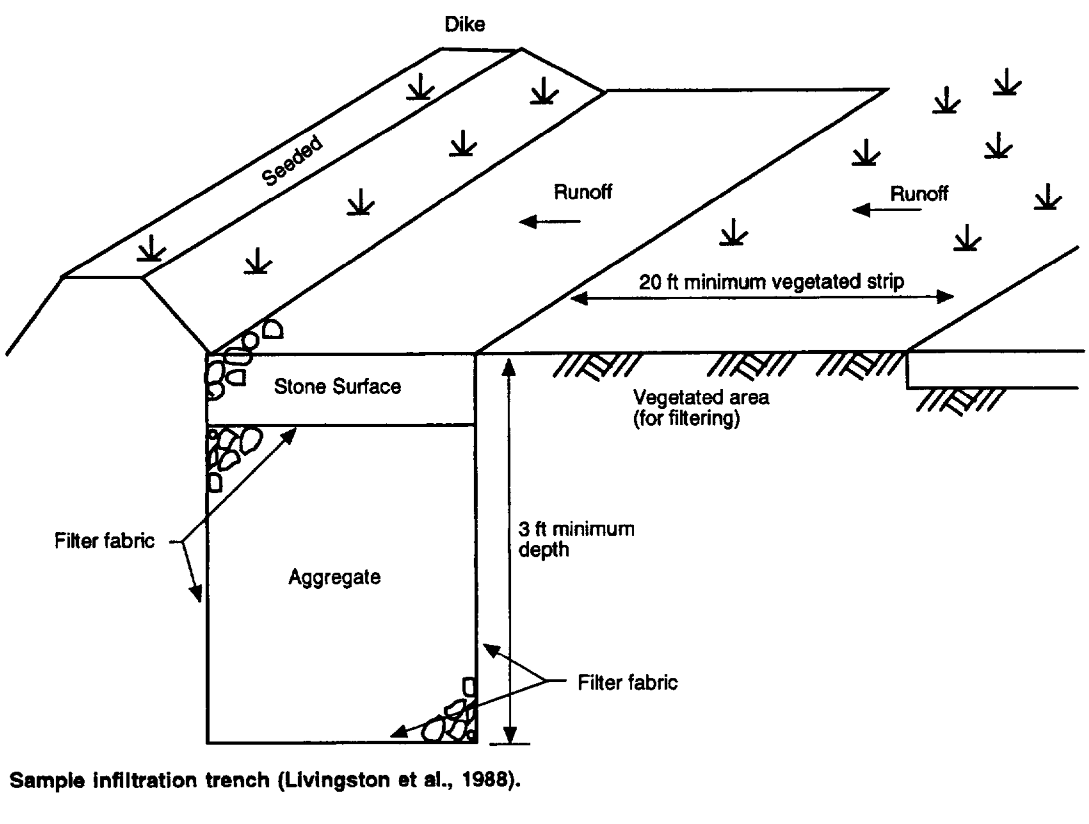


Figure 7-7. Sample infiltration trench (Livingston et al., 1988).

structures can also minimize the discharge to ground water of some pollutants, such as solids. While addressing these issues in the design of infiltration structures can reduce routine maintenance requirements, the design still should include an observation well that allows inspectors to determine sediment deposition.

Limitations on Use. Subsurface infiltration structures can be used for end-of-pipe treatment as well as be located at different points in the drainage system. If located at the downstream end of a drainage system, infiltration structures can have large land requirements. Subsurface infiltration structures, because they are located underground, can be located in areas such as parking lots and access roads.

The primary physical limitation to locating infiltration structures, other than land requirements, is the suitability of soil, which must be neither too impermeable to runoff (e.g., clay, silt, or till) nor too rapidly permeated (e.g., sand). Another potential physical limitation is the depth to ground water. To provide proper treatment and reduce the possibility of ground-water contamination, a distance of at least 2 feet should be maintained between the bottom of the infiltration structure and the mean high ground-water elevation.

Porous Pavement. Paved roads and parking areas, because they increase watershed imperviousness, are major contributors to storm water runoff problems in urban areas. Porous pavement, however, allows water to flow through a porous asphalt layer and into an underground gravel bed. Porous concrete pavement can also be used. Use of this porous pavement can thereby reduce runoff volume and pollutant discharge. This practice, used in areas with gentle slopes, is generally designed into parking areas that receive light vehicle traffic.

Pollutant Removal. Field studies have shown that porous pavement systems can remove significant levels of both soluble and particulate pollutants (Schueler, 1987). Porous pavement is primarily designed to remove pollutants deposited from the atmosphere, as coarse solids can clog the pavement pores. In these systems, pollutant removal occurs primarily after the runoff has infiltrated into the underlying soils. Pollutant removal is accomplished by trapping of sediments, and infiltration through the underlying soils which can remove pollutants such as bacteria. The removal efficiency depends on the storage volume of the pavement, the basin surface area, and the soil percolation rate (U.S. EPA, 1991b).

Design Considerations. Porous asphalt pavement generally is designed with an upper pavement layer 2- to 4-inches thick, a 1- to 2-inch layer of coarse sand, a stone reservoir to provide storage, and a bottom filter fabric as shown in Figure 7-8. Other types of porous pavement include poured-in-place concrete slabs, pre-cast concrete grids, and modular units of brick or cast concrete (Livingston et al., 1988). The differences in pavement design result in different ways that the collected runoff is discharged. Some systems let all the runoff discharge through the underlying soils and into

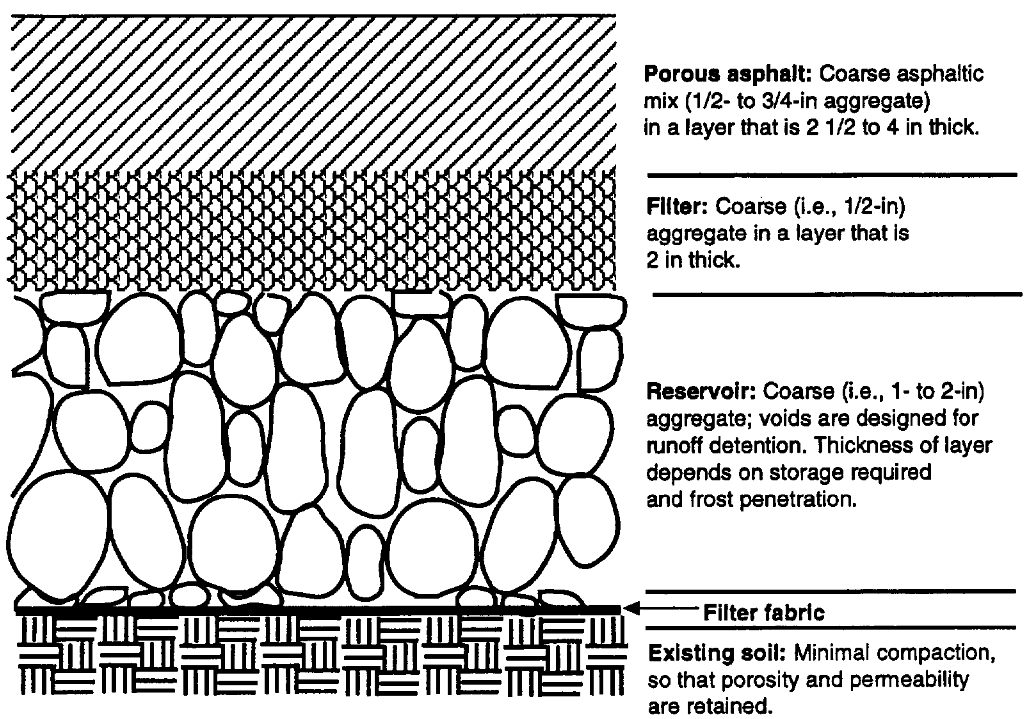


Figure 7-8. Porous pavement cross section (WA DOE, 1991).

the ground water. While these systems provide good pollutant removal, they can result in ground-water contamination. Other systems include perforated pipes to collect the runoff and discharge it directly to a surface water; while these systems protect the ground water below the pavement, they do not provide the same level of pollution removal as the full infiltration systems.

Porous pavement is designed so that a certain amount of runoff is collected and stored in the stone reservoir. The design criteria, therefore, determines the depth of the stone reservoir. The maximum depth of the stone reservoir also is affected by the infiltration rate of the underlying soils. Runoff should be completely drained within a maximum of 3 days after the maximum design storm event to allow the underlying soils to dry, maintaining aerobic conditions that improve pollutant removal (Schueler, 1987).

Maintenance Requirements. Porous pavement can have extensive maintenance requirements. The pavement must be kept free of coarse particles that can clog the pavement and prevent runoff from collecting. The pavement must, therefore, be regularly inspected and cleaned with a vacuum sweeper and high pressure jet. The state of Maryland, by reviewing its porous pavement practices, found that after 4 years of use only two of the 13 systems were functioning as designed (Lindsey et al., 1991). The 11 malfunctioning sites were affected primarily by clogging and excessive sediment and debris.

Limitations on Use. Because porous pavement is expensive to replace or repair, it is generally only used on parking areas that receive moderate to low traffic. The area to be paved also should be relatively flat with a depth of 2 to 4 feet from the bottom of the stone reservoir to the high water table. In addition, the soils under the pavement must allow for infiltration.

Vegetative Practices

Urbanization results in the elimination of vegetation and increases in impervious area. Vegetative practices in urban areas decrease the impervious area and promote runoff infiltration and solids capture. These practices generally provide moderate to low pollutant removal and are therefore used as pretreatment for the removal of suspended solids from runoff prior to more intensive treatment by other practices. The two major types of vegetative practices commonly used in urban areas are grassed swales and filter strips (both sometimes referred to as biofilters). Native vegetation is recommended since it requires less site preparation and maintenance.

Grassed Swales. Grassed swales are channels covered with vegetation to reduce erosion of soil during storms (see Figure 7-9). They are used to replace conventional catch basin and pipe network systems for transporting runoff to surface waters. Storm water runoff flows through the grassed swale reducing runoff velocity and promoting the removal of suspended solids.

Pollutant Removal. Infiltration of the runoff and associated pollutants is the most important pollutant removal process accomplished by grassed swales. Grassed swales also remove pollutants through filtering by the vegetation and settling of solids in low-flow areas. Because of these pollutant removal mechanisms, swales are most effective at removing suspended solids and associated pollutants, such as metals. The mechanism of infiltration also allows removal of bacteria.

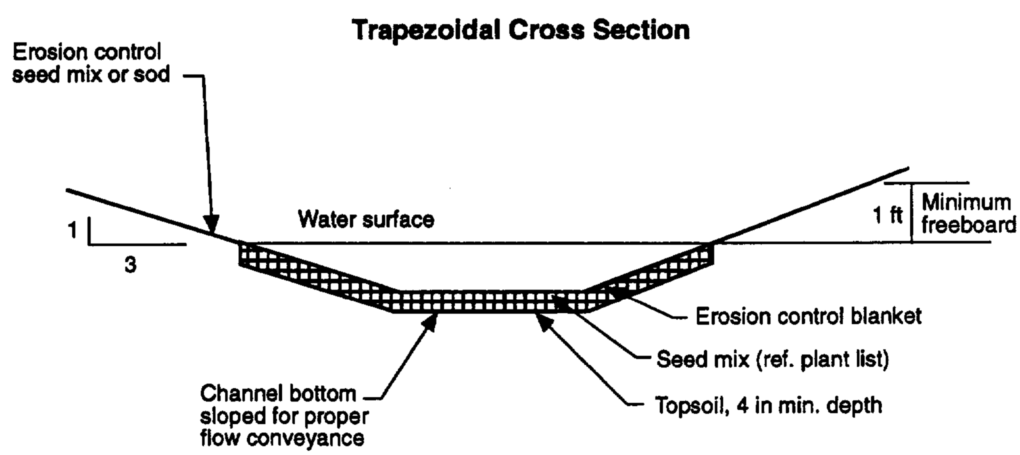


Figure 7-9. Sample grass-lined swale (Horner, 1988).

Grassed swales provide little removal of dissolved pollutants, such as nutrients. Based on many studies of grassed swale effectiveness, removal rates are high for metals and particulates (Pitt, 1989).

Design Considerations. Pollutant removal in grassed swales can be increased by reducing runoff velocity—reducing the slope, increasing the vegetation density, and installing check dams to promote ponding. Also, the underlying soils should have a high permeability to help promote infiltration.

Maintenance Requirements. Grassed swale maintenance is aimed at preserving dense vegetation and preventing erosion of underlying soils. This maintenance includes regular mowing, weed removal, and watering during drought periods and after initial seeding. In conjunction with mowing, the cut material should be removed.

Limitations on Use. Grassed swales might be difficult to retrofit in already developed areas. They can replace curb and gutter drainage systems, but work best in low-slope areas with soil that is not susceptible to erosion.

Filter Strips. Filter strips, shown in Figure 7-10, are similar to grassed swales. Runoff entering these systems, however, generally is sheet flow, is evenly distributed across the filter strip, and flows perpendicular to the filter strip. Because these systems can accept only overland sheet flow, level spreading devices are used so that water is not ponded.

Pollutant Removal. Pollutant removal in filter strips depends on the filter strip's length, size, slope, and soil permeability; the size of the watershed; and the runoff velocity (Horner, 1988). Filter strips are most effective at removing pollutants such as sediment, organic material, and some trace metals, and less effective at removing dissolved pollutants such as nutrients.

Design Considerations. The major design aspects of filter strips that can be effectively changed are the length, width, slope, and vegetative cover of the strip. Greater pollutant removal results from filter strips that are long and flat. A level spreading device must also be incorporated in the design of a filter strip to ensure that concentrated flow does not enter and create a channel. If concentrated flows enter a filter strip, they can cause erosion of the vegetation and soil and reduce the structure's pollutant removal efficiencies. In addition to these considerations, filter strips should be constructed in areas with porous soil to promote infiltration.

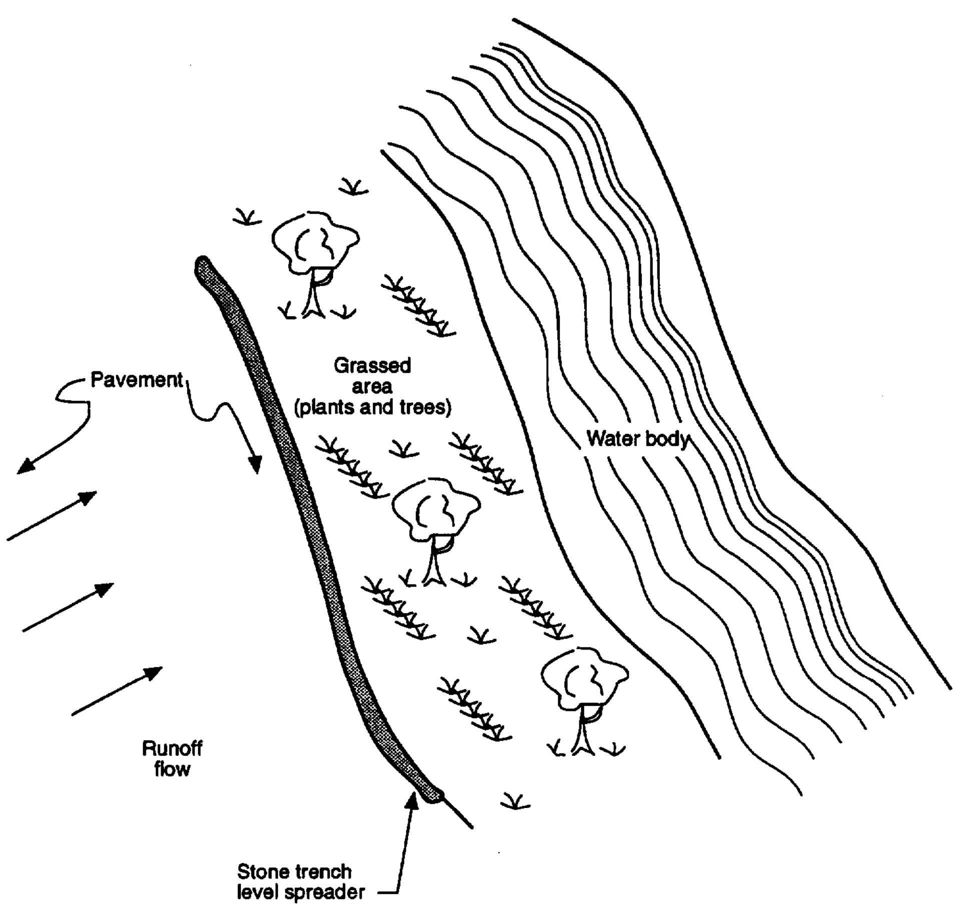


Figure 7-10. Schematic design of a filter strip.

Maintenance Requirements. Filter strips must be mowed and weeded regularly—the same maintenance practices as grassed swales. In addition, the strip must be watered after initial seeding. In some cases, however, large filter strips can be "left on their own" so that large vegetation can grow and create a natural filter strip. This option reduces the level of maintenance required and can enhance the pollution removal of the strip.

Limitations on Use. The major limitation on the use of filter strips is the slope of the land; these strips operate best when placed on flat surfaces that have permeable soils. Also, filter strips treating large watersheds can have large land requirements that preclude their location in urban areas.

Filtration Practices

Filtration practices provide runoff treatment through settling and filtering using a specially placed layer of sand or other filtration medium. Flow enters the structure, ponds for a period of time, and filters through the media to an underdrain that discharges to a surface water. These practices attempt to simulate the pollutant removal of infiltration practices using less land area. Two different types of filtration practices currently in use are filtration basins and sand filters.

Filtration Basins. Storm water runoff diverted to a filtration basin can be detained, allowed to percolate through filter media, and collected in perforated pipes as shown in Figure 7-11. These perforated pipes then transport the filtered runoff to the receiving water. These systems have been used extensively in Austin, Texas, showing good pollutant removal efficiencies and low failure rates (City of Austin, TX, 1990). Communities in other regions might experience some initial problems in importing the technology (U.S. EPA, 1991a). One major question regarding filtration basins is the effect of cold temperature and freezing conditions on the operation of these systems.

Pollutant Removal. Pollutant removal in filtration basins occurs because of settling during the initial ponding time and filtering through the soil media. Removal efficiencies in filtration basins depend on several factors, including the storage volume, detention time, and filter media used. In general, longer detention times increase the system's pollutant removal efficiency. Increasing the detention time usually requires increasing the overall size of the filtration basin.

Initial settling of suspended solids occurs in filtration basins during the initial ponding of the runoff. Increasing detention time therefore promotes settling and increases the pollutant removal efficiency. Reducing the size of the perforated pipe, increasing the depth of filter medium, or decreasing the percolation rate of the filter medium can be used to increase the detention time. Changes in the filter medium also affect the pollutant removal efficiency of filtration basins. To date, filtration basins have primarily used sand as the filtering medium. Recent studies, however, have investigated the use of a combination of sand and peat, taking advantage of the adsorptive properties of peat to increase pollutant removal efficiencies (Galli, 1990). These sand-peat systems, however, are generally untested and their pollutant removal efficiencies are only theoretical.

Design Considerations. In Austin, Texas, sand filtration basins are typically designed to provide a detention time of 4 to 6 hours and have been used to treat runoff from drainage areas from three to 80 acres (City of Austin, TX, 1990). An experimental storm water sand-peat filtration basin to be constructed in Montgomery County, Maryland, is being designed to store the first one-half inch of rainfall from the impervious land in the watershed. In the Maryland area, this sizing criterion results in the treatment of 50 to 60 percent of the annual storm runoff volume (Galli, 1990). Runoff from larger storms will exceed the capacity of these filtration systems and will be diverted away from the filtration basin or discharged through an emergency spillway. To improve the longevity of sand and sand-peat filtration basins, runoff entering the systems is typically pretreated to remove suspended solids. Such pretreatment techniques as the use of a wet pool or

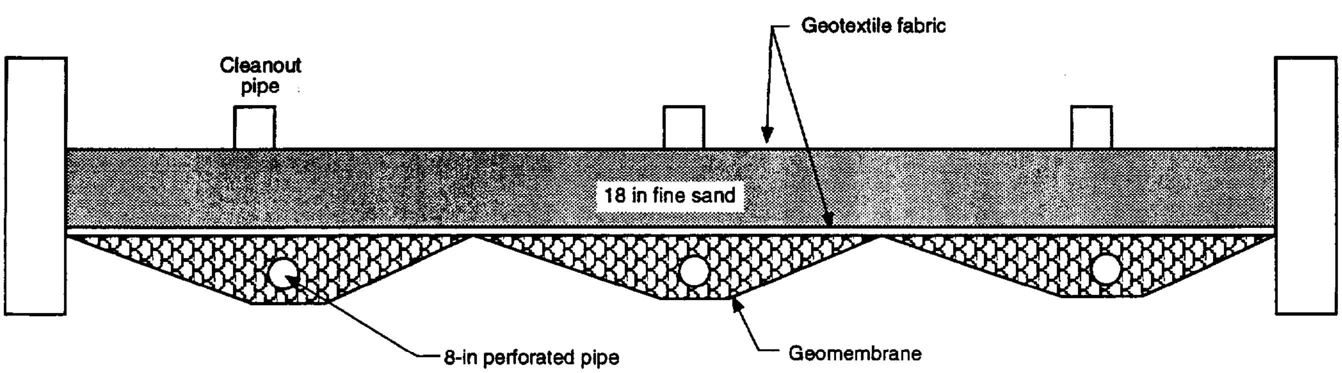


Figure 7-11. Conceptual design of a filtration basin (City of Austin, TX, 1990).

water quality inlets can be used in conjunction with filtration basins.

Maintenance Requirements. Storm water runoff filtration basins require extensive maintenance to remove accumulated sediments and prevent clogging of the filtering medium. Maintenance requirements include inspecting the basin after every major storm event for the first few months after construction and annually thereafter; removing litter and debris; and revegetating eroded areas. In addition, the accumulated sediment should be removed periodically and the filter medium, when clogged with sediment deposits, should be removed and replaced (U.S. EPA, 1991b).

Limitations on Use. Filtration basins can often be difficult to locate in highly urbanized areas because of their large land requirements. In addition, high ground-water levels can restrict their use. Finally, they have not been widely used throughout the country and might not be considered a proven technology.

Sand Filters. Sand filters are similar to the filtration basins outlined above but can be built underground to reduce the amount of land required. These systems consist of a catch basin for settling of heavy solids and a filtration chamber (see Figure 7-12). Runoff enters the catch basin and collects to the basin capacity, overflows into a sand-filled chamber that provides filtration, and is discharged through an outlet pipe in the bottom of the filtration chamber. Other types of systems can be designed in conjunction with wet ponds or other practices, using natural or imported soil banks or bottoms, to increase their pollutant removal capability. The use of sand filters for storm water runoff treatment has been demonstrated in Maryland (Shaver, 1991).

Pollutant Removal. Sand filters use the same pollution removal mechanisms as filtration basins and provide similar pollutant removal. Initial removal of heavy solids occurs through settling in the catch basin and further treatment is provided by filtration through the sand-filled

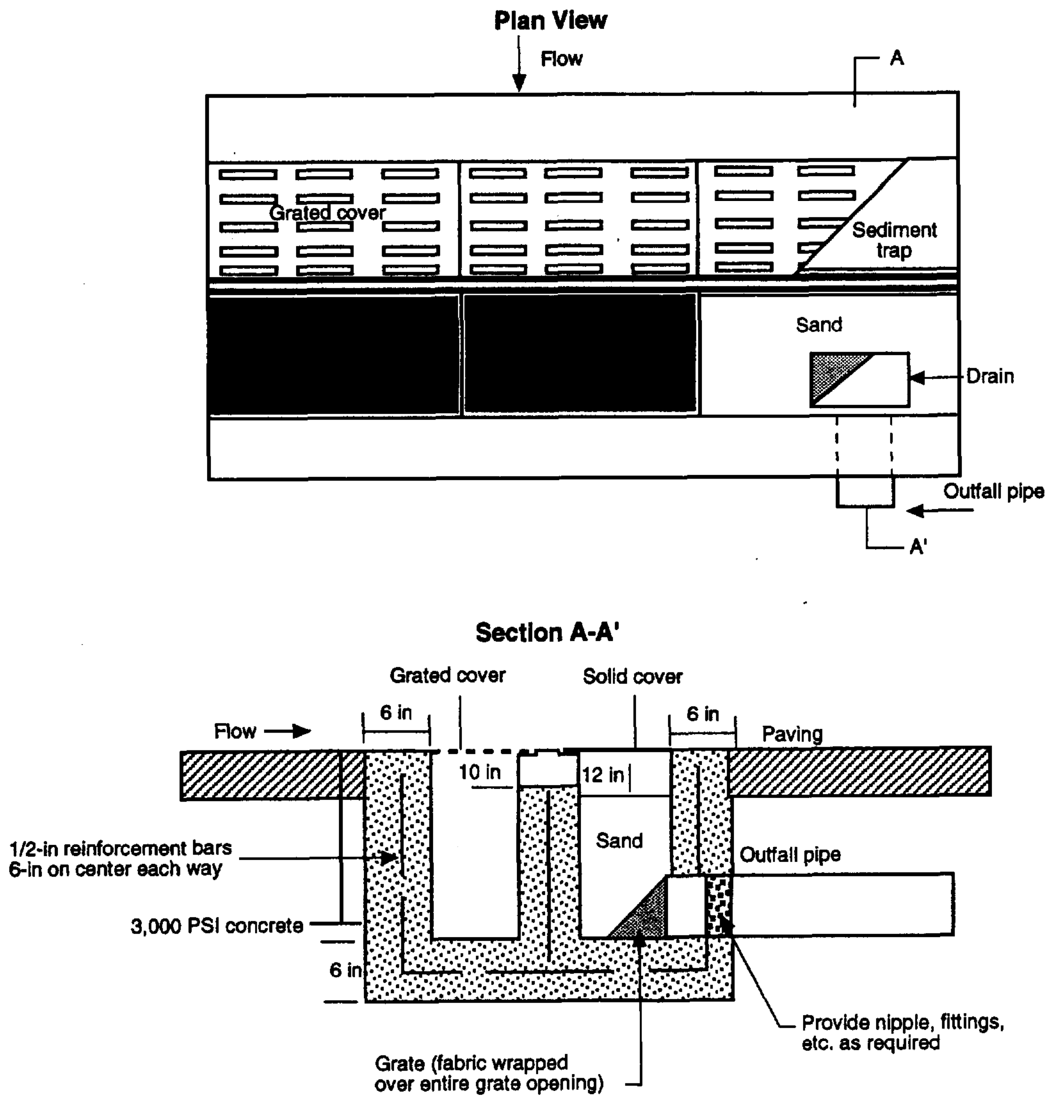


Figure 7-12. Schematic design of sand filter (Shaver, 1991).

chamber. Sand filters are particularly effective at removing suspended solids and pollutants that attach to suspended solids, such as metals. Moderate removal of bacteria can be expected, but these systems cannot provide removal of soluble pollutants such as nitrogen and phosphorus.

Design Considerations. Because this BMP has not been widely used, there are few generally accepted design criteria for sand filters. The catch basin section must be designed to provide some sediment removal and to ensure that flow enters the filtration chamber as sheet flow to prevent scouring of the sand. The maximum drainage area that can be treated by a sand filter has been reported as about 5 acres (Shaver, 1991). Sand filters generally are used to treat impervious areas, such as parking lots, so that smaller sediment particles typical of pervious areas will not clog the sand filter.

Maintenance Requirements. Sand filters require minimal maintenance, consisting of periodically removing accumulated sediment and the top layer of sand from the filtration chamber and removing accumulated sediment and floatables from the catch basin. Regular inspections of the filter system can indicate when this maintenance is required.

Limitations on Use. Because of their small size, sand filters are designed to be used for pretreatment in large watersheds or full treatment in small watersheds. They cannot provide sufficient treatment for large watersheds (Shaver, 1991).

Water Quality Inlets

Water quality inlets, also known as oil and grit separators, are similar to septic tanks used for removing floatable wastes in onsite wastewater disposal systems. These inlets provide removal of floatable wastes and suspended solids through the use of a series of settling chambers and separation baffles as shown in Figure 7-13. These systems have been designed and used for many years, but storm water pollutant removal efficiencies are generally unknown.

Given the limited pollutant removal expected from water quality inlets, they are usually used in conjunction with other BMPs. Fairly effective at removing coarse sediments and floating wastes, water quality inlets can be used to pretreat runoff before it is discharged to infiltration systems or detention facilities. In this way, some of the routine maintenance other BMPs require (e.g., sediment removal and unclogging of outlet structures) can be reduced. Water quality inlets also can serve to capture petroleum spills that could enter other treatment structures or surface waters.

Pollutant Removal. The primary pollutant removal mechanisms of water quality inlets are separation and settling. The use of three chambers in these inlets serves to increase the detention time of the runoff in the tank, allowing settling to occur. In this way, suspended solids, and the attached pollutants, are removed from the runoff. In addition, the use of baffles and inverted elbows helps to remove floating litter and petroleum products from the storm water. The level of removal of these pollutants depends on the volume of water permanently detained in the tank, the velocity of flow through the tank, and the depth of the baffles and inverted elbows in the tank. By increasing detention time and decreasing flow velocity, the level of sediment and floatables expected to be removed from water quality inlets can be improved.

Design Considerations. There are few generally accepted design criteria for water quality inlets. Their design depends on the size of the watershed being treated and the detention time required. Since suggested detention times are usually measured in terms of minutes rather than days, water quality inlets generally do not remove pollutants from storm water runoff as effectively as some of the more intensive detention facilities discussed in this section. Water quality inlets have the advantage of being relatively small so they can be placed throughout a drainage system rather than just at the downstream end of the system.

In water quality inlet design, provisions should be made to reduce the entering flow velocity. Sediment and petroleum products collect in the water quality inlets. If entering flow has a sufficiently high velocity, the accumulated pollutants can be resuspended and discharged from the inlet. The flow and velocity of the entering runoff can be hydraulically restricted by limiting the size of the inlet pipe. Flows greater than the maximum design flow should be diverted away from the water quality inlet by a diversion structure in an upstream manhole.

Maintenance Requirements. Water quality inlets require periodic maintenance to remove accumulated pollutants; in general, these inlets should be cleaned about twice a year. Cleaning can be performed with a vacuum truck similar to those used to clean catch basins. The waste removed from water quality inlets, which includes petroleum products as well as sediments that have accumulated in the bottom, should be tested to determine proper disposal requirements, though their characteristics are similar to those of catch basin wastes. Periodic inspections between scheduled maintenance are also required to determine the level of accumulated pollutants.

Limitations on Use. There are few physical site limitations on the use of water quality inlets. The inlets are generally designed as belowground structures and do not require large amounts of land. Given their small size, however, large watersheds cannot be drained into

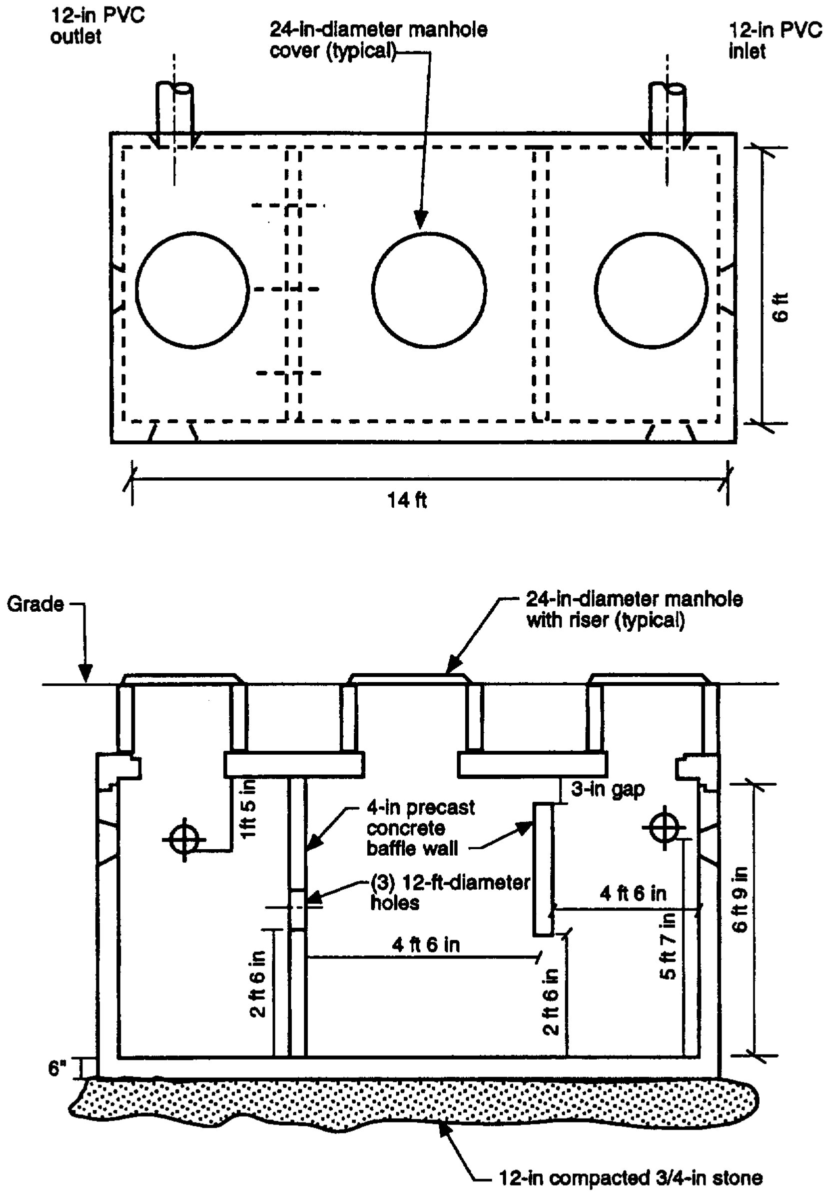


Figure 7-13. Conceptual water quality inlet (U.S. EPA, 1992b).

a water quality inlet. Removal efficiencies depend on the detention time in the water quality inlets. Their use is usually restricted to small watersheds of less than 2 acres. Another restriction on the use of water quality inlets is dry-weather base flow. If dry-weather base flow cannot easily be removed from a drainage system, a larger water quality inlet and more frequent maintenance are needed to accommodate this flow as well as the flow resulting from a rainfall event.

Combined Sewer Overflow Control Practices

Some of the urban runoff BMPs discussed above are applicable to CSO control. Additional control practices commonly used for CSO control are described in this section, including a general discussion of each practice's applicability, its pollutant removal effectiveness, and its maintenance requirements. More detailed references on CSO control are presented in Appendix B. Because CSOs contain sanitary sewage and other waste streams, the primary pollutants of concern in CSO control are suspended solids, biochemical oxygen demand, and pathogens. CSOs, however, also contain nutrients, metals, and other toxic substances.

Source Controls

Many of the source control practices that address urban runoff pollution are applicable to CSOs because they address contaminants that can enter any storm water collection system, whether separate or combined. Additional source control measures include water conservation and pretreatment programs.

Water Conservation Programs. One way of reducing the amount of sewage in a combined system is to attempt to control the amount of water used by homes and businesses that is then converted to wastewater. Typical programs and practices for control include:

- *Plumbing retrofit:* Using low-flush toilets, flush dams, faucet aerators, and other water-saving devices.
- *Plumbing code changes:* Requiring implementation of water-saving devices in new construction or as they are replaced.
- *Education programs:* Encouraging water conservation in businesses and homes by providing information on its benefits.
- *Technical assistance:* Providing water-use audits or case studies demonstrating potential savings to businesses.
- *Rate system modifications:* Adjusting rate systems to promote or reward water savings.

While these programs might require minor changes in personal habits, they can be cost effective compared to end-of-pipe treatment. There are limits, however, to the reductions in water use that can be achieved reasonably.

Pretreatment Programs. These programs are implemented at the local level to control industrial and commercial sources of wastewater discharging to a municipal sewer system. The goals of a local pretreatment program are to stop or prevent industrial and commercial pollutants from passing through a municipal wastewater treatment plant, thereby violating state water quality standards; to stop or prevent disruption of treatment plant operations caused by industrial and commercial pollutants, including the contamination of municipal treatment plant residuals; and to ensure the safety of municipal sewer system and treatment plant workers by minimizing their exposure to potentially dangerous or toxic pollutants. While pretreatment programs historically have controlled large industrial wastewater sources, programs increasingly are focusing on controlling the discharges from small businesses and households. Local pretreatment programs typically include the following activities:

- *Development of sewer-use regulations:* To establish requirements on the quality and quantity of nondomestic wastewater that can be discharged to a municipal sewer system and to provide the municipality with legal authority to ensure compliance with pretreatment requirements.
- *Monitoring and surveillance:* To sample and analyze industrial and commercial discharges and to conduct onsite inspections of industrial and commercial facilities to determine the compliance with pretreatment requirements.
- *Permitting and enforcement:* To issue permits to individual industrial and commercial wastewater discharges that establish site-specific pretreatment requirements and to take all necessary actions to ensure compliance with those requirements.
- *Technical assistance and education programs:* To provide assistance to the regulated industries and commercial facilities, including encouragement to use pollution prevention measures to address wastewater control problems and to educate the general public on the effects of common household products and wastes that are discharged to the sewer system.

A pretreatment program implemented in a municipality with combined sewers can help control industrial and commercial pollutants discharged from CSOs during storm events. The level to which a pretreatment program can control the quality of CSO discharges, however, is very difficult to determine. Nonetheless, as part of an overall program to decrease the deleterious effects of CSOs, a pretreatment program can provide positive results.

Collection System Controls

Many collection system controls exist for addressing pollution from CSO discharges. These controls focus on modifying the sewer system to reduce CSO flow, volume, and contaminant load.

Sewer Separation. One method for addressing CSO pollution is to convert the combined collection system to separate storm water and sanitary sewer systems by constructing a new separate sanitary sewer. Sewer laterals from homes and businesses are then connected into the new system. Inappropriate connections to the old system from buildings are plugged. This conversion eliminates the possibility of sanitary wastes entering the drainage system and being discharged to a surface water. Sewer separation, however, can be very expensive and disruptive. A municipality implementing this practice likely has to address urban runoff pollution problems. In systems that consist of both combined and separate drainage areas, partial separation (i.e., separation of some combined areas) could be cost-effective.

Infiltration Control. Sources of infiltration include ground water entering the collection system through defective pipe joints, cracked or broken pipes, and manholes as well as footing drains and springs. Infiltration flow rates tend to be relatively constant, and result in lower volumes than inflow contributions. Infiltration problems are usually not isolated, and often reflect a more general sewer (or drainage) system deterioration. Extensive rehabilitation is typically required to remove infiltration effectively. The rehabilitation effort often must include house laterals, which are normally a significant source. Except in very large drainage systems, control of infiltration generally has a much smaller impact on CSO reduction than control applied to inflow.

Inflow Control. CSO control can be achieved by diverting some of the surface runoff inflows from the combined sewer system, or by retarding the rate at which these flows are permitted to enter the system. Inflow of surface runoff can be retarded by using special gratings, restricted outlet pipes, or hydrobrakes (or comparable commercial devices) to modify catch basin inlets to restrict the rate at which surface runoff is permitted to enter the conveyance system. Inlet flow restrictions can be designed to produce acceptable levels of temporary ponding on streets or parking lot surfaces, allowing runoff to enter the system eventually at the inflow point, but reducing the peak flow rates that the combined sewer system experiences. Flow detention to delay the entry of runoff into the collection system by storing it temporarily and releasing it at a controlled rate can also be accomplished by rooftop storage under appropriate conditions. Elimination of the direct connection of roof drains to the CSO collection system and causing this runoff to reach the system inlets by overland flow patterns (preferably via unpaved or vegetated areas) is another method of retarding inflows.

When site conditions permit, some surface runoff flows can be prevented from entering the combined system, by diverting them via overland flow to pervious areas or to separate storm drains. When these outlets are not available, excess surface runoff flows can be diverted to more favorable locations in the combined system (called flow-slipping).

Regulator and System Maintenance. Malfunctioning regulators are a common problem for combined sewer systems and can result in dry-weather overflows to receiving waters or in system backups and flooding. Static regulators often malfunction because of plugging or interference by debris in the sewer system. Mechanical regulators tend to require frequent maintenance. Municipalities should, therefore, develop an inspection and maintenance program designed to keep these regulators operating as designed. The expected reduction in CSO flows and loads resulting from this maintenance is site specific and depends on the existing conditions in the system.

In-System Modifications. These practices are designed to reduce CSO discharges by modifying the system to store more flow and allow it to be carried to the treatment plant. Possible modifications include adjusting regulator control features, such as weir elevation; installing new regulators; or installing new relief conduits. The effectiveness and applicability of these practices is site specific and depends on the existing capacity of the system and the treatment plant. These practices can be cost effective in locations where excess capacity exists.

Sewer Flushing. Sewer flushing is an additional practice to address CSO pollution problems. In this practice, water is used to flush deposited solids from the combined system to the treatment plant during dry weather. This practice is typically used in flat areas of the collection system where solids are most likely to settle out. The effectiveness of this practice is site specific and depends on the flush volume; flush discharge rate; wastewater flow; and sewer length, slope, and diameter. Though not currently a widely used practice, sewer flushing has been tested in selected areas (WPCF, 1989).

Storage

CSO discharges occur when the flow in a combined system exceeds the capacity of the sewer system or the treatment plant. Storing all or a portion of the CSO discharges for treatment during dry weather can effectively reduce these overflows. Storage techniques include in-line and off-line storage.

In-Line Storage. In-line storage uses existing capacity in major combined sewer trunk lines or interceptors to store combined flows. During storms, regulators are used to cause flow to back up in the system allowing it to be stored in the system. While not all flow can be stored in the sewer system, this practice can reduce overflow volumes during large storms and eliminate overflow volumes during small storms. After a storm, stored flow proceeds to the treatment plant for treatment. The overall pollutant removal in this practice depends on the level of storage space available in the existing system. Care must be taken to ensure that flows do not back up onto streets or into homes.

Off-Line Storage. Off-line storage consists of constructed near-surface or deep tunnel detention facilities. Near-surface facilities usually consist of concrete tanks or, in some cases, large conduits which also convey flow to a treatment facility. Tunnels can provide large storage volumes with relatively minimal disturbance to the ground surface, which can be very beneficial in congested urban areas. Overflows are directed to the storage facility, held during the storm, and pumped to the POTW after the storm, thus reducing the overflow quantity and frequency. The overall pollutant removal in this practice depends on the design capacity of the storage facility and the percentage of overflows that can be stored.

Flow Balance Method. The in-receiving water flow balance method involves using floating pontoons and flexible curtains to create an in-receiving water storage facility. CSO flows fill the facility by displacing the receiving water that normally occupies the storage facility. The CSO flows are then pumped to the collection system following a storm. The technology has been used for CSO control in Brooklyn, New York. This alternative involves permanently installing the floating pontoons in the receiving water near the CSO outlets. The feasibility of this technology, therefore, depends in part on whether the storage facility would have a significant impact on the aesthetic value of the surrounding area, and whether the structure would be a hindrance to navigation. Other site-specific concerns include the availability of volume due to tidal variations in coastal waters and the need for protection from damage due to high winds or wave action.

Physical Treatment

Most of the urban runoff BMPs previously discussed employ physical processes to reduce pollution. Physical treatment practices can also be used to reduce pollutant discharges from CSOs. The practices discussed in this section include bar racks and screens and swirl concentrators/vortex solids separators.

Bar Racks and Screens. These practices use screening technologies to reduce the flow of solids in combined systems. They are typically used as a preliminary treatment step to remove floatables upstream of other processes. Different screens have different size openings to provide various levels of solids removal. Bar racks have the largest openings (typically 1 inch or more) and microstrainers have the smallest openings (typically as small as 15 microns). All these practices require periodic and regular cleaning to prevent the accumulation of solids. Typically only the smaller screens provide significant pollutant removal. Screens are most effective at removing floatables and, depending on screen size, can remove suspended solids and can provide some BOD removal.

Swirl Concentrators/Vortex Solids Separators. These technologies are designed to provide flow regulation and remove solids from combined flow by forcing flow into a vortex path, so that solids and nonsolids can be separated. The resulting underflow containing separated solids can then be conveyed to a treatment facility. One advantage of these structures is that they have no moving parts and thus require less maintenance than other structures. The effectiveness of swirl concentrators and vortex solids separators depends on the settling characteristics of the CSO solids, the amount of turbulence created in the structure, and the flow rate. Data have shown that these practices can provide up to 60-percent removal of solids and BOD, with the greatest removal occurring during the first flush washoff (WPCF, 1989). They are, however, most effective in removing larger solids; their performance is highly dependent on the influent solids particle size distribution and specific gravity.

Dissolved Air Floatation. Dissolved air floatation (DAF) removes solids from wastewater by introducing fine air bubbles which attach to solid particles suspended in the liquid, causing the solids to float to the surface where they can be skimmed off. While this technology has been tested in CSO applications, it has not been widely applied. Because of its relatively high overflow rate and short detention time, DAF does not require as large a facility as conventional sedimentation. Oil and grease are also more readily removed by dissolved air floatation. The high operating costs for DAF are due to large energy demand; skilled operators are required for its operation.

Fine Screens and Microstrainers. These devices remove solids through capture on screen media. The most common fine-screening devices include rotary drum and rotary disk devices. In the rotary drum screen, media is mounted on a rotating drum. Flow enters the end of the drum, and passes out through the filter media. Drum rotational speed is usually adjustable. Solids retained on the inside of the drum are backwashed to a collection trough. Filter media aperture size typically ranges from 15 to 600 microns. The rotary disk screen has the screening media mounted on a circular frame placed perpendicular to the flow. Flow passes through the bottom half of the rotating disk, which is submerged. Solids retained on the disk are directed to a discharge launder using spray water.

One form of static screens features wedge-shaped steel bars, with the flat part of the wedge facing the flow. These wedge-wire screens typically have openings ranging from 0.01 to 0.05 in. These screens require daily maintenance to prevent clogging (Metcalf & Eddy, Inc., 1991). Screens are subject to blinding from grease and first-flush solids loads; a high-pressure backwash, as well as the collection and conveyance of backwash solids, are typically required. Effective cleaning of screens after storm events using high pressure steam or cleaning agents is typically required to maintain performance. Removal efficiencies can be increased by decreasing media aperture size, but smaller apertures are more likely to blind. Coarse screening and disinfection facilities are often provided in conjunction with microstrainers.

Filtration. Dual-media high-rate filtration has been piloted for treatment of CSO flows using a two-layer bed, consisting of coarse anthracite particles on top of less coarse sand. After backwash, the less dense anthracite remains on top of the sand. Filtration rates of 8 gal/ft^2/min or more result in substantially smaller area requirements compared with sedimentation.

Demonstration test systems include pretreatment by microstrainers. The use of chemical coagulants improves performance considerably. A disadvantage to filtration is the filters' tendency to clog during use in treating wastewater, thus limiting hydraulic capacity and effectiveness of solids removal. Filtration is more appropriately applied after sedimentation or fine screening to provide pretreatment. While operation can be automated, filtration tends to be O&M intensive.

Chemical Precipitation

Chemical precipitation facilities store and use polymer, alum, or ferric chloride to cause solids to precipitate. Chemical precipitation can increase the pollution removal that generally occurs from other settling practices, thereby allowing for the design of smaller sedimentation tanks. Chemical precipitation generates more sludge than other settling techniques. Pollutant removal depends on the types of chemicals used and the characteristics of the combined flow. Removal rates for these practices are up to 70 percent for BOD and 85 percent for suspended solids. Because CSO treatment facilities are intermittently operated, however, sludge buildup and handling can become a major problem.

Biological Treatment

While biological treatment processes have the potential to provide a high quality effluent, disadvantages of biological treatment of CSOs include:

- The biomass used to break down the organic material and assimilate nutrients in the combined sewage must be kept alive during dry weather, which can be difficult except at an existing treatment plant; biological processes are subject to upset when exposed to intermittent and highly variable loading conditions.
- The land requirements for these types of processes can preclude their use in urban areas.
- Operation and maintenance can be costly and the process requires highly skilled operators.

Some biological treatment technologies are utilized in CSO control as elements of a wastewater treatment plant. Pump-back flows from CSO storage facilities commonly receive secondary treatment at the treatment plant, once wet-weather flows have subsided. In a treatment plant that has maximized the wet-weather flows it accepts, flows are sometimes split, with only a portion of the primary treated flows receiving secondary treatment, to avoid process upset. The split flows are blended and disinfected for discharge.

Disinfection

Because pathogens are the primary pollutant of concern in CSO control, practices focusing on disinfection are commonly used.

Chlorination. Combined flows can be treated with dissolved or gaseous chlorine to reduce the level of pathogens in the flow. Chlorination is typically used in conjunction with upstream solids removal. Chlorination, however, is not effective at addressing aesthetic or other water quality impacts of CSOs. Dissolved chlorine (hypochlorite) is currently more commonly used than gaseous chlorine because the equipment is more reliable and storage of the chemicals is safer. Dechlorination might be necessary to minimize the adverse effects of chlorine on aquatic life. Effectiveness of disinfection depends on the amount of chlorine used and the contact time between the chlorine and the wastewater. With sufficient dosage and mixing, close to 100-percent destruction of pathogens is possible. These facilities require regular inspection and maintenance.

UV Radiation. Introduction of ultraviolet radiation to combined wastewater is designed to provide disinfection without the addition of harmful chemicals. This practice uses an ultraviolet lamp submerged in a baffled channel located downstream of an effective solids removal process. The effectiveness of this practice depends on the lamp intensity, the contact time between the lamp and the wastewater, the distance between the wastewater and the lamp, and the level of solids in the wastewater. This system provides disinfection only and does not contribute to removing other pollutants. The high amount of solids in CSO flows limits the performance of UV radiation unless the solids can first be reduced.

An overview of urban runoff and CSO BMPs is given to help develop a list of BMPs to be screened. As noted earlier, many references also can be used (see Appendix B). After the BMPs have been screened, BMP selection is the next step of the planning approach.

Case Study:
City of Austin, Texas,
Local Watersheds Ordinances

Austin, a highly urbanized city bisected by the Colorado River, contains a number of high quality lakes, aquifers, and streams. The major water resources in the area include three lakes—Lake Travis, Lake Austin, and Town Lake—which form a major drinking-water reservoir acting as the main water supply for the city; Edwards Aquifer and Barton Springs are the area's other major water resources. These water resources are potentially threatened by urban runoff pollution from urbanized areas; Town Lake already is affected significantly. To reduce and prevent urban runoff pollution problems in these resources, Austin has developed and passed three major watershed ordinances:

- The Comprehensive Watersheds Ordinance, 1986
- The Urban Watersheds Ordinance, 1991
- The Barton Springs Ordinance, 1992

The primary goal of these ordinances is to protect the water resources of the Austin area from degradation from nonpoint source pollution. Other goals include preventing the loss of recharge to the Edwards Aquifer, preventing adverse impacts from wastewater discharges, and protecting the natural and traditional character of the water resources in the Austin area. In addition, the city has implemented other ordinances that control NPS pollution.

Water pollution problems in the Austin area have been extensively studied since the mid-1970s. In 1981, the city participated in NURP and began implementing and monitoring the effectiveness of urban runoff structural controls. The city has been a leader in developing and implementing NPS regulatory controls. The city's first NPS control ordinance, the Lake Austin Watershed Ordinance in 1978, was followed by other watershed ordinances in 1981 and 1984 designed to protect additional sensitive watersheds and upgrade the level of protection. The experience and data gathered as a result of these ordinances led the city to propose and adopt a more complete set of protections for water resources as described in this summary.

The Comprehensive Watersheds Ordinance

The Comprehensive Watersheds Ordinance (CWO) is directed at preventing urban runoff pollution by placing requirements on proposed new developments within a 700-square-mile area of the city and its extraterritorial jurisdiction. It was developed in 1986 by a task force, appointed by the city council, with representatives from environmental groups, citizens, developers, and a council-appointed environmental board. The ordinance includes requirements for limiting impervious cover, using water quality buffer zones, protecting critical environmental features, limiting the disturbance of natural streams, implementing erosion control practices, constructing sedimentation and filtration basins, and restricting onsite wastewater disposal. The ordinance divides the city into four different watershed categories that each allow for different levels of development intensity: urban, suburban, water supply suburban, and water supply rural. While urban watersheds were not originally covered by the CWO, they are addressed in the Urban Watersheds Ordinance which is described later. Requirements for all the applicable watershed categories are shown in Table 7-3.

The waterways located in each watershed category are classified as minor, intermediate, or major depending on the total drainage area contributory to the waterway (see Table 7-3). Each waterway classification has an associated critical water quality (WQ) zone which encompasses the 100-year floodplain boundary and is located 50 to 100 feet from minor waterways, 100 to 200 feet from intermediate waterways, and 200 to 400 feet from major waterways. No development is allowed in this critical WQ zone. Each waterway type also has an associated water quality buffer zone that begins at the end of the critical WQ zone and extends upland for a defined distance as shown in Table 7-3. Development in this zone is restricted by limits on the allowed percent imperviousness of the site. Areas outside the WQ buffer zone are considered upland areas and have less stringent percent imperviousness

Table 7-3. Maximum Development Intensity

Watershed Category	Waterways: Minor	Waterways: Intermediate	Waterways: Major	Development Limits: Water Quality Buffer Zone	Development Limits: Area Type	Development Limits: Uplands Zone[a]	Development Limits: Transfer	Acceptable Structural Pollution Controls
Suburban								
						% Impervious Cover		
Drainage area:	320 ac	640 ac	1,280 ac	30-percent impervious cover	Residential:	50	60	Sedimentation
Critical WQ zone:	100 ft	200 ft	400 ft		Duplex:	55	60	Sedimentation
WQ buffer zone:	None	100 ft	150 ft		Multifamily:	60	70	Filtration
					Commercial:	80	90	Filtration
Water Supply Suburban—Class I								
						% Impervious Cover		
Drainage area:	128 ac	320 ac	640 ac	18-percent impervious cover; no development over recharge zone	Residential:	30	40	Filtration
Critical WQ zone:	100 ft	200 ft	400 ft		Multifamily:	40	55	Filtration
WQ buffer zone:	100 ft	200 ft	300 ft		Commercial:	40	55	Filtration
Water Supply Suburban—Class II								
						% Impervious Cover		
Drainage area:	128 ac	320 ac	640 ac	30-percent impervious cover; no development over recharge zone	Residential:	40	55	Filtration
Critical WQ zone:	100 ft	200 ft	400 ft		Multifamily:	60	65	Filtration
WQ buffer zone:	100 ft	200 ft	300 ft		Commercial:	60	70	Filtration
Water Supply Suburban—Class III								
						% Impervious Cover		
Drainage area:	320 ac	640 ac	1,280 ac	30-percent impervious cover	Single-family:	45	50	Filtration
Critical WQ zone:	100 ft	200 ft	400 ft		Duplex:	55	60	Filtration
WQ buffer zone:	100 ft	200 ft	300 ft		Multifamily:	60	65	Filtration
					Commercial:	65	70	Filtration
Water Supply Rural								
						Units/ac		
Drainage area:	64 ac	20 ac	640 ac	One unit per 3 acres; no development over recharge zone	Single-family:	0.5	1.0	—
Critical WQ zone:	100 ft	200 ft	400 ft		Cluster:	1.0	2.0	40% buffer[b]
WQ buffer zone:	100 ft	200 ft	300 ft					
						% Impervious Cover		
					Multifamily:	20	25	40% buffer
					Commercial:	20	25	40% buffer
					Planned:	50	50	40% buffer
					Retail:	50-60[c]	60-70	Filtration

[a] Net site area.
[b] Except in Lake Austin/Lake Travis, where filtration is required.
[c] Only at major intersections.

restrictions. In this zone, the restrictions are tied to the type of development proposed for the site as shown in Table 7-3. Some development restrictions can be reduced if the developer transfers land located in the watershed to the city. In this way, development density can be increased by the developer in exchange for an increase in publicly held lands. For example, a multifamily development in suburban Class I water supply watershed is restricted to 40-percent impervious unless the developer is able to use development rights transfers (see Table 7-3). In this case, the development can reach 55-percent impervious and still meet the requirements of the ordinance.

In addition to the restrictions on site percent imperviousness, developments in these watersheds are required to incorporate structural control practices. The acceptable control practices are sedimentation basins, filtration basins, and vegetative buffers as outlined in Table 7-3. Basins must be designed to capture, isolate, and hold at least the first one-half inch of runoff from contributing drainage areas. Also, nonstructural requirements serve to prevent pollution. These include limitations on the depth of cuts and fills, limitations on construction on steep slopes (greater than 15 percent), and limitations on the disturbance of natural streams including restrictions on the number of stream crossings. Temporary erosion controls, such as silt fences and rock berms, are required during construction.

In Austin, proposed new development plans are reviewed by a separate environmental review staff, autonomous from other departments. This allows for a focused review that includes field surveys of projects in sensitive areas. Once the plans are approved, city inspectors monitor construction for compliance with the approved plans. Approximately 50 percent of the financing for reviews and inspections required by this ordinance comes from development permit fees. The fees vary depending on the development size and are higher in sensitive watersheds because of the increased review requirements. The rest of the expenses are covered through a drainage utility fund which consists of monthly service charges to the residents in the utility service area.

Since these requirements apply to new developments, the CWO is designed to prevent or reduce future increases in pollutant load to the target water bodies. The ordinance can be applied to a variety of watershed characteristics and water resource types.

Given the short time this ordinance has existed and its focus on prevention, assessing its effectiveness is difficult. These control measures, however, have been shown to reduce urban runoff pollution on a nationwide and a local level. The city's analysis of its nonpoint source monitoring program, completed in 1990, showed that pollutant loads increase with increased impervious cover. Figure 7-14, based on that 1990 report, compares total suspended solid loads from land with various levels of development as measured by percent impervious cover. This type of data was used to define the impervious land limitations in the ordinance.

Urban Watersheds Ordinance

In 1991, the city council approved task force recommendations to include urban area watersheds among those covered by development ordinances. This ordinance, created in response to increased pollution in Town Lake due to urban runoff discharges, focuses on the urban watersheds not previously covered by the CWO. It requires the implementation of structural controls in new developments undergoing site plan review. All new residential, multifamily, commercial, industrial, and civic development in the urban watersheds are required to construct water quality basins (either sedimentation or filtration basins) or provide a cash payment to the city for use in an Urban Watersheds Structural Control Fund. Structural controls must be used to capture the first one-half inch of runoff from all contributing areas. The Watersheds Structural Control Fund is used to retrofit and maintain structural controls where required in the urban watersheds. In addition to this requirement, new developments in the urban watersheds are required to provide for removal of floating materials from storm water runoff through the use of oil/water separators or other practices. Redevelopment projects in the urban watersheds are also included in this ordinance, where structural controls and the removal of floatable materials are required. For redevelopment projects, the city has developed a Cost Recovery Program Fund to provide 75 percent of the cost of structural controls. These funds will be allocated through the drainage utility fund.

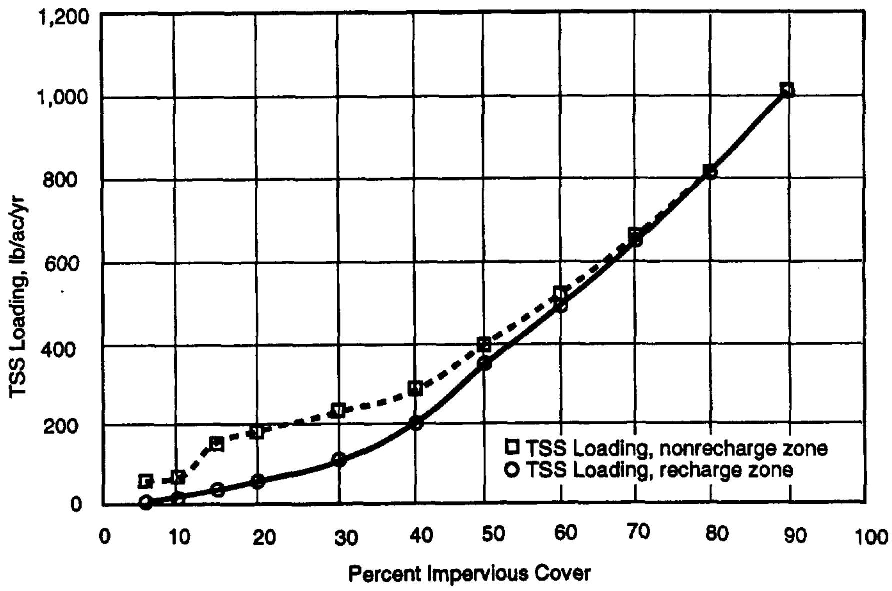


Figure 7-14. Total suspended solids loading vs. percent impervious cover.

In urban watersheds, the critical WQ zone is the boundary of the 100-year floodplain and is generally located 50 to 400 feet from the waterway. As with the Comprehensive Watersheds Ordinance, no development is allowed in the critical WQ zone.

Since this ordinance was passed only recently, there are no data concerning its effectiveness. Like the CWO, however, it focuses on using proven structural and nonstructural control measures that the city believes will effectively prevent urban runoff pollution.

Other Nonpoint Source Control Programs

In addition to the CWO and the Urban Watersheds Ordinance, Austin has developed other ordinances designed to reduce nonpoint source pollution from new developments and redevelopments. One of these, the Barton Springs Zone Ordinance, provides special protection to watersheds contributing to Barton Springs, a widely visited and used natural spring bathing area in Austin. This ordinance, created to be a nondegradation ordinance with specific performance requirements, includes definitions of waterways and development limits similar to those specified in the CWO. Only one- or two-family residential development with a density of 1 unit per 3 acres is allowed in the Barton Springs watershed transition zone, which extends up to 300 feet from the water body. In addition, new developments in the Barton Springs watershed must comply with the following requirements (see Table 7-4): reduce pollutant concentrations compared with the undeveloped conditions and discharge no greater than a specific maximum pollutant concentration after development. The city measures these requirements quarterly on each development through a developer-funded monitoring program.

Additional NPS control programs in Austin include:

- *Land Development Code:* Enforces landscaping regulations and protects trees and natural areas in the city.
- *Underground Storage Tank Program:* Develops guidelines for underground storage of hazardous materials, permitting and inspection of these underground storage tanks, and investigation of problems and response to emergency situations.
- *Water Quality Retrofit Program:* Involves engineering and building, with private sector participants, permanent controls for already developed areas and are producing storm water runoff pollution problems for the city's key receiving waters.

Table 7-4. Barton Creek Development Requirements

Pollutant	Percent Reduction from Background	Maximum Discharge Concentration, mg/L
Total suspended solids	60%	144
Total phosphorus	15%	0.11
Total nitrogen	15%	0.95
Total organic carbon	50%	14

- *Water Quality Monitoring Program:* Monitors and characterizes pollutants from various land uses and structural controls, monitors surface and ground-water quality, and develops water quality models and data bases; also conducts specific studies on known nonpoint source problems.
- *Household Chemical Collection Program:* Provides for safe disposal of hazardous materials and other wastes generated from household use; conducted for the past 6 years, this program is currently located at a permanent site where collection events occur each year.
- *Storm Sewer Discharge Permit Program:* Involves permitting and regular inspection of industrial and commercial discharges to storm sewers and water courses.
- *Emergency and Pollution Incident Response Program:* Involves responding to emergency spills, general water pollution incidents, and citizen complaints related to water quality.
- *Street Cleaning and Litter Collection Program:* Provides regular street cleaning—nightly in the central business district, monthly on other major roads, and bimonthly in residential neighborhoods.
- *Integrated Pest Management Program:* Encourages application of the most environmentally safe pesticide techniques practicable for pest management in municipal operations.

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

City of Austin, TX. 1990. Removal efficiencies of stormwater control structures. Environmental Resource Management Division, Environmental and Conservation Services Department.

Galli, J. 1990. Peat-sand filters: a proposed stormwater management practice for urbanized areas. Department of Environmental Programs, Metropolitan Washington Council of Governments. Washington, DC.

Horner, R. 1988. Biofiltration systems for urban runoff water quality control. Washington State Department of Ecology. Seattle, WA.

Lindsey, G., L. Roberts, and W. Page. 1991. Stormwater management infiltration practices in Maryland: a second survey. Maryland Department of the Environment, Sediment and Stormwater Administration. Baltimore, MD.

Livingston, E., E. McCarron, J. Cox, and P. Sanzone. 1988. The Florida development manual: a guide to sound land and water management. Florida Department of Environmental Regulation. Stormwater/Nonpoint Source Management Section.

MD WRA. 1986. Maryland Water Resources Authority. Minimum water quality and planning guidelines for infiltration practices. Maryland Department of Natural Resources.

Metcalf & Eddy, Inc. 1991. Wastewater engineering: treatment, disposal, reuse. New York, NY: McGraw-Hill, Inc.

MPCA. 1989. Minnesota Pollution Control Agency. Protecting water quality in urban areas. St. Paul, MN.

Moffa, P. 1990. Control and treatment of combined sewer overflows. New York, NY: Van Nostrand Reinhold.

Pitt, R. 1989. Source Loading and Management Model: an urban nonpoint source quality model—volume I: model development and summary. University of Alabama, Birmingham.

RIDEM. 1989. Rhode Island Department of Environmental Management. Artificial wetlands for stormwater treatment: processes and designs. Rhode Island Nonpoint Source Management Program.

Roesner, L.A., B. Urbonas, and M.B. Sonnen. 1988. Design of urban runoff quality controls: proceedings of an engineering foundation conference on current practice and design criteria for urban quality control. Potosi, MO. July. Published by the American Society of Civil Engineers, New York, NY.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments.

Shaver, E.H. 1986. Infiltration as a stormwater management component. Maryland Department of the Environment, Sediment and Stormwater Administration. Delaware Department of Natural Resources. Dover, DE.

Shaver, E.H. 1991. Sand filter design for water quality treatment. Delaware Department of Natural Resources. Dover, DE.

ULI. 1981. Urban Land Institute. Water resource protection technology: a handbook of measures to protect water resources in land development. Washington, DC.

U.S. EPA. 1973. U.S. Environmental Protection Agency. Water pollution and associated effects from street salting. EPA/R2-73/257 (NTIS PB-222795). U.S. EPA National Environmental Research Center.

U.S. EPA. 1974a. U.S. Environmental Protection Agency. Manual for deicing chemicals: storage and handling. EPA/670/2-74/033 (NTIS PB-236152).

U.S. EPA. 1974b. U.S. Environmental Protection Agency. Manual for deicing chemicals: application practices. EPA/670/2-74/045 (NTIS PB-239694).

U.S. EPA. 1974c. U.S. Environmental Protection Agency. Urban storm water management and technology: an assessment. EPA/670/2-74/040 (NTIS PB-240687).

U.S. EPA. 1977. U.S. Environmental Protection Agency. Urban storm water management and technology: update and users' guide. EPA/600/8-77/014 (NTIS PB-275654). Washington, DC.

U.S. EPA. 1979. U.S. Environmental Protection Agency. Demonstration of nonpoint pollution abatement through improved street cleaning practices. EPA/600/2-79/161 (NTIS PB80-108988). U.S. EPA Office of Research and Development.

U.S. EPA. 1983. U.S. Environmental Protection Agency. Results of the nationwide urban runoff program: vol. 1–final report. (NTIS PB84-185552.) Water Planning Division. Washington, DC.

U.S. EPA. 1987. U.S. Environmental Protection Agency. Guide to nonpoint source control. Office of Water. Washington, DC.

U.S. EPA. 1991a. U.S. Environmental Protection Agency. A current assessment of urban best management practices: techniques for reducing nonpoint source pollution in the coastal zone. U.S. EPA Office of Wetlands, Oceans, and Watersheds.

U.S. EPA. 1991b. U.S. Environmental Protection Agency. Postconstruction stormwater runoff treatment. Washington, DC.

U.S. EPA 1992a. U.S. Environmental Protection Agency. The use of wetlands for controlling stormwater pollution. Region V. Chicago, IL. Distributed by the Terrene Institute. Washington, DC.

U.S. EPA. 1992b. U.S. Environmental Protection Agency. Casco Bay storm water management project: Concord Gully, Frost Gully and Kelsey Brook watersheds. U.S. EPA Region I. Boston, MA. January.

U.S. EPA. 1992c. U.S. Environmental Protection Agency. Decision-maker's storm water handbook: a primer. U.S. EPA Region V. Chicago, IL.

U.S. EPA. 1993a. U.S. Environmental Protection Agency. Investigation of inappropriate pollutant entries into storm drainage systems. Storm and Combined Sewer Control Program.

U.S. EPA. 1993b. U.S. Environmental Protection Agency. Guidance specifying management measures for source of nonpoint pollution in coastal waters. EPA/840/B-92/002. U.S. EPA Office of Water.

WA DOE. 1991. Washington State Department of Ecology. Storm water management manual for the Puget Sound Basin.

Woodward-Clyde Consultants. 1989. Santa Clara Valley nonpoint source study. Santa Clara Valley Water District.

Woodward-Clyde Consultants. 1990. Urban targeting and BMP selection: an information and guidance manual for state NPS program staff engineers and managers. Final report.

WPCF. 1989. Water Pollution Control Federation. Combined sewer overflow pollution abatement: manual of practice FD-17.

Chapter 8
Select Best Management Practices

Urban runoff problems, because of their diverse nature, need to be addressed through a combination of source control, regulatory, and structural BMPs. The selected combination needs to reflect the program goals (Chapter 3) and the priorities set during the assessment and ranking of existing problems (Chapter 6). The planning approach in this handbook recommends a two-step process for BMP selection. This chapter covers the second part of the BMP selection process, which uses the screened list of potentially applicable BMPs to develop and select the BMPs to be implemented.

To select BMPs, the alternatives typically are developed and compared to ensure that all options are considered and that the best possible plan is selected based on a predetermined set of selection criteria. While a specific problem caused by a specific source, might not require development of alternative BMP plans, for most programs which tend to deal with multiple sources and impacts, it is wise to investigate alternatives before selecting a final set of BMPs. This chapter first addresses development of alternative plans and then the selection of recommended BMPs. At the end of this chapter, two separate case studies on methods of BMP selection are presented.

Alternatives Development

Alternatives are developed using the BMPs still under consideration after the screening process (Chapter 7). The alternatives can include various combinations of source control, regulatory, and structural BMPs. Source control and regulatory BMPs are often implemented across entire regions or jurisdictions. Structural BMPs can be directed at specific pollutant sources or implemented across geographic areas, including both structural BMPs for new development in currently undeveloped areas or for retrofit in already developed areas. To address fully the urban runoff pollution problems in an area, BMPs from all these categories are often required.

Three commonly used methods for developing alternatives are discussed in this section. The first starts with known urban runoff problems and known pollutant reductions desired. The second develops a range of possible control levels for evaluation. The third involves applying specific BMPs throughout a project area. Any one or a combination of these methods can be used to develop an urban runoff pollution prevention and control plan.

In the first method, before developing the alternative plans, the problems to be addressed and desired level of control are decided. This information could be obtained from the problem assessment and ranking step described in Chapter 6. Various types or combinations of practices are then developed to meet the desired control level to address the known problems. For example, if a program goal is to reduce fecal coliform bacteria levels to below the criterion for safe consumption so that shellfishing beds can be opened, the level of control needed must reduce the bacteria counts to a known level. Information on the expected bacteria loadings from various sources is needed. Combinations of BMPs can then be developed to achieve the needed control level by focusing on BMPs that control the various sources. Criteria for developing alternative BMPs to meet the control level can include cost, pollutant removal efficiency, site characteristics, public acceptance, and others.

This alternative development method might lead to an emphasis on structural controls because these BMPs focus on addressing pollution problems from known sources, such as septic tanks, illicit cross-connections in storm water drains, and others. It has the advantage, however, of ensuring that known priority problems are addressed by each alternative. While this method can be used to develop alternatives for meeting either water quality or technology-based goals, it is especially applicable for meeting specific water resource or pollutant removal goals.

An example of this BMP selection method is shown in Table 8-1. In this example, multiple pollution problems, such as agricultural runoff, urban runoff, and failed onsite septic systems, were contributing to closed shellfish beds. Table 8-1 compares various urban runoff control practices for cost, level of expected improvement, public agency support, and other factors

Table 8-1. Sample BMP Selection (Metcalf & Eddy, Inc., 1989)

BMP	Technical Feasi-bility	Monetary Factors: Capital	O&M	Funding	Water Quality Improve-ment	Public and Agency Support	Other NPS Control Efforts	Demon-stration Value	Comments
Urban Runoff									
Source controls	+	Low	Mod.	+	–	+	+	+	Does not achieve WQ goals
Infiltration	+	Mod.	Low	+	+	+	+	+	Soil and ground water might preclude its use Effective pollutant removal
Storage	+	High	High	–	–	–	–	–	No bacteria removal
Treatment	+	High	High	–	+	–	–	–	High capital cost Environmental impacts
Land Disposal									
Sewering	+	High	High	–	–	–	–	–	High capital cost
Alternative disposal	+	High	Low	–	–	–	–	–	High capital cost Likely public opposition
Nonstructural									
Regulation and enforcement	+	Low		–	–	–	–	–	Extensive public support required
Tax incentives	–			–	+	+	–	+	No programs in place
Local financing	–			–	+	–	–	+	Town funding not available
Beneficiaries financing	–			–	+	–	–	+	Complete organizational requirements
Public education	+	Mod.	Low	+	+	+	+	+	Builds public awareness and support

+ = Favorable or present
– = Unfavorable or not present

to determine the best mix of practices for implementation.

Based on this review, a combination of regulatory, educational, and structural runoff pollution prevention and control practices was recommended: enacting stricter local zoning and conservation bylaws oriented toward runoff pollution prevention, constructing an infiltration system along a stretch of roadway with known high pollution levels, conducting a public education program, and improving ongoing water resource monitoring efforts.

In the second method, alternatives representing a range of control levels are developed. For example, three levels of control could be formulated based on a range of pollutant removals (i.e., low, medium, and high). The low-level control alternative might consist of a minimum mix of BMPs designed to address priority problems. The medium-level control alternative might consist of the same practices as the low-level control alternative plus additional BMPs designed to address additional problems or to address more fully the same priority problems. The high-level control alternative might include the practices of the medium-level control alternative as well as additional practices. Each alternative plan therefore contains a subset of the BMPs included in the next higher level control alternative, allowing for a cost-effectiveness comparison among various control levels.

An example of this approach performed as part of the Santa Clara Valley NPS pollution control plan development is shown in Figure 8-1. Three BMP categories were considered: educational (E), regulatory (R), and public agency actions (P). Within each category, specific BMP practices were identified (e.g., E1, E2) and compared to evaluate the cost and benefit of each level. Some of the individual practices shown on Figure 8-1 were considered but not included. This approach is analogous to the screening step described in Chapter 7. The complete process used in the Santa Clara Valley study is described in the case study at the end of this chapter.

Another example of this approach which includes structural controls is shown in Figure 8-2 (Pitt, 1989). In this example, 10 different urban runoff pollution

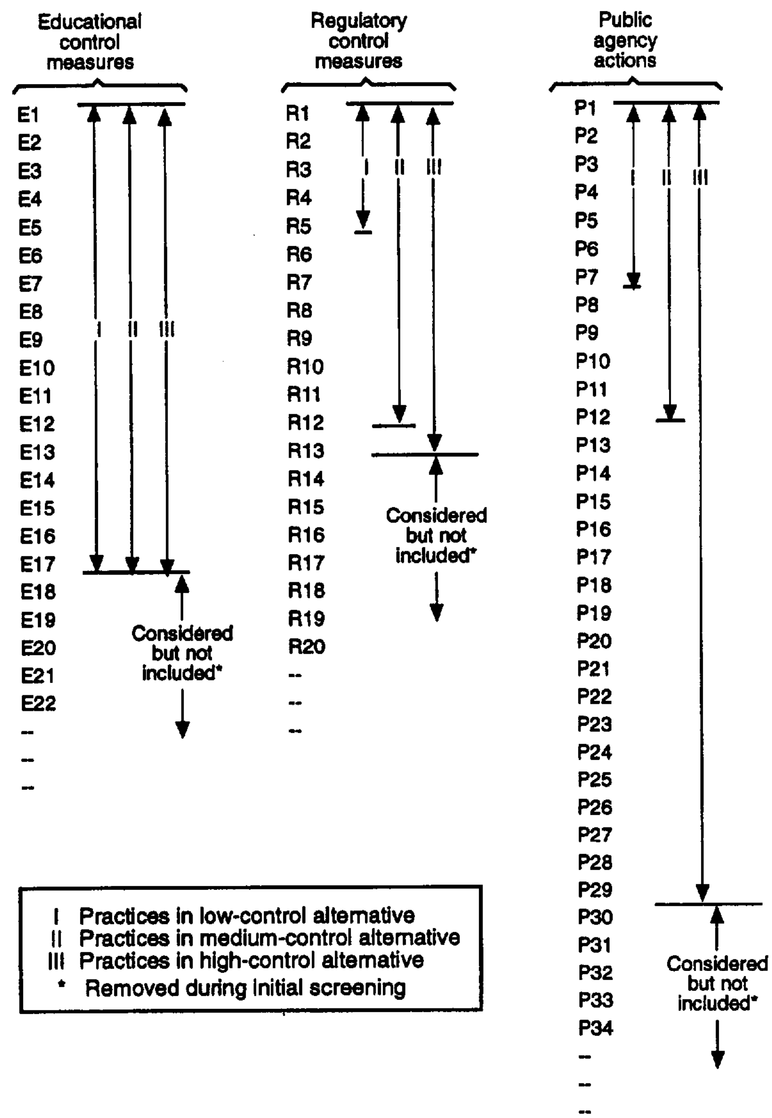


Figure 8-1. Example alternative development process (Woodward-Clyde Consultants, 1989).

prevention and control practices alternatives are plotted to compare phosphorus reduction with annual cost. The practices analyzed include various combinations of street sweeping, catch basin cleaning, construction of detention basins, and implementation of infiltration practices. Similar plots were also developed for solids and lead removal. Based on this analysis, Program 8 was recommended, a combination of infiltration and wet detention.

This second method is especially applicable for meeting general goals that do not include specific pollutant removal requirements. For example, if the goal is to reduce nitrogen discharges to a coastal embayment by the maximum extent practicable, then a series of alternatives can be developed covering a range of pollutant reduction levels and costs. These alternatives then can be compared on a cost-benefit and affordability basis.

The third method of developing alternatives begins with the screened list of appropriate control measures. Each BMP is then assessed for its ability to address the known and anticipated problems. As an example, preference might generally be given to BMPs that:

- Address more than one problem or lead to meeting more than one goal.
- Have lower construction and operating costs.
- Are most effective at removing the pollutants of concern.
- Emphasize pollution prevention rather than treatment.
- Are likely to address future problems.
- Concentrate on addressing the priority problems.

The assessment of individual BMPs results in alternatives based on implementing each BMP throughout the study

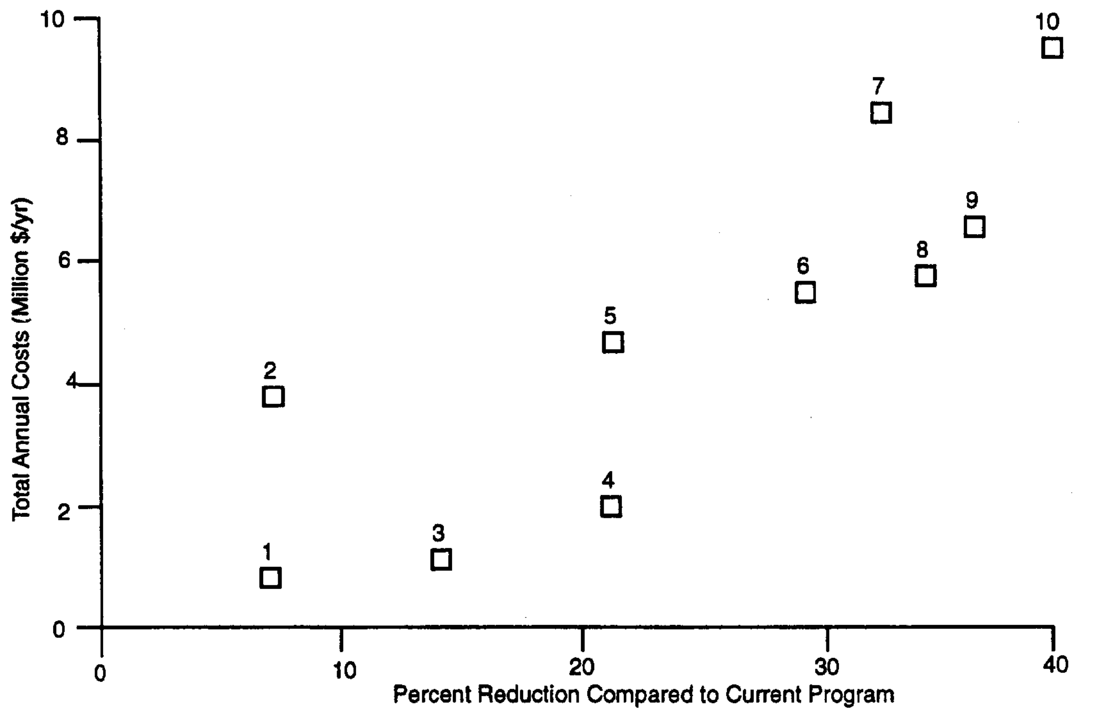


Figure 8-2. Phosphorus removal for candidate control programs (Pitt, 1989).

area. The comparison of alternatives is then in effect a comparison of different BMPs. This approach yields useful data on systemwide implementation of particular BMPs. While one type of BMP might not address the range of urban runoff problems or goals in a study area, an urban runoff pollution problem might exist which a particular BMP is well suited to control. In this case, implementation of that BMP on a regional basis, with the BMPs strategically located by the municipality, can be more effective and more easily controlled than requiring each developer to implement that BMP for individual developments.

An example of this method of alternative development is the Henrico County, Virginia, regional storm water detention program (George and Hartigan, 1992). Early in the process of developing a storm water management plan, it was decided that, given the conditions existing in the watershed, regional detention basins would be used to control runoff pollution. Regional detention basins were chosen because they provide both flood and pollution control, had fewer site restrictions than other pollution control structures, and can be designed to accommodate expected new developments. Therefore, the major remaining decision in the program was the number, location, and size of the detention basins.

All the above methods lead to the development of alternative plans to address the urban runoff pollution problems of concern. While the actual contents of each alternative plan are site specific and depend on the type of alternative evaluation to be conducted, some general guidelines for presenting the alternative plans can help in assessing them. Preliminary sketches, rough cost estimates, expected pollutant removals, and environmental effects can be included for each alternative so comparisons can be made.

BMP Selection Process

After the alternatives have been developed, they are compared using a decision process (Figure 8-3) that evaluates the relative merits of each plan. Because of the complexity of urban runoff control problems, a number of factors must be considered in assessing alternative plans. These alternatives are represented in Figure 8-3 as inputs to the decision process, and include analysis tools, design conditions, and decision factors. The analysis tools are those used to assess and rank the existing pollution problems (see Chapter 6). The design conditions are the set of conditions under which to compare the alternatives. The decision factors are the criteria used to compare the alternatives. All these inputs are then used to evaluate the alternatives using one or more decision analysis methods. This section first describes each input to the decision analysis, then describes the various decision analysis methodologies that can be used to select BMPs that will comprise the urban runoff pollution prevention and control plan.

Analysis Tools

These tools, described in detail in Chapter 6, can include watershed models, receiving-water models, and

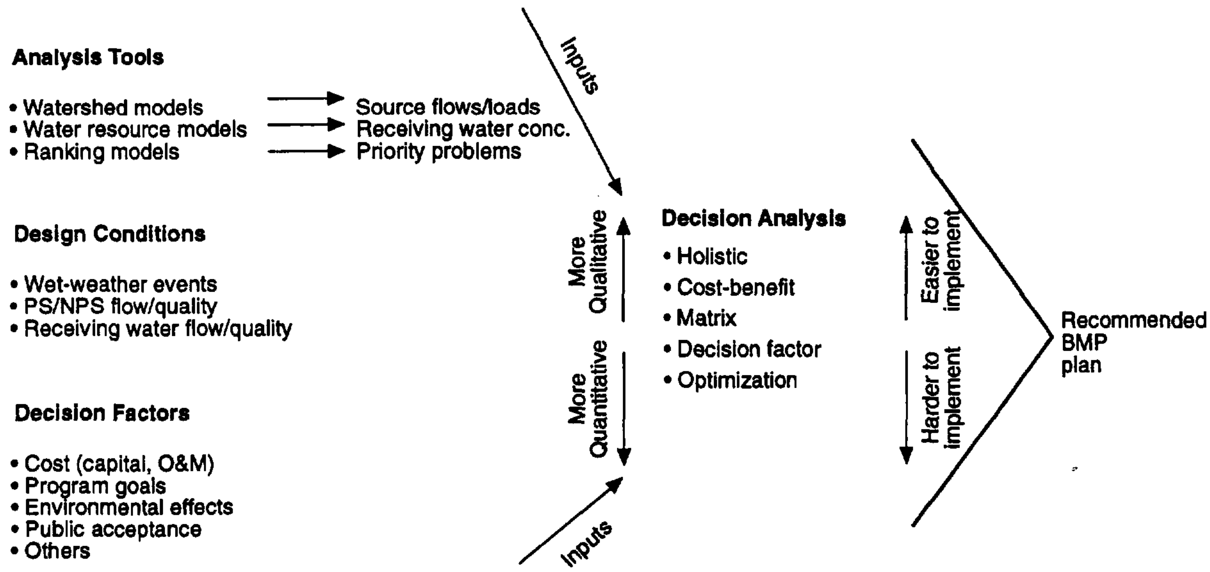


Figure 8-3. Conceptual diagram of BMP selection method.

ranking models. The numerous types of models range from simple to complex, and selection of appropriate models to use has been discussed. The analysis tools are used to project future conditions, given the alternatives being investigated. For example, the total pollutant loads for each alternative can be calculated (whether using a unit load method or complex models such as SWMM), yielding one item of input information as the alternatives are compared. Similarly, the impacts to receiving waters can be assessed using these tools, to compare these effects before making a decision.

In the Humber River drainage area in Toronto (Figure 8-2), for example, SLAMM was used to analyze 10 different control programs (Pitt, 1989) for program cost and pollutant removal. The final decision was based largely on the cost-effectiveness information determined for each of the alternatives using this analysis tool.

Design Conditions

One major consideration in BMP selection is to determine appropriate conditions under which to compare the alternatives. These so-called design conditions are generally set up to reflect various future conditions, including future no-action conditions which reflect future expected conditions with no new BMPs. Some important design conditions to be developed as part of an urban runoff pollution prevention and control plan include:

- Population
- Land use/expected development (i.e., buildout)
- Point source/NPS flows/concentrations
- Background receiving-water flows/concentrations

Each condition is defined for specific future planning periods (e.g., 20 years).

Part of the comparison involves the selection of worst-case or critical conditions. In the case of a receiving water, this condition could be a summer low-flow period. In the case of urban runoff flow and load estimation, it often involves selection of wet-weather design conditions. These wet-weather conditions are often in the form of design storms. For example, runoff from a new development site might be required to meet preexisting conditions up to a 25-year frequency design storm. A state CSO policy might require control up to a 1-year, 6-hour design storm. Two significant concerns exist when developing wet-weather design conditions. One is distinguishing between wet-weather design criteria used for pollution control and for flood control. The second is the use of individual design storms versus multiple storms, continuous simulation, or probabilistic methods.

Historically, design storms have been used to size structures for flood control purposes. These facilities were often sized to control storms of 5-year, 10-year, 25-year, or greater return periods. In contrast, BMPs used for wet-weather pollution control can be sized for much smaller storm events (e.g., 1-year storm or less), because most rainfall events (over 90 percent) are smaller than a 1-year storm. Thus, a BMP sized for a 1-year storm would control more than 90 percent of the total runoff volume. Of course, many other BMP design factors are important (e.g., retention time and peak flow capacity), but design criteria appropriate for pollution control should be kept in mind. This also points out the need to consider multiple design conditions for dual purpose (water quality and flood control) BMPs.

Individual design storms have been and still are often used to size structural BMPs. They are also frequently specified in various federal, state, and local regulations. While use of a design storm is a simple, understandable criterion, deciding on the size storm is less clear cut. A review of wet-weather design conditions stresses the benefits of using continuous or probabilistic simulation rather than relying on a single design storm event (Freedman and Marr, 1992). The increasing power and speed of personal computers allows modeling of a long time series of rainfall-runoff conditions (using the watershed models, and in some cases receiving water models, described in Chapter 6) at a reasonable cost. This method allows investigations of a large number of storm events and the ability to develop a frequency distribution of values of concern (i.e., number of overflows, amount of pollutant load, or number of water quality violations) for the range of rainfall conditions.

An example (Figure 8-4) of the use of continuous simulation (Freedman and Marr, 1992) indicates a frequency distribution of bacteria concentrations with and without CSOs at a particular location. Such results frame the range of possible CSO control effects and help determine appropriate control goals and level of desired reduction for a range of conditions rather than for one event.

Decision Factors

An important step in BMP plan selection is to determine the important decision factors. The selection of these factors is site specific and needs to be determined by the program team based on the characteristics of the watershed and the financial and personnel resources available. Typical decision factors are discussed below.

Cost

One of the most important decision factors is the relative cost of each alternative. In cost assessment, costs of development and implementation for nonstructural BMPs, as well as of construction and operation for structural BMPs, need to be considered. The program benefits such as those associated with restored resources also need to be considered. Costs should generally reflect the life-cycle cost of an alternative over the planning period and are usually easy to derive. The cost benefits associated with the implementation of a control plan, however, are usually more difficult to determine. For example, if an urban runoff control plan is designed to reduce the discharge of fecal coliform to a closed shellfish area, monetary benefits are derived from opening these beds. While analysis of these benefits can be difficult, they should be included in determining total program costs.

Meeting Program Goals

Alternatives are also assessed on their ability to meet program goals, including the control of major sources and effects on priority watersheds. Since at this stage in a program, the goals have been reassessed and expanded upon a number of times, a large number of specific goals might exist, and each alternative might not meet all the program goals. Preference generally is given to alternatives that address the most goals or the most important goals. Priority resources and pollution sources should be the focus of the selected alternative.

Operability

The decision factors included here take into consideration the reliability of structural controls, the reliance of the alternative plan on existing structures, and the number

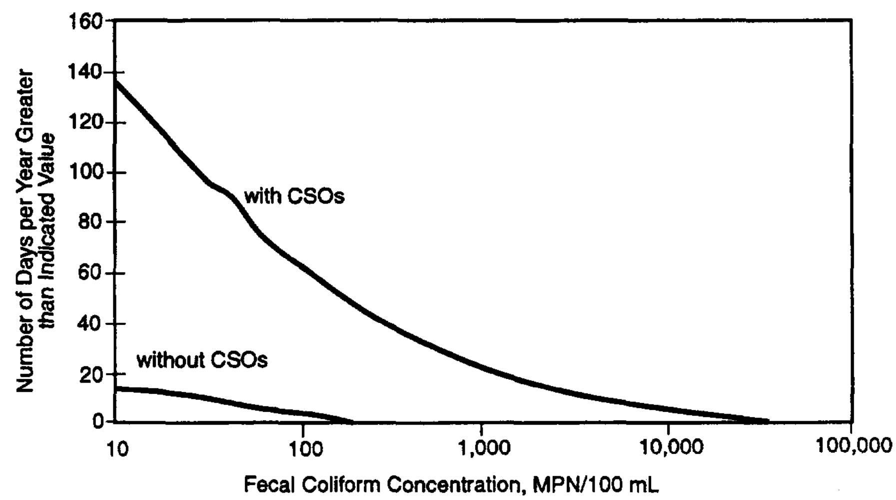


Figure 8-4. Example continuous simulation results (Freedman and Marr, 1992).

of structures included in the alternative. Operability is generally a measure of a system's complexity. Complicated systems and plans might be difficult or expensive to implement and operate; these factors are, therefore, taken into consideration in the BMP selection. Typically, this decision factor favors source control and regulatory practices that do not have the level of complexity and possible operational problems of structural controls.

Buildability

This decision factor is directed primarily at the selection of structural BMPs. Taking into consideration the various aspects of construction, the criteria investigated under this category include the site requirements, extent of disruption, and degree of construction difficulty. When relying on complex structural controls, difficulties inherent in construction and future maintenance might need to be overcome. While not a consideration in source control and regulatory control practice, this factor can be very important for structural controls.

Environmental Effects

Implementing urban runoff pollution control plans can affect the environment both positively and negatively. The positive effects on resources result from the removal of pollution sources. Resources that can be positively affected include water resources, aquatic animal and plant life, wildlife, wetlands, and many others. The negative environmental effects, which can include aesthetic problems, cross-media contamination, the loss of useable land, wetlands impacts, and many others, must also be considered in the assessment.

The importance of this decision factor is becoming more widely recognized. There seems to be a shift away from viewing urban runoff control structures only on their pollution control ability. Incorporating structures into new developments or retrofitting them in existing areas can gain wider acceptance if additional aesthetic qualities are considered. For example, unvegetated aboveground infiltration basins or dry ponds are generally not attractive elements of the environment and could serve as insect breeding grounds. Natural-looking wet ponds or vegetated wetlands, however, can be incorporated into the environment and even serve to improve aesthetics. These issues can greatly affect public acceptance.

Institutional Factors

This decision factor relates to existing governmental structures, legal authority, and implementation responsibilities. To implement alternatives, the logistical resources must be in place, and the proper authority to pass and enforce regulatory practices must exist. If the proper authority does not exist, an analysis of attaining it must be undertaken. In addition to these considerations, the team should investigate existing urban runoff programs in the community, region, or state. Often, cost savings can be realized and total program efforts can be reduced by taking advantage of material and data compiled during these existing programs.

Public Acceptance

In many instances, the public will be responsible for at least a portion of the funding required to implement the recommended plan. Public reaction to the urban runoff control plan should, therefore, be assessed through the use of public meetings. Measuring public acceptance can be difficult, but can be important to the overall success of a program.

Other Decision Factors

Additional decision factors—such as maintainability, level of pollution control, or size requirements—can be included in the assessment of alternative plans if they are more important than those discussed above.

Once the final decision factors have been chosen and applied to the alternative plans, the plans can be assessed through applying a decision analysis tool. Methods for conducting this decision analysis are presented below.

Decision Analysis Methods

Assessing alternatives takes into account a variety of factors, both quantitative and qualitative. The type of assessment conducted in these programs, which involves an integration and comparison of these factors, is an example of multiattribute decision-making and can be performed with various decision analysis methods. The following decision analysis methods, which are listed in order from the most qualitative to the most quantitative, can be utilized:

- Holistic
- Cost-benefit ratios
- Matrix comparisons
- Decision factor analysis
- Optimization

Two additional BMP selection processes, which combine aspects of a number of the above approaches, are discussed in the case studies at the end of the chapter.

Holistic

This approach is qualitative and relies on certain basic facts, intuition, and professional judgment. One key deciding factor (e.g., cost) can guide the process. Given the inherent complexity of assessing alternative urban runoff control plans and the large number of available inputs to the decision, this approach is usually over-simplified. Selecting an appropriate plan from the developed alternatives will generally require an assessment of multiple factors and should be done in as quantitative a manner as is reasonably possible.

Cost-Benefit Ratios

The relative value of different alternatives can be measured using cost-benefit ratios, such as cost per pound of pollutant removed or cost per day of effect on resources. This approach can be used as a tool to determine which BMP should be used first. For example, if it is determined that reducing solids using source control measures costs less per pound than using a structural BMP, then source control measures should be utilized first. Since the unit cost of source control measures increases with the amount of solids eliminated, the cost per pound of solids removed increases with the number of pounds removed. The extent to which source control measures should be used for pollutant removal is then given by the point at which the marginal cost-benefit ratio (i.e., change in cost/change in benefit) becomes larger than that of another alternative.

Another advantage of the cost-benefit ratio approach is that it allows use of the knee-of-the curve methodology, which seeks to determine the point in the cost-benefit curve where the marginal cost to achieve a marginal benefit becomes significantly higher. This factor is measured by the marginal cost-benefit ratio defined above. Figure 8-5 shows an example of this methodology where the cost-effectiveness drops dramatically as practices are implemented to reduce lake standards exceedance to below 10 days per year.

The cost-benefit ratio approach, however, is limited by the number of cost-benefit ratios that can be conveniently considered simultaneously. To represent the different elements of a complex issue better, where some benefits might be counterbalanced by some detriments, multiple costs and benefits must be considered.

Matrix Comparison

Matrix comparison, a common decision-making method used in facilities planning and siting, is suggested in EPA's Construction Grants guidelines (see Table 8-2). Environmental impacts in Table 8-2 can be divided into short-term construction-related impacts and long-term operational impacts. The matrix comparison approach is also applicable to the assessment of urban runoff control alternatives. This approach involves preparing a matrix that compares alternatives against selected decision factors, both quantitative and qualitative. Where possible, numerical values are given to compare the alternatives, and, for qualitative factors, subjective comparisons are used (such as poor, fair, good, and excellent).

An example of the matrix comparison approach for CSO abatement is shown in Table 8-3. In this example, three alternative control programs are compared for cost, conformance with objectives, operability, and buildability. While Alternative 1 provides the greatest pollutant removal and reliability, it also has the highest cost. If cost is an important factor, Alternative 3 would be the selected alternative, since it has the lowest present worth cost. Alternative 2, however, provides better reliability than Alternative 3 and has equivalent

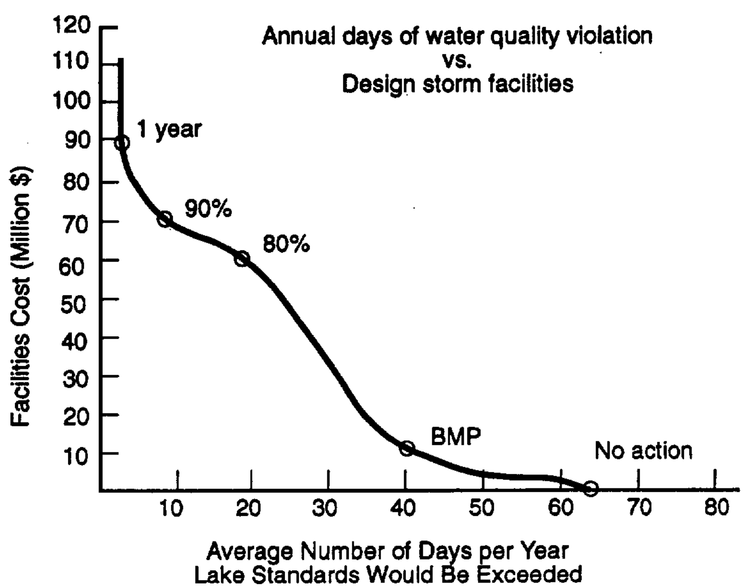


Figure 8-5. Example cost-benefit ratio curve (Moffa, 1990).

Table 8-2. Example Matrix Comparison (adapted from U.S. EPA, 1985)

	Alternatives			
Type of Impact	**#1**	**#2**	**#3**	**#4**
Monetary Cost, $				
Capital cost	++	–	–	+
Annual O&M cost	–	+	+	+
Cost per household unit	+	+	+	–
Environmental Impact				
Cultural resources	o	+	––	–
Floodplains and wetlands	+	–	–	–
Agricultural lands	–	++	+	–
Coastal zones	+	–	+	+
Wild and scenic rivers	o	+	–	+
Fish and wildlife	++	–	++	+
Endangered species	+	–	+	+
Air quality	o	o	–	+
Water quality and uses	+	++	+	+
Noise, odor, aesthetics	–	+	–	––
Land use	o	+	–	+
Energy requirements	o	–	o	–
Recreational opportunity	+	++	–	–
Reliability	–	–	+	–
Implementability	+	+	––	+

Legend:
++ Significant beneficial impact
\+ Minimal beneficial impact
o No impact
– Minimal adverse impact
–– Significant adverse impact

cost-effectiveness in terms of present worth dollars per gallon controlled. While this approach is useful, it can be quite subjective and care and professional judgment must be taken in defining the appropriate decision factors and applying the method.

Decision Factor Analysis

This is a matrix approach, which further quantifies the decision factors by using weighting methods. In this approach, quantitative factors are used to eliminate the subjective comparisons required in other matrix approaches. These criteria should be:

1. Nondominant—no criterion should be dominant.
2. Complete—no pertinent information should be left out.
3. Scorable—criteria cannot be vague, since it must be weighted clearly.
4. Independent—criteria should not overlap each other.

Weights are then generated for each decision factor. These weights must have a common scale, and the relative importance of each factor to the decision should be reflected in the weights. One example of this approach for site priority setting was described in Chapter 6. A further example is the BMP selection approach in the ME DEP case study at the end of this chapter. The major difference between this approach and the matrix approach outlined above is that, in this approach, the decision factors must be quantitative. Therefore, subjective comparison terms, such as good or fair, cannot be utilized. The decision factors must be able to be described by values that can be summed. Variations on this type of approach and various decision support software can facilitate the conduct of these analyses.

Optimization

Optimization, a widely used method of quantitative decision making, involves formulating a problem as the

Table 8-3. Example CSO Abatement Alternative Matrix Comparison (Metcalf & Eddy, Inc., 1988)

Selection Criteria	Alternatives #1	#2	#3
Monetary Factors			
Capital cost	$176,000,000	$106,000,000	$92,800,000
Annual O&M cost	—	$4,070,000	$4,080,000
Present worth (PW), 20 yr	$162,000,000	$139,000,000	$126,000,000
PW, $/gal	$9.08	$7.77	$7.77
Conformance with Objectives			
Control of major discharges	Good	Good	Good
Elimination of problem areas	Good	Fair	Fair
Impact of priority areas	Good	Good	Good
Operability			
Number of facilities	0	3	3
Reliability	High	Medium	Low
Level of O&M	Low	High	High
Reliance on existing facilities	Low	High	High
Impacts on downstream facilities	Low	High	High
Buildability			
Site requirements	Low	High	High
Extent of disruption	High	Low	Low
Degree of difficulty	High	High	High
Adaptability to phased implementation	Good	Fair	Fair
Conformance with current plans	Fair	Poor	Poor

maximization (or minimization) of an objective function, subject to a series of constraints. In linear optimization, both the objective function and the constraints must be linear functions of the decision variables. Various methods are available for finding the optimum set of decision variables and several software packages can perform the analysis. These methods are summarized in basic textbooks on optimization (Monks, 1987).

For plan selection, the objective function can be cost or a more complicated function of cost, benefits, and detriments. Examples of benefits that could be included are gallons of discharge removed, pounds of pollutants removed, and days of beach closure avoided. A multifactor objective function can account for tradeoffs among costs, benefits, and detriments by incorporating relative weight for each factor:

$$F = \Sigma a_i y_i$$

where:

F = objective function
a_i = weight and conversion factor
y_i = cost-benefit factor

All terms in the above equations must have the same dimension (e.g., dollars) so that weights also incorporate a conversion factor. The optimization process then consists of maximizing the objective function, by optimally selecting the values of the decision variables on which the different factors depend. Then, each cost-benefit factor, y_i, must be expressed linearly in terms of each of the decision variables, x_j:

$$y_i = \Sigma b_{ij} x_j$$

where:

b_{ij} = a different weight or conversion factor

This relationship is relatively easily established for cost (such as life-cycle cost), but more difficult for other factors, such as pounds of pollutant removed or days of beach closure. For these types of factors, models need to be applied with different values of the decision variable and straight-line fitted to the result. Constraints must also be established as linear functions of the decision variables. Possible constraints are the maximum number of excursions of standards per year or the maximum amount of pollutant reduction achievable given background conditions. Once the objective function and constraints are defined, various algorithms and software packages are available to determine the combination of decision variables maximizing the objective function.

A major problem with this approach is that many relationships pertaining to BMP selections are nonlinear. Qualitative factors are also difficult to incorporate in the process, especially in the form of linear functions of the decision variables. Nonlinear optimization, while accounting for the nonlinear dependence of various factors, is mathematically complex. It also tends to suffer from the same types of drawbacks as linear programming because it is not effective for problems that include qualitative factors.

Determination of Appropriate Decision Analysis Approaches

Matrix comparison and decision factor analysis approaches are typically best suited to BMP selection. Such approaches rely on the analytical tools available to analyze the system and on the best professional judgment of those assessing the alternatives. Given specific problems that can be quantified, optimization could be tried. Most BMP selection projects involving urban runoff, however, would be too complex. If the problems being addressed are simple, then the holistic or cost-benefit ratio techniques can be utilized. These simple, qualitative approaches can also be implemented as first approximations for plan assessments whose final results must be made using more complex approaches. In summary, an appropriate decision analysis method or methods must be selected that reflect:

- The complexity of the problems and the plans to address them.
- The data needs of each method and the ability to obtain the required data.
- The financial and personnel resources available to conduct the assessment.

A matrix comparison or decision factor analysis most likely would be involved.

Conclusions

The selection of BMPs to control urban runoff pollution is difficult and can best be performed by undertaking a systematic assessment process, aided by the use of analytical tools and the selection of appropriate design conditions and decision factors. Because of the qualitative nature of some inputs to the decision, subjective comparisons among the alternative plans typically are necessary. The process outlined in this chapter is a guide for decision making, but cannot account for all possible circumstances. Professional judgment and care are needed in determining the methods for developing alternatives, the decision factors to be employed, and the decision analysis method to utilize. Once these choices have been made and the BMP plan has been selected, the urban runoff pollution prevention and control plan can be developed in more detail so that it can be implemented.

The following case studies provide examples of BMP selection approaches used by the State of Maine for runoff control in new developments and by the Santa Clara Valley Water Quality Control Board in the development and implementation of a major runoff pollution prevention and control plan.

Case Study: Maine Department of Environmental Protection BMP Selection Matrix

To address storm water and NPS pollution control in areas of new development, the Maine Department of Environmental Protection (ME DEP) has developed a method to select BMPs. The method which is presented in a state guidance document is based on the following information:

- Development land use type and size
- Receiving-water type (e.g., estuary, wetland, river, or stream)
- Watershed priority (either priority or non-priority)
- Erosion and sediment control target or level to achieve
- Storm water quality control target or level to achieve
- Erosion and sediment control options and treatment level codes
- Storm water quality control options and treatment level codes

To implement the BMP selection method, ME DEP developed a series of eight matrices, two matrices for each receiving water type (i.e., estuary, wetland, river, and stream). One matrix is applied to development in designated priority watersheds and the other is applied to development in nonpriority watersheds. A priority watershed list has been developed by ME DEP based on environmental sensitivity, local support for water quality, and importance of the watershed to the state. Example matrices for priority and non-priority estuary watersheds are shown in Tables 8-4 and 8-5.

Each matrix has two major components, which are broken down by land use type: an erosion and sediment control level to achieve and a storm water quality level to achieve. The level to achieve for a given combination of land use and receiving-water category is a relative, qualitative measure of the impact of storm runoff pollution. It ranges from 1 to 5, with 1 being the lowest impact and 5 being the greatest impact. For example, a multihousing development proposed for a priority estuary watershed is given an erosion and sediment level to achieve of 2 and a water quality level to achieve of 3. By comparison, a small residential development in the same priority watershed is given an erosion control level to achieve of 1 and a water quality level to achieve of 1. In all cases, the levels to achieve for priority watersheds are greater than or equal to those for nonpriority watersheds.

Each matrix also addresses the types of BMPs that can be implemented for pollution control. ME DEP selected a number of BMPs and assigned each a treatment level code based on the expected level of pollutant removal. The treatment level code is a relative, qualitative measure designed to indicate the relative pollutant removal expected from various BMPs. Treatment level codes range from 1 to 3, with 1 providing the lowest level of control and 3 providing the greatest level of control. The BMPs and their treatment level codes are shown in Table 8-6. As indicated, various designs for each BMP are given different treatment level codes. For example, a 50-foot buffer is given a treatment level code of 1; a 125-foot buffer is given a treatment level code of 2; and a 200-foot buffer is given a treatment level code of 3.

For a proposed development to be approved, the sum of treatment level codes for the proposed BMPs must be greater than or equal to the level to achieve. For example, if a multihousing unit development is proposed for a priority estuary (erosion level to achieve of 2 and water quality level to achieve of 3), the developer could implement erosion and sediment controls (treatment level 2) and a combination of a swale (treatment level 1) and an infiltration system (treatment level 2). Additional combinations also could be implemented as long as the total treatment level provided is greater than or equal to the total level to achieve. ME DEP has also recommended that at least one vegetative BMP be implemented unless the site is already 100-percent impervious. The specified vegetative BMPs are buffers, grassed swales with level spreaders, and swales.

Table 8-4. Priority Estuary Storm Water Control Matrix

Land Use Category	Erosion and Sediment Level to Achieve	Erosion and Sediment Controls	Water Quality Level to Achieve	Storm Water Controls
Low-density residential, >2 ac/lot	1	Erosion and sediment 1	1	Buffer 1
High-density residential, <2 ac/lot	2	Erosion and sediment 2	3	Buffer 1 or 2 Wet pond 2 Infiltration 1 or 2 Created wetland 2
Commercial, <1 ac disturbed	1	Erosion and sediment 1	1	Buffer 1
Commercial, 1-3 ac disturbed	1	Erosion and sediment 1	2	Buffer 1 or 2 Infiltration 1 Swale 1
Commercial, >3 ac disturbed	2	Erosion and sediment 2	4	Buffer 1 or 2 Infiltration 1 or 2 Created wetland 2 Wet pond 2 or 3 Fertilizer control 1 Shallow impoundment 1
Intensive-use open space (e.g., golf courses, nurseries)	2	Erosion and sediment 2	5	Buffer 1 or 2 Fertilizer control 1 Pesticide control 1 Created wetland 2 or 3 Wet pond 2 or 3
Multihousing users	2	Erosion and sediment 2	3	Buffer 1 or 2 Fertilizer control 1 Pesticide control 1 Created wetland 2 Wet pond 2 Infiltration 1 or 2
Industrial, <1 ac disturbed	1	Erosion and sediment 1	1	Buffer 1 Swale 1
Industrial, 1-3 ac disturbed	1	Erosion and sediment 1	2	Buffer 1 or 2 Swale 1
Industrial, >3 ac disturbed	2	Erosion and sediment 2	5	Buffer 1 or 2 Swale 1 Created wetland 2 or 3 Wet pond 2 or 3

This BMP selection system is in its early stages of implementation. Its success will depend on the ability to establish levels to achieve that adequately protect water bodies in new developments. It will also depend on the ability of treatment level codes to quantify the effectiveness of the identified control measures. Thus, the system is a technology-based approach for erosion and sediment control, as well as for storm water pollution control.

Currently this method is outlined in a statewide guidance document and is not a regulatory requirement. Municipal officials can incorporate this process at their discretion in subdivision regulations. This method of BMP selection requires extensive upfront work to develop the matrices and BMP levels of treatment. Once these are developed, however, this method provides a simple and direct technology-based approach to BMP selection. It has flexibility in terms of the range of BMPs that can be selected for given types of proposed development and given site constraints.

Table 8-5. Nonpriority Estuary Storm Water Control Matrix

Land Use Category	Erosion and Sediment Level to Achieve	Erosion and Sediment Controls	Water Quality Level to Achieve	Storm Water Controls
Low-density residential, >2 ac/lot	1	Erosion and sediment 1	1	Buffer 1
High-density residential, <2 ac/lot	2	Erosion and sediment 2	2	Buffer 1 or 2 Infiltration 1
Commercial <1 ac disturbed	1	Erosion and sediment 1	1	Buffer 1
Commercial, 1-3 ac disturbed	1	Erosion and sediment 1	1	Buffer 1
Commercial, >3 ac disturbed	2	Erosion and sediment 2	2	Buffer 1 or 2 Infiltration 1 Swale 1 Shallow impoundment 1
Intensive-use open space (e.g., golf courses, nurseries)	2	Erosion and sediment 2	3	Buffer 1 or 2 Infiltration 1 or 2 Fertilizer control 1 Created wetland 2 Wet pond 2
Multihousing units	2	Erosion and sediment 2	2	Buffer 1 or 2 Infiltration 1
Industrial, <1 ac disturbed	1	Erosion and sediment 1	1	Buffer 1 Swale 1
Industrial, 1-3 ac disturbed	1	Erosion and sediment 1	2	Buffer 1 or 2 Swale 1
Industrial, >3 ac disturbed	2	Erosion and sediment 2	4	Buffer 1 or 2 Swale 1 or 2 Created wetland 2 or 3 Wet pond 2 or 3

Table 8-6. Summary of BMP Treatment Level Codes

BMPs	Level of Treatment
Erosion and Sediment Control	
One line of erosion control	1
Two lines of erosion control	2
Nongrassed Buffers	
50 ft	1
125 ft	2
200 ft	3
Infiltration Systems	
Single system	1
Multiple systems	2
Wet Ponds	
Single-pond system holding 2.5 in of runoff	2
Double-pond system each pond holding 2.5 in of runoff	3
Created Wetlands	
Single created wetland	2
Two created wetlands	3
Other BMPs	
Swales	1
Shallow impoundments	1
Street cleaning	1
Fertilizer application control	1
Pesticide use control	1
Grassed swales with level spreaders	1
Reverting land (i.e., allowing currently impervious land to be a vegetative buffer)	1

Case Study: Santa Clara Valley, California, Nonpoint Source Control Program BMP Screening Procedure

Background

In 1986, the San Francisco Regional Water Quality Control Board developed a basin plan for San Francisco Bay which involved regulatory activities to control point and nonpoint source discharges. The basin plan was the driving force behind initiating the Santa Clara Valley Nonpoint Source Control Program. This program involves a number of local governments and county agencies and is designed to address water quality problems in Lower South San Francisco Bay. In developing the Santa Clara Valley Nonpoint Source Plan, a 12-step process that closely follows the process outlined in this handbook was used. The steps in this process are:

- Initiate program
- Determine existing conditions
- Conduct field monitoring
- Define program objectives
- Develop evaluation and planning criteria
- Compile inventory of candidate controls
- Apply criteria to screen candidates
- Apply professional judgment to select a practical set of controls
- Estimate overall program cost and effectiveness
- Revise the previously defined control programs to balance cost, effectiveness, and other factors
- Describe the roles of various agencies
- Develop an implementation schedule

Development of the Santa Clara Valley Nonpoint Source Control Plan began in 1986 and has continued through various stages to initial implementation and preliminary assessment of effectiveness.

Watershed Description

Santa Clara County, which incorporates the entire study area, is located at the southern end of San Francisco Bay (see Figure 8-6). The 690-square-mile watershed consists primarily of the relatively flat Santa Clara Valley. Land use in the watershed is approximately 30 percent residential, 5 percent industrial (predominantly light industry associated with high technology manufacturing), and 62 percent open space. Three large cities—San Jose, Sunnyvale, and Santa Clara—account for the majority of urban areas in the watershed.

Overview of Water Quality

To characterize existing water quality in Lower South San Francisco Bay, a comprehensive monitoring program was undertaken. This program included hydrologic monitoring, wet- and dry-weather water quality monitoring, sediment monitoring, and biological monitoring. The monitoring was conducted primarily to determine the levels of toxic pollutants, such as heavy metals and pesticides, as well as nutrients and fecal coliform bacteria. Data obtained through this monitoring program were input to data bases and used for developing computer models. Watershed loads were estimated using the Storm Water Management Model (SWMM), calibrated to the observed data gathered in the monitoring program.

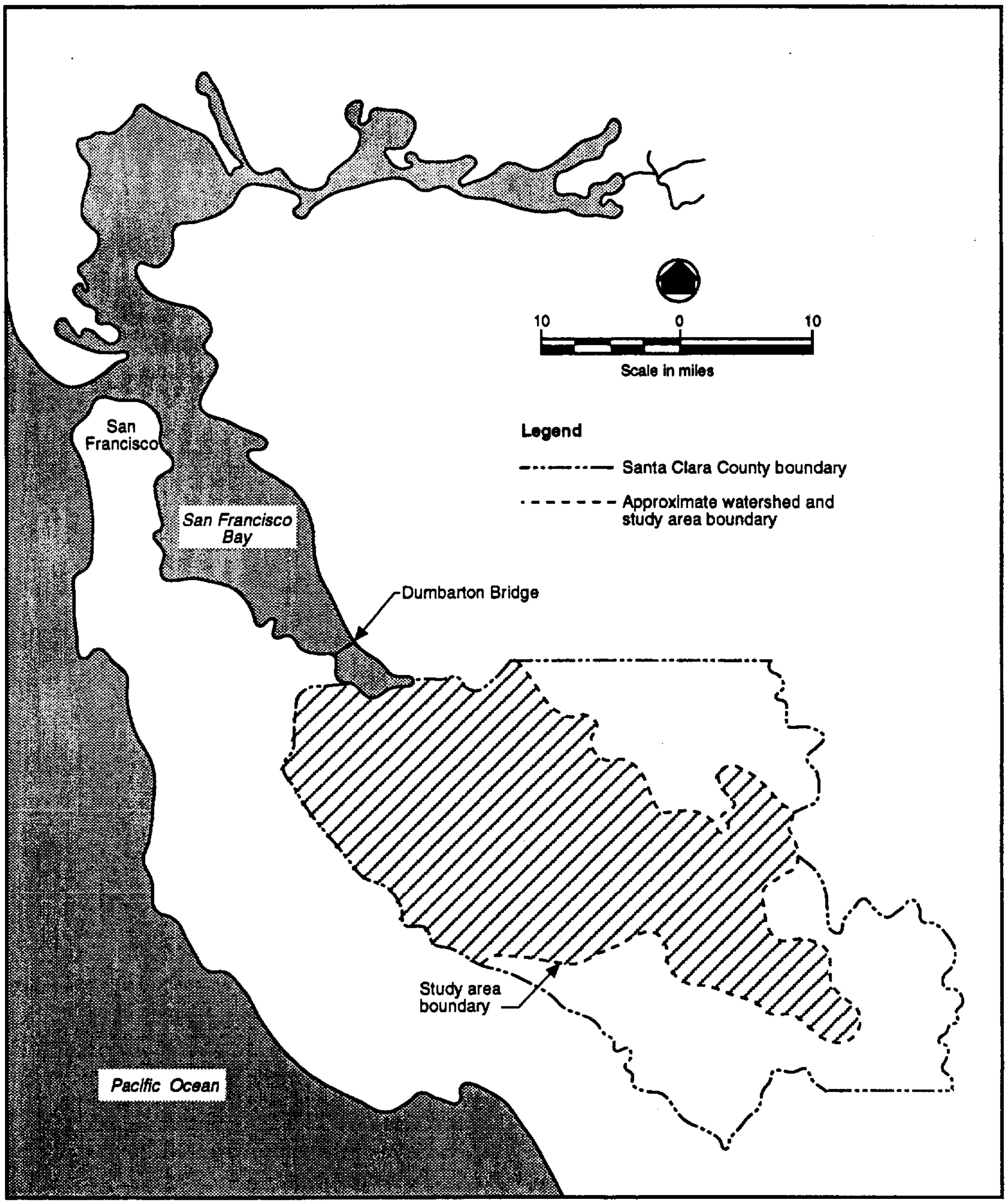


Figure 8-6. Santa Clara Valley watershed.

The data were also used to compare the relative contributions of point (e.g., waste water treatment plants) and nonpoint source pollution to the bay.

Water quality monitoring results indicated that heavy metal concentrations in receiving waters increase during wet weather, because of contaminated runoff as well as resuspension of contaminated sediments. The metals primarily detected were cadmium, chromium, copper, lead, nickel, and zinc. Copper was the primary metal regularly detected at levels greater than the EPA aquatic life criteria; these criteria were exceeded only occasionally for cadmium, lead, and zinc. Also, during wet weather, hydrocarbons and pesticides were detected in approximately 25 percent of the ambient water samples collected, while none were detected during dry weather. The limited bacteria data gathered indicated increased levels (by a factor of about 10) of fecal coliform bacteria during wet weather as compared to dry-weather conditions.

In comparing point and nonpoint source contributions to water quality problems in Lower South San Francisco Bay, the monitoring results showed that point sources account for approximately 98 percent of the nutrient load. Nonpoint sources, however, accounted for 60 to 80 percent of the load for metals and about 98 percent of the total suspended solids yearly load.

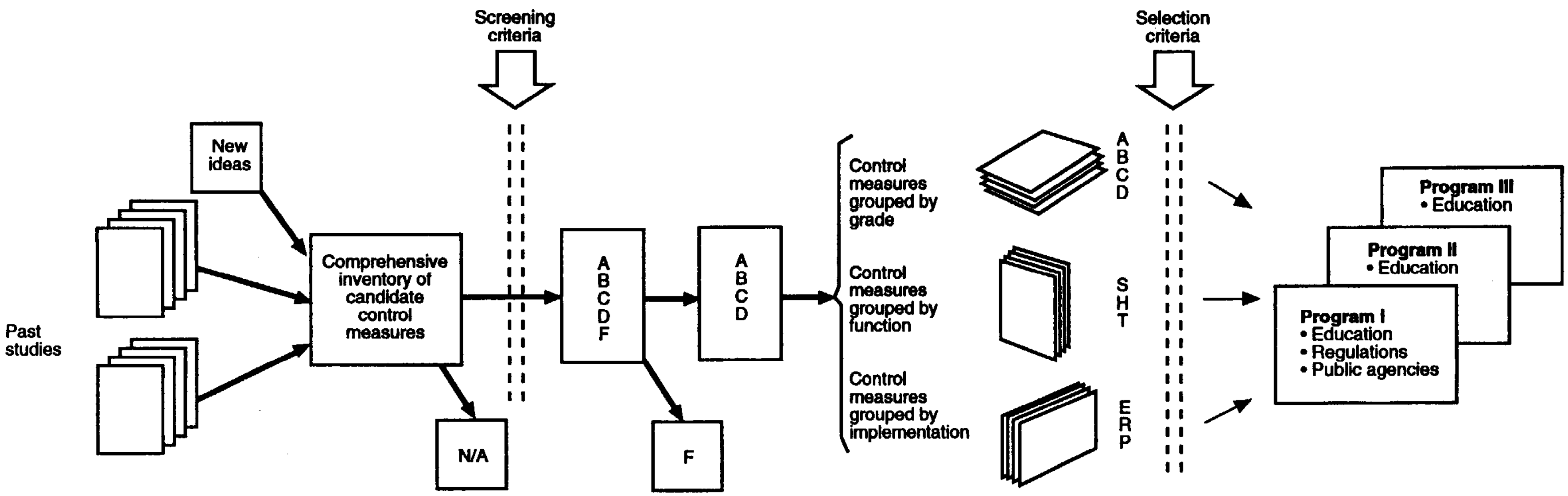
Management Practice Screening

Because of the large size of the watershed and the variety of pollutants entering the Lower South San Francisco Bay, the emphasis of the nonpoint source pollution control program was on pollution prevention measures and nonstructural controls that could be implemented across municipal boundaries. Selection of appropriate pollution prevention measures and controls was accomplished through a process consisting of preliminary screening followed by final control measure selection (see Figure 8-7).

In order to screen the extensive list of potential pollution prevention and control practices, the program team first listed important criteria for the selected measures. The criteria developed for this project were:

- *Pollutants controlled:* Controls for metals, pesticides, oil and grease, bacteria, and sediments are emphasized.
- *Effectiveness:* Each control measure should provide sufficient pollution control toward the overall program to warrant its inclusion.
- *Reliability/sustainability:* Control measures should be effective over an extended time period and be able to be properly implemented over time.
- *Implementation cost:* Control measures with low planning, design, land acquisition, construction, and equipment acquisition costs were emphasized.
- *Continuing costs:* Emphasis was placed on control measures with low operation, maintenance, repair, support service, and equipment replacement costs.
- *Equitability:* Controls were evaluated regarding the degree to which costs and benefits would be equitably distributed among the participating agencies.
- *Universality:* Controls were evaluated in terms of how universally they would have to be applied to be effective.
- *Public acceptability:* Control measures were assessed on the expected public response to implementation.
- *Agency acceptability:* Control measures were evaluated on the expected response of agencies responsible for implementation.
- *Relationship to regulatory requirements:* Control measures were evaluated on their consistency with existing and anticipated regulatory requirements.
- *Risk/liability:* Control measures were evaluated in terms of the risks or liabilities which could occur in implementation.
- *Environmental implications:* Control measures were evaluated regarding the positive and negative environmental impacts resulting from their use.

Once the control measure criteria were developed and agreed upon, the program team developed a comprehensive list of potential measures for implementation. The inventory of potential measures was developed through a review of technical literature and other nonpoint source control programs. In addition, technical and managerial personnel from other state agencies, county agencies, and city public works and planning agencies were interviewed.



Legend

A, B, C, and D are letter grades.

S, H, and T are functions
(i.e., source controls, hydraulic controls, treatment-based controls).

E, R, and P are modes of implementation
(i.e., education, regulation, public agency actions).

Figure 8-7. BMP selection process.

This review resulted in a list of more than 120 separate measures to be screened. This initial list was to be comprehensive; no consideration was given to the applicability of the measures. Once the list had been developed, however, obviously inappropriate measures were eliminated—primarily those designed to address specific situations that did not exist in the watershed. This initial screening reduced the list of potential pollution prevention and control measures to 92.

This list of 92 measures was then assessed qualitatively using the criteria developed earlier in the program. Each potential control measure was assigned a letter grade (A through F) for its ability to meet the criteria. Measures receiving an A were viewed to meet all or a large number of the assessment criteria, while those receiving an F were viewed to meet none or very few of the assessment criteria. The control measures that fell into the category of F were immediately eliminated from further consideration in the Santa Clara Valley watershed.

The final list of potential pollution prevention and control measures was then arranged into three groups by grade, function, and implementation method as shown in Figure 8-7. The control measures arranged by function included source controls, hydraulic controls, and treatment-based controls. The control measures arranged by implementation method included educational controls, regulatory controls, and public agency actions. By arranging the controls in these various ways, the program team could select control measures that gave a good mix of type and implementation method.

Management Practice Selection

At this point, the assessment criteria used in the initial screening were applied to each potential control measure to develop three alternative programs: Program I, the smallest scale program, was designed to be low cost and provided a minimal level of pollution control. Program III, the largest scale program, was designed to provide a high level of pollution control but had a high cost. Program II, designed to represent a middle road between Programs I and III, was the program recommended in the report because it was felt to provide the best cost-benefit of the three alternatives.

The recommended alternative included educational, regulatory, and public works (structural) control measures. Most of these measures are to be implemented across the watershed, but some recommendations specific to known problems areas are also included.

Implementation

In order to efficiently implement the NPS control plan, the task force determined high-priority actions for immediate implementation. The following actions are considered to be high priority because they can be implemented across the watershed.

- Conduct wet-weather monitoring.
- Develop and implement a public information program.
- Develop and begin implementation of illicit connection identification and removal.
- Conduct illegal dumping monitoring program and provide training.
- Evaluate treatment based controls.
- Develop and begin implementation of areawide and community-specific storm water management program.

Still in the early stages of implementation, the program cannot yet be evaluated. Implementation of many of the above high-priority measures, however, is progressing. This case study shows a qualitative selection process that utilizes a set of screening and selection criteria to develop low, medium, and high pollution prevention and control alternatives.

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

Freedman, P.L., and Marr, J.K. 1992. Design conditions for wet weather controls. Proc. Water Environment Federation Specialty Conference, Control of Wet Weather Water Quality Problems. Indianapolis, IN. May 31-June 3.

George, T.S. and J.P. Hartigan. 1992. Regional detention planning for stormwater management: model for NPDES management programs. Proc. Water Environment Federation Specialty Conference, Control of Wet Weather Water Quality Problems. Indianapolis, IN. May 31-June 3.

Metcalf & Eddy, Inc. 1988. Lower Connecticut River phase II combined sewer overflow study. Massachusetts Division of Water Pollution Control.

Metcalf & Eddy, Inc. 1989. Coastal nonpoint source demonstration project: nonpoint source control for the watershed of Snell Creek—Westport, Massachusetts. Massachusetts Department of Environmental Protection.

Moffa, P. 1990. Control and treatment of combined sewer overflows. New York, NY: Van Nostrand Reinhold.

Monks, J.G. 1987. Operations management: theory and problems, 3rd ed. New York, NY: McGraw-Hill.

Pitt, Robert. 1989. Source Loading and Management Model: an urban nonpoint source water quality model—volume I: model development and summary. University of Alabama, Birmingham.

U.S. EPA. 1985. U.S. Environmental Protection Agency. Construction grants 1985. EPA/430/09-84/004. U.S. EPA Office of Water. Washington, DC.

Woodward-Clyde Consultants. 1989. Santa Clara Valley nonpoint source study. Santa Clara Valley Water District.

Chapter 9
Implement Plan

The final step in the planning process is to develop an implementation plan for prevention and control of urban runoff pollution. This plan sets forth the recommended control program in a form readily usable by the team charged with program implementation. The information obtained through the earlier tasks of assessing existing conditions, collecting and analyzing additional data, identifying and assessing problems, and screening and selecting BMPs must be clearly summarized as a "roadmap" or work plan for future activities.

Contents of an Urban Runoff Pollution Prevention and Control Plan

The urban runoff pollution prevention and control plan should contain the following information:

- Conceptual information on recommended BMPs
- Schedule of activities
- Responsibilities for BMP implementation
- Description of monitoring plan
- Summary of regulatory requirements
- Public involvement program
- Identification of funding sources/mechanisms

Each item is important to implementation of the plan and is described in the following pages. At the end of this chapter, a case study using the Pipers Creek watershed implementation plan shows how each of these plan components was developed.

Description of Recommended Best Management Practices

The first part of the urban runoff pollution prevention and control plan is a description of the BMPs selected for implementation. This includes regulatory BMPs, municipal practices, structural BMPs, and any other BMP activities selected for implementation.

Regulatory BMPs

Regulatory BMPs, which play an important role in urban runoff pollution prevention and control, should be included and summarized in the control plan. The summary requires a clear description of the proposed regulatory changes and the approach to implement the changes. Regulatory BMPs can address requirements for an entire community or can be focused on a specific area targeted for protection. The level of effort necessary to implement the control program varies depending on these regulatory requirements. This information is included in the BMP description along with a discussion of the method required to comply with the regulation, and any required enforcement and maintenance activities. Some regulations require passage through the vote of a specific board or committee, while others require a full vote of residents in the community. The process needs to be outlined in the urban runoff pollution prevention and control plan. Finally, costs need to be developed. These include one-time costs associated with implementing the regulation as well as recurring costs associated with education, information, oversight, and enforcement. Case studies of regulatory control approaches are presented at the end of Chapter 4 (Lewiston, Maine) and Chapter 7 (Austin, Texas).

Municipal BMPs

Municipal BMPs include the nonstructural and source control practices carried out by each responsible public entity—street-sweeping, catch basin cleaning, and cross-connection identification and removal. For each of these BMPs, a plan needs to be prepared that details the frequency of conducting each practice, the locations at which the practice takes place (preferably on a map), a schedule of activities, the required staffing, and the cost. Initial program startup costs could include training staff and purchasing equipment. In addition, municipal BMPs typically include ongoing operational costs—labor for public works and maintenance staff efforts. A record system should also be designed to track activities and pertinent data (e.g., pounds of debris removed and areas swept). Municipal source control and nonstructural practices are discussed in Chapters 4 and 7 and in the Lewiston, Maine, case study, which is presented at the end of Chapter 4.

Structural BMPs

Structural BMPs eventually require engineering design and construction. At this stage of planning, information needed to support each BMP includes a description, pictures, diagrams or concept sketches (see Figures 9-1 and 9-2), design information and assumptions, as well as pertinent conceptual details of the structural BMPs. The details should indicate known site conditions such as existing structures; topography; and other site-specific information such as soil conditions, utility locations, and wetlands, as available. Also included should be a general plan of the watershed showing

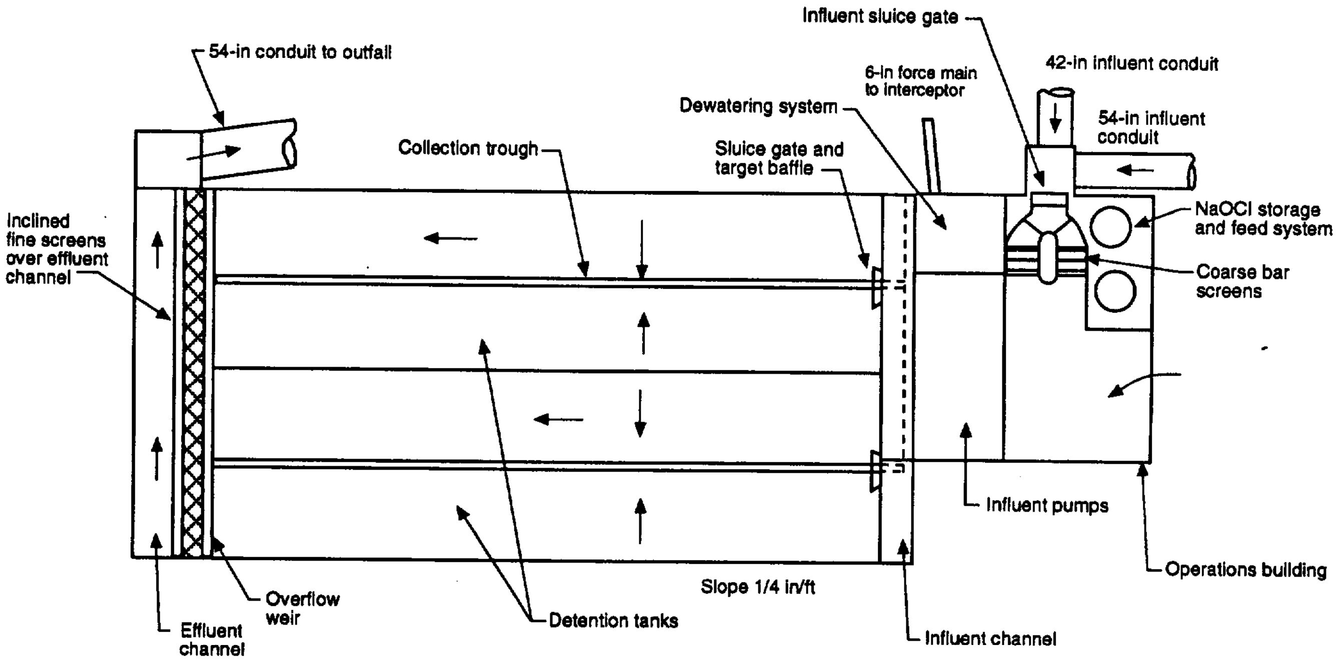


Figure 9-1. Example CSO control conceptual design of a sedimentation/disinfection facility (Metcalf & Eddy, Inc., 1988).

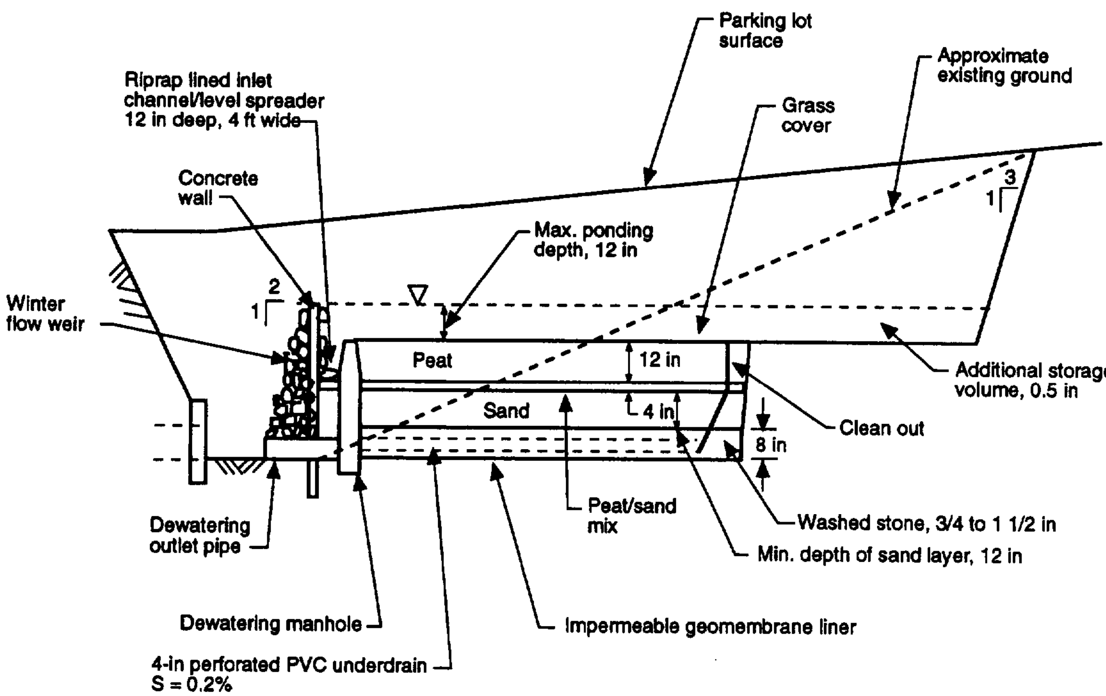


Figure 9-2. Example runoff control conceptual design for a filter system (U.S. EPA, 1992).

locations of the recommended BMPs and the pollution sources they are designed to address. Final detailed design plans and specifications for each structural BMP are developed later, once the plan is approved.

For each BMP, a cost estimate is also developed. After the initial cost estimate during the alternatives development step, this estimate is refined to a more detailed estimate for purposes of the implementation plan. Improved accuracy is important since it could provide a basis for allocation of funds. Given the uncertainty at this stage (site survey and engineering work normally is still to be done), contingencies should be included in the estimate; and the cost perhaps should be presented as a range. For structural BMPs, ranges of costs can be obtained by consulting the Chapter 7 references. These costs, however, provide only guidelines and often vary widely depending on site-specific characteristics, such as soil conditions, depth to bedrock, and level of surrounding development. Costs include those for design, capital, and operations and maintenance. Costs for engineering, field surveys, borings, construction labor and materials, and contingency are also usually included. These costs can be presented in terms of present worth and tied to an applicable price index, such as the *Engineering News Record* (ENR) cost index, so the costs can be adjusted by others in the future.

Proper operation and maintenance is particularly important to the long-term functioning of structural BMPs. A method must be developed for ensuring that maintenance requirements are included in the management plan along with inspection and/or enforcement mechanisms. For example, if a community requires an industry or developer to construct a detention facility to remove suspended solids from runoff, the community must also develop a method for ensuring that the practice is properly maintained. Some municipalities have addressed this issue by establishing special funds designed to ensure maintenance of BMPs. In these circumstances, a municipality might require the industry or developer to contribute a fee to a fund that pays for inspection and maintenance of the BMP by municipal employees. Another option is for the municipality to require the private party to perform the maintenance. This option, however, gives the municipality less control over the BMP and still requires that the municipality conduct periodic inspections of the BMPs.

Other Related Activities

Several related activities, which might not fall strictly into the earlier categories identified, include public participation and education, monitoring, and maintenance and enforcement. Both public participation and education, and monitoring are addressed as separate plan components later in this chapter. Maintenance and enforcement is discussed under the section on responsibilities for BMP implementation. In general, however, all BMPs and activities which are to be included in the program should be described and discussed as part of the implementation plan.

Schedule of Activities

Because of the complex nature of urban runoff planning, implementing all the recommended BMPs in a short time generally is not possible. In some cases, the implementation schedule must allow time for pilot testing of BMPs in selected areas, monitoring the results of these pilot tests, and final design of full-scale BMPs. In fact, implementation of complex and expensive urban runoff BMPs is often conducted in a series of steps. These steps can include the following (U.S EPA, 1991):

- *Planning phase:* Analyzing, evaluating, and planning initial tasks.
- *Preparation phase:* Preparing budgets, resources, and necessary permits.
- *Pilot-scale implementation phase (only if necessary):* Testing selected BMPs for effectiveness and cost prior to full-scale implementation.
- *Full-scale implementation:* Designing and constructing the selected BMPs.
- *Evaluation/documentation phase:* Evaluating the effectiveness of the implemented BMPs to guide future action; preparing periodic reports documenting the results.

These considerations are incorporated into a schedule with start and finish dates for major tasks and milestones. The schedule should also include interim dates of reporting BMP results and monitoring program results.

Depending on the program's size, the schedule could be shown by means of a simple bar chart or a more complex critical path method (CPM) system using project scheduling/management computer software. The type of schedule selected depends on the level of program complexity—the number of tasks and subtasks (activities) required, the number of involved entities, the length of time over which the program will extend, and the available program management resources.

Implicit in developing an implementation schedule is the need to set priorities. The program team should review the recommended BMPs and determine an order of implementation (or phasing), taking into account extenuating circumstances in any particular case. If funding is a major issue, for example, the least expensive recommendations can be implemented early in the process. Individual projects need to be phased in accordance with available funding.

One set of priorities that might be considered is to first implement regulatory and nonstructural controls, then evaluate them over time, and later implement structural controls. This approach might be effective in developing areas where BMPs can be required as development occurs. In addition, nonstructural and regulatory BMPs are less costly to implement than structural BMPs. This approach would not be as effective in areas where retrofit of BMPs is necessary. In general, priorities and thus the schedule of program implementation, must be tailored to each situation.

If the development of public support for the program is critical, the team might choose to address BMPs with potential for significant pollution reduction. In this case, BMPs that could improve the water quality of widely used water bodies should be implemented, if possible, before other steps are taken. These decisions should be reflected by the implementation schedule. A cost-benefit analysis (see Chapter 8) can be used to assist in setting priorities. For example, an analysis could be performed to determine total cost per pound of pollutant removed and projects implemented accordingly.

Responsibilities for BMP Implementation

The individuals and entities responsible for implementing each aspect of the program must be identified in the urban runoff pollution prevention and control plan. Since a well-defined institutional framework for urban runoff pollution prevention and control might be lacking, much of the effort for implementing plans must come from local and regional governments. Officials at the state and federal levels will likely be responsible for enforcement and oversight, and technical and financial assistance might also be available.

To develop a plan, municipal officials must coordinate, initiate activities, and motivate others in the community or other agencies to get involved. Figure 9-3 is an example format showing recommended actions and the agencies charged with implementation. Obtaining firm commitments from these agencies prior to program implementation is important to the final success of the program. Table 9-1 identifies groups, agencies, and individuals that can provide support for aspects of the management plan, including monitoring, design, permitting, regulations, public education, maintenance, and enforcement.

Description of Monitoring Plan

A monitoring program should be conducted during and after urban runoff pollution prevention and control program implementation to assist the municipality in determining the effectiveness of its overall program in achieving water resource goals. Monitoring during program implementation includes data collection to measure the overall program effects on water resources and determine the effectiveness of BMPs. Existing water resource conditions determined during the planning process provide a good understanding of water resource quality before program implementation. A monitoring plan to assess water resource conditions during and after program implementation allows the level of resulting improvements to be assessed by comparison to existing conditions.

Trend analyses are important in understanding the effects of watershed activities on water resources, and can provide important feedback to assessments of the success of urban runoff pollution prevention and control measures. Long-term data can be used to demonstrate the influence of program activities on water resource quality. Sampling data can also be used to educate the public on the effects of urban runoff pollution on water resources and the need for control. To increase public awareness, information that identifies the effects of urban runoff pollution can be disseminated in newsletters, at public meetings, or by other means.

Overall program effectiveness can usually be determined more easily than the effectiveness of individual BMPs. As part of the urban runoff control program, a long-term monitoring plan should be designed to measure program effectiveness and provide program accountability. The plan should use existing monitoring stations (both those used in previous studies and those used for collecting additional data as outlined in Chapter 5) to collect long-term data with which comparisons can be made. In this way, the progress of the program in addressing pollution problems and preventing further water resource degradation can be determined. Monitoring plan components (e.g., a map of monitoring stations, a record of the frequency of sampling at each station, a parameter list, and a QA/QC project work plan) should be identified in a work plan similar to that outlined for sampling in Chapter 5.

Collecting sufficient data to clearly demonstrate BMP effectiveness is difficult for many reasons, including the variability of runoff flow and quality, and the difficulty in separating the effect of a particular BMP on a receiving water. Caution should be exercised in developing these types of monitoring programs because they can be very expensive; sufficient data to reach a conclusion might not be obtained. More detailed discussions of BMP effectiveness sampling is available elsewhere (U.S. EPA, 1976).

The effectiveness of nonstructural and regulatory BMPs is difficult to assess. These BMPs are usually implemented slowly over time and affect a geographically wide area (typically within a political boundary). Patience

	Recommended Areawide NPS Control Measures (Program II)	Cities				County				State		
		Manager/attorney	Planning	Public works	NPS coordinator	Manager/attorney	Planning	Public works	NPS coordinator	General manager	Water quality	Environmental
	Public Agency Actions											
P1	Label storm drain inlets and provide signs along the banks of drainage channels and creeks	ab	cd	cd e	cd ek	ab	cd	cd c	cd	a	cd k	
P2	Develop and implement programs to properly dispose of oil, antifreeze, pesticides, herbicides, paints, solvents, and other potentially harmful chemicals (recycle if possible)	ab hi	cd	cd e	cd eg k	ab hi	cd	cd e	ed ek	a	k	
P3	Develop and implement an aggressive field program to search for, detect, and prevent dumping or routine discharging of pollutants into storm sewers and drainage channels	ab cj		ce f	ef gj k	ab cj		ce f	ef gj k	a	ce fg jk	ef
P4	Develop and implement an aggressive field program to search for, detect, and control illicit connections of sewers	ab cj		ce f	ef gj k	ab cj		ce f	ef gj k	a	ce fg jk	ef
P5	Determine the effectiveness of increasing the frequency of cleaning out storm sewer inlets, catch basins, storm sewers, and drainage channels in areas where sediment and/or debris tend to accumulate	ab		ce f	cf jk	ab		ce f	ef jk	a	ce fg jk	c
P6	Search for, test, remove, and properly dispose of sediment deposits (in drainage channels and streams) that contain relatively high concentrations of pollutants	ab		ce f	cf jk	ab		ce f	ef jk	a	ce fg jk	c
P7	Develop and implement a program to record the observations of field inspection and maintenance personnel, to help locate the source(s) of pollutants	ab		ce	ce k	a		ce	ce k	a	ck	ce

Legend

a Initiate/authorize program.
b Appoint or hire staff person to coordinate program.
c Work with inhouse personnel and consultant.
d Work with inhouse personnel and volunteers.
e Provide technical information and guidance.
f Conduct technical studies and/or inspections.
g Develop focused educational materials and/or work with media.
h Research existing regulations, authority, and precedent.
i Develop new regulations and/or policy statements.
j Coordinate enforcement actions.
k Coordinate with NPS Task Force.

Figure 9-3. Sample agency responsibility matrix (Woodward-Clyde Consultants, 1989).

is needed in assessing the effects of these types of BMPs because improvements in water quality will usually occur over a span of years. A long-term monitoring program should be used to determine BMP effectiveness. Other nonconventional types of monitoring might provide a more rapid and quantifiable means of BMP effectiveness. These monitoring methods include (CDM, 1993):

- *Record keeping/program tracking:* Keeping careful records of the quantities of pollutants removed by source control activities (e.g., length of streets swept and quantity of street sweepings removed, number of catch basins cleaned and amount of material removed, and the number, flow, and quality of illicit connections removed).
- *Level of participation:* Maintaining information on the number of participants and results of programs involving participation of the public and businesses (e.g., volumes and types of waste collected during a special collection program).
- *New programs implemented:* Measuring what has been accomplished, such as the number of new ordinances enacted or the number of public education meetings held.

Another nonconventional method to assess program effectiveness is an overall rating index. An example of this type of index has been developed and tested in two test case projects within the Rural Clean Water Program (Dressing et al., 1992). The index comprises four subindices: beneficial use support status, water quality data, extent of critical area treatment, and pollution control expected from treatment applied. Each subindex has its own scoring system, and the overall score is a weighted average of the subindex score. This type of

Table 9-1. Potential Implementation Responsibilities

Program Component	Potentially Responsible Parties	Other Potentially Involved Parties
Monitoring	Local boards of health State water pollution control agency State marine fisheries department	Local environmental groups University students Volunteer organizations Environmental consulting companies
Engineering design	Local engineering department State department of public works SCS	University engineering departments Engineering consulting companies
Permitting and regulatory controls	Local boards of health Local conservation office Local planning board EPA State water resources agency Federal coastal zone management U.S. Army Corps of Engineers	Local environmental groups Environmental consulting companies
Public education	Regional environmental agency Local environmental groups Watershed associations State environmental agency Soil and water conservation districts EPA	Local environmental groups Local civic groups Private organizations Cable TV/newspapers
Maintenance	Local department of public works SCS Private owners of BMPs	Contract maintenance providers
Enforcement	Local conservation agency Local board of health Planning board Local code enforcement officer Federal coastal zone management U.S. Army Corps of Engineers EPA	

rating system can be useful to assess program effectiveness semiquantitatively over time, or at critical periods before and after BMP implementation.

These types of nonconventional monitoring methods are not as direct as demonstrable water resource quality improvements, but they are valuable in documenting program success.

Summary of Regulatory Requirements

Regulatory issues that need to be addressed include both the implementation of regulatory BMPs and the application for regulatory approvals and permits needed to implement nonstructural and structural BMPs. Regulatory BMPs are discussed in Chapter 7. The urban runoff pollution prevention and control program could involve the modification or strengthening of existing regulations, including zoning, site plan review, subdivision, or wetlands protection or the development of new regulations.

In addition, a municipality must obtain appropriate regulatory approvals and permits before implementation and construction of BMPs that could alter wetlands, waterways, or water quality, even if the BMP results in environmental benefit. These requirements should be summarized as part of the urban runoff pollution prevention and control program. Coordination with appropriate agencies is advisable before applying necessary approvals and permits. Agencies from which permits will be required should be contacted early in the planning process to determine requirements for securing all necessary approvals and permits.

Major permits required in implementing urban runoff control BMPs originate at all levels of government—federal, state, and local. The permits of concern usually address the following issues:

- Alterations to wetlands.
- Dredging and filling operations.
- Disturbances within a specified distance of a waterway.
- Soil and erosion control at construction sites.
- Alterations to the water quality of a water body.
- Alterations to existing or construction of new discharges to a water body.
- Impacts on endangered species.
- Impacts on historic/archaeological sites.
- Impacts on natural resources and ecologically sensitive areas.

Major permitting programs at the federal level include: the National Environmental Policy Act (NEPA); the U.S. Army Corps of Engineers—Section 10 of the Rivers and Harbors Act and CWA Section 404; EPA's NPDES Permit Program; and the CZMA Federal Consistency Concurrence Certificate. Additional requirements can be in place for many of the regulatory programs outlined in Chapter 2. Information is available through regional EPA offices and the state agencies dealing with these issues. Requirements for state and local permits are site specific vary widely, and are available from the responsible local or state agency.

Public Involvement

Support and involvement of the general public, both homeowners and businesses, is considered crucial to plan implementation and its ultimate success. While public involvement should be an integral part of the planning process, a public involvement program should be developed as part of overall program implementation.

Components of public involvement programs can be wide ranging, involving one or more of the following components:

- Program meetings and presentations to provide information and updates.
- Program materials such as newsletters, fact sheets, brochures, and posters.
- School education programs such as special classes and tours.
- Homeowner education programs on individual control of urban runoff related pollution.
- Consumer education programs on appropriate product purchasing and handling.
- Business education programs.
- Media campaigns including radio, newspaper, or television.
- Coordinating and coalition building with local watershed or activist groups to support the program.

The numerous other possibilities include setting up a program hotline, sponsoring special events, and conducting surveys. A task force can be set up to coordinate and help focus these activities.

Public involvement can be approached in numerous ways. The case study on the Pipers Creek watershed at the end of this chapter identifies the elements used for that program. The Santa Clara Valley case study at the end of Chapter 8 shows how public involvement activities can be identified and evaluated as BMP options.

Funding Sources and Mechanisms

Since a large percentage of funding for urban runoff pollution prevention and control programs comes from local sources, this section focuses on local funding mechanisms. Sources of funding at the federal and state levels are uncertain and likely only to provide a small percentage of the total needed funding. It is important to keep in touch with the regional EPA offices and the state agencies dealing with urban runoff pollution prevention and control to determine the current status of funding for program implementation. Funding sources usually available to local jurisdictions fall into the following categories:

- Local funding mechanisms
- Matching fund programs
- Grant programs

An urban runoff pollution prevention and control program budget typically includes funds from a combination of sources. The actual funding sources utilized depend on many factors, including the following (PSWQA, 1989):

- The sustainability of the funds.
- The ease with which the funds can be obtained.
- The administrative requirements of the funding option.
- The correlation between the funding option and the problem.
- The typical use made of the funding.

The construction of a structural BMP, for example, typically requires one-time, short-term funding that can be obtained through a grant or cost share program. The development of a monitoring or maintenance program, however, typically requires continuing funding.

Local Funding Mechanisms

Regional, state, and federal storm water and NPS funding programs are usually intended for small-scale projects to collect data and demonstrate control methods. Larger scale programs, therefore, have to be financed primarily through local mechanisms, including (U.S. EPA, 1990):

- General funds
- Long-term borrowing
- Pro-rata share fees
- Storm water utilities
- Special assessment districts

General Funds. General funds are raised locally, usually through property taxes, fees, and fines and can be directed to urban runoff pollution prevention and control. The use of general funds might require reallocating existing revenues or creating additional revenue sources. These funds can be used either for one-time costs or annual operation and maintenance costs.

Long-Term Borrowing. Local entities can also fund pollution prevention and control projects through bonds and other long-term borrowing. Funding through bond issues is usually used only for one-time expenses, such as the design and construction of large structural BMPs.

Pro-Rata Share Fees. Pro-rata share fees can be used to finance the construction and maintenance of urban runoff projects. This mechanism requires land developers to contribute funds to a local entity in charge of local BMPs. Fees are typically based on a technical assessment of the development's potential to contribute to the urban runoff pollution problem. For example, a municipality can require developers to pay a fee based on the amount of impervious surface in the development. The fees could vary depending on the development's location (e.g., watershed or proximity to protected resources). These pro-rata share fees are often used in currently undeveloped areas where future development could threaten water resources.

Storm Water Utilities. Many municipalities in urban areas have begun to set up storm water utilities. Storm water utilities usually assess all existing residential and commercial buildings a fee based on their percentage of impervious area. A survey of 25 storm water utilities conducted by the Maryland Department of the Environment in 1987 outlined many of the similarities and differences among these utility programs (Lindsey, 1988). According to the survey, storm water utilities had been established in small communities as well as large urban centers. Most utilities are administered by local departments of public works, which also have the responsibility for operation and maintenance of BMPs. These programs have proved to be good, stable funding sources.

Special Assessment Districts. Some states have enacted legislation that allows for the development of special assessment districts for flood control, lake management, aquifer protection, drainage, or shellfish protection. Once a special district is formed, funds for projects in a district can be raised by levying fees on landowners in the district. Such programs are viewed as more equitable forms of financing. Because these programs require approval of residents in the special district these funding programs can be difficult to establish (PSWQA, 1989).

Matching Fund Programs

Matching fund programs (also called cost share programs) can exist at the regional, state, and federal level and are typically restricted to financing specific activities or control measures. In these programs, entities implementing control programs can obtain funding for a certain percentage of the cost. Matching fund programs have been available from the federal government through the Construction Grants Program, State Revolving Loan Fund, NPS program (CWA Section 319), the Clean Lakes Program (CWA Section 314), and the National Estuary Program (CWA Section 320). Each of these programs is described in Chapter 2. Matching funds are also available from the Department of Agriculture through the Soil Conservation Service and the Agricultural Stabilization and Conservation Service.

Grant Programs

Regional, state, and federal agencies might also offer special grants which typically are limited and can change from year to year. Because of the uncertain nature of these grants, they are not reliable sources of funding for long-term programs; however, they can provide funding for short-term needs. Grants are available through many of the same federal sources as for matching funds.

Summary

The final recommended urban runoff pollution prevention and control plan should be summarized in a document which can be used by responsible officials and agencies in plan implementation. An example of such a plan is provided in the case study on the Pipers Creek watershed at the end of this chapter. By developing a thorough and accessible final implementation document and periodic reports, the plan will have a greater chance of success. In addition, valuable information can be compiled for other communities.

While completion of the urban runoff pollution prevention and control plan signifies the end of the planning process described in this handbook, it is only the first step in the overall program. Plan implementation will likely be a long-term effort and the planning is by no means over at this stage. As implementation and further monitoring occurs, the plan might need to be updated, refined, and modified. When this occurs, the planning process described in this handbook (Figure 3-1) may be re-entered at any point. For example, a new problem assessment might be needed, a change in priorities (or problem ranking) could be necessary, or new BMP options (or deletion of BMPs previously thought appropriate) might need to be considered. The program needs to be reevaluated and updated constantly throughout implementation.

As a final note, achieving the critical balance between resources expended on program planning and those used for program implementation is a challenging task. The program team must develop a pollution prevention and control plan using its valuable resources cost-effectively. Every dollar and manhour not used in the planning process can be applied to program implementation. Difficult choices must be made throughout the planning process to ensure that technically defensible decisions are made while still maintaining adequate resources for future implementation.

Case Study: Pipers Creek Watershed Action Plan for the Control of Nonpoint Source Pollution

The Pipers Creek watershed, an urban drainage basin of approximately 3.5 square miles, is located in northern Seattle, Washington, bordering Puget Sound. To improve the water quality in Puget Sound and its tributaries, a comprehensive study of the Pipers Creek watershed was conducted during 1989 and 1990 by the city of Seattle and the Washington State Department of Ecology (WA DOE, 1990). This study led to the development of the Pipers Creek Watershed Action Plan for the Control of Nonpoint Source Pollution. The plan presents recommended actions, an implementation schedule, regulatory issues, and remaining needs for the watershed.

The Pipers Creek Action Plan was developed through a 12-step process that closely follows the 7-step process used in this handbook (see Chapter 3). The steps include:

- Initiate public participation
- Define existing conditions
- Review regulatory requirements
- Define goals and objectives
- Define and describe the problem
- Identify candidate measures to control NPS pollution
- Employ a practical approach to evaluate candidate pollution control measures
- Develop criteria for evaluating candidate controls
- Examine, evaluate, and screen candidates
- Select most promising source control measures
- Continue assessment of selected source control measures
- Recommend source control measures and an implementation program

In this program, the existing conditions were defined prior to developing and stating program goals. Goals were reevaluated and redefined at numerous points during the program.

NPS pollution and erosion problems were of highest concern in the Pipers Creek watershed. A watershed management committee (WMC) was created to develop the action plan, made up of local residents and representatives of community and environmental organizations, businesses, and local government agencies. The committee determined that, since NPS pollution is difficult to link precisely to sources, a broad range of control measures should be recommended. The following five programs for controlling NPS pollution were developed:

- *Public education:* Since some pollution problems were caused by public actions, public education programs were recommended to inform the general public of actions that result in pollution of surface waters.
- *Regulation:* Since some existing regulations could be used to address NPS pollution, regulatory programs were recommended to increase coordination and enforcement of the existing laws and regulations designed to prevent water pollution.
- *Operation and maintenance:* Since existing drainage structure operation and maintenance activities could be used to reduce NPS pollution, the action plan recommended ways to protect water resources through improving and coordinating these efforts.
- *Public works:* Even with full implementation of municipal and regulatory control practices throughout the watershed, pollution problems would still exist. The action plan therefore, included recommendations for structural control practices where appropriate, to reduce water quality degradation.
- *Monitoring:* The action plan includes recommendations for monitoring management practice implementation to determine the effectiveness of individual practices as well as a recommendation for monitoring overall water resources to further characterize the NPS problems.

The recommendations given within these programs are broad in scope and focus primarily on municipal and regulatory controls (Table 9-2). Controls for specifically identified pollution sources are included in the public works recommendations and consist of demonstration projects designed to determine the effectiveness of specific structural controls.

For each of the five programs, WMC has developed detailed recommendations and summarized them in an action plan that includes conceptual information on recommended BMPs, a schedule of activities, responsibilities involved in implementation, a description of the monitoring plan, a summary of regulatory requirements, and identification of funding requirements and sources. The plan also includes a discussion of pollution prevention and reduction activities that have been implemented already and additional water resource data that should be obtained.

To increase the effectiveness of the public education program, the WMC and the WA DOE recommended that some public education activities begin before the action plan is completed. As a result, a number of actions to inform and educate the watershed community have been initiated with the approval of the city, including:

- Posting informational signs at key areas in the watershed.
- Stenciling storm drains with a warning against dumping wastes.
- Providing staff assistance to community efforts related to water quality protection.
- Staging a media event and dedicating a billboard promoting the protection of water quality.
- Starting a public education pilot project that provides a half-time watershed educational specialist to undertake a variety of activities in the watershed.

A detailed plan to implement the recommendations has been developed, including:

- Obtaining written commitments from local and state agencies and citizen's groups responsible for implementation; these commitments are important given the wide array of agencies and organizations involved in the program.
- Creating an implementation committee staffed by community representatives and members of agencies responsible for implementation; this committee is responsible for evaluating program progress.

Table 9-2. Pipers Creek Action Plan Recommendations

Public Education	**Operation and Maintenance (cont.)**
Provide public information during action plan development	Develop a program to determine the correct cleaning schedule for catch basins
Develop a household educational brochure	Improve maintenance of open drainage ditches
Hire a watershed specialist to provide education	Provide additional trash receptacles in parks
Develop a park educational display	Expand the existing spill-response program
Develop a watershed educational video	**Public Works**
Continue volunteer activities in the watershed	Construct a test grassed swale in the watershed
Institute an annual watershed awareness week	Conduct a program to test erosion controls
Paint signs on storm drains—"Dump No Waste, Drains to Stream"	Conduct a test program to increase in-system detention
Regulatory Controls	Reduce erosion from an identified pipe discharge
Develop a septic system inspection program	Reduce erosion from waterside park trails
Develop a water quality training program for all city inspectors	Install current deflectors to reduce in-stream erosion
Monitor permanent detention systems	Improve the fisheries habitat in park areas
Require BMPs at many new construction sites	Reduce odor from two sewer systems
Install additional pet waste signs	**Monitoring Program**
Conduct a study to determine the effectiveness of current regulations	Create an implementation committee to oversee the action plan
Install additional dumping enforcement signs	Conduct routine water quality monitoring
Operation and Maintenance	Conduct storm event monitoring in Pipers Creek
Develop a program to trace pollution in storm drainage systems	Conduct periodic video surveys and a refuse dumping survey in Pipers Creek
Locate septic systems serving basements	Periodically review watershed land use
Expand sanitary sewer system inspections	Require annual agency status reports
Inspect the major sanitary system trunk line in the Pipers Creek watershed	Require annual summary reports of progress in Pipers Creek

- Developing assessment criteria for the implementation committee to evaluate the program's success; assessment criteria should include:
  - source control recommendations implemented,
  - water quality monitoring results,
  - opinion surveys,
  - recycling participation,
  - yard waste collection,
  - results of the annual neighborhood cleanup program,
  - Earth Day participation,
  - return of salmon to Pipers Creek,
  - participation in educational events, and
  - attention from the local media.
- Developing and implementing a long-term monitoring program, including:
  - routine water resource monitoring,
  - specific storm event monitoring,

- visual monitoring, and
- land use monitoring.

- Requiring biannual status reports from each agency responsible for implementation; these reports should address:
  - progress and accomplishments in general,
  - problems with implementation,
  - actual versus estimated costs,
  - suggested modifications to the program, and
  - actions for the following year.

Since the recommendations made in this program rely heavily on the data available to the program team, the initial focus of implementation is on pollution prevention activities, public education, demonstration projects, and additional data gathering. In this way implementation is not delayed while further water resource sampling is conducted. Additional sampling and assessment of control measures could lead to further implementation.

References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
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CDM. 1993. Camp Dresser & McKee. State of California storm water best management practice handbooks. California State Water Quality Control Board.

Dressing, S.A., J.C. Clausen, and J. Spooner. 1992. A tracking index for nonpoint source implementation projects. Proc. National Rural Clean Water Program Symposium. Orlando, FL.

Lindsey, G. 1988. A survey of stormwater utilities. Stormwater Management Adminstration, Maryland Department of the Environment.

Metcalf & Eddy, Inc. 1988. Lower Connecticut River phase II combined sewer overflow study. Massachusetts Division of Water Pollution Control.

PSWQA. 1989. Puget Sound Water Quality Authority. Managing nonpoint pollution: an action plan handbook for Puget Sound watersheds.

U.S. EPA. 1976. U.S. Environmental Protection Agency. Methodology for the study of urban storm generated pollution and control. EPA/600/2-76/145.

U.S. EPA. 1990. U.S. Environmental Protection Agency. Financing mechanisms for BMPs. Urban Nonpoint Source/Stormwater Management Fact Sheets. U.S. EPA Region V. Chicago, IL.

U.S. EPA. 1991. U.S. Environmental Protection Agency. Evaluating nonpoint source control projects in an urban watershed. In Seminar Publication: Nonpoint Source Watershed Workshop. EPA/625/4-91/027 (NTIS PB92-137504).

U.S. EPA. 1992. U.S. Environmental Protection Agency. Casco Bay storm water management project: Concord Gully, Frost Gully and Kelsey Brook watersheds. U.S. EPA Region I. Boston, MA.

WA DOE. 1990. Washington State Department of Ecology. Pipers Creek watershed action plan for the control of nonpoint source pollution: final control plan. Pipers Creek Watershed Management Committee.

Woodward-Clyde Consultants. 1989. Santa Clara Valley nonpoint source study. Santa Clara Valley Water District.

Appendix A
Additional References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
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703-487-4650

Hydrology References

Andersen, D.G. 1970. Effects of urban development on floods in northern Virginia. U.S. Geological Survey Water Supply Paper 2001-C. Washington, DC.

Hammar, T.R. 1972. Stream channel enlargement due to urbanization. Water Resource Research 8(6).

Klein, R.D. 1979. Urbanization and stream quality impairment. Water Resources Bull. 15(4).

Leopold, L.B. 1968. Hydrology for urban planning—a guidebook on the hydrologic effect of urban land use. U.S. Geological Survey Circular 554. Washington, DC.

Water Resource Sampling References

Plumb, R.H., Jr. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical report no. EPA/CE-81-1. U.S. EPA/U.S. ACOE Technical Committee on Criteria for Dredged and Fill Material. Vicksburg, MS: U.S. Army Waterways Exp. Station.

U.S. EPA. 1973. U.S. Environmental Protection Agency. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA/670/4-73/001. U.S. EPA Office of Research and Development. Cincinnati, OH.

U.S. EPA. 1975. U.S. Environmental Protection Agency. An assessment of automatic sewer flow samplers. EPA/600/2-75/065 (NTIS PB-250987).

U.S. EPA. 1975. U.S. Environmental Protection Agency. Sewer flow measurement: a state-of-the-art assessment. EPA/600/2-75/027 (NTIS PB-250371). Municipal Environmental Research Laboratory. Cincinnati, OH.

U.S. EPA. 1976. U.S. Environmental Protection Agency. Design and testing of a prototype automatic sewer sampling system. EPA/600/2-76/006 (NTIS PB-252613).

U.S. EPA. 1976. U.S. Environmental Protection Agency. Methodology for the study of urban storm generated pollution and control. EPA/600/2-76/145 (NTIS PB-258743). Office of Research and Development. Cincinnati, OH.

U.S. EPA. 1982. U.S. Environmental Protection Agency. Handbook for sampling and sample preservation of water and wastewater. EPA/600/4-82/029.

U.S. EPA. 1983. U.S. Environmental Protection Agency. Guidelines for the monitoring of urban runoff quality. EPA/600/2-83/124 (NTIS PB84-122902).

U.S. EPA. 1986. U.S. Environmental Protection Agency. Quality criteria for water, 1986. EPA/440/5-86/001. Washington, DC: U.S. EPA Office of Water, Regulations and Standards.

U.S. EPA. 1990. U.S. Environmental Protection Agency. Monitoring lake and reservoir restoration. EPA/440/4-90/007. Prep. by North American Lake Management Society. Washington, DC.

U.S. EPA. 1992. U.S. Environmental Protection Agency. NPDES storm water sampling guidance document. EPA/833/B-92/001. Office of Water.

WA DOE. 1989. Washington State Department of the Environment. Guidance for conducting water quality assessments. Olympia, WA.

Other Nonpoint Source Pollution References

Metcalf & Eddy, Inc. 1991. Wastewater engineering: treatment, disposal, and reuse, 3rd ed. New York, NY: McGraw-Hill.

U.S. EPA. 1992. U.S. Environmental Protection Agency. Economic analysis of coastal nonpoint source controls: marinas. U.S. EPA Nonpoint Source Control Branch. Washington, DC.

U.S. EPA. 1992. U.S. Environmental Protection Agency. Storm water management for industrial activities: developing pollution prevention plans and best management practices. EPA/832/R-92/006. Office of Water.

Woodward-Clyde Consultants. 1991. Urban BMP cost and effectiveness. Summary data for 6217(g) guidance: onsite sanitary disposal systems. December.

Appendix B
Table of Annotated References

Document Title	Author, Date*	BMPs Included	Information Available
Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs	Schueler, 1987	Detention Infiltration Vegetative Filtration Quality inlets	General descriptions Effectiveness Design Use limitations Maintenance Cost Examples
Protecting Water Quality in Urban Areas	MPCA, 1989	Housekeeping Detention Infiltration Vegetative Quality inlets	General descriptions Effectiveness Use limitations Maintenance Cost Examples
Guide to Nonpoint Source Control	U.S. EPA, 1987	Housekeeping Detention Infiltration	General descriptions Effectiveness Cost
Water Resource Protection Technology: A Handbook of Measures to Protect Water Resources in Land Development	ULI, 1981	Housekeeping Detention Infiltration Vegetative Quality inlets	General descriptions Effectiveness Design Use limitations Maintenance Cost
Urban Targeting and BMP Selection: An Information and Guidance Manual for State NPS Program Staff Engineers and Managers	Woodward-Clyde Consultants, 1990	Housekeeping Detention Infiltration Vegetative	General descriptions Effectiveness Design Use limitations
Combined Sewer Overflow Pollution Abatement	WPCF, 1989	Housekeeping Collection system Storage Treatment	General Descriptions Design Effectiveness Maintenance Cost
Urban Storm Water Management and Technology: An Assessment	U.S. EPA, 1974c	Housekeeping Collection system Storage Treatment	General descriptions Design Maintenance Use limitations
Decision Maker's Storm Water Handbook: A Primer	U.S. EPA, 1992c	Housekeeping Detention Infiltration Vegetative Filtration Quality inlets	General descriptions Effectiveness Design Use limitations Maintenance Examples
Urban Storm Water Management and Technology: Update and User Guide	U.S. EPA, 1977	Source control Collection system Storage Treatment	General descriptions Design Maintenance Use limitations
Control and Treatment of Combined Sewer Overflows	Moffa, 1990	Source control Collection system Storage Treatment	General descriptions Design Maintenance Use limitations

Document Title	Author, Date*	BMPs Included	Information Available
Guidance Specifying Management Measures for Source of Nonpoint Pollution in Coastal Waters	U.S. EPA, 1993b	Housekeeping Infiltration Vegetative Filtration Quality inlets	General descriptions Effectiveness Design Use limitations Maintenance Cost Examples
The Florida Development Manual: A Guide to Sound Land and Water Management	Livingston et al., 1988	Housekeeping Infiltration Vegetative Detention Filtration Site planning	General descriptions Effectiveness Design Use limitations Maintenance Cost Examples
Storm Water Management Manual for the Puget Sound Basin	WA DOE, 1991	Housekeeping Infiltration Vegetative Quality inlets	General descriptions Effectiveness Design Use limitations Maintenance Cost Examples

* For complete citations, see Chapter 7 reference list.

Appendix C
Acronyms and Abbreviations

ARM	agricultural runoff model
ASCS	Agriculture Stabilization and Conservation Service
ATV	all-terrain vehicle
BAT	best available technology economically achievable
BCT	best conventional technology
BMP	best management practice
BNA	base/neutral and acid extractable compound
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
BPJ	best professional judgment
CBOD	carbonaceous biochemical oxygen demand
CCMP	Comprehensive Conservation and Management Plan
CFR	Code of Federal Regulations
CMA	calcium magnesium acetate
CMP	Central Maine Power
CPM	critical path method
COD	chemical oxygen demand
CSO	combined sewer overflow
CWA	Clean Water Act
CWO	Comprehensive Watersheds Ordinance
CZMA	Coastal Zone Management Act
DAF	dissolved air floatation
DEM	digital elevation model
DLG	digital line graph
DO	dissolved oxygen
ED	extended detention
EMC	event mean concentration
ENR	Engineering News Record
EPA	U.S. Environmental Protection Agency
EPT	*Ephemeropter, Plecoptera, Trichoptera*

EXAMS II	Exposure Analysis Modeling Systems II
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GC	ground-water conservation
GIS	geographic information system
GNIS	geographic names information system
GWA	ground water A (classification)
HEC	Hydrologic Engineering Center (U.S. Army Corps of Engineers)
HSPF	Hydrological Simulation Program—Fortran
IBI	index of biotic integrity
ICI	invertebrate community index
I/I	infiltration and inflow
LC	lake conservation
LULC	land use and land cover
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
ME DEP	Maine Department of Environmental Protection
MIwb	modified index of well being
MPN	most probable number
N/A	not applicable
NEP	National Estuary Program
NEPA	National Environmental Policy Act
NH_3	ammonia
NO_3	nitrate
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NURP	Nationwide Urban Runoff Program
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
PCS	Permit Compliance System
PS	point source
PSI	pounds per square inch
PVC	polyvinyl chloride
PW	present worth
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control

QUAL2E	Enhanced Stream Water Quality Model
RC	resource conservation
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SLAMM	Source Loading and Management Model
SOD	sediment oxygen demand
SS	suspended solids
SSES	sanitary sewer evaluation survey
STORM	Storage, Treatment, Overflow, Runoff Model
SWMM	Storm Water Management Model
SWTR	Surface Water Treatment Rule
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TSS	total suspended solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UV	ultraviolet
VOC	volatile organic compound
WA DOE	Washington Department of Ecology
WASP4	Water Quality Analysis Simulation Program
WMC	watershed management committee
WQ	water quality
WSE	water surface elevation

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