National Management Measures to Control Nonpoint Source Pollution from Urban Areas

United States Environmental Protection Agency
Office of Water
Washington, DC 20460
(4503F)

EPA-841-B-05-004
November 2005

Disclaimer

This document provides guidance to States, Territories, authorized Tribes, and the public regarding management measures that may be used to reduce nonpoint source pollution from urban areas. This document refers to statutory and regulatory provisions which contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose legally-binding requirements on EPA, States, Territories, authorized Tribes, or the public and may not apply to a particular situation based upon the circumstances. EPA, State, Territory, and authorized Tribe decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Interested parties are free to raise questions and objections about the appropriateness of the application of the guidance to a particular situation, and EPA will consider whether or not the recommendations in this guidance are appropriate in that situation. EPA may change this guidance in the future.

Table of Contents

List of Figures

List of Tables

INTRODUCTION

The nation's aquatic resources are among its most valuable assets. Although environmental protection programs in the United States have improved water quality during the past several decades, many challenges remain. Of special concern are the problems in our urban streams, lakes, estuaries, aquifers, and other water bodies caused by runoff that is inadequately controlled or treated. These problems include changes in flow, increased sedimentation, higher water temperature, lower dissolved oxygen, degradation of aquatic habitat structure, loss of fish and other aquatic populations, and decreased water quality due to increased levels of nutrients, metals, hydrocarbons, bacteria, and other constituents.

The *National Water Quality Inventory: 2000 Report to Congress* identified urban runoff as one of the leading sources of water quality impairment in surface waters (USEPA, 2002b). Of the 11 pollution source categories listed in the report, "urban runoff/storm sewers" was ranked as the fourth leading source of impairment in rivers, third in lakes, and second in estuaries (Table 0.1).

Table 0.1: Leading sources[b] of water quality impairment related to human activities for rivers, lakes, and estuaries (USEPA, 2002b).

Rivers and Streams	Lakes, Ponds, and Reservoirs	Estuaries
Agriculture (48%) [a]	Agriculture (41%) [a]	Municipal point sources (37%)[a]
Hydrologic modifications (20%)	Hydrologic modifications (18%)	Urban runoff/storm sewers (32%)
Habitat modifications (14%)	Urban runoff/storm sewers (18%)	Industrial discharges (26%)
Urban runoff/storm sewers (13%)	Misc. nonpoint source pollution (14%)	Atmospheric deposition (24%)

[a]Values in parentheses represent the percentage of assessed river miles, lake acres, or estuary square miles that are classified as impaired. States assessed 19% of stream miles, 43% of lakes, ponds, and reservoirs, and 36% of square mileage of estuaries.
[b] Excluding unknown, natural, and "other" sources.

0.1 Purpose and Scope of the Guidance

National summaries, such as those shown in Table 0.1, are useful in providing an overview of the magnitude of the problems associated with urban runoff. Solutions, however, are usually applied at the local level. State and local elected officials and agencies, landowners, developers, environmental and conservation groups, and others play a crucial role in protecting, maintaining, and restoring water resources. Their efforts, in aggregate, form the basis for changing the status of urban runoff from a local problem to a national problem.

This document provides guidance to states, territories, authorized tribes, and the public regarding management measures that can be used to reduce nonpoint source pollution from urban activities. This document refers to statutory and regulatory provisions that contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose legally binding requirements on the U.S. Environmental Protection Agency (EPA), states, territories, authorized tribes, or the public and may not apply to a particular situation based upon the circumstances. EPA, state, territory, and authorized tribe decision-makers retain the discretion to adopt approaches that differ from this guidance on a case-by-case basis. Interested parties are free to raise questions and objections about the appropriateness of the application of the guidance to a situation, and EPA will consider whether or not the recommendations in this guidance are appropriate in that situation. EPA may change this guidance in the future.

This guidance document *is* intended to provide technical assistance to state and local program managers and other practitioners on the best available, most economically achievable means of managing urban runoff and reducing nonpoint source pollution of surface and ground waters from urban sources. It describes how to develop a comprehensive runoff management program that deals with all phases of development—from predevelopment watershed planning and site design, through the construction phase of development, to the operation and maintenance of structural controls. It also provides information for other situations such as retrofitting existing development, implementing nonstructural controls, and reevaluating the runoff management program. Figure 0.1 presents the components of a comprehensive runoff management program.

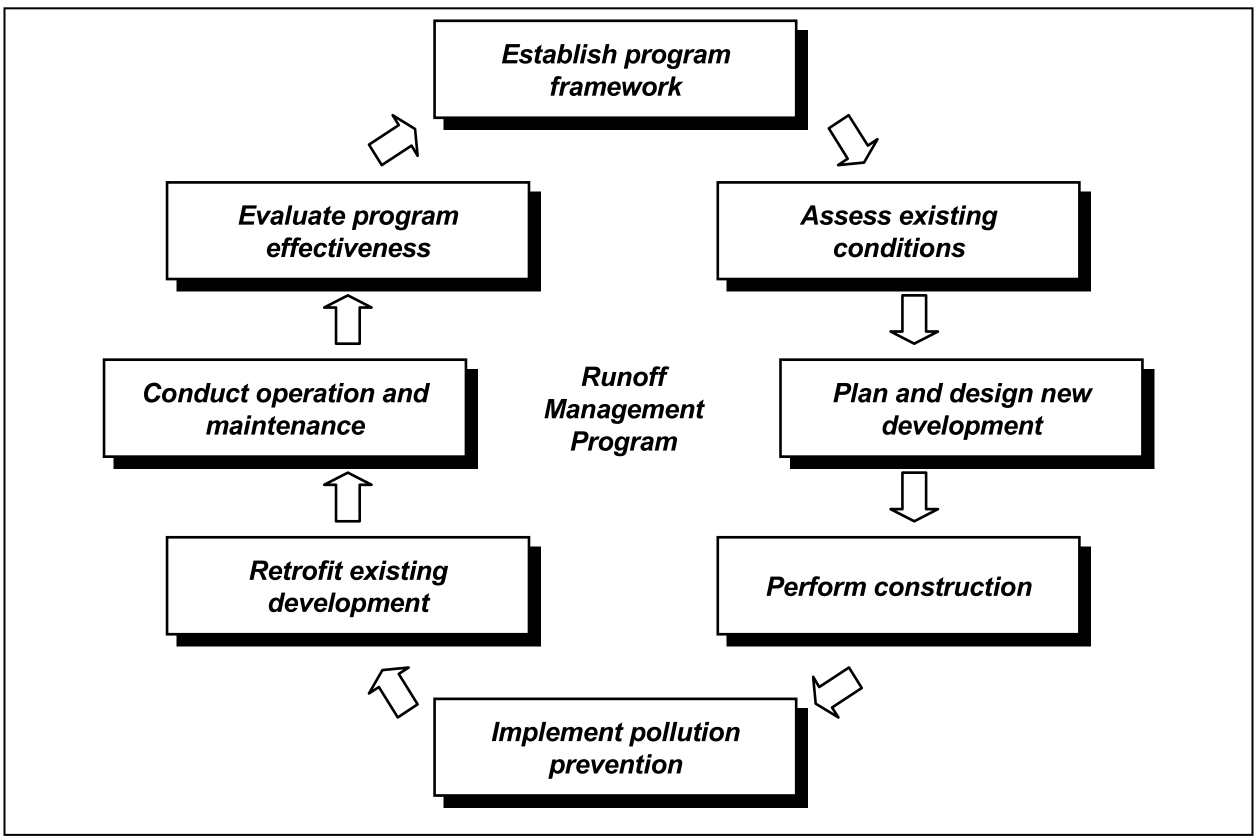


Figure 0.1: Components of a comprehensive runoff management program.

This document is intended to provide guidance for all urban areas, not just those covered by National Pollutant Discharge Elimination System (NPDES) phase II requirements. While the document can serve as a resource for meeting NPDES phase II requirements, there are still a number of smaller jurisdictions that are not regulated by the NPDES program and that can benefit from guidance in developing an urban runoff program.

0.1.1 Management Measures

Management measures can be used to guide the development of a runoff management program. They establish performance expectations and, in many cases, specify actions that can be taken to prevent or minimize nonpoint source pollution or other negative impacts associated with uncontrolled and untreated urban runoff. Twelve management measures have been included in this guidance. Figure 0.2 groups these measures within the context of the runoff management program cycle.

Each management measure listed in Figure 0.2 deals with an important aspect of the runoff management cycle. For example, Management Measure 8 focuses on construction site erosion, sediment, and chemical control. Local officials and developers should address these issues because if exposed soils are allowed to erode and move off construction sites as sediment, they can clog storm drains, streams, and other water bodies, harm habitat, and impair water quality.

This management measure has four elements:

- Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions.
- Reduce erosion and, to the extent practicable, retain sediment on-site during and after construction.
- Use good housekeeping practices to prevent off-site transport of waste material and chemicals.
- Minimize application and generation of potential pollutants, including chemicals.

Note that specific actions or practices for achieving the performance expectations are not included in the management measure statement. This is by design. Local officials and other practitioners need the flexibility to choose management practices that best achieve the management measure's performance expectations given their own unique circumstances. To aid in their decision, however, this guidance presents several management practices that can potentially be used to achieve each management measure.

The components of the runoff management program shown in Figure 0.2 are organized in a cycle that can be followed stepwise if desired. The elements are meant to work together, but each can stand alone. The elements of the cycle do not have to be implemented consecutively.

The cycle begins with establishing a program framework that provides legal authority, funding, and staffing for watershed initiatives (Management Measure 1). Once this framework is established, watershed managers can commence an assessment of existing conditions (Management Measure 2) to identify areas in need of protection or restoration. This assessment also provides stream channel and water quality baselines (i.e., environmental indicators) against which the success of watershed initiatives can be compared (Management Measure 12: Evaluate Program Effectiveness).

Management Measures 3 through 7 address issues associated with new development. The watershed protection management measure (3) focuses on siting development and establishing

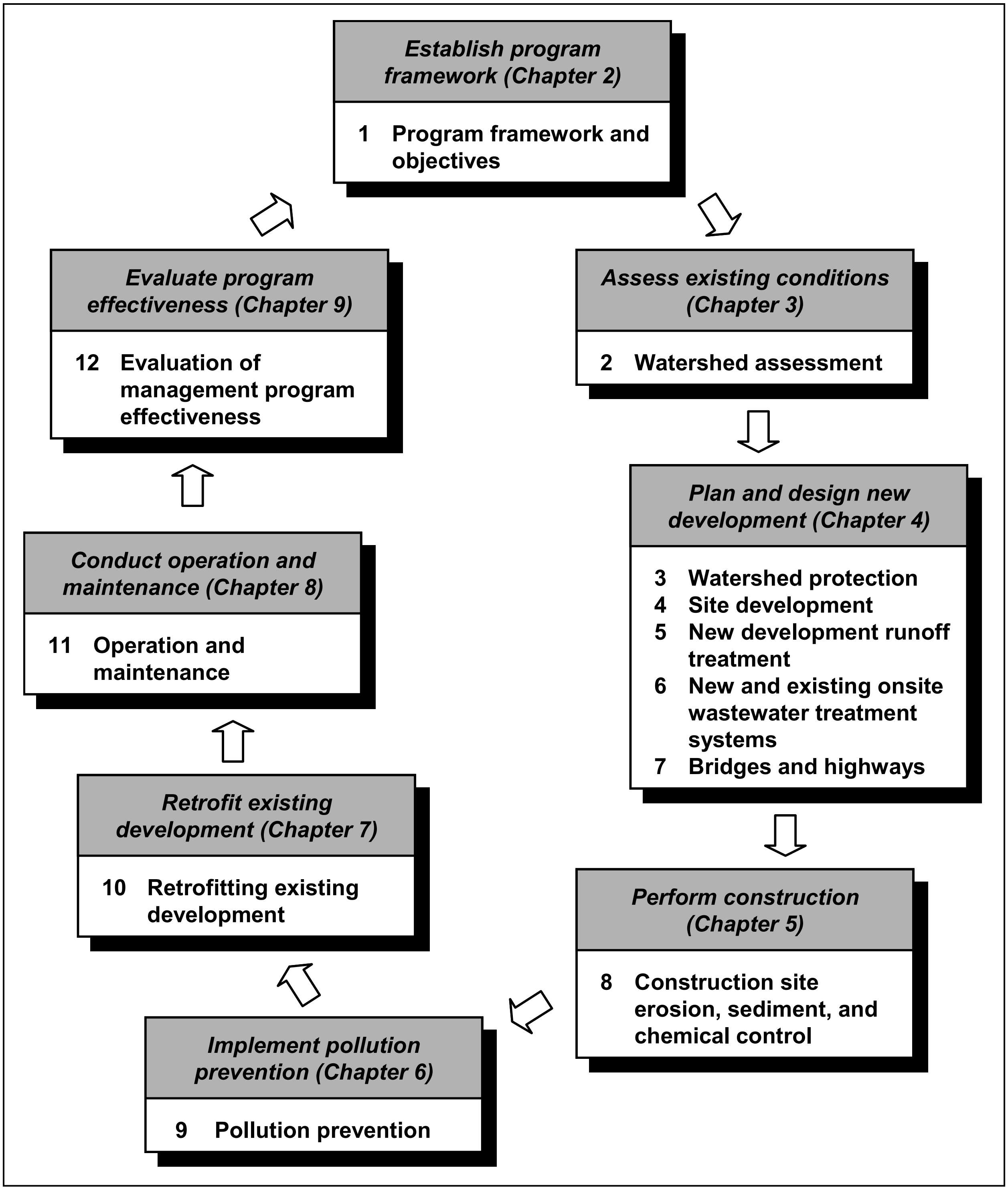


Figure 0.2: Twelve management measures associated with the runoff management program cycle.

actions to protect areas identified as sensitive or ecologically valuable. The Site Development Management Measure (4) provides guidance for planning development on the site scale with alternative, low-impact site layouts and infrastructure options that protect sensitive areas and reduce the quantity of runoff leaving the site. The New Development Runoff Treatment Management Measure (5) details practices that can be identified to prevent pollutants in runoff generated from newly developed areas. The onsite wastewater treatment systems management measure (6) provides guidance on how to reduce pollutant loadings from both new and existing on-site systems. Finally, the Highways and Bridges Management Measure (7) addresses pollutants generated from activities related to new and existing transportation infrastructure.

Once development plans have been made, watershed managers can refer to Management Measure 8: Construction Site Erosion, Sediment, and Chemical Control. This measure presents practices that reduce pollutant loadings from land-disturbing activities.

Throughout the runoff management program cycle, watershed managers can use the Pollution Prevention Management Measure (9) to target municipalities, businesses, and individual citizens with education and awareness programs to reduce pollutants generated from day-to-day activities. Managers also can use the practices presented in the Existing Development Management Measure (10) to address areas in need of restoration or retrofitting of existing management practices. Additionally, the Operation and Maintenance Management Measure (11) describes activities needed to maintain and extend the life of new and existing management practices.

Once programs have been established and management practices implemented, managers can evaluate their effectiveness using program and administrative indicators (Management Measure 12). This evaluation involves reassessing conditions in the watershed to determine whether the implemented practices effectively reduced nonpoint source pollution. This evaluation also identifies areas where additional restoration or preservation activities are needed, guiding future watershed initiatives and thereby restarting the management cycle.

North Branch of the Chicago River Demonstration Project

Through the North Branch of the Chicago River Demonstration Project, the Friends of the Chicago River, and the Lake County Storm Water Management Commission joined to develop a plan to address NPS pollution and flooding while educating and involving citizens and community leaders in the process (USEPA, 2000a). The result was an urban watershed planning model, similar to the one presented in this guidance, that any city can use to protect its water resources.

This 96-square-mile watershed was affected by storm water runoff from two counties and 24 towns. The partners in the North Branch of the Chicago River Demonstration Project divided the project into four tasks—developing a watershed plan, conducting an information and education campaign, developing a handbook to guide them through the process, and conducting a series of demonstration projects. For more information, contact Friends of the Chicago River (http://www.chicagoriver.org).

0.1.2 Document Organization

Chapters 2 through 9 of this document consecutively focus on the eight components of the runoff management program cycle (Figure 0.2). Each chapter describes a component, introduces one or more management measures that define the performance expectation(s) for that component, and presents a range of management practices that potentially can be implemented to achieve the management measure(s). When available, information concerning effectiveness and costs of practices is included in the discussion, as are case studies that illustrate how select management practices have been implemented within communities.

0.2 Origin and Regulatory Context

0.2.1 Origin of This Guidance

This document is an update of the urban management measures and practices provided in Chapter 4 of an EPA manual entitled *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA, 1993). That document, referred to hereafter as the Coastal Management Measures Guidance, was published in January 1993 for the specific purpose of providing state and territorial officials with management measures to incorporate into their coastal nonpoint source (NPS) pollution control programs.

Through the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), Congress mandated that EPA develop the Coastal Management Measures Guidance, and that every state and territory with an approved coastal zone management program develop an NPS pollution control program, including enforceable policies and mechanisms to implement all of the specified management measures. The programs were submitted to EPA and the National Oceanic and Atmospheric Administration (NOAA) for approval. All were subsequently approved, some with conditions. The Coastal Management Measures Guidance functions as a blueprint for the coastal states and territories in their efforts to put together their NPS control programs.

The Coastal Management Measures Guidance included management measures for urban areas (Chapter 4), agriculture (Chapter 2), silviculture (Chapter 3), marinas (Chapter 5), and hydromodification (Chapter 6). It also addressed protection of wetlands and riparian areas from NPS pollution impacts and the use of vegetative treatment systems, such as constructed wetlands, as management practices to control runoff (Chapter 7).

Of all the NPS pollution sources identified in the Coastal Management Measures Guidance, none has experienced the rapid technical advancement that has occurred in the areas of urban NPS pollution control. Many communities have set their sights beyond simple NPS pollutant reduction targets and are now seeking ways to achieve balance and integration of many quality-of-life factors, including economic growth, community livability, and environmental protection.

Based on these changes, EPA perceived a need to update and expand the information in Chapter 4 of the Coastal Management Measures Guidance to help local urban officials in both coastal and inland areas remain current with state-of-the-art management measures and practices. Readers should note, however, that this guidance does *not* supplement or replace the 1993 *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* for the purpose of implementing programs under CZARA. It simply serves as an additional resource guide for local officials seeking to develop or improve their urban runoff management programs.

Fundamental differences between this guidance and the Coastal Management Measures Guidance are presented in Table 0.2.

Table 0.2: Key differences between the *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA, 1993) and *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*.

	Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters	National Management Measures to Control Nonpoint Source Pollution from Urban Areas
Date	1993	2005
Target audience	*Primary:* state and territory officials *Secondary:* all others interested in NPS pollution	All persons interested in urban NPS pollution and control practices
Focus	NPS management measures and control practices in coastal areas	NPS management measures and control practices in coastal and inland areas
Use	Required under CZARA	Voluntary
Organization	Management measures and practices presented by source category	Management measures and practices presented in the context of a comprehensive watershed program

0.2.2 Regulatory Context

During the first 15 years (1972–1987) of the national program to abate and control water pollution, EPA and the states focused most of their activities on traditional point sources. These point sources have been regulated by EPA and the states through the NPDES permit program established by Section 402 of the Clean Water Act. The NPDES program functions as the primary regulatory tool for ensuring compliance with water quality standards. NPDES permits, issued by either EPA or an authorized state, contain discharge limits designed to meet water quality standards and national technology-based effluent regulations.

In 1987, in view of the progress achieved in controlling point sources and growing national awareness of the increasingly dominant influence of NPS pollution on water quality, Congress amended the Clean Water Act to focus greater national efforts on nonpoint sources. Under this amended version, referred to as the 1987 Water Quality Act, Congress revised Section 101, "Declaration of Goals and Policy," to add the following fundamental principle:

> It is the national policy that programs for the control of nonpoint sources of pollution be developed and implemented in an expeditious manner so as to enable the goals of this Act to be met through the control of both point and nonpoint sources of pollution.

The Water Quality Act of 1987 also included language that required comprehensive storm water regulation using a two-phased approach. (Detailed information on both phases of the NPDES Storm Water Program is available at http://www.epa.gov/npdes/stormwater.) Phase I, in place since 1990, required operators of medium and large municipal separate storm sewer systems (MS4s) located in incorporated areas and counties with populations of more than 100,000, certain industrial activities, and construction activities disturbing 5 acres or more to obtain an NPDES permit to discharge storm water runoff. In October 1999 EPA expanded the federal storm water program with the promulgation of the Phase II rule.

Phase II requires operators of small MS4s (non-Phase I regulated MS4s) in "urbanized areas" (as defined by the Bureau of the Census) and small construction activities disturbing between 1 and

5 acres of land to obtain an NPDES permit. Further, the NPDES permitting authority may require operators of small MS4s not in urbanized areas and small construction activities disturbing less than 1 acre to obtain an NPDES permit based on the potential for contribution to a violation of a water quality standard. NPDES permitting authorities are required under the rule to assess for potential designation all small MS4s located outside an urbanized area that are in areas with a population of at least 10,000 and a population density of 1,000 per square mile. The Phase II rule also includes a revised conditional no-exposure provision for industrial facilities, which provides for a waiver from the permit program if the storm water pollutant sources at a facility can be demonstrated to be isolated from precipitation and runoff.

For small MS4 permits, Phase II prescribes a set of six minimum control measures, as well as requirements for evaluation and assessment efforts. The minimum measures are: (1) public education and outreach on storm water impacts; (2) public involvement/participation; (3) illicit discharge detection and elimination; (4) construction site runoff control; (5) postconstruction storm water management in new development and redevelopment; and (6) pollution prevention/good housekeeping for municipal operations. The regulated operators must choose and implement appropriate best management practices (BMPs) and define measurable goals for each measure. The operators must also periodically evaluate and assess program compliance, the appropriateness and effectiveness of their chosen BMPs, and progress toward achieving their identified measurable goals. This guidance is expected to be consistent with any guidance issued for regulated small MS4 operators to meet the requirements of Phase II NPDES storm water discharge permits. Therefore, the management measures and practices herein can serve as a resource in developing a community's storm water management program. It is important to note, however, that additional requirements not addressed in this guidance may be imposed under an NPDES storm water permit. Table 0.3 specifies how the management measures relate to each of the six minimum control measures.

Table 0.3: Comparison of management measures to the six minimum control measures of NPDES Phase II.

	Public Education	Public Involvement	Illicit Discharge	Construction Site ESC	Post Construction	Pollution Prevention
Program Framework and Objectives						
Establish Legal Authority			✓	✓	✓	✓
Develop an Institutional Structure						
Provide Adequate Funding and Staffing						
Foster Input From Technical Experts, Citizens, and Stakeholders		✓				
Establish Intergovernmental Coordination		✓				
Develop Training and Education Programs and Materials	✓	✓				
Watershed Assessment						
Characterize Watershed Conditions	Measurable Goals					
Assess Cumulative Effects						
Estimate the Effectiveness of Treatment Programs						
Establish a Set of Watershed Indicators						
Establish Water Quality Indicators						
Establish Physical and Hydrological Indicators						
Establish Biological Indicators						
Establish Programmatic Indicators						
Develop a Suite of Social Indicators						
Watershed Protection						
Resource Inventory and Information Analysis					✓	
Development of Watershed Management Plan					✓	
Implement the Plan					✓	
Land or Development Rights Acquisition Practices					✓	
Site Development						
Site Planning Practices					✓	
On-Lot Impervious Surfaces					✓	
Residential Street and Right-of-Way Impervious Surfaces					✓	
Parking Lot Impervious Surfaces					✓	
Xeriscaping Techniques					✓	
New Development Runoff Treatment						
Infiltration Practices					✓	
Vegetated Open Channel Practices					✓	
Filtering Practices					✓	
Detention and Retention Practices					✓	
Other Practices					✓	
New and Existing Onsite Wastewater Treatment Systems						
Permitting and Installation Programs			✓			✓
Operation and Maintenance Programs			✓			✓

Table 0.3 (continued).

	Public Education	Public Involvement	Illicit Discharge	Construction Site ESC	Post Construction	Pollution Prevention
Bridges and Highways						
Site Planning and Design Practices					✓	
Soil Bioengineering and Other Runoff Controls for Highways					✓	
Structural Runoff Controls for Bridges					✓	
Bridge Operation and Maintenance Controls						✓
Nonstructural Runoff Control Practices						✓
Construction Site Erosion, Sediment, and Chemical Control						
Erosion and Sediment Control Programs				✓		
Erosion Control Practices				✓		
Sediment Control Practices				✓		
Develop and Implement Programs to Control Chemicals and Other Construction Materials				✓		
Pollution Prevention						
Household Chemicals	✓	✓				✓
Lawn, Garden, and Landscape Activities	✓	✓				✓
Commercial Activities	✓	✓	✓			✓
Trash	✓	✓				✓
Nonpoint Source Pollution Education for Citizens	✓	✓				
Existing Development						
Identify, Prioritize, and Schedule Retrofit Opportunities					✓	
Implement Retrofit Projects as Scheduled					✓	
Restore and Limit the Destruction of Natural Runoff Conveyance Systems					✓	
Restore Natural Streams					✓	
Preserve, Enhance, or Establish Buffers					✓	
Redevelop Urban Areas to Decrease Runoff-Related Impacts					✓	
Operation and Maintenance						
Establishing an Operation and Maintenance Program					✓	✓
Source Control Operation and Maintenance					✓	✓
Treatment Control Operation and Maintenance					✓	✓
Evaluate Program Effectiveness						
Assess the Runoff Management Program Framework	Measurable Goals					
Track Management Practice Implementation						
Gauge Improvements in Water Quality Resulting from Management Practice Implementation						
Develop and Implement a Schedule to Improve the Management Program Framework						

The Clean Water Act establishes several reporting, funding, and regulatory programs that address pollutants carried in runoff that is not subject to confinement or treatment. These programs relate to watershed management and urban NPS control. Readers are encouraged to use the information contained in this guidance to develop nonpoint source management programs/plans that comprehensively address the following EPA reports and programs:

- *Section 303(d) Lists and TMDLs*. Under section 303(d) of the Clean Water Act, states are required to compile a list of impaired waters that fail to meet any of their applicable water quality standards or cannot support their designated or existing uses. This list, called a "303(d) list," is submitted to Congress every two years, and states are required to develop a Total Maximum Daily Load (TMDL) for each pollutant causing impairment for water bodies on the list. More information on the TMDL program and 303(d) lists is provided at http://www.epa.gov/owow/tmdl.
- *Section 305(b) and the National Water Quality Inventory: Report to Congress*. Every two years, states are required to submit a report to Congress detailing the health of their waters. These periodic reports allow Congress to gauge progress toward meeting the goals of the Clean Water Act and to help identify priorities for future pollution control funding and activities. More information on the 305(b) program and the National Water Quality Inventory is provided at http://www.epa.gov/owow/305b.
- *Section 319 Grant Program*. Under Section 319 of the Clean Water Act, EPA awards funds to states and eligible tribes to implement NPS management programs. These funds can be used for projects that address urban sources of pollution. More information about the Section 319 program is provided at http://www.epa.gov/owow/nps/cwact.html.
- *Section 404 Discharge of Dredged and Fill Material*. Under Section 404 of the Clean Water Act, persons planning to discharge dredged or fill material to wetlands or other waters of the United States generally must obtain authorization for the discharge from the U.S. Army Corps of Engineers (Corps), or a state approved to administer the Section 404 program. Such authorization can be through issuance of an individual permit, or may be subject to a general permit, which applies to certain categories of activities having minimal adverse environmental effects. Implementation of Section 404 is shared between the Corps and EPA. The Corps is responsible for reviewing permit applications and deciding whether to issue or deny permits. EPA, in consultation with the Corps, develops the Section 404(b)(1) Guidelines, which are the environmental criteria that the Corps applies when deciding whether to issue permits. EPA also has authority under Section 404(c) to "veto" Corps issuance of a permit in certain cases. More information about the 404 program is provided at http://www.epa.gov/owow/wetlands.
- *Clean Water State Revolving Fund*. EPA established the Clean Water State Revolving Fund (CWSRF) to provide states with low- or no-interest loans for projects that improve water resources. These funds can be used to support urban NPS pollution programs and projects. To receive CWSRF loans from EPA for water quality projects, states must develop annual Intended Use Plans that outline the expected use of these funds. More information on the CWSRF program is provided at http://www.epa.gov/OWM/finan.htm.
- *National Estuary Program.* Under the National Estuary Program, states work together to evaluate water quality problems and their sources, collect and compile water quality data,

and integrate management efforts to improve conditions in estuaries. So far 28 estuaries have been accepted into the program. Estuary programs can be an excellent source of water quality data and can provide information on management practices. More information on the National Estuary Program is provided at http://www.epa.gov/owow/estuaries/nep.html.

Two excellent resources for learning more about the Clean Water Act and the many programs established under it are *The Clean Water Act: An Owner's Manual* (Elder et al., 1999) and *The Clean Water Act Desk Reference* (WEF, 1997).

Safe Drinking Water Act. Many urban areas, especially urban fringe areas, need to maintain or improve the quality of surface and ground waters that are used as drinking water sources. This act requires states, among other things, to develop Source Water Assessment Reports and implement Source Water Protection Programs. Low- or no-interest loans are available under the Drinking Water State Revolving Fund Program. More information about the Safe Drinking Water Act and Source Water Protection Programs can be found at http://www.epa.gov/safewater/protect.html.

0.3 Key Concepts

0.3.1 Watershed Approach

Since 1991, EPA has promoted the watershed approach as the key framework for dealing with problems caused by urban runoff and other sources that impair surface and ground waters (USEPA, 1998). Five principles guide the watershed approach:

- *Place-based focus*. Activities are directed within specific geographic areas known as management units. When surface runoff is the primary issue, these management units are defined by watershed boundaries. Other types of boundaries can also be used to define management units in special circumstances. If ground water is an issue, for example, ground water recharge areas might be a logical designation.

- *Stakeholder involvement and partnerships*. The people most affected by management decisions are involved throughout the process. Stakeholder participation helps to ensure that local quality of life, economic stability, and other important community issues are incorporated into planning and implementation activities. Partnerships among public agencies and private groups at all levels are also crucial for long-term success.

- *Environmental goals and objectives*. The success of watershed initiatives is measured by improvements of the water resource rather than by programmatic objectives. For example, reestablishing the pool and riffle structure in a stream channel to increase aquatic insect and fish populations might be an objective. Local goals and objectives need to be consistent with all applicable state, tribal, and federal statutes and regulations, including water quality standards.

- *Problem identification and prioritization*. Sound scientific data and methods are used to identify and prioritize threats to human and ecosystem health. This process usually begins with the assessment and characterization of current natural resource and community conditions within the management unit(s). Problems, including their causes and sources, are also documented. Stakeholders and partners then work jointly to set priorities among the various water resource concerns, taking into account priorities already established at scales above and below the management unit.

- *Integration of actions*. Stakeholders and partners take actions in a comprehensive and integrated manner. Results are then evaluated and actions are adjusted as needed.

A key attribute of the watershed approach is that it can be applied with equal success to large- and small-scale watersheds. Federal agencies, states, interstate commissions, and tribes usually apply the approach on watersheds of approximately 100 square miles. Local agencies and urban communities, however, can apply the approach to watersheds as small as 1 square mile. Although specific objectives, priorities, actions, timing, and resources might vary from large scale to small scale, the basic goals of the watershed approach remain the same—protecting, maintaining, and restoring water resources.

Local runoff management program officials must be especially conscious of watershed scale when planning and implementing specific management practices. Nonstructural practices, such as stream protection ordinances and public education campaigns, are usually applied community-wide. Consequently, the results benefit many small watersheds. In contrast, structural practices, such as infiltration basins and sand filters, usually provide direct benefits to a single stream. Regional structural management practices such as retention ponds for larger watersheds can be used, but they do not protect smaller contributing streams. Given limited resources, runoff program officials must often analyze costs and benefits and choose between large- and small-scale practices. Often, a combination of nonstructural and structural practices is the most cost-effective approach.

British Columbia's Watershed Approach

The Province of British Columbia has taken a watershed approach in planning for water quality protection through runoff volume management. Program officials have recognized the link between surface water volume and watershed health, and are incorporating land use planning into urban runoff management efforts. The Water Balance Model is a decision support tool developed to assist in the integration of land use planning and urban runoff management by simulating the effects of source controls within the watershed. This tool allows the province to establish priorities and efficiently evaluate the potential effectiveness of management efforts (Stephens et al., 2003).

0.3.2 Stream Network

The size of a watershed is closely related to the network of streams contained within its borders. Streams with no upstream tributaries are designated as first-order streams down to their first confluence. A second-order stream is formed when two first-order streams meet. A third-order stream is created by the confluence of two second-order streams, and so on.

Headwater streams are defined as first- and second-order streams. What they lack in individual size and length, they make up through sheer numbers. Headwater streams dominate the landscape, accounting for roughly 75 percent of the total stream and river mileage in the United

States (Table 0.4). Because they are the dominant drainage feature, headwater streams also directly receive the bulk of runoff from construction sites, developments, parking lots, highways, and other features of the urban landscape. In most communities, runoff is collected by a storm sewer system and discharged with no treatment. Increases in the volume and rate of storm water runoff have historically resulted in construction of concrete channels and drainage pipes, eliminating many headwater streams.

Table 0.4: National stream order statistics (Leopold et al., 1964).

Stream Order	Number of Streams	Total Length of Stream Miles	Mean Drainage Area (square miles)
1	1,570,000	1,570,000	1
2	350,000	810,000	4.7
3	80,000	420,000	23
4	18,000	220,000	109
5	4,200	116,000	518
6	950	61,000	2,460
7	200	30,000	11,700
8	41	14,000	55,600
9	8	6,200	264,000
10	1	1,800	1,250,000

0.3.2.1 Watershed scales

Any number of watersheds can be defined by the streams within the network. Larger watersheds encompass progressively smaller watersheds in a hierarchical manner. Larger watershed scales, or national scales, are classified using the Hydrologic Unit Code (HUC), a system of hierarchical codes used by federal agencies, states, interstate commissions, tribes, and others to identify watersheds at the national level. Smaller local watersheds, existing at scales below the smallest HUC scale, are identified more informally.

The U.S. Geological Survey (USGS) has developed the National Hydrography Dataset (NHD), which is a comprehensive set of digital spatial data derived from USGS digital line graphs and EPA's reach file 3 that contains information about surface water features such as lakes, ponds, streams, rivers, springs, and wells. Within the NHD, surface water features are combined to form "reaches," which provide the framework for linking water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream and downstream order. More information about the NHD is provided at http://nhd.usgs.gov.

0.3.2.2 National-level scales

USGS developed the HUC system for the purpose of inventorying all "national scale" watersheds in the United States. To accomplish this objective the agency first divided the country into 21 regions that account for the watersheds of 21 major river basins. Within those major river basins the agency identified a total of 222 watershed subregions. The subregions, in turn, were classified as 352 accounting units. The accounting units were further broken down into 2,262 smaller watersheds called cataloging units.

Each level, or scale, in the watershed hierarchy is identified by a numerical code. The cataloging unit, the smallest scale in the hierarchy, has an eight-digit code that uniquely identifies its location. The region where the cataloging unit resides is designated by the first two digits of the code, the subregion by the second two digits, and so on until the four scales are identified. For example, the watershed of the Upper Mississippi River at Hasting, Minnesota, has a HUC code of 07010206. This code breaks down as follows:

Major River Basin ID	07
Subbasin ID	0701
Accounting Unit ID	070102
Catalog Unit ID	07010206

0.3.2.3 Local-level scales

The hierarchy established by the HUC system identifies scales useful for watershed planning and management by national, regional, state, and multi-state jurisdictions. In many instances, a municipality or urban community is part of a larger team and undertakes activities in a large-scale context. However, because even the smallest scale, the cataloging unit, usually describes watersheds of 100 to 1,000 square miles, local practitioners of runoff management typically find the HUC-designated scales simply too large to be of practical use. This is especially true when designing and implementing runoff control practices for individual developments and sites. Consequently, the watershed hierarchy must be extended to include smaller-scale management units. A national effort is under way to designate 14-digit HUCs.

The Center for Watershed Protection (Caraco et al., 1998) proposed three progressively smaller scales in the watershed hierarchy below the subbasin cataloging unit (Figure 0.3):

- *Watershed*. The scale encompassed by the cataloging unit. Generally, this is the largest management unit that falls within the local land use planning authority. A community might have one or more watersheds within its borders, depending on its size.

- *Subwatershed*. The scale encompassed by the watershed. Its boundaries include all the land area draining to the point where two second-order streams come together to form a third-order stream. In most regions, subwatersheds are a few square miles in area and are drained by a stream several feet in width.

- *Catchment*. The smallest scale in the hierarchy. The Center for Watershed Protection defines it as the area that drains an individual development site to its first intersection with a stream. In some cases this intersection is in the form of a pipe outfall. Depending on the size of the development site, the catchment might also include some off-site drainage.

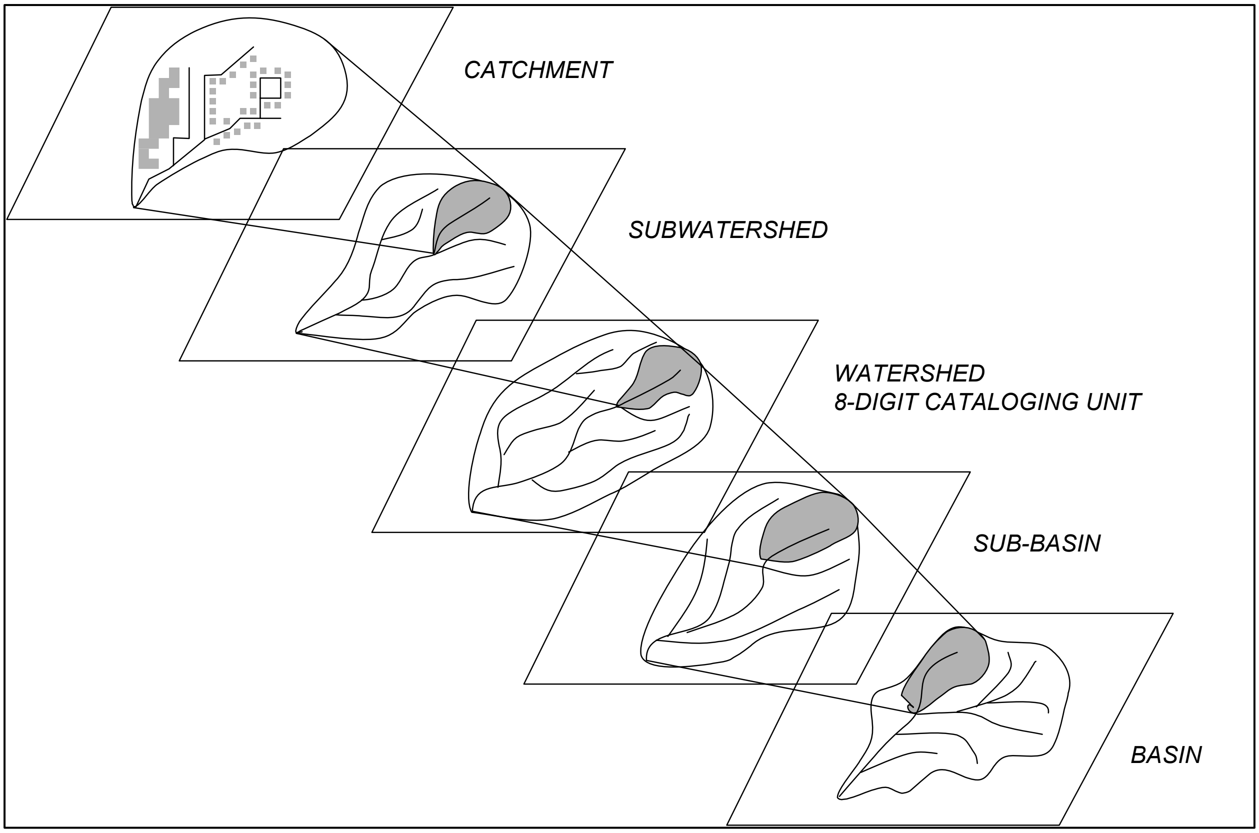


Figure 0.3: Scales of watershed management units (Schueler, 1995).

0.3.3 Impervious and Pervious Surfaces in the Urban Landscape

The term impervious surface refers to land cover, both natural and human-made, that cannot be penetrated by water. Consequently, precipitation that falls on impervious surfaces does not infiltrate into the soil. Instead, it runs off to a pervious area where all or a portion infiltrates into the soil, or it continues to travel down-slope on impervious surfaces including saturated soils until it is eventually conveyed to a ditch, a storm drain network, a stream, a lake, a wetland, an estuary, or some other type of surface receiving water. For additional discussion on the water quality impacts of imperviousness, see Section 1.3.5, Changes in the Watershed Due to Increased Imperviousness.

Most of the impervious cover in an urban watershed or subwatershed can be organized into three main categories:

– *Rooftops*. Impervious cover created by buildings, homes, garages, stores, warehouses, and other structures with roofs.

– *Transport systems*. Impervious cover created by structures such as roads, sidewalks, driveways, and parking lots. Most of these structures are associated with transportation of people or materials, hence the name transport systems.

– *Recreational facilities*. Impervious cover created by tennis and basketball courts, playgrounds, decks, and swimming pools.

In most areas the transport systems component covers a larger percentage of land than the rooftops component. A study in the city of Olympia, Washington, for example, revealed that transport system imperviousness constituted 63 to 70 percent of the total impervious cover at 11 sites of varying land use, including residential, multifamily, and commercial areas (City of Olympia, 1995).

0.3.3.1 Total and effective impervious surface

The amount of impervious cover in a watershed or subwatershed is reported in two basic ways:

– *Total (or mapped) impervious area*. Includes all impervious cover in a watershed or subwatershed—rooftops, transport systems, and recreational facilities. It is usually expressed as a percentage of the total watershed or subwatershed area. It can be calculated by direct measurement or by percentage estimation based on land use, road density, population density, or another indicator.

– *Effective impervious area (EIA)*. The portion of total impervious cover that is directly connected to the storm drain network (Sutherland, 1995). These surfaces usually include street surfaces and paved driveways and sidewalks connected to or immediately adjacent to them, parking lots, and rooftops that are hydraulically connected to the drainage network (e.g., downspouts running directly to gutters or driveways). EIA also is usually expressed as a percentage of the total watershed or subwatershed area. It is the preferred statistic for use when estimating runoff volumes because it is the portion of the impervious cover that generates direct runoff.

Subtracting EIA from the total impervious area yields the amount of impervious area that is not directly connected to the storm drain network, or the ineffective impervious area. Residential rooftops are an example of possible ineffective impervious areas because downspouts can direct runoff to yards and other pervious landscaping areas, where a portion of the water can infiltrate the ground. Rooftops in some residential and most commercial areas, however, will likely be classified as effective impervious areas because their downspouts typically will be tied directly to the storm drain network. Filtration, infiltration, evaporation, and biological uptake of pollutants can substantially reduce runoff volume and improve water quality when runoff is directed over vegetated areas. For further discussion on downspout disconnection, see Management Measure 4: Site Development and Management Measure 10: Existing Development.

Both the amount of impervious area and the relationship between total and effective impervious areas varies according to land use (Caraco et al., 1998). For example, work in the Puget Sound area revealed that total impervious area in low-density residential sites averaged approximately 10 percent, with an effective impervious area of only 4 percent. In commercial and industrial areas, however, total impervious area averaged about 90 percent. Almost all of the total impervious area is also effective impervious area because of the lack of pervious areas to break up direct connections.

0.3.3.2 Pervious surfaces

The urban and suburban landscape has a variety of pervious surfaces, including

- Forests and wetlands
- Lawns and other private turf
- Public turf
- Intensively landscaped areas
- Vacant lands
- Runoff treatment areas

Although most of these areas are green, it would be a mistake to think of them as hydrologically equivalent to an undisturbed meadow, forest, or other natural pervious area, especially in terms of their ability to allow runoff to infiltrate. Soils in urban landscapes are usually highly disturbed and compacted, poor in structure, and low in permeability. In addition, they often receive runoff from adjacent impervious areas, resulting in water inputs many times greater than normal. These factors and others tend to decrease the ability of pervious urban areas to infiltrate runoff, which means an increased fraction of water moves off these areas to impervious areas and storm drainage networks. In extreme cases, the amount of runoff generated is close in volume to that generated from impervious surfaces. Consequently, some "pervious" areas function as impervious areas and cause analysts to underestimate peak flow, runoff volumes, and time of concentration. Refer to Management Measure 9: Pollution Prevention, for more information on runoff from lawns.

0.3.4 Impervious Cover Model

A simple tool, the *Impervious Cover Model*, can be used to project the current and future quality of streams and other water resources at the subwatershed scale based on impervious cover (Caraco et al., 1998). The objective of this model is to assist local officials and other watershed practitioners in devising realistic goals and objectives given present and future levels of development. The impervious cover model is a simple urban stream classification system that contains three stream categories based on the percentage of impervious cover present in the subwatershed. It is intended to help managers decide how to adapt and refine management measures given the intensity of urban development in their watersheds. The impervious cover model has some limitations. These are (Caraco et al., 1998):

- *Reference condition*. The model predicts potential, not actual, stream quality, so in some cases stream reaches might depart from the model's predictions.

- *Scale effect*. The model should be applied only to small, first- to third-order streams because the influence of impervious cover is strongest at these spatial scales.

- *Statistical variability*. There is a moderate degree of scatter exhibited in individual impervious cover/stream quality indicator relationships, although the indicators show a general downward trend as imperviousness increases. The model predicts the average behavior of multiple indicators over a range of imperviousness, and the impervious cover thresholds are not sharp breakpoints but transitions.

- *Measuring and projecting impervious cover*. Accurately quantifying actual and projected impervious cover is important for the model. However, there is no standardized method for measuring total or effective imperviousness.

- *Regional adaptability*. The model has been tested mostly in the mid-Atlantic and Puget Sound ecoregions but little research has been conducted to determine the applicability of the model in western, midwestern, and mountain streams.

- *Defining thresholds for nonsupporting streams*. More sampling and study are needed to more firmly establish the threshold for the transition between impacted streams and nonsupporting streams, projected to occur at 25 percent impervious cover for small urban streams.

- *Influence of management practices in extending thresholds*. The changes in hydraulic and pollutant loadings, and their effects on receiving streams, should be carefully considered when practices are used to extend the threshold of imperviousness.

- *Influence of riparian cover in extending thresholds*. Conservation or restoration of a riparian zone has been shown to extend the impervious cover threshold.

- *Pervious area*. Urban landscapes contain pervious areas, but many of them are highly disturbed and do not resemble pervious areas in non-urban landscapes. However, planners can integrate pervious and impervious areas to greatly reduce effective impervious area and reduce the impact of imperviousness on stream quality.

0.3.4.1 Subwatersheds as the primary management unit

The impervious cover model relies on the subwatershed as the primary management unit. Table 0.5 displays the influence of impervious cover in the context of a hierarchy of watershed-based management units. The subwatershed scale is ideal for planning purposes at the local level for many reasons, including:

- The influence of impervious cover on hydrology, channel stability, water quality, and biodiversity is most evident at the subwatershed scale because the receiving water body is typically a headwater stream.

- The smaller scale helps local officials more easily identify impacts of individual development projects and sources of pollutants.

- Subwatersheds are typically small enough to be within the borders of one or two jurisdictions. This eases the burden of establishing regulatory authority as well as keeping the number of stakeholders to a manageable number.

- Assessments and evaluations can be conducted more easily because most subwatersheds can be mapped on a standard 24-inch by 36-inch sheet with sufficient detail to provide useful management information. The smaller scale also allows assessments and evaluations to be completed more rapidly than similar efforts at larger scales. This creates the opportunity for phasing the development of subwatershed plans (or focusing on areas needing priority attention), making the best use of limited resources. Officials and local citizens can more easily recognize progress as plans are completed and implemented over a coordinated cycle.

Table 0.5: Idealized characteristics of five watershed management units with respect to size and the influence of impervious cover (adapted from Caraco et al., 1998).

Watershed Management Unit	Typical Area (square miles)	Influence of Impervious Cover
Catchment	0.05–0.50	Very strong
Subwatershed	1–10	Strong
Watershed	10–100	Moderate
Subbasin	100–1,000	Weak
Basin	1,000–10,000	Very weak

0.3.4.2 Classification levels

The impervious cover model designates three levels of classification based on impervious cover:

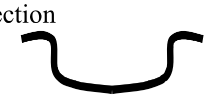
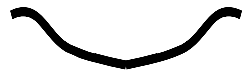
- *Sensitive subwatersheds*, which have less than 10 percent impervious cover. Streams found in sensitive subwatersheds are at, or close to, predevelopment conditions. Urban runoff management strategies, therefore, should focus on maintaining these conditions. New development and redevelopment should be discouraged or designed to have no impact to prevent any increase of impervious cover in subwatersheds of this type.

- *Degrading subwatersheds*, which have 11 to 25 percent impervious cover. Degrading subwatersheds have crossed the 10 percent imperviousness threshold, and have experienced degradation of key stream attributes or can be expected to experience such degradation over time. Some of the more sensitive organisms probably have disappeared or will disappear. Resource objectives consequently should focus more on maintaining or restoring key conditions than on resource protection as a whole. Structural and nonstructural practices that deal with, or counteract, increased urban runoff are recommended.

- *Nonsupporting subwatersheds*, which have more than 25 percent impervious cover. Streams in nonsupporting subwatersheds are well beyond the impervious cover thresholds and may never recover predevelopment conditions no matter how many management practices are implemented. Resource objectives are primarily aimed at reducing peak flows and preventing and removing urban pollutants so they will not be carried downstream. Limited restoration of some attributes such as increased biodiversity can sometimes be achieved given the right circumstances. Pollution prevention and retrofitting in existing urban areas are the most frequently used practices.

Table 0.6 describes channel stability, water quality, and biodiversity attributes, as well as general resource and water quality objectives associated with each category.

Table 0.6: Characteristics of aquatic integrity in urban watersheds.

Integrity Rating	Low	Moderate	High
Riparian Habitat Characteristics	– Riparian zone greatly reduced – Increased sediment deposition – Completely bare/exposed banks – Deeply incised and widened channel cross-section 	– Riparian zone partly cleared – Moderate sediment deposition, sand bar formation – Banks slightly exposed – Steep banks and widened channel cross-section 	– Mature riparian zone – Decreased sediment deposition, mostly rocky substrates – Bank well-vegetated and forested – Floodplain terrace channel cross-section 
Macroinvertebrate Community Characteristics	– Pollution-tolerant species – Tolerant of low dissolved oxygen (DO) levels – Reduced feeding and life history requirements – Decreased diversity and number of species	– Moderately pollution-tolerant species – Tolerant of moderate DO levels – Some general reduction in life history and feeding requirements	– Pollution-intolerant species – Intolerant of low DO levels – Unaltered life history and feeding requirements – Increased number and diversity of species
Fish Assemblage Characteristics	– Pollution-tolerant species – Exotic/introduced species – Reduced feeding and life history requirements – Decreased diversity and number of species	– Moderately pollution-tolerant species – Intermediate number of individuals and species – Some general reduction in life history and feeding requirements	– Pollution-intolerant species – Unaltered life history and feeding requirements – Increased number and diversity of species
Rehabilitation Process	Degraded		Improved

0.3.5 Changes in the Watershed Due to Increased Imperviousness

Watershed imperviousness plays an important role in determining the conditions in streams and other bodies of water. Impervious cover, however, is an inescapable attribute of development and a permanent part of the urban/suburban landscape. Figure 0.4 illustrates how four important components in the water cycle are affected by increasing levels of imperviousness (FISRWG, 1998). In natural landscapes, there is usually very little or no surface runoff. Water either percolates into the ground or is returned to the atmosphere by evaporation and transpiration. As imperviousness increases:

- Runoff increases because the surface area of rooftops and transportation systems is increased.
- Soil percolation decreases because pervious areas are reduced.

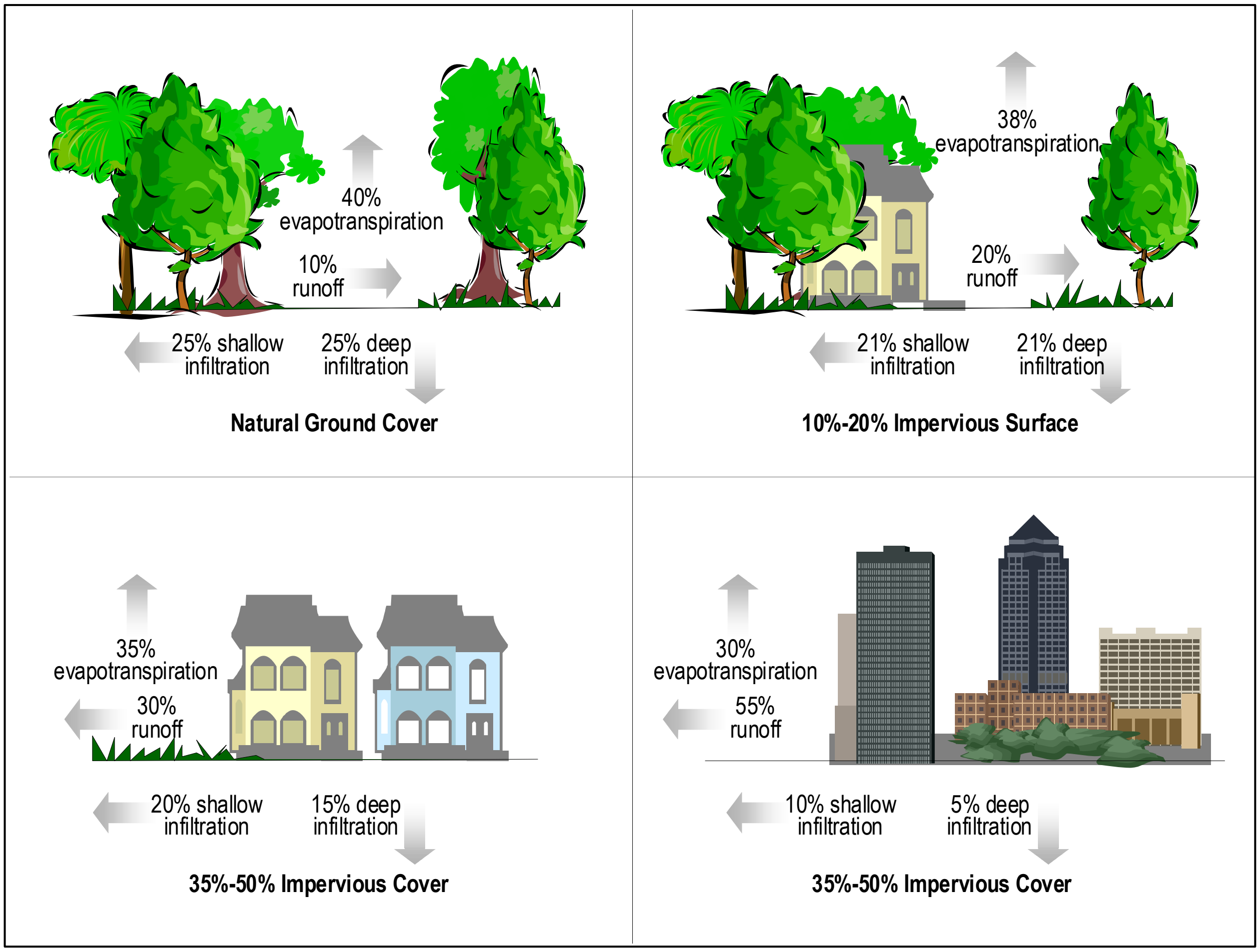


Figure 0.4: Impacts of urbanization on the water cycle (Adapted from FIRSWG, 1998).

– Evaporation decreases because there is less time for it to occur when runoff moves quickly off impervious surfaces.

– Transpiration decreases because vegetation has been removed.

As might be expected, there is a linear relationship between the amount of impervious surfaces in a given area and the amount of runoff generated. What is unexpected is what this means in terms of both the volume of water generated and the rate at which it exits the surface. Depending on the degree of impervious cover, the annual volume of storm water runoff can increase to anywhere from 2 to 16 times the predevelopment amount (Schueler, 1994). Impervious surface coverage as low as 10 percent can destabilize a stream channel, raise water temperature, and reduce water quality and biodiversity (Schueler, 1995). One recent study found that connected imperviousness levels between 8 and 12 percent represented a threshold region where minor changes in urbanization could result in major changes in stream condition (Wang et al., 2001).

Figure 0.5 shows a hydrograph comparing stream flow rates before, during, and after a storm under pre- and postdevelopment conditions (Schueler, 1987). As indicated, streams with developed watersheds have substantially higher peak flows, and these peak flows occur more quickly than under predevelopment conditions. This is reflective of typical urban conditions, where runoff moves quickly over impervious surfaces and drains into a channel.

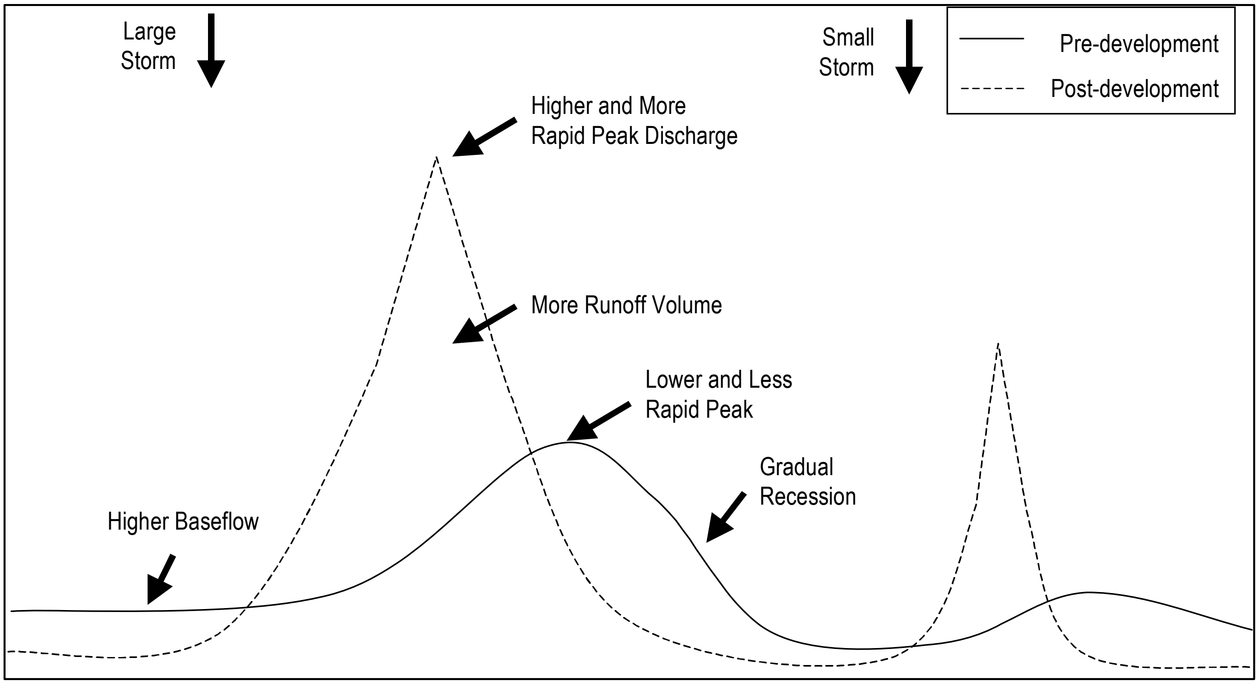


Figure 0.5: Changes in stream flow hydrograph as a result of urbanization (Schueler, 1987).

Development and increased impervious cover also lead to erosion and undercutting of streambanks, widening of channels, and depositing of in-channel sediment. In addition, decreased base flow occurs in dry weather because a greater portion of runoff flows off the

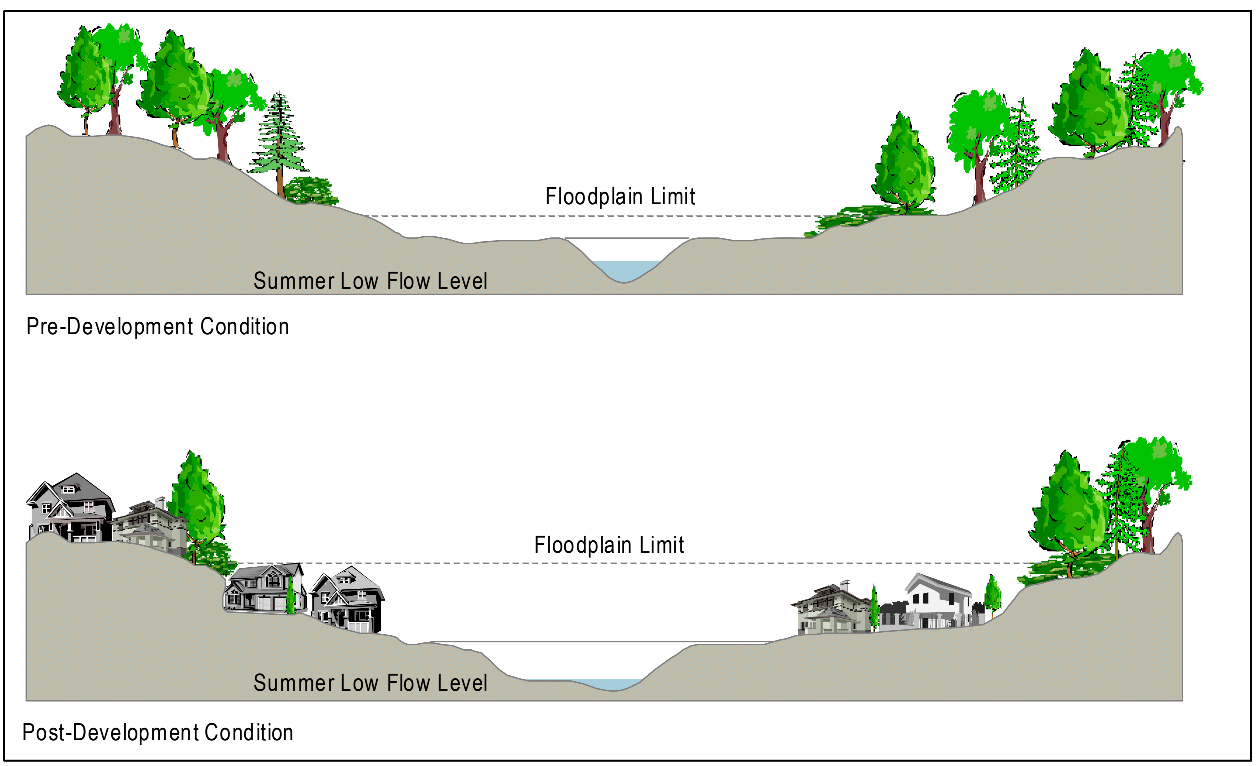


Figure 0.6: Response of stream geometry to urbanization (Schueler, 1987).

surface, resulting in less infiltration to ground water reserves that normally provide base flow to streams. Figure 0.6 shows changes to stream geometry in response to urbanization (Schueler, 1987).

EPA (1997) reviewed the literature for case studies that quantitatively examined the relationship between increased impervious surfaces and stream impacts. Table 0.7 lists these relationships, and Table 0.8 summarizes the case studies used to derive the relationships.

Table 0.7: Impacts from increases in impervious surfaces (USEPA, 1997).

Increased Imperviousness Leads to:	Resulting Impacts				
	Flooding	Habitat Loss	Erosion	Channel Widening	Streambed Alteration
Increased Volume	✓	✓	✓	✓	✓
Increased Peak Flow	✓	✓	✓	✓	✓
Increased Peak Duration	✓	✓	✓	✓	✓
Increased Stream Temperature		✓			
Decreased Base Flow		✓			
Sediment Loading Changes	✓	✓	✓	✓	✓

Table 0.8: Summary of case studies linking urbanization to hydrological impacts on streams (USEPA, 1997).

Case Study	Location	Documented Impacts	Inferred Impacts
East Meadow Brook	Nassau County, NY	– Increased peak flows	Flooding, habitat loss, erosion, channel widening, streambed alteration
Holmes Run Watershed	Fairfax, VA	– Frequent flooding – Severe streambank erosion – Sedimentation	Flooding, habitat loss, erosion, channel widening, streambed alteration
Kelsey Creek	Bellvue, WA	– Degradation of designated uses – Decreased base flow – Loss of fish populations	Habitat loss, channel widening
Patuxent River System	Maryland	– Increased instream sediment load – Changes in morphology of urban channels	Habitat loss, erosion, channel widening
Peachtree Creek	Atlanta, GA	– Increased bankfull events – Decreased base flow	Flooding, habitat loss, erosion, channel widening, streambed alteration
Pheasant Branch Basin	Middleton, WI	– Stream incision – Increase in bankfull events – Sedimentation	Flooding, habitat loss, erosion, channel widening, streambed alteration
Pipers Creek	Seattle, WA	– Increased peak flows – Loss of fish populations – Aesthetic degradation	Flooding, habitat loss, erosion, channel widening, streambed alteration
Several creeks	Dekalb County, GA	– Stream enlargement – Stream incision – Increased sediment transport	Habitat loss, erosion, channel widening, streambed alteration
Valley Stream, Pines Brook, Bellmore Creek, and Massapequa Creek	Nassau County, NY	– Decreased base flow	Habitat loss

Recent research has shown that streams in urban watersheds have a fundamentally different character from that of streams in forested, rural, or even agricultural watersheds. The amount of impervious cover in the watershed can be used as an indicator to predict how severe these differences might be. In many regions of the country, as little as 10 percent watershed impervious cover has been linked to stream degradation, with the degradation becoming more severe as impervious cover increases (Schueler, 1995).

Some key changes in urban streams that merit special attention are detailed below:

- *Bankfull and subbankfull floods increase in magnitude and frequency.* The peak discharge associated with the bankfull flow (the 1.5- to 2-year return storm) increases sharply in magnitude in urban streams. In addition, channels experience more bankfull and subbankfull flood events each year and are exposed to critical erosive velocities for longer intervals (Booth et al., 1996; Hollis, 1975; and MaCrae, 1996).

- *Dimensions of the stream channel are no longer in equilibrium with its hydrologic regime*. The hydrologic regime that defined the geometry of the predevelopment stream channel irreversibly changes, and the stream experiences higher flow rates on a more frequent basis. The higher-flow events of the urban stream are capable of moving more sediment than before.

- *Channels enlarge.* The customary response of an urban stream is to increase its cross-sectional area to accommodate the higher flows. This is done by streambed downcutting, channel widening, or a combination of both. Urban stream channels often enlarge their cross-sectional area by a factor of 2 to 5 depending on the degree of impervious cover in the upland watershed and the age of development (Arnold et al., 1982; Gregory et al., 1992; and Macrae, 1996).

- *Stream channels are highly modified by human activity.* Urban stream channels are extensively modified in an effort to protect adjacent property from streambank erosion or flooding. Headwater streams are frequently enclosed within storm drains, while other streams are channelized, lined, and/or “armored” by heavy stone. Another modification unique to many urban streams is the installation of sanitary sewers underneath or parallel to the stream channel.

- *Upstream channel erosion contributes greater sediment load to the stream*. The prodigious rate of channel erosion coupled with sediment erosion from active construction sites increases sediment discharge to urban streams. Researchers have documented that channel erosion constitutes as much as 75 percent of the total sediment budget of urban streams (Crawford and Lenat, 1989; Trimble, 1997). Urban streams also tend to have a higher sediment discharge than non-urban streams, at least during the initial period of active channel enlargement.

- *Dry weather flow in the stream declines*. Because impervious cover prevents rainfall from infiltrating the soil, less flow is available to recharge ground water. Consequently, during extended periods without rainfall, baseflow levels are often reduced (Simmons and Reynolds, 1982).

- *Wetted perimeter of the stream declines*. The wetted perimeter of a stream is the proportion of the total cross-sectional area of the channel that is covered by flowing water during dry weather, and it is an important indicator of habitat degradation in urban streams. Given that urban streams develop a larger channel cross-section at the same time that their base flow rates decline, it follows that the wetted perimeter will become smaller. Thus, for many urban streams, this results in a very shallow, low-flow channel that "wanders" across a very wide streambed, often changing its lateral position in response to storms.

- *Instream habitat structure degrades*. Urban streams are routinely scored as having poor instream habitat quality, regardless of the specific metric or method employed. Habitat degradation is often exemplified by loss of pool and riffle structure, embedding of streambed sediments, shallow depths of flow, eroding and unstable banks, and frequent streambed turnover.

- *Large woody debris (LWD) is reduced*. LWD is an important structural component of many low-order stream systems because it creates complex habitat structure and generally makes the stream carry more water. In urban streams, the quantity of LWD found in stream channels declines sharply because of the loss of riparian forest cover, storm washout, and channel maintenance practices (Booth et al. 1996; May et al., 1997).

- *Stream crossings and potential fish barriers increase*. Many forms of urban development are linear in nature (e.g., roads, sewers, and pipelines) and cross stream channels. The number of stream crossings increases in direct proportion to impervious cover (May et al., 1997), and many crossings can become partial or total barriers to upstream fish migration, particularly if the streambed erodes below the fixed elevation of a culvert or pipeline.

- *Riparian forests become fragmented, narrower, and less diverse.* The important role that riparian forests play in stream ecology is often diminished in urban watersheds as tree cover is often partially or totally removed along the stream as a consequence of development (May et al., 1997). Even when stream buffers are preserved, encroachment often reduces their effective width and native species are supplanted by exotic trees, vines, and ground covers.

- *Water quality declines*. The water quality of urban streams during storms is consistently poor. Urban storm water runoff contains moderate to high concentrations of sediment, carbon, nutrients, trace metals, hydrocarbons, chlorides, and bacteria (Schueler, 1987). Although considerable debate exists as to whether storm water pollutant concentrations are actually toxic to aquatic organisms, researchers agree that pollutants deposited in the streambed exert an undesirable impact on the stream community.

- *Summer stream temperatures increase*. The impervious surfaces, ponds, and poor riparian cover in urban watersheds can increase mean summer stream temperatures by 2 ºF to 10 ºF (Galli, 1991). Because temperature plays a central role in the rate and timing of instream biotic and abiotic reactions, such increases have an adverse impact on streams. In some regions, summer stream warming can irreversibly shift a cold-water stream to a cool-water or even warm-water stream, resulting in deleterious effects on salmonids and other temperature-sensitive organisms.

– *Reduced aquatic diversity*. Urban streams are typified by fair to poor fish and macroinvertebrate diversity, even at relatively low levels of watershed impervious cover or population density (Couch, 1997; Crawford and Lenat, 1989; May et al., 1997; Miltner, 2003; Schueler, 1995; Shaver et al., 1994). Declines in sensitive species have been observed at levels of impervious cover as low as 4 percent. Impervious cover in highly urbanized areas comprising greater than 25 percent of a watershed may even preclude the Clean Water Act goal of "fishable" waters (Miltner, 2003). The ability to restore predevelopment fish assemblages or aquatic diversity is constrained by a host of factors, including irreversible changes in carbon supply, temperature, hydrology, lack of instream habitat structure, and barriers that limit natural recolonization.

Figure 0.7 shows the relationship between impervious cover and aquatic insect diversity; Figure 0.8 shows the relationship between imperviousness and fish diversity. Both studies were conducted in Maryland streams (Schueler and Galli, 1992, as cited in Schueler, 1995).

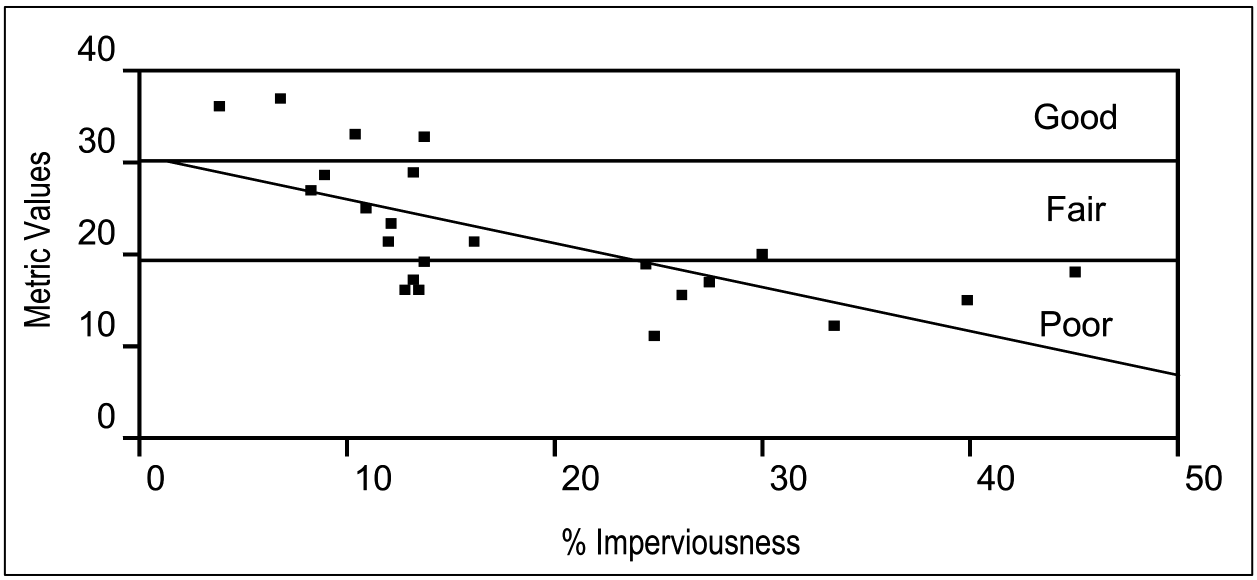


Figure 0.7: Relationship between impervious cover and aquatic insect diversity in Anacostia River subwatersheds (Schueler and Galli, 1992, as cited in Schueler, 1995).

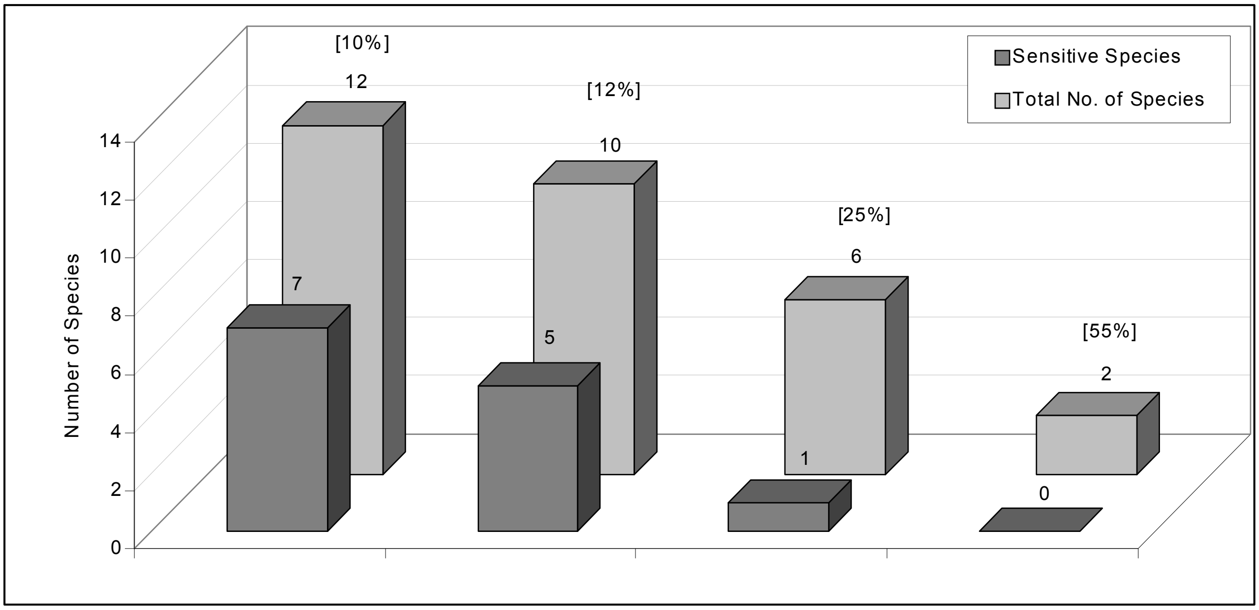


Figure 0.8: Fish diversity in four subwatersheds of different impervious cover in the Maryland Piedmont (Schueler and Galli, 1992, as cited in Schueler, 1995).

0.3.6 Nonpoint Source Pollutants and Their Impacts

Urban areas are a source for many different types of pollutants. Table 0.9 shows typical pollutant concentrations found in storm water. The following discussion identifies the principal types of pollutants found in urban runoff and describes their potential adverse effects:

0.3.6.1 Sediment

Excessive erosion, transport, and deposition of sediment in surface waters are significant sources of pollution in the United States, resulting in major water quality problems. Sediment imbalances impair waters' designated uses. Excessive sediment can impair aquatic life by filling interstitial spaces of spawning gravels, impairing sources of fish food, filling rearing pools, and reducing beneficial habitat structure in stream channels. In addition, excessive sediment can cause taste and odor problems in drinking water supplies and block water intake structures.

According to the *National Water Quality Inventory: 2000 Report to Congress* (required under section 305(b) of the Clean Water Act), states, tribes, and other jurisdictions surveyed water quality conditions in 19 percent of the nation's 3.6 million miles of rivers and streams (USEPA, 2002b). Some 39 percent of these surveyed waters were impaired by various pollution sources. Sediment was the second-leading cause of impairment, accounting for 31 percent of the impaired waters. Furthermore, sediment, especially its fine fractions, is the primary carrier of other pollutants such as organic components, metals, ammonium ions, phosphates, and toxic organic compounds.

Table 0.9: Typical pollutant concentrations found in urban storm water (adapted from MDE, 1999, and Terrene Institute, 1994).

Typical Pollutants Found in Storm Water Runoff	Units	Residential[a]	Mixed[a]	Commercial[a]	General Urban[b]
Total suspended solids	mg/L	101	67	69	80[c]
Total phosphorus	mg/L	383	263	201	0.30[c]
Total nitrogen	mg/L	–	–	–	2.0[c]
Total Kjeldahl nitrogen	mg/L	1.9	1.3	1.2	–
Nitrate + Nitrite	µg/L	736	558	572	–
Total organic carbon	mg/L	–	–	–	12.7[c]
Biological oxygen demand	mg/L	10	7.8	9.3	–
Chemical oxygen demand	mg/L	73	65	57	–
Fecal coliform bacteria	MPN/100 mL	–	–	–	3,600[c]
E. coli bacteria	MPN/100 mL	–	–	–	1,450[c]
Petroleum hydrocarbons	mg/L	–	–	–	3.5[c]
Oil and grease	mg/L	–	–	–	2 to 10[d]
Cadmium	µg/L	–	–	–	2[c]
Copper	µg/L	33	27	29	10[c]
Lead	µg/L	144	114	104	18[c]
Zinc	µg/L	135	154	226	140[c]
Chlorides (winter only)	mg/L	–	–	–	230[c]
Insecticides	µg/L	–	–	–	0.1 to 2.0[c]
Herbicides	µg/L	–	–	–	1 to 5.0[c]

[a] Source: USEPA, 1983.
[b] These concentrations represent mean or median storm concentrations measured at typical sites and may be greater during individual storms. Also note that mean or median runoff concentrations from storm water "hotspots" are 2 to 10 times higher than those shown here. Units: mg/L = milligrams/liter, µg/L = micrograms/l, MPN = most probable number.
[c] Source: MDE, 1999.
[d] Source: Terrene Institute, 1994.

A recent study of the economic impact of excessive erosion and transport of sediment in surface water systems estimates the annual cost of damage due to sediment pollution in North America at approximately $16 billion (Osterkamp et al., 1998). Sediment pollution costs can be measured in physical damages, chemical damages, and biological damages. Physical damages include harm to water conveyance, treatment, and storage facilities, and interference with recreational and navigational use. Chemical damages include deposition and storage of nutrients, metals, and pesticides associated with eroded sediments. Biological damages include harm to aquatic habitat from the movement and storage of sediment.

Potential sources of sediment pollution include agricultural erosion, deforestation, overgrazing, silvicultural erosion, urban runoff, construction activities, and mining activities. Sediments can also be dislodged and transported directly from the water body's shoreline, bank, or bottom. Atmospheric sources might also be a factor. In an informal study of atmospheric deposition of dust, Urbonas and Doerfer (2004) found that each 100 ft^2 of impervious surface can yield up to 1 to 1.2 pounds of solids in runoff on an average annual basis. Assuming that all of this dust enters storm water and that 30 percent of impervious surfaces are directly connected to the storm drain system, the authors estimate that 1 square mile of mixed-use urban development could yield 40 to 50 tons of total suspended solids in storm water each year.

The following is a summary of impacts of suspended and deposited sediments on the aquatic environment (adapted from Schueler, 1997):

Suspended sediments

- Abrasion of and damage to fish gills, increasing risk of infection and disease
- Scouring of periphyton from stream
- Loss of sensitive or threatened fish species when turbidity exceeds 25 nephelometric turbidity units (NTU)
- Shifts in fish community toward less-diverse, more sediment-tolerant species
- Decline in sunfish, bass, chum, and catfish when average monthly turbidity exceeds 100 NTU
- Reduction in sight distance for trout, with reduction in feeding efficiency
- Reduction in light penetration, resulting in a reduction in plankton and aquatic plant growth
- Reduction in filtering efficiency of zooplankton in lakes and estuaries
- Adverse impacts on aquatic insects, which are the base of the food chain
- Slight increases in stream temperature in summer
- Particles are a major vector for transport of nutrients and metals
- Turbidity, which increases probability of boating, swimming, and diving accidents
- Increased water treatment costs to meet drinking water standards of 5 NTU
- Increased wear and tear on hydroelectric and water intake equipment
- Reduction of anglers' chances of catching fish
- Diminishing quality of direct and indirect recreational experience of receiving waters
- Decreased submerged aquatic vegetation (SAV) populations

Deposited sediments

- Physical smothering of benthic aquatic insect community
- Reduced survival rates for fish eggs
- Destruction of fish spawning areas and redds

- Imbedding of stream bottom, which reduces fish and macroinvertebrate habitat value
- Loss of trout habitat when fine sediments are deposited in spawning habitat or riffle-runs
- Potential for elimination of sensitive or threatened darters and dace from fish community
- Increase in sediment oxygen demand, which can deplete dissolved oxygen in lakes or streams
- Significant contributing factor in the rapid decline of freshwater mussels
- Reduced channel capacity, exacerbating downstream bank erosion and flooding
- Reduced flood transport capacity under bridges and through culverts
- Loss of storage and lower design life for reservoirs, impoundments, and ponds
- Dredging costs to maintain navigable channels and reservoir capacity
- Spoiling of sand beaches
- Changes in the composition of bottom substrate
- Coral reef degradation in tropical and subtropical coastal areas
- Deposits that diminish the scenic and recreational value of waterways

Additional chronic effects may occur where sediments rich in organic matter or clay are present. These enriched depositional sediments may present a continued risk to aquatic and benthic life, especially where the sediments are disturbed and resuspended.

Although most concerns are due to excessive sedimentation, some ecological problems can result from insufficient sediment in a water body caused by hydrological modifications. Too little sediment can lead to channel scour and destruction of habitat dependent on an optimum level of sediment. In lakes, reservoirs, and estuaries, insufficient total suspended sediments can lead to increased light levels, resulting in the growth of nuisance algae.

The term *sediment* is broadly used to describe a problem associated with suspended solids, siltation, erosion, weathering, sedimentation, and other factors. Erosion, sediment transport, and deposition are natural processes caused by stresses placed on the earth's surface. Sediment movement is the result of water and air moving against the sediment (gravitation stresses) and natural weathering (molecular and chemical stresses). Because erosion is a natural process and significant quantities of sediments are being moved as a result of natural denudation, it would be unrealistic to expect complete control or elimination of sediment loads to receiving waters. However, it is feasible to control or manage excessive sediment loadings that have resulted from various land use activities and would be detrimental to the quality of the receiving bodies of water and to the aquatic and terrestrial habitat.

0.3.6.2 Nutrients

Nutrient overenrichment is especially prevalent in agricultural areas where manure and fertilizer inputs to crops significantly contribute to nitrogen and phosphorus levels in streams and other receiving waters. Urban streams have been shown to have the second-highest nitrate and total phosphorus levels, second only to agricultural streams (Barth, 1995). There are several nonpoint sources of nutrients in urban areas, mainly fertilizers in runoff from lawns, pet wastes, failing septic systems, and atmospheric deposition from industry and automobile emissions. Deposition of airborne pollutants is beyond the scope of this guidance. More information can be found at North Carolina State University's Web site, http://h2osparc.wq.ncsu.edu/wetland/aqlife/atmosdep.html.

Excessive nutrient levels in receiving waters can lead to exceedance of drinking water criteria (10 mg/L for nitrate-nitrogen), although monitoring data suggest that urban sources of nitrate are not high enough to pose a human health risk. However, moderately high concentrations of nutrients can result in eutrophication of sensitive receiving waters. These sensitive waters include oligotrophic or mesotrophic lakes where phosphorus is a limiting nutrient, or coastal or estuarine areas where nitrogen is limiting. Eutrophication can lead to changes in periphyton, benthic, and fish communities; extreme eutrophication can cause hypoxia or anoxia, resulting in fish kills. Surface algal scum, water discoloration, and the release of toxins from sediment can also occur.

0.3.6.3 Oxygen-demanding substances

Proper levels of dissolved oxygen (DO) are critical to maintaining water quality and aquatic life. Decomposition of organic matter by microorganisms may deplete DO and result in the impairment of the water body. Data have shown that urban runoff with high concentrations of decaying organic matter can severely depress DO levels after storms. The Nationwide Urban Runoff Program (NURP) study (USEPA, 1983) found that oxygen-demanding substances can be present in urban runoff at concentrations similar to those in secondary wastewater treatment discharges.

0.3.6.4 Pathogens

Urban runoff typically contains elevated levels of pathogenic organisms, including bacteria, viruses, and protozoa. The bacteria standard is one of the most commonly violated water quality standards in terms of both the number of water bodies and stream miles impaired. Approximately 50 percent of stream miles in Virginia are impaired due to bacteria contamination (Waye, 2002).

The presence of pathogens in runoff may result in water body impairments such as closed beaches and shellfish beds, and contaminated drinking water sources. Pathogen contamination related to onsite wastewater treatment systems (OWTSs) has been implicated in a number of shellfish bed closings. This problem may be especially prevalent in areas with porous or sandy soils and/or shoreline areas with a high concentration of OWTSs. Epidemiological studies have shown that pathogens can have significant effects on human health in contaminated marine swimming areas (Haile et al., 1999). While the most common effects of bathing in contaminated water are gastrointestinal illnesses, other conditions affecting the upper respiratory tract, ear, eye, and skin may also be contracted (USEPA, 2002a).

Indicator organisms have long been used to determine the level of risk for contracting illnesses from recreational activities in surface waters contaminated by fecal pollution. These organisms often do not cause illness directly, but have demonstrated characteristics that make them good indicators of harmful pathogens in water bodies. Until 1986, EPA recommended the use of fecal coliforms as an indicator for bacteria. However, after conducting epidemiological studies, EPA published *Ambient Water Quality Criteria for Bacteria*, which recommends that states use *Escherichia coli* (*E. coli*) for fresh recreational waters and enterococci for fresh and marine recreational waters because they are better predictors of acute gastrointestinal illness than fecal coliforms (USEPA, 1986). Some states and tribes have replaced their fecal coliform criteria with water quality criteria for *E. coli* or enterococci, but many other states and tribes have not yet made this transition (USEPA, 2002a).

Two protozoa of major concern as waterborne pathogens are *Giardia lamblia* and *Cryptosporidium parvum*. *Cryptosporidium* has become an increasingly serious pathogen problem in urban areas since the 1993 outbreak in Milwaukee, Wisconsin, when pathogens passed through a water treatment plant and left 400,000 people ill and almost 100 dead. Three major sources of pathogens in urban areas are human waste, pet waste, and anthropogenic wildlife. Anthropogenic wildlife includes raccoons, geese, pigeons, seagulls, and rats (Waye, 2002). Human waste can contaminate urban runoff through illicit connections of sanitary sewers with storm water systems, resulting in high bacterial counts and human health risks. These non-storm water sources are often a major contributor of pathogens to discharges from storm drain systems (Pitt et al., 2001).

While some types of waste can be treated before entering water bodies, others, such as feces from pets, should be disposed of properly. When pet waste is not properly disposed of, it can wash into nearby water bodies or be carried by runoff into storm drains. Since most urban storm drains do not connect to treatment facilities, but rather drain directly into lakes and streams, untreated animal feces can become a significant source of pathogens in surface waters.

As pet waste decays in a water body, it uses up oxygen, sometimes releasing ammonia. Low oxygen levels and ammonia combined with warm temperatures can be detrimental to fish and aquatic life. Pet waste also contains nutrients that promote weed and algae growth, which can cause eutrophication. Perhaps most importantly, pet waste carries bacteria, viruses, and other parasites that can pose health risks to humans and wildlife. For more information, refer to the discussion of microbial contamination in Management Measure 2: Watershed Assessment, and the discussion of pet waste in Management Measure 9: Pollution Prevention.

0.3.6.5 Road salts

According to a study by the Department of the Interior and USGS (1996), road salt has become a problem for both surface water and ground water quality, especially in the Northeast and Midwest. Nationally, an estimated $10 million are spent annually by state and local governments to remedy road salt contamination. The Northeastern Illinois Planning Commission (undated) estimates that 18 million tons of deicing salt, primarily sodium and calcium chlorides, are used each year in the United States. When the dissolved salts in runoff from highways and bridges enter soils, ground water, and surface waters, salinity levels increase and can become toxic to plants, fish, and other aquatic organisms. These impacts are especially pronounced in smaller water bodies adjacent to salted areas. Additionally, salt is corrosive and may cause damage to roadways, bridges, and vehicles. Deicing is very important for pedestrian and driver safety, and there are a number of new technologies available for reducing the threat to water quality from this activity. For a discussion of management practices to minimize the environmental impact of road salt application, see Management Measure 7: Bridges and Highways.

0.3.6.6 Hydrocarbons

The sources of oil, grease, and other petroleum hydrocarbons in urban areas include spillage and seepage of fossil fuels, discharge of domestic and industrial wastes, atmospheric deposition, and runoff. Atmospheric deposition is beyond the scope of this guidance (see North Carolina State University's Web site, http://h2osparc.wq.ncsu.edu/wetland/aqlife/atmosdep.html).

Runoff can be contaminated by leachate from asphalt roads, wearing of tires, deposition from automobile exhaust, and oiling of roadsides and unpaved roadways with crankcase oil (USEPA, 2000b). Also, many do-it-yourself auto mechanics dump used oil and other automobile-related fluids directly into storm drains (Klein, 1985). Petroleum hydrocarbons, such as polycyclic aromatic hydrocarbons (PAHs), can accumulate in aquatic organisms from contaminated water, sediments, and food, and are known to be toxic to aquatic life at low concentrations (USEPA, 2000b). Hydrocarbons can persist in sediments for long periods and result in adverse impacts on the diversity and abundance of benthic communities.

Hydrocarbons can be measured as total petroleum hydrocarbons (TPH), as oil and grease, or as individual groups of hydrocarbons, such as PAHs (see Management Measure 7).

0.3.6.7 Heavy metals

Heavy metals are typically found in urban runoff, with automobiles suspected to be the leading source (CWP, 1994). For example, Klein (1985) reported in a study of the Chesapeake Bay that designated urban runoff was the source for 6 percent of the cadmium, 1 percent of the chromium, 1percent of the copper, 19 percent of the lead, and 2 percent of the zinc.

Heavy metals are of concern because of toxic effects on aquatic life and the potential for ground water contamination. Copper, lead, and zinc are the most prevalent NPS pollutants found in urban runoff. High metal concentrations can bioaccumulate in fish and shellfish, and affect beneficial uses of a water body.

0.3.6.8 Toxic pollutants

Many different toxic compounds (priority pollutants) have been associated with urban runoff. The NURP studies (USEPA, 1983) indicated that at least 10 percent of urban runoff samples contained toxic pollutants. Methylene chloride and bis (2-ethylhexyl) phthalate were the most commonly reported and detected organic constituents in an ongoing evaluation of stormwater data from NPDES Phase 1 Municipal Separate Storm Sewer System permit holders. PAHs were also found in several hundred storm events (Pitt, 2004).

0.3.6.9 Temperature

Temperature changes result from increased flows, removal of vegetative cover, and increases in impervious surfaces. Impervious surfaces act as heat collectors, which heat urban runoff as it passes over them. Data indicate that intensive urbanization can increase stream temperature by as much as 5 to 10ºC during storms (Galli and Dubose, 1990). Elevated temperatures can be caused when streambeds become wider and shallower due to higher flows, removal of riparian vegetation along streambanks, and detaining water in runoff management facilities during warm weather. Elevated temperatures disrupt aquatic organisms that have finely tuned temperature limits, such as trout, salmon, and the aquatic insects on which they feed, by decreasing the amount of dissolved oxygen in the water column. Increased water temperatures can also lead to a shift in the algal community, disrupting the aquatic food chain (Galli, 1991).

0.3.7 Nonpoint Source Pollutant Loading

Nonpoint source pollution has been associated with water quality standard violations and the impairment of designated uses of surface waters. The *National Water Quality Inventory: 2000 Report to Congress* (USEPA, 2002b) reported the following:

Siltation, pathogens, oxygen-depleting substances, and nutrients are leading causes of water quality impairments in the nation's rivers and streams; and agriculture, hydromodification, habitat alteration, and urban runoff/storm sewers, all of which are nonpoint sources, were the leading sources of impairment.

The pollutants described previously can have a variety of impacts on coastal resources. Examples of water bodies that have been adversely affected by nonpoint source pollution are varied. The Miami River and Biscayne Bay in Florida have experienced loss of habitat, loss of recreational and commercial fisheries, and decrease in productivity partly as the result of urban runoff (SFWMD, 1988). Additionally, shellfish beds in Port Susan, Puget Sound, Washington, have been declared unsafe for the commercial harvest of shellfish in part because of bacterial contamination from OWTSs (USEPA, 1991). Also, impairment due to toxic pollution from urban runoff continues to be a problem in the southern part of San Francisco Bay (USEPA, 1992). Finally, nonpoint sources of pollution have been implicated in degradation of water quality in Westport River, Massachusetts, which discharges to Buzzards Bay. High concentrations of coliform bacteria have been observed after rainfall, and shellfish bed closures in the river have been attributed to loadings from surface runoff and OWTSs (USEPA, 1992).

0.3.8 Other Impacts of Urban Runoff

Other impacts not related to a specific pollutant can also occur as a result of urbanization. Salinity can be affected by urbanization. Freshwater inflows due to increased runoff can affect estuaries, especially if they occur in pulses, disrupting the natural salinity of an area. Increased impervious surface area and the presence of storm water conveyance systems commonly result in elevated peak flows in streams during and after storms. These rapid pulses or influxes of fresh water into saline receiving waters (i.e., bays, estuaries, and oceans) may be 2 to 10 times greater than normal (ABAG, 1991) This may lead to a decrease in the number of aquatic organisms living in the receiving waters (McLusky, 1989).

The alteration of natural hydrology due to urbanization and accompanying runoff diversion, channelization, and destruction of natural drainage systems have resulted in riparian and tidal wetland degradation or destruction. Deltaic wetlands have also been adversely affected by changes in historic sediment deposition rates and patterns. Hydromodification projects designed to prevent flooding can reduce sedimentation rates and decrease the marsh aggradation that would normally offset erosion and apparent changes in sea level within the delta (Cahoon et al., 1983).

0.3.9 Management Practices

Management practices are specific actions taken to achieve, or aid in the achievement of, a management measure. A more familiar term might be *best management practice* (BMP). The word "best" has been dropped for the purposes of this guidance (as it was in the Coastal Management Measures Guidance) because the adjective is too subjective. The “best” practice in one area or situation might be entirely inappropriate in another area or situation.

Four major runoff management themes dominate the management practices presented in this guidance document:

- Minimize the amount of impervious land coverage and disconnect impervious areas.
- Promote infiltration.
- Prevent polluted runoff by not allowing pollutants and runoff to mix.
- Remove pollutants from runoff before allowing it to flow into natural receiving waters.

The management practices can be grouped into two basic categories:

- *Nonstructural practices*. Nonstructural practices prevent or reduce urban runoff problems in receiving waters by reducing potential pollutants or managing runoff at the source. These practices can take the form of regulatory controls (e.g., codes, ordinances, regulations, standards, or rules) or voluntary pollution prevention practices. Nonstructural controls can be further subdivided:

    - *Land use practices*. Land use practices are aimed at reducing impacts on receiving waters resulting from runoff from new development by controlling or preventing land use in sensitive areas of the watershed. They can also be used to minimize total land used for development while accommodating growth.

    - *Source control practices.* Source control practices are aimed at preventing or reducing potential pollutants at their source before they come into contact with runoff or aquifers. Some source controls are associated with new development. Others are implemented after development occurs and include pollution prevention activities that attempt to modify aspects of human behavior, such as educating citizens about the proper disposal of used motor oil and application of lawn fertilizers and pesticides.

- *Structural practices*. Structural practices are engineered to manage or alter the flow, velocity, duration, and other characteristics of runoff by physical means (USEPA, 1993).

In doing so they can control storm water volume and peak discharge rates and, in some cases, improve water quality. They can also have ancillary benefits such as reducing downstream erosion, providing flood control, and promoting ground water recharge.

0.4 Information Resources

The Center for Watershed Protection is a non-profit organization that provides information concerning watershed restoration, planning, research, and training, storm water management, better site design, education, and outreach. Among other achievements, the Center has completed 20 plans to protect or restore local watersheds and 30 watershed research projects, responded to 5,000 requests for watershed advice, and trained more than 15,000 individuals through workshops. The Center for Watershed Protection's Web site (http://www.cwp.org) provides links to upcoming workshops, current and ongoing projects, surveys, and publications. Example publications available electronically include *Stormwater BMP Design for Cold Climates*, *Codes and Ordinances Worksheet*, and *Site Planning for Urban Stream Protection*. The Center for Watershed Protection also manages the Stormwater Manager's Resource Center Web site, which is designed to provide technical information to storm water managers.

Coordinated through the European Rivers Network, Rivernet is a multilingual service providing information concerning river ecological projects, river basins, and organizations currently working on problems associated with rivers. Access to newsletters, water policy and river management information, educational materials, international news related to rivers, and regional river basin news are available at the Rivernet homepage (http://www.rivernet.org/welcome.htm).

The Natural Resources Defense Council (NRDC), an organization with more than 500,000 members nationwide, seeks to protect and restore the natural environment. Information relevant to storm water management and pollution can be accessed at their Web site (http://www.nrdc.org/water/pollution). An example is *Stormwater Strategies*, which is a publication intended for municipal officials, local decision-makers, citizens, and environmental activists that provides examples of effective storm water management programs employed across the U.S. *Stormwater Strategies* can be downloaded at http://www.nrdc.org/water/pollution/storm/stoinx.asp.

The U.S. Geological Survey's Web site offers water quality and use data; publications, products, and technical resources; and links to water resource-related programs. Individual USGS case studies and reports of grants related to urban runoff programs are available through this site, which is located at http://water.usgs.gov.

Part of EPA's Office of Wetlands, Oceans, and Watersheds, the Nonpoint Source Control Branch provides information on many aspects of nonpoint source pollution. Resources include introductory information about nonpoint source pollution, nonpoint source publications and information resources, funding, information on the Clean Water Act and Coastal Zone Act Reauthorization Amendments, and educational information. More information and access to a full list of available resources can be found at http://www.epa.gov/OWOW/NPS/index.html.

EPA's Office of Wastewater Management (OWM), in cooperation with state and local agencies, administers the NPDES permit program, which includes regulating storm water discharges from municipal separate storm sewer systems. The OWM Web site provides technical and regulatory information on the NPDES Storm Water program as well as publications dealing with urban runoff. The OWM Web site can be accessed at http://www.epa.gov/npdes and information specific to the Storm Water program can be accessed at http://www.epa.gov/npdes/stormwater.

The Water Environment Federation (WEF) is a nonprofit technical and educational organization dedicated to the preservation and enhancement of the global water environment. The Water Environment Federation Web site contains a search engine for periodicals, newsletters, technical magazines, and other publications related to wastewater treatment and water quality protection. Members of the organization provide technical expertise and training on issues, including nonpoint source pollution, hazardous waste, residuals management, and groundwater; sponsor conferences and other special events around the world; and review, testify, and comment on environmental regulations and legislation. More information on WEF is available at http://www.wef.org.

The Sierra Club and American Rivers sponsored the publication of *Where Rivers Are Born: The Scientific Imperative for Defending Small Streams and Wetlands*, which provides an argument for protecting small, intermittent or "headwater" streams and wetlands based on the numerous environmental functions of these systems and their close connectivity with activities on land. The authors detail such functions as flood control, maintenance of water supplies, sediment trapping, and maintenance of biological diversity. The document can be downloaded in PDF format at http://iowa.sierraclub.org/Steve-Sierra%20web%20docs0526/WhereRiversAreBorn.pdf.

0.5 References

Arnold, C., P. Boison, and P. Patton. 1982. Sawmill Brook: An Example of Rapid Geomorphic Change Related to Urbanization. *Journal of Geology* 90:155–166.

Association of Bay Area Governments (ABAG). 1991. *San Francisco Estuary Project: Status and Trends Report on Wetlands and Related Habitats in the San Francisco Bay Estuary*. Prepared under cooperative agreement with USEPA, Agreement No. 815406-01-0. Association of Bay Area Governments, Oakland, CA.

Barth, C.A. 1995. Nutrient Movement from the Lawn to the Stream? *Watershed Protection Techniques* 2(1):239–246.

Booth, D., and C. Jackson. 1997. Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection and the Limits of Mitigation. *Journal of the American Water Resources Association* 33(5):1077–1089.

Booth, D., D. Montgomery, and J. Bethel. 1996. Large Woody Debris in the Urban Streams of the Pacific Northwest. In *Effects of Watershed Development and Management on Aquatic Systems,* ed. L. Roesner. Proceedings of Engineering Foundation Conference, Snowbird, UT. August 4-9, 1996, pp. 178–197.

Cahoon, D.R., D.R. Clark, D.G. Chambers, and J.L. Lindsey. 1983. Managing Louisiana's Coastal Zone: The Ultimate Balancing Act. In *Proceedings of the Water Quality and Wetland Management Conference*. Louisiana Environmental Professionals Association, New Orleans, LA.

Caraco, D., R. Claytor, P. Hinkle, H.Y. Kwon, T. Schueler, C. Swann, S. Vysotsky, and J. Zielinski. 1998. *Rapid Watershed Planning Handbook*. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1994. Cars are Leading Source of Metal Loads in California. Technical Note 13, *Watershed Protection Techniques* 1(1):28.

City of Olympia. 1995. *Impervious Surface Reduction Study: Final Report*. City of Olympia Public Works Department, Water Resources Program, Olympia, WA.

Couch, C. 1997. Fish Dynamics in Urban Streams Near Atlanta, Georgia. Technical Note 94. *Watershed Protection Techniques* 2(4):511–514.

Crawford, J., and D. Lenat. 1989. *Effects of Land Use on Water Quality and the Biota of Three Streams in the Piedmont Province of North Carolina*. U.S. Geological Survey Water Resources Investigations Report 89-4007. U.S. Geological Survey, Raleigh, NC.

Elder, D., G. Killam, and P. Koberstein. 1999. *The Clean Water Act: An Owner's Manual.* The River Network, Portland, OR.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. PB98-158348LUW.

Galli, J. 1991. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Metropolitan Washington Council of Governments, Washington, DC, and Maryland Department of the Environment, Annapolis, MD.

Galli, J., and R. Dubose. 1990. *Water Temperature and Freshwater Stream Biota: An Overview*. Maryland Department of the Environment, Sediment and Stormwater Administration, Baltimore, MD.

Gregory, K., R. Davis, and P. Downs. 1992. Identification of River Channel Change Due to Urbanization. *Applied Geography* 12:299–318.

Haile, R.W., Witte, J.S., Gold, M., Cressey, R., McGee, C., Millikan, R.C., Glasser, A., Harawa, N., Ervin, C., Harmon, P., Harper, J., Dermand, J., Alamillo, J., Barrett, K., Nides, M., and Wang, G. 1999. The health effects of swimming in ocean water contaminated by storm drain runoff. *Epidemiology* 10: 355–363.

Hollis, F. 1975. The Effects of Urbanization on Floods of Different Recurrence Intervals. *Water Resources Research* 11:431–435.

Horner, R.R., J.J. Skupien, E.H. Livingston, and H.E. Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues*. Terrene Institute, Washington, DC.

Karr, J.R. 1991. Biological Integrity: A Long-Neglected Aspect of Water Resources Management. *Ecological Applications* 1(1):66–84.

Klein, R.D. 1985. *Effects of Urbanization on Aquatic Resources: Draft*. Maryland Department of Natural Resources, Tidewater Administration, Annapolis, MD.

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

MacRae, C. 1996. Experience From Morphological Research on Canadian Streams: is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection? In *Effects of Watershed Development and Management on Aquatic Systems,* ed. L. Roesner. Proceedings of Engineering Foundation Conference, Snowbird, UT, August 4–9, 1996, pp. 144–160.

Maryland Department of the Environment (MDE). 1999. *Maryland Stormwater Design Manual.* Maryland Department of the Environment, Annapolis, MD.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, and E.B. Welch. 1997. Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion. *Watershed Protection Techniques* 2(4):483–494.

McLusky, D.S. 1989. *The Estuarine Ecosystem*. Chapman and Hall, Inc., New York, NY.

Miltner, R.J. 2003. Fish Community Response in a Rapidly Suburbanizing Landscape. In *Proceedings, National Conference on Urban Storm Water: Enhancing Programs at the Local Level*, February 17-20, 2003, Chicago, IL.

Northeastern Illinois Planning Commission (NIPC). Undated. *Pavement Deicing: Minimizing the Environmental Impacts*. Northeastern Illinois Planning Commission, Chicago, IL.

Osterkamp, W.R., P. Heilman, and L. J. Lane. 1998. Economic Considerations of Continental Sediment-Monitoring Program. *International Journal of Sediment Research* 13(4): 12–24.

Pitt, R., A. Maestre, and R. Morquecho. 2004. The National Stormwater Quality Database (NSQD, version 1.1). http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html. Last updated February 16, 2004. Accessed September 29, 2005.

Pitt, R., M. Lalor and J. Easton. 2001. Potential Human Health Effects Associated with Pathogens in Urban Wet Weather Flows. Submitted to the Journal of the American Water Resources Association. http://www.eng.ua.edu/~rpitt/Publications/MonitoringandStormwater/Stormwater Pathogens JAWRA.pdf. Accessed June 19, 2003.

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

Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100–111.

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

Schueler, T. 1997. Impact of Suspended and Deposited Sediment: Risks to the Aquatic Environment Rank High. *Watershed Protection Techniques* 2(3): 443–444.

Schueler, T., and J. Galli. 1992. Environmental Impacts of Stormwater Ponds. In *Watershed Restoration SourceBook: Anacostia Restoration Team*. Metropolitan Washington Council of Governments, Washington, DC. Cited in Schueler, 1995.

Shaver, E., J. Maxted, G. Curtis, and D. Carter. 1995. Watershed Protection Using an Integrated Approach. In *Stormwater NPDES Related Monitoring Needs*, ed. B. Urbonas and L. Roesner. Proceedings of Engineering Foundation Conference, Mount Crested Butte, CO, August 7–12, 1994, pp. 168–178.

Simmons, D., and R. Reynolds. 1982. Effects of Urbanization on Baseflow of Selected South Shore Streams, Long Island, NY. *Water Resources Bulletin* 18(5):797–805.

South Florida Water Management District (SFWMD). 1988. *Biscayne Bay Surface Water Improvement and Management Plan*. South Florida Water Management District, West Palm Beach, FL.

Stephens, K.A, T. van der Gulick, L. Maclean and E. von Euw. 2003. Re-inventing Urban Hydrology in British Columbia: Runoff Volume Management for Watershed Protection. In *Proceedings, National Conference on Urban Storm Water: Enhancing Programs at the Local Level*, February 17-20, 2003, Chicago, IL.

Sutherland, R.C. 1995. Methodology for Estimating the Effective Impervious Area of Urban Watersheds. Technical Note 58. *Watershed Protection Techniques* 2(1): 282–283.

Terrene Institute. 1991. A Method for Tracing On-Site Effluent from Failing Septic Systems. *Nonpoint Source News-Notes* 12: 14.

Terrene Institute. 1994. *Urbanization and Water Quality*. Prepared by Terrene Institute, Washington, DC, for the U.S. Environmental Protection Agency, Washington, DC.

Trimble, S. 1997. Contribution of Stream Channel Erosion to Sediment Yield From an Urbanizing Watershed. *Science* 278: 1442–1444.

U.S. Department of the Interior (USDOI) and U.S. Geological Survey (USGS). 1995. *Effectiveness of Highway-Drainage Systems in Preventing Road-Salt Contamination of Ground Water, Southeastern Massachusetts*. U.S. Department of the Interior, Washington, DC, and U.S. Geological Survey, Marlborough, MA.

U.S. Environmental Protection Agency (USEPA). 1983. *Final Report of the Nationwide Urban Runoff Program*. U.S. Environmental Protection Agency, Water Planning Division, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1986. *Ambient Water Quality Criteria for Bacteria—1986*. EPA 440-5-84-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1992. *Environmental Impacts of Stormwater Discharges*. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997. *Urbanization and Streams: Studies of Hydrologic Impacts*. EPA841-R-97-009. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1998. *National Water Quality Inventory: 1996 Report to Congress*. EPA841-R-97-008. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2000a. 1999 National Watershed Awards spotlight outstanding volunteer projects. *Nonpoint Source News-Notes* 60:14.

U.S. Environmental Protection Agency (USEPA). 2000b. *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 1: Fish Sampling and Analysis, Third Edition*. EPA 823-B-00-007. U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2002a. *Implementation Guidance for Ambient Water Quality Criteria for Bacteria (Draft).* U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://www.epa.gov/waterscience/standards/bacteria/. Last updated August 5, 2003. Accessed August 7, 2003.

U.S. Environmental Protection Agency (USEPA). 2002b. *2000 National Water Quality Inventory.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://www.epa.gov/305b/2000report. Last updated August 18, 2003. Accessed August 19, 2003.

Urbonas , B.R., and J.T. Doerfer. 2004. Some observations on atmospheric dust: Fallout in the Denver , Colorado, area. *Stormwater* 5(5): 46–50.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. *Environmental Management* 28(2): 255–266.

Water Environment Federation (WEF). 1997. *The Clean Water Act Desk Reference: 25th Anniversary Edition*. Water Environment Federation, Alexandria, VA.

Waye, D. 2002. Current Understandings of Bacteria in Waterways and Implications for TMDLs. In *Proceedings, The Race for Clean Water Conference*, October 21-23, 2002, Dover, DE.

MANAGEMENT MEASURE 1
PROGRAM FRAMEWORK AND OBJECTIVES

1.1 Management Measure

Develop, implement, and enhance a runoff management program framework that

- Has adequate legal authority to implement the program effectively;
- Has an effective institutional structure;
- Has adequate funding and staffing;
- Incorporates comprehensive watershed planning, including watershed/subwatershed goals and objectives; and
- Fosters input from citizens, stakeholders, and technical experts, and coordinates with other agencies.

1.2 Management Measure Description and Selection

1.2.1 Description

The goal of this management measure is to ensure that urban runoff management programs are developed and implemented with a solid institutional foundation. Federal, state, regional, and local governments all play important roles in establishing and maintaining programs. Consequently, a team approach must be taken to avoid overlap of key responsibilities and authorities, and to ensure that the appropriate levels of government function cooperatively.

1.2.1.1 Role of federal government

Because nonpoint source runoff management programs are within the purview of state and local governments, the federal government's primary role in nonpoint source runoff management programs is to develop broad urban runoff control guidance with participation of state, regional, and local governments, and to provide technical and financial assistance to support the implementation of effective programs and practices.

1.2.1.2 Role of state government

State programs play an especially important role in establishing the team approach to runoff management. State officials interpret and coordinate federal mandates for implementation at the local level, establish state performance standards, and design criteria for runoff control. States also typically take the lead in conducting research, providing technical assistance, developing public education programs, running training and certification programs for practitioners of runoff management, and implementing monitoring programs to help evaluate the effectiveness of management practices (WMI, 1997a).

Many states allow runoff management programs to be delegated to local jurisdictions while the states retain important oversight and enforcement responsibilities to ensure statewide consistency. States should maintain the authority to intervene if necessary. The following is a list of regulatory elements that might be included in a state's runoff legislation, or in rules and regulations to help guide local program implementation (WMI, 1997b):

- Criteria for local program implementation or delegation
- Types of activities that require runoff control
- Waivers, exemptions, and variances
- Plan approval and inspection fees, including construction or maintenance performance bonds
- Authority for a local storm water utility
- Specific design criteria
- Permit application and approval process
- Operation permit requirements and time frames
- Development and implementation of mandated educational programs related to site inspection of active and completed storm water management systems
- Requirements for any other educational programs
- Inspection requirements, including certification of inspectors
- Maintenance requirements for postconstruction runoff control facilities
- Penalty provisions in the event of noncompliance with requirements for the design, construction, or operation of storm water management systems

1.2.1.3 Role of regional authorities

Regional authorities often share some of the duties of state agencies but customize their services to fit the needs and attributes of the region. They provide a link between local communities and the state, and often work with state officials to establish region-based performance standards and design criteria for runoff controls. They also serve as a focal point for coordinating issues and interests among communities in the region, especially in terms of implementing the watershed approach, developing watershed plans, ensuring consistency of storm water runoff master planning, and resolving situations that affect downstream communities.

1.2.1.4 Role of local government

Counties and municipalities integrate local runoff management planning with land use and regional watershed management plans, floodplain management, wastewater planning, and other programs that affect the management of urban runoff. They are involved with the day-to-day administrative, operational, and technical aspects of runoff management and are responsible for performing inspections, enforcing compliance, performing operation and maintenance, identifying and removing illicit connections, and coordinating program funding.

Wisconsin DNR Revisits their Approach to Watershed Programs

The Wisconsin Department of Natural Resources (WDNR) recognized a need for a more holistic approach to watershed programs (Nemke, 1997). They recognized the following problems associated with planning, coordination, cooperation, funding, and implementation of watershed initiatives:

– Although money is available for implementing watershed initiatives, no formal mechanisms exist to raise and allocate money needed to carry plans forward.

– There is no single agency or organization that has regulatory authority over all of the resources that are involved in watershed initiatives, which sometimes results in conflicting priorities.

– Groups that plan and implement watershed initiatives typically are made up of a diverse group of stakeholders with different leadership abilities, motivations and priorities, and technical backgrounds. This diversity makes it difficult to keep the group moving in a consistent direction and becomes problematic when a consensus is needed to allocate funding for implementation.

– Rules and guidance documents often dictate inflexible solutions for dischargers and discourage more creative, innovative, or cost-effective solutions that could be equally or more beneficial to the watershed initiative.

WDNR presented the following recommendations for watershed districts to help overcome logistical problems associated with watershed programs:

– Staff should stay current on watershed issues and initiatives by attending conferences and keeping abreast of relevant journal articles and reports to get a better idea of what practices and policies work best.

– Staff should take a leadership role on technical issues relating to evaluation of watershed problems and solutions.

– The district should avoid taking an expanded role in solving watershed problems unless this role is clearly defined in their statutory authority and other government bodies agree that this role is appropriate and prudent.

– The district should only commit funds to initiatives that are clearly tied to potential benefits for the district's users.

– The district should encourage and participate in evaluations of legislative initiatives that will provide adequate authority to implement watershed-based solutions.

– The district should critically evaluate proposed solutions to watershed problems to ensure they will adequately and sensibly address these problems.

All runoff management programs share common needs, including the legal authority to create, adopt, and enforce ordinances; an institutional structure designed to carry out the goals and objectives of the program; and adequate funding for staff and program activities. Planning serves as the foundation for runoff programs; it establishes management measures and determines how and where management practices will be applied. The program framework should also include the input of citizens and other stakeholders, technical experts, and other agencies in the program planning and implementation. Communities will need to balance stakeholder concerns for the environment and the economy. Community groups must work together as they develop their own sustainable development concepts to contribute to the betterment of the environment and the residents of the watershed. Finally, ongoing program evaluation and feedback are critical (see Management Measure 12: Evaluate Program Effectiveness).

1.2.2 Management Measure Selection

This management measure was selected because successful runoff management programs require an established program framework and objectives. The measure is intended to provide general guidance on the common aspects of a program framework that should be considered and addressed when developing a runoff management program. Examples are provided to illustrate how the practices can be used to implement the management measure.

1.3 Management Practices

1.3.1 Establish Legal Authority

A successful urban runoff program must have the legal authority to accomplish its goals and objectives. State-level programs derive their legal authority from various laws, codes, and regulations enacted by the state legislature. Only a few states have passed comprehensive statewide runoff management legislation. States whose laws often serve as models include Delaware, Florida, Maryland, New Jersey, and Washington.

The language in state runoff legislation is usually general and might include the runoff program's goals, procedures, and general requirements for maintenance. Details concerning design, construction, operation, and maintenance of runoff management practices are established by the program's implementing regulations and guidance materials (runoff management manual).

If authorized by state law, the state can delegate program implementation authority to local entities. Delegation is usually beneficial to local governments because they have a direct interest in seeing that practices are installed, operated, and maintained correctly. Delegation also provides them the flexibility to implement the program based on the needs of the community. To aid local communities in this endeavor and to ensure statewide consistency in runoff management, state program officials typically develop a state manual that presents design criteria and guidance for implementing specific management practices. State and local regulation writers typically adopt the state manual by reference into their regulations wherever appropriate to ensure that the information contained in the document is used and applied correctly.

EPA's Office of Wetlands, Oceans, and Watersheds has developed a Web site that has examples of model ordinances that address issues such as aquatic buffers, erosion and sediment control, open space development, storm water control operation and maintenance, illicit discharges, and postconstruction controls (USEPA, 1999b). The Web site, http://www.epa.gov/owow/nps/ordinance, also has materials that support particular ordinances, such as maintenance agreements and inspection checklists. Additionally, the Center for Watershed Protection's Stormwater Manager's Resource Center Web site has a collection of model ordinances, which can be accessed at http://www.stormwatercenter.net/.

The primary focus of the management practices discussed below is on how local governments can increase their ability to manage runoff by developing new ordinances or regulations, or modifying existing ones. It should be noted that many of these practices could also be adopted at the state level to ensure statewide consistency of runoff management practices.

1.3.1.1 Examine existing laws and regulations

The first step in crafting ordinances to improve runoff management controls at the local level is to examine all the existing mandates, authorities, laws, regulations, codes, ordinances, review processes, and so forth that pertain to environmental review in the community. By comparing current rules and practices with the rules needed to achieve the goals and objectives of the runoff management program, a community can identify gaps and weaknesses that need to be addressed.

Frederick County, Maryland, Site Planning Roundtable

The Frederick County Department of Planning and Zoning and the Center for Watershed Protection facilitated a local site planning roundtable in Frederick County, Maryland. The roundtable worked to review the county's current subdivision and zoning codes, define the local hurdles that impede the implementation of more innovative site planning techniques, and hammer out changes to local codes and ordinances that would foster more environmentally friendly development. By January 2000 the diverse group of planners, developers, watershed planners, and other community professionals arrived at a consensus on the modifications necessary to achieve widespread implementation for more environmentally sensitive site designs. The changes the group recommended are designed to guide future site development in the county toward the goals of reducing impervious cover, conserving natural areas, and minimizing storm water pollution.

The resulting document, Fred*erick County Roundtable Recommendations: A Consensus Agreement*, was presented to the Frederick County Commissioners in February 2000. While certainly fostering better site design in Frederick County, the successful Frederick County roundtable also is an important example for other communities interested in implementing similar projects. In addition, this project complements other ongoing regional, state, and local growth management efforts occurring throughout Maryland.

For more information on the Frederick County Site Planning Roundtable's recommendations, contact the Center for Watershed Protection, 8391 Main Street, Ellicott City, Maryland 21043; phone 410-461-8323; fax 410-461-8324; e-mail: mailto:center@cwp.org.

Revision of Development Rules for the City of High Point, North Carolina

The state of North Carolina plans to build a reservoir, called Randleman Lake, to meet the growing need for water in North Carolina's Piedmont Triad region (Brewer et al., 2000). Recognizing that the watershed has one of the highest rates of urbanization in the region, the state has developed a set of rules, called the Randleman Lake Water Supply Watershed Protection Rules, to establish requirements for wastewater dischargers, protect and maintain riparian areas, and provide for urban runoff management in areas draining to Randleman Lake. The City of High Point was charged with developing a watershed protection ordinance to comply with the Randleman Lake Rules, which require strict development limitations for areas within the watershed (Table 1.1).

Table 1.1: Summary of the Randleman Lake water supply watershed protection rules.

Development Option	1.1.1.1.1 Description
Critical area low density	– 6% impervious surface limit or 1 dwelling unit per 2 acres. – 50-foot stream buffers around perennial and intermittent streams.
Critical area high density	– 30 percent impervious surface limit. – 100-ft and 50-ft buffers for perennial and intermittent streams, respectively. – Structural controls required for developments with 6 to 30% imperviousness.
General watershed area—low density	– 12% impervious surface limit or 1 dwelling unit per acre. – 50-foot stream buffers around perennial and intermittent streams.
General watershed area—high density	– 50% impervious surface limit. – 100-ft and 50-ft buffers for perennial and intermittent streams, respectively. – Structural controls required for developments with 12 to 50% imperviousness.

The city undertook a two-part study to facilitate development of an ordinance that protects water quality while providing flexibility to accommodate projected growth. The first part of the study involved a committee of stakeholders charged with identifying and evaluating different strategies for watershed protection. The city used an iterative approach to involve the stakeholder groups with an important "feedback loop" and key checkpoints throughout the process to gauge and document each stakeholder group's buy-in and formal approval. The second part of the study involved a comparative analysis of impacts of different protection strategies for the watershed. The comparative analysis focused on phosphorus as an indicator of water quality impacts on Randleman Lake. The analysis involved establishing a baseline of phosphorus loading that is not to be exceeded by alternative strategies for new development. It also involved identifying and estimating additional loadings from areas that are expected to be developed more intensely and are expected to exceed the baseline phosphorus loading. Strategies for offsetting these loadings elsewhere in the watershed or mitigating them with more protective on-site management practices were then developed and evaluated.

The plan (see Figure 1.1) and ordinance adopted as a result of this study were based on a phosphorus banking principle and included the following elements:

- Maintenance of a 6.4-square-mile critical area, which is larger and more restrictive than that required in the Randleman Lake Rules and yields a phosphorus loading reduction/offset of approximately 800 lb/yr.
- Use of 440 lb/yr, or approximately 55 percent of the phosphorus offset, to allow increased imperviousness for planned higher-density nonresidential development.
- Use of the remaining offset as a phosphorus reduction reserve.
- Revision of ordinance(s) and engineering specifications to encourage low-impact design and alternatives to traditional storm water ponds.

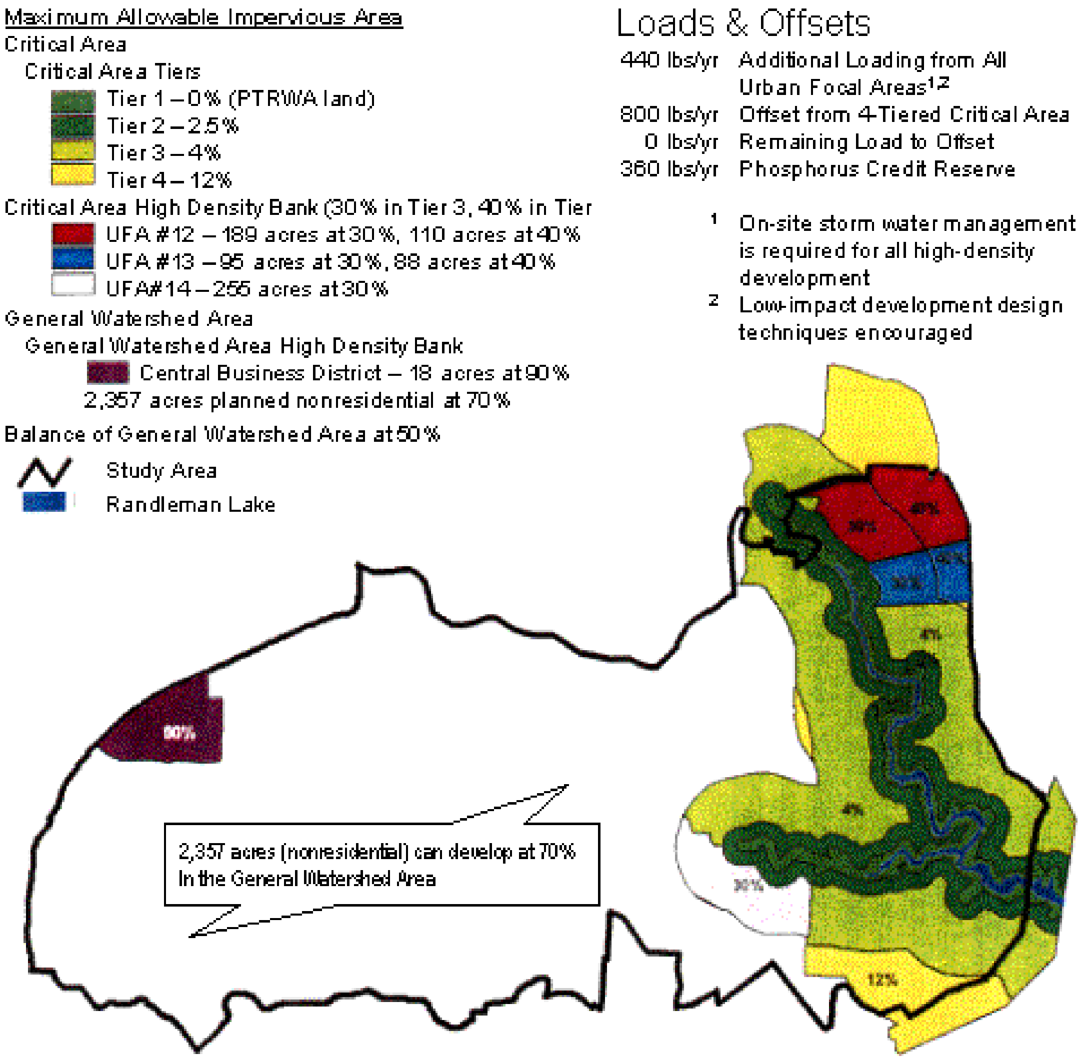


Figure 1.1: Adopted watershed protection plan for the City of High Point, North Carolina.

The city has adopted a watershed protection ordinance for the Deep River 1 watershed that incorporates the strategies listed above and has modified its engineering specifications to allow bioretention facilities and to provide guidance for their design. In the coming year, the city will work to:

- Review local monitoring data and recommend additional monitoring protocols that can track the effectiveness of best management practices used, including new low-impact development design techniques. Possible funding sources for monitoring will be identified.
- Review and revise the city's development ordinance and engineering specifications to further allow and encourage low-impact design techniques.
- Plan and host a spring 2000 low-impact development design workshop for city staff, local contractors, and engineers.

1.3.1.2 Develop or improve ordinances for water quality enhancement

(1) *Aquatic buffer ordinance*. Aquatic buffers serve as natural boundaries between local waterways and existing development. They help protect water quality by filtering pollutants, sediment, and nutrients from runoff. Some other benefits of buffers are flood control, streambank stabilization, controlling stream temperature, and providing room for lateral movement of the stream channel. Good aquatic buffer ordinances specify the size and management of the stream buffer and are a specific planning tool to protect stream quality and aquatic habitat.

Effective buffer ordinances provide guidelines for buffer creation and maintenance and should require:

- Buffer boundaries that are clearly marked on local planning maps;
- Maintenance language that restricts vegetation and soil disturbance;
- Tables that illustrate buffer width adjustment by percent slope and type of stream; and
- Direction on allowable uses and public education.

(2) *Erosion and sediment control ordinance*. A basic goal of erosion and sediment control programs should be to minimize off-site impacts by first preventing erosion and then maximizing control of sedimentation on-site (WMI, 1997a). A key tool for accomplishing this goal is an effective erosion and sediment control (ESC) ordinance.

An ESC ordinance typically requires developers to submit an ESC plan to a state or local regulatory agency for approval prior to initiating construction activities. This plan contains specific practices to prevent erosion and control sediment, as well as information concerning phasing of clearing and grading activities. Once the plan is approved by the regulatory agency, the developer and contractor are responsible for following the plan and implementing the management practices. If follow-up inspection reveals a lack of

Residents' Willingness to Pay for Riparian Buffers

In St. Charles County, Missouri, rapid growth has resulted in serious threats to the environment such as flooding, water pollution, and habitat loss for aquatic organisms and wildlife. To combat these problems, the St. Charles "Natural Watercourse Protection Ordinance" was passed, and requires 50-foot riparian buffer along major streams and a 25-foot buffer along tributaries when adjacent land is being developed for residential or other non-agricultural uses. In anticipation of potential increases in development costs and home prices resulting from the ordinance, a study was conducted in the Dardenne Creek watershed to evaluate the residents' willingness to pay for adopting buffers in newly developed residential communities. Survey respondents identified wildlife, environmental benefits, and natural appearance and sounds as the primary values of Dardenne Creek. Respondents were concerned about the damaging impacts of flooding, erosion, and safety of children on property values. 43.7 percent of the respondents were willing to pay a median value of $1000 for community-owned and open accessible buffers. The study indicates that residents generally recognize the potential environmental benefits of the buffer ordinance, but outreach efforts should focus on informing homeowners that the ordinance may result in increased construction costs and higher home prices. The study's author concludes that the residents' willingness to pay indicates that the real estate market can absorb the possible increases in the construction costs due to implementing the ordinance (Qiu, 2003).

compliance, the inspector may issue a permit violation, stop-work order, or fine, or take other steps to compel action.

Whether program authority is implemented at the state level or delegated to a local government, the ordinance should include goals, performance standards, and design criteria for both erosion prevention and sedimentation control. At a minimum, the ordinance should define the following erosion prevention design criteria:

- The threshold for disturbed areas at which regulatory action/compliance is required; and
- The maximum time frame for permanent site stabilization after final grading or temporary stabilization if construction ceases and the site is left dormant.

(3) *Open space ordinance*. Open space development, also known as “cluster development,” is a planning technique that concentrates dwelling units in a compact area and leaves the balance of the site as natural, open space. Lot sizes, setbacks, and frontage distances are minimized, thereby reducing the amount of impervious cover on-site. Open space development reduces the need for clearing and grading by 35 to 60 percent, and increases opportunities for using the reserved land for a variety of purposes such as conservation, recreation, habitat preserves, and storm water management. Table 1.2 shows a summary of studies that contrasted conventional and open space designs in terms of impervious cover and storm water runoff (CWP, 1998a). Specific recommendations on how to limit imperviousness and maximize pervious areas can be found in Management Measure 4: Site Development.

Table 1.2: Redesign analyses comparing impervious cover and storm water runoff from conventional and open space subdivisions (CWP, adapted 1998a).

Residential Subdivisions	Conventional Zoning for Subdivision	Impervious Cover at the Site			Percent Reduction in Runoff
		Conventional Design	Open Space Design	Net Change	
Remlik Hall	5-acre lots	5.4%	3.7%	-31%	20%
Duck Crossing	3- to 5-acre lots	8.3%	5.4%	-35%	23%
Tharpe Knoll	1-acre lots	13%	7%	-46%	44%
Chapel Run	½-acre lots	29%	17%	-41%	31%
Pleasant Hill	½-acre lots	26%	11%	-58%	54%
Prairie Crossing	½- to ⅓-acre lots	20%	18%	-10%	66%
Rapahannock	⅓-acre lots	27%	20%	-24%	25%
Buckingham Greene	⅛-acre lots	23%	21%	-7%	8%
Belle-Hall	High density	35%	20%	-43%	31%

For open space development to be successful, the ordinance needs to be crafted to foster development that is both marketable and environmentally sensitive. The ordinance also needs to effectively address issues such as maintenance, liability, and access by emergency vehicles. In addition, the community needs to be prepared to manage the space or to dedicate open space to a responsible organization.

The Center for Watershed Protection and EPA Present Model Ordinances on the Web

Communities can strengthen the language of their regulations and ordinances to better protect environmental resources by referring to examples of exemplary ordinances from across the country. The following is a list of ordinances available for download from http://www.epa.gov/owow/nps/ordinance.

Aquatic Buffers
- Language from Baltimore County, MD
- Coastal Zone Program, RI (an example of a buffer ordinance in a coastal region)
- Ordinance on Riparian Habitat Areas, Napa, CA
- Portland Metro Floodplain Preservation Ordinance
- Model Land Trust Agreement from the Natural Lands Trust

Erosion and Sediment Control
- Erosion and Sediment Control Ordinance from Minneapolis, MN
- Clearing and Grading Ordinance from Olympia, WA
- Erosion and Sediment Control Inspection Checklist from the Lower Platte South Natural Resources District, NE
- Small Site Design Guideline from the Indiana Department of Natural Resources
- Preconstruction Meeting Notice from Montgomery County, MD

Open Space Development
- Open Space Development Ordinance from Calvert County, MD
- Land Preservation District Model Zoning from Montgomery County, PA
- Open Space Ordinance from Hamburg Township, MI

Storm Water Operation and Maintenance
- Ordinance Language from Grand Traverse County, MI
- Example Maintenance Agreement from Albemarle County, VA
- Easement and Right-of-Way Agreement from Montgomery County, MD
- Inspection Checklist from Anne Arundel County, MD
- Performance Bond from Colorado

Illicit Discharges
- Fort Worth, TX, Environmental Code: Storm Water Protection
- Washentaw County, MI, Regulation for Inspection of Residential Onsite Disposal Systems at Property Transfer
- Metro. St. Louis Sewer District Sewer Use
- City of Monterey, CA, Storm Water Ordinance
- Montgomery County, MD, Illicit Discharge Ordinance

Postconstruction Controls
- Maryland Department of the Environment Proposed Storm Water Management Regulations
- Grand Traverse County, MI, Soil Erosion and Storm Water Runoff Control Ordinance
- City of Seattle Storm Water, Grading, and Drainage Control Code
- St. Johns River Water Management District, FL: Environmental Resource Permits
- City of Santa Monica, CA, Municipal Code of Ordinances: Urban Runoff Pollution

Source Water Protection: Ground Water Ordinances
- Aquifer Protection District Ordinance from Stratham, NH
- Ground Water Protection and Siting Ordinance from Hernando County, FL
- Ground Water Source Protection Overlay District Ordinance from Salt Lake City, UT
- Sinkhole Ordinance from Lexington, KY
- Wellhead Protection District Ordinance from Weston, WI

Source Water Protection: Surface Water Ordinances
- Tahoe Regional Planning Agency Source Water Protection Ordinance
- Shoreland Management Overlay District Ordinance from Buffalo, MN
- Water Supply Watershed District Overlay Ordinance from Greensboro, NC
- Watershed Management and Protection Area Overlay District Ordinance from County of York, VA
- Town of Skaneateles Lake Watershed District Ordinance, NY

Miscellaneous Ordinances
- Lake Travis Nonpoint Source Ordinance
- Storm Water Utility Ordinance from Takoma Park, MD
- Transfer of Development Rights Ordinance from Sarasota, FL
- Golf Course Management Guidelines from Baltimore County, MD
- Wetlands and Watercourses Ordinance from Croton-on-Hudson, NY
- Forest Conservation Ordinance from Frederick County, MD

(4) *Storm water operation and maintenance ordinance*. The expense of maintaining most storm water management practices is relatively small compared to the original construction cost. Too frequently, however, maintenance is not completed, particularly when the practice is privately owned. Improper maintenance decreases the efficiency of management practices and can also detract from the aesthetics of the practices. The operation and maintenance language within a storm water ordinance can ensure that designs facilitate easy maintenance and that regular maintenance activities are completed.

(5) *Illicit discharge ordinance*. An illicit discharge is defined as any discharge to the municipal separate storm sewer system that is not composed entirely of storm water, except for discharges allowed under an National Pollutant Discharge Elimination System permit or waters used for firefighting operations. These non-storm water discharges occur because of illegal connections to the storm drain system from residential, business, or commercial establishments. As a result of these illicit connections, contaminated wastewater enters storm drains or directly enters local waters before it receives treatment at a wastewater treatment plant. Illicit connections might be intentional or can be unknown to the business owner; often they are the result of connection of floor drains to the storm sewer system. Additional sources of illicit discharges include improperly connected sanitary sewer lines, failing septic systems, illegal dumping practices, and the improper disposal of sewage from recreational activities like boating and camping.

Illicit discharge detection and elimination programs are designed to prevent contamination of ground and surface waters by monitoring, inspection, and removal of these illegal non-storm water discharges. An essential element of these programs is an ordinance granting the authority to inspect properties suspected of releasing contaminated discharges into storm drain systems. Another important factor is the establishment of enforcement actions for those properties that are found to be in noncompliance or refuse to allow access to their facilities.

(6) *Postconstruction runoff control*. The management of runoff from sites after the construction phase is vital to controlling the adverse effects of development on urban water quality. The increase in impervious surfaces such as rooftops, roads, parking lots, and sidewalks due to land development can have a detrimental effect on aquatic systems. High amounts of impervious cover have been associated with stream warming, habitat alteration, and decreased aquatic integrity in urban areas (Karr, 1991; May et al., 1997; Schueler, 1995; Shaver et al., 1994). Runoff from impervious areas can also contain a variety of pollutants that are detrimental to water quality, such as sediment, nutrients, road deicers, heavy metals, pathogenic bacteria, and petroleum hydrocarbons.

The main goal of a runoff management ordinance for existing development is to limit surface runoff volumes and reduce runoff pollutant loadings. For example, the ordinance could specify which nonstructural and structural storm water practices are allowed in the community. Communities might also wish to add language pertaining to on-site runoff requirements, and should identify whether off-site treatment is an option. Example ordinances can be found on EPA's Model Ordinances to Protect Local Resources Web site at http://www.epa.gov/owow/nps/ordinance/index.htm.

(7) *Source water protection ordinances*. Source water protection involves preventing the pollution of the ground water, lakes, rivers, and streams that serve as sources of drinking water for local communities. Source water protection ordinances help safeguard community health and reduce the risk of water supply contamination. When drafting an ordinance aimed at protecting these sources, drinking water supplies can be divided into two general sources: ground water (aquifers and wells) and surface water (lakes and reservoirs). Wellhead Protection Zones and Aquifer Protection Areas are two examples of source water protection ordinances that seek to protect ground water sources. Water Supply Watershed Districts and Lake Watershed Overlay Districts are examples of local management tools that provide protection of surface water supplies by restricting land uses around a reservoir used for drinking water.

(8) *Runoff management ordinances/regulations*. The primary purpose of runoff regulations is to ensure that runoff management systems (within the area of jurisdiction) are properly designed, constructed, inspected, operated, and maintained. A comprehensive ordinance should incorporate the issues addressed below (WMI, 1997b).

(a) *Design and review requirements*. Runoff management systems must be properly designed and constructed to function efficiently. A design manual tailored to local topographic, geologic, and climatic conditions and local regulations should be developed to accompany a runoff management ordinance. National and regional guidance is available to assist local governments in developing technical guidance. For example, the National Association of Homebuilders (NAHB, 1995) has produced a guidance manual entitled *Storm Water Runoff and Nonpoint Source Pollution Control Guide for Builders and Developers* that can be used to develop a technical design manual. The design manual is typically referenced in the ordinance to direct users to technical support for their runoff management projects.

(b) *Construction requirements*. Runoff management facilities can fail prematurely if they are poorly constructed or if sediments and other pollutants are not carefully managed during the construction phase. Techniques for protecting structural practices from construction-related pollution are usually addressed in the state runoff management manual and incorporated by reference into the ordinance. Specific practices to mitigate construction site erosion and control sediment are discussed in Chapter 5 under the construction site erosion and sediment control management measure (8).

To ensure that a facility is constructed properly, a runoff management ordinance should include the following:

- *Financial assurances*. A guarantee, usually in the form of a surety or cash bond, should be made that the completed runoff management facility functions properly. The amount typically should not be less than 50 percent of the estimated construction cost of the system (WMI, 1997b).
- *Inspections*. Inspectors should maintain a presence throughout the construction phase and conduct inspections at specified stages of construction, not at assigned time intervals (WMI, 1997b).

- *As-built certifications and record drawings*. Completed facilities should have official documentation prepared and sealed by a professional engineer or other qualified design professional (WMI, 1997b).
- *Allowances for damage to temporary practices*. Funds should be set aside specifically to repair damage to erosion and sediment controls (e.g., silt fences) at temporary construction sites caused by severe storm flows, high winds, or fallen trees. Funds may be used only if documented inspections show erosion and sediment controls are installed and maintained as required. This allowance helps to ensure 100 percent compliance by contractors (Deering, 1999).

(c) *Operation and maintenance requirements*. Ensuring that runoff management facilities are properly operated and maintained, both in the short term and the long term, is another critical element that should be addressed in the design phase. For the short term, the ordinance should stipulate a warranty period (perhaps one or two years) during which the original developer must retain all operation and maintenance responsibilities. The developer should be required to post a bond or other security to ensure that costs will be covered if any design defects or construction failures are discovered during the warranty period.

Several techniques can be used to ensure longevity of management practices, including warranties, operating permits, and maintenance bonds. Specific requirements for operation and maintenance to be set forth in an ordinance might include the following:

- An easement that provides an access road for maintenance equipment
- Ownership of the system and maintenance access road by those who use the system
- Inspection by a certified site inspector at defined intervals
- Land set aside for disposal of sediments removed during maintenance
- Clear documentation of maintenance responsibilities and maintenance schedule
- A written maintenance agreement

When the initial warranty period is over, long-term operation and maintenance responsibilities typically revert to a property owners' association. Unfortunately, in many instances these types of groups do not perform important operation and maintenance tasks because they lack the financial, legal, and/or administrative capability. Very often, this neglect results in failed systems and problems for downstream property owners. The ordinance needs to incorporate specific elements to ensure that a system is in place for collecting fees, contracting for services, and establishing rules and regulations before a property owners' association is granted authority for long-term maintenance. In some cases, it is more prudent for an alternative entity such as local government, special taxing district, or public utility to be responsible for long-term operation and maintenance functions.

(d) *Maintenance inspection requirements*. Periodic inspections and certifications are necessary to ensure that the legal operation and maintenance entity is keeping the storm water system in good working order and making all necessary repairs. An ordinance needs to include language that identifies the inspectors and specifies how often the inspections are to be conducted. Depending on the framework, inspections could be done by the permitting authority or some other public agency. Alternatively, private inspectors might be used. In either case, inspectors should be required to complete a state-sponsored course and receive certification.

The frequency of inspection depends on the type of management practices employed at the site. Some types of facilities (e.g., a wet pond) might need to be inspected only annually. A sand filter, in contrast, might need to be inspected once a month or even more frequently during the wet season. The entity responsible for maintenance inspections should maintain inspection and maintenance records on file. In addition, procedures need to be established to ensure that problems identified during the inspection process are fixed in a timely manner and that reinspection occurs as soon as practicable.

(9) *Wetlands protection ordinance*. Local governments can protect wetlands by adopting a wetland protection ordinance that supplements the permitting program established under Section 404 of the Clean Water Act (for more information on Section 404, see the Introduction (section 1.2.2 Regulatory Context) or http://www.epa.gov/owow/wetlands/facts/fact10.html). Section 404 does not cover all wetlands, nor does it cover all activities that may infringe on a wetland. A local regulatory program can be used to provide additional protection. A local ordinance should, however, be compatible with, supplement, and/or streamline the Section 404 program while tailoring wetland protection plans to meet local conditions and circumstances (Patton et al., 2000).

Following are some of the important components of a wetlands ordinance (Cowles et al., 1991).

- The applicant should be required to submit a detailed wetland analysis, performed by a trained wetland ecologist, of the subject property, including a professional survey of the wetland edge.
- A wetland should be protected by an adequate undisturbed buffer and placed within a permanent open space or protective easement tract to preclude future subdivision of the wetland.
- Wetlands should not be used as surrogate runoff detention structures. Any runoff directed into a wetland should be pretreated.
- Construction near wetland areas should utilize management practices, including proper placement and installation of sedimentation control and clearly marked limits of construction to avoid inadvertent wetland impacts.
- Non-wetland field staff such as building inspectors, grading inspectors, or any other appropriate staff should be trained to recognize wetlands and to ensure management practices are used and enforced during the construction process.

(9) *Miscellaneous ordinances*. Other ordinances capture issues that are important for protection of water resources but do not fall into a single category. The following are examples of miscellaneous ordinances:

- The Nonpoint Source Ordinance for Lake Travis, which is located along the lower Colorado River near Austin, Texas, addresses techniques required to control nonpoint source pollution from permitted and unpermitted activities.
- The Transfer of Development Rights Ordinance of Sarasota, Florida, allows for the transfer of development rights to protect environmentally sensitive areas from impacts caused by new development by directing new development to less-sensitive areas.

1.3.1.3 Explore market-based regulatory approaches

Water quality trading is a market-based approach to improving and preserving water quality. Trading allows one pollution source to meet its regulatory obligation by purchasing pollutant reductions created by another source that reduces pollution below levels required by federal and state regulations. Trading is a cost-effective solution because pollution control is achieved where the cost is lowest.

EPA is currently targeting water quality trading and providing guidance and procedures. Trading is a possibility in all watersheds, even where water quality is not impaired, but the focus is on watersheds with approved TMDLs. Water quality trading is encouraged for nutrients and sediments. For pollutants other than nutrients or sediment, a higher level of scrutiny would be applied. EPA does not support the trading of persistent bioaccumlative toxic pollutants, or trading where water quality standards would be exceeded.

Water quality programs should include the following provisions for trading:

- Permits under Sections 402 and 404.
- For NPDES permits, information on how trading baselines and conditions have been established and how they are consistent with water quality standards.
- Standard methods for measuring compliance.
- Designated uses to be protected (e.g. the antidegradation policy will be upheld).

Credible trading programs generally include:

- Legal authority and mechanisms
- Clearly defined units of trade
- Creation and duration of credits
- Protocols for quantifying credits and addressing uncertainty
- Provisions for compliance and enforcement
- Public participation and access to information
- Periodic program evaluations

This box is intentionally left empty.

EPA's trading Web site (http://www.epa.gov/owow/watershed/trading.htm) provides a number of resources related to the current policy, new developments, case studies, and links to other trading programs.

1.3.2 Develop an Institutional Structure

The following practices follow the approach presented by the Center for Watershed Protection in the *Rapid Watershed Planning Handbook* (CWP, 1998c). This approach applies mainly to local efforts in small watersheds. State and regional agencies might need to conduct their efforts on a larger scale. Other resources that address establishing a watershed planning framework on a larger scales include *Framework for a Watershed Management Program* (Clements et al., 1996) and *Know Your Watershed* (CTIC, 2000).

1.3.2.1 Establish a watershed baseline

The first step in a watershed assessment process is to gather basic background information about the watershed and subwatersheds. This process can be used as a foundation for developing the rest of the watershed plan.

(1) *Define watershed and subwatershed boundaries*. Watershed and subwatershed boundaries need to be mapped on a good topographic map such as those produced by the U.S. Geological Survey. These maps, an example of which is shown in Figure 1.2, can help in identifying the political jurisdictions and citizens that should participate in the watershed planning effort, and the land use patterns in the watershed and each subwatershed (CWP, 1998c).

(2) *Identify "embedded" agricultural areas*. Livestock waste management is typically not considered an issue in urban areas. However, the urban/suburban landscape can build up around an existing agricultural area, or property owners can board animals on residential property, making animal waste management an important component of maintaining water

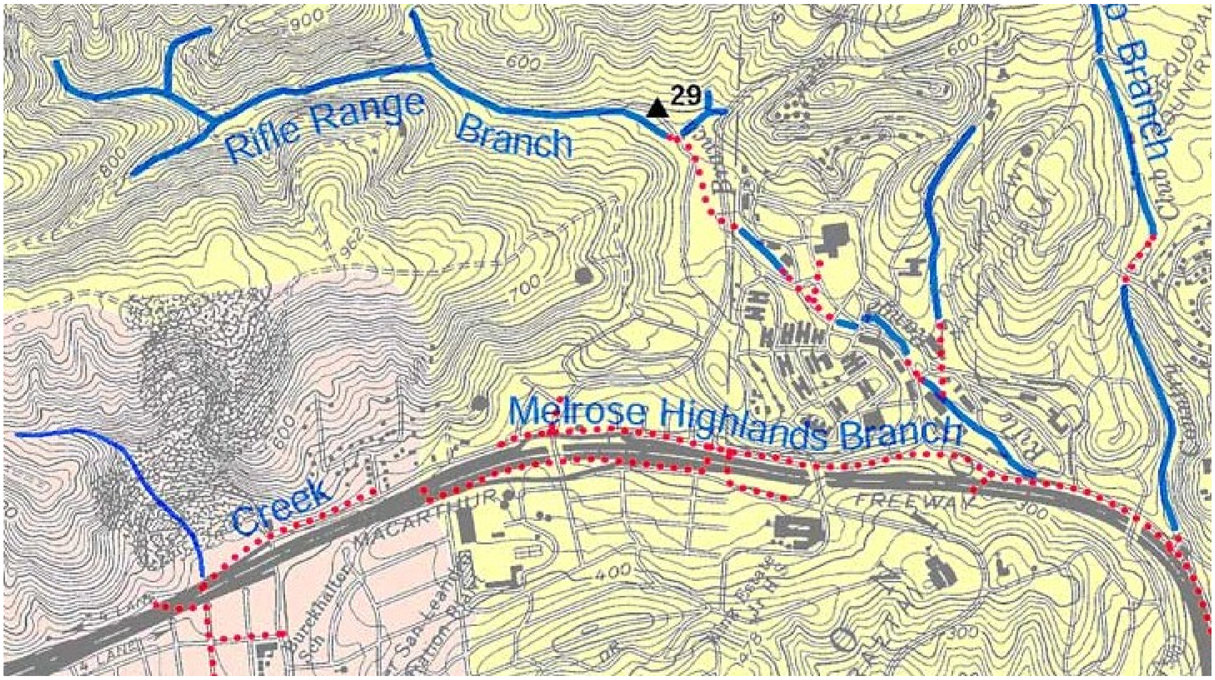


Figure 1.2: Example of part of a subwatershed base map (Oakland Museum of California, No date).

quality in urban areas. Animal wastes from stables or backyard pens contribute nutrients and pathogens to runoff and ground water. Manure can also be a nuisance because of odors and flies, and animals can contribute to the destruction of vegetation through trampling and overgrazing.

Water quality problems can be associated with stables and backyard livestock pens. Management techniques to address these agricultural nonpoint sources include (Terrene Institute, 1994):

- Siting animal areas to drain away from water bodies
- Planting or maintaining as much vegetation as possible between animal areas and water bodies
- Establishing diversions upslope from a high-use area to divert clean water away from bare soils and manure
- Establishing berms or diversions downslope of high-use areas to collect contaminated runoff for treatment
- Establishing fenced areas for animal use to protect vegetation
- Collecting manure and bedding regularly and protecting stored manure from rainfall and runoff

Good Horse Keeping

Horse owners in Massachusetts and the Patriot Resource Conservation and Development (RC & D) Council have launched the Horse Manure Management Initiative (HMMI). The Initiative involves collaboration between horse owners, the Massachusetts Farm Bureau, the Massachusetts Stable Owners, and the Operators and Instructors Association to improve and protect water quality in Essex, Middlesex, Norfolk, and Suffolk counties. The HMMI is focused on education, outreach, and policy initiatives to promote good horse keeping practices and manure management. The Patriot RC&D Council plans to release a *Good Horse Keeping* video and a *Horse Owner Directory and Resource Guidebook* in 2003. For more information, visit http://patriotrcd.org/horse_manure_management.html.

- Applying animal wastes as fertilizer for pastures, croplands, lawns, gardens, nurseries, and greenhouses at rates dictated by soil analyses
- Composting raw manure to reduce bulk, odors, and bacteria

Sources of information for managing pollution from livestock areas include local cooperative extension service offices, soil and water conservation district offices, and U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) offices. NRCS published the *Agricultural Waste Management Field Handbook*, which is a comprehensive guide for livestock operators that provides detailed technical information about practices to properly manage animal wastes (USDA NRCS, 1992). This document can be accessed online at http://www.wcc.nrcs.usda.gov/awm/awmfh.html. Additionally, EPA published *National Management Measures to Control Nonpoint Source Pollution from Agriculture*. This document is available for download from the Office of Wetlands, Oceans, and Watersheds' Web site at http://www.epa.gov/owow.

(3) *Identify possible stakeholders*. Stakeholder participation in planning for watershed management is crucial. Stakeholders have power and a variety of insights that will play a large role in whether the plan succeeds or fails. Stakeholders are affected by the outcome of the watershed plan, have a responsibility for implementing the plan, or have the ability to impede or assist the plan's implementation. See below for a list of organizations and people that might be stakeholders. This group is not limited to people living or working in the watershed or subwatershed delineated on the watershed map. Because several local management units can be encompassed by a single watershed, state, tribal, interstate, and federal officials often are considered stakeholders in a local watershed initiative. In addition to identifying the stakeholders, the planning process should include developing a technical advisory team or committee to assist with the scientific aspects of the watershed program.

Federal Agencies
- Environmental Protection Agency
- Army Corps of Engineers
- Fish and Wildlife Service (Department of the Interior)
- Federal Emergency Management Agency

Nonprofit Organizations
- Greenways coalitions
- "Friends of …" groups
- Watershed coalitions or foundations
- Anglers' groups
- Volunteer organizations
- Recreation/hiking groups

State/Local Agencies
- Environmental or wildlife agency
- Flood control district
- Water rights agency (primarily in the southwestern United States)
- Public works department
- Planning/zoning department or board
- State department of transportation
- Local conservation commissions
- Extension services from land grant universities

Private Sector
- Consulting engineers
- Local businesses
- Real estate companies
- Builders/developers
- Trade associations

Other Citizens
- Local residents
- Schools/teachers
- "Downstream" users (i.e., drinking water consumers)

(4) *Measure existing impervious cover*. The amount of impervious cover is a key attribute of watersheds. The impervious cover model (CWP, 1998a) directly links imperviousness levels to the quality of water resources at the subwatershed scale. Crucial to the use of the model is an estimation of the percentage of the subwatershed covered by impervious surfaces. A number of practices can be used to make this estimate, ranging from measuring cover directly using aerial photographs to predicting cover based on the relationship between imperviousness and population or road density statistics.

(5) *Assemble historical monitoring data*. Most water resources in urban and suburban areas have been monitored at one time or another. The challenge is to identify who has collected data and whether the data are in an accessible and usable form. Often the people that collect data in a particular watershed are also stakeholders or members of the technical committee. Whatever the source, watershed data need to be assessed in terms of quality and usefulness. The technical advisory team plays an important role in this endeavor. Once organized, historical data provide the background knowledge necessary for guiding the other steps of the local watershed planning process.

(6) *Assess existing mapping resources*. Resource maps are used to present many aspects of the watershed management plan in a clear, reader-friendly format. Natural and cultural features that can be included on a resource map are:

- Floodplain boundaries
- Stream corridors
- Soils and geologic features
- Current and future land use
- Transportation routes
- Buffers
- Wetlands
- Detention/retention ponds
- Direction of drainage

(7) *Conduct an audit of local watershed protection capabilities*. A sometimes overlooked but very important task associated with baseline assessment is a critical evaluation of local capabilities to implement watershed practices. The audit should be as complete as possible and should include examination of local programs, regulations, ordinances, master plans, staff resources, and funding. If deficiencies or potential problems are found, the audit can be used as a basis for making changes.

Watershed Assessment, Tracking, and Environmental Results

EPA has developed an integrated information system for the nation's surface waters that combines data from various EPA Office of Water programs into one large framework. Data from the information system, Watershed Assessment, Tracking and Environmental Results (WATERS), is available online through interactive Web-based applications and mapping tools. The following is a list of programs that are incorporated or scheduled to be incorporated into the database:

- *Water Quality Standards*: The Water Quality Standards Database contains information on designated uses for waterbodies
- *Water Quality Inventory 305(b) Report*: The National Assessment Database includes information on the attainment of water quality standards. Waterbodies are classified as Fully Supported, Threatened or Not Supporting these designated uses.
- *Total Maximum Daily Load 303(d) List*: The TMDL Tracking System provides information on waterbodies that are designated as Not Supporting. These waterbodies are required by law to have TMDLs developed, and the database tracks the status of those TMDLs.
- *Water Quality Monitoring*: The STORET database contains water quality, biological and physical data.
- *NPDES Permits*: The Permit Compliance System stores data on NPDES facilities, permits, compliance status, and enforcement activities for up to six years.
- *Safe Drinking Water*: The Safe Drinking Water Information System contains information on public water systems and drinking water standard violations.
- *Fish Consumption Advisories*: The National Listing of Fish and Wildlife Advisories database includes information on fish consumption advisories issued by states, tribes, and the federal government.
- *Nonpoint Source Pollution*: The Section 319 Grants Reporting and Tracking System is a compilation of information on projects and activities funded by CWA Section 319(h) funds.
- *Nutrient Criteria*: The Nutrient Criteria Database stores and analyzes nutrient water quality data.
- *The BEACH Program*: The Beaches Environmental Assessment, Closure & Health (BEACH) Watch database provides information on whether a specific beach is being monitored for water quality, the party responsible for the monitoring, the pollutants that are being monitored, and advisories or closures that have been issued.
- *Vessel Sewage Discharge*: Vessel sewage discharge is regulated under Clean Water Act Section 312, which mandates the use of marine sanitation devices (on-board equipment for treating and discharging or storing sewage) on all commercial and recreational vessels that are equipped with installed toilets. Under Section 312 States may request a No-Discharge Zone designation that prohibits the discharge of sewage from all vessels into defined waters.

The WATERS database can be accessed online at http://www.epa.gov/waters.

1.3.2.2 Set up an institutional structure

A successful runoff management program requires a strong institutional structure (CWP, 1998c). A typical institution carries out many functions, including:

- Setting goals for the watershed and subwatersheds
- Identifying gaps in monitoring data and taking steps to acquire needed information
- Operating as a forum for stakeholder input
- Reviewing and prioritizing management strategies to achieve maximum watershed protection
- Establishing links with other groups and agencies
- Encouraging cooperative exchanges of information
- Providing funding for planning actions and exploring funding options for management practice implementation
- Ensuring long-term implementation of the runoff management plan

Key attributes needed to perform these functions are:

- Adequate permanent staff to perform facilitation and administrative duties
- A consistent, long-term funding source to ensure a sustainable organization
- Inclusion of all stakeholders in planning efforts
- A core group of dedicated people that have the support of local governmental agencies
- Local ownership of the runoff management plan throughout the process
- A process for monitoring and evaluating implementation strategies
- Open communication channels to increase cooperation among organization members

There are three types of runoff management institution models:

- Government-directed model
- Citizen-directed model
- Hybrid model

The primary difference among the three management options is the authority that is ultimately responsible for directing the watershed plan. In the government-directed model, local or regional agencies assume responsibility for making decisions about how the watershed is managed. The citizen-directed model is driven by citizen activists or grassroots organizations, and the hybrid model combines the best of both models and is recommended for most watersheds. Each paradigm has particular strengths and weaknesses, but whatever form the model takes, the framers of the institution must define its goals and carefully lay out the responsibilities and contributions that will be made by each element. Table 1.3 compares the typical components of the three models, lists advantages and disadvantages associated with each model, and specifies conditions where each model might best be applied.

Table 1.3: Elements of three watershed management structures (CWP, 1998c).

Element	Government-Directed Model	Citizen-Directed Model	Hybrid Model
Formation	Created by legislative authority.	Created at grassroots level by citizens or other interested parties.	Created with some governmental authority and support from citizens.
Membership	Organization membership appointed by governmental authority.	Stakeholder participation is voluntary.	Some members are required to participate, but many are volunteers.
Authority	Structure has regulatory authority over land use and other permits.	Advisory capacity with no regulatory authority over land use or permits.	Some members of the structure have regulatory authority; others act in a volunteer or advisory capacity.
Funding	Funding is through taxes or levied fees.	Funding is by grant, donations, or sometimes local government contributions.	Much of the funding is through a steady source, such as an agreement with a local government, but grants might also compose a significant portion of the budget.
Implementa-tion	Government agencies at the state, local, and federal levels implement the plan.	Local governments implement the plan.	Local governments implement the plan with some assistance from state and federal agencies.
Advantages	Has legal authority to influence development. Has a secure funding source. Consistent staff are available.	Local community has ownership in the plan. No stakeholders are forced to participate. Residents are less intimidated by other citizens than by the government.	Has some authority to implement the plan. Incorporates stakeholders from the public and the government. Usually has some stable funding source and permanent staff. Technical expertise from many sectors can be used to formulate the plan.
Disadvan-tages	Might not incorporate all interests. Citizens and local governments might not have a sense of ownership in the process.	Might be difficult to secure a stable funding source. Implementation might be difficult without legal authority. Because most members are volunteers, it might be difficult to complete the plan quickly. The most vocal groups might be over-represented.	Demands significant input from citizens and government.
Where best applied	Where the plan will require extensive regulations and land use rules to implement. Where the local community cannot raise the funds to develop and implement a plan. Where the community is not strongly mobilized to take the initiative.	Where the local community has a very strong interest in the water resource. Where the local government has an excellent relationship with local citizens' groups and developers. Where some external funding source, or a steady supply from local governments, can support the citizen groups. Where disagreements between different interests are not expected to slow the group's progress.	Most watersheds.

(1) *Government-directed model*. In this model, an agency of government takes on the responsibility for determining the goals of the runoff management program and directing the means by which those goals are met. Such a structure can consist of one agency vested with regulatory responsibility or a coalition of agencies from the local, state, and federal levels.

The program framework under the government model is strong because of its legal authority and consistent funding, whether required by legislation or instituted as a reflection of an administrative priority. Government involvement ensures that the management process draws on broad public goals and balances the utility of various courses of action. However, government-directed programs often do little to raise public awareness of the need for resource protection, and if a government-led watershed management plan makes inadequate provisions for public input, feelings of disenfranchisement can result. In addition, interagency rivalry can hamper the effectiveness of a government-led management structure.

The government-directed model is frequently employed when a government agency is best positioned to address a particular problem, or when public interest and awareness are not sufficient to motivate citizen participation in the runoff management process.

(2) *Citizen-directed model*. This type of framework is highly legitimate in the public eye because it concentrates heavily on co-opting public involvement throughout the management process and gives the public a strong sense of ownership of the plan. Management recommendations coming solely from the community have no legal authority, however, and community leaders must rely on their ability to engage and motivate governmental entities to accomplish their goals. For that reason, the citizen model usually is effective only where there is a healthy relationship between community leaders and local government.

(3) *Hybrid model*. A quasi-governmental structure, a hybrid runoff management institution is designed to combine legislative authority with technical advice, allowing additionally for stakeholder and citizen input. By representing both government and citizen interests, the model usually provides the most effective means of incorporating public opinion and activity into the needs of the locality and watershed. The specific form that a hybrid management structure takes depends on a variety of factors, but it will usually concentrate heavily on incorporating as many stakeholders as possible into the watershed planning process. Hybrid structures are not vested with regulatory authority but use one of several structures to recommend courses of action to the governing body and plan and implement runoff management practices.

1.3.2.3 Determine budgetary resources available for watershed planning

One of the most important challenges confronting a watershed manager is how to develop watershed and subwatershed plans within existing budget constraints. The manager needs to identify what sources of funding are available and develop budgets for the subwatershed and watershed plans. The cost of a watershed plan varies depending on choices the watershed manager makes regarding mapping, monitoring, modeling, and ongoing management. The budget also depends on the area and complexity of the watershed and its subwatersheds.

1.3.2.4 Project future land use change in the watershed/subwatershed

Land use in a watershed and individual subwatersheds has a strong influence on aquatic ecosystems. Current impervious cover should have been measured as a part of the watershed baseline analysis. The watershed manager needs to forecast the future impervious cover based on available land use planning information, such as existing zoning or master plans.

Impervious cover projection helps watershed managers determine if aquatic resources will degrade from current conditions (see Section 6 of the Introduction for more information about impervious cover). If the analysis indicates that impervious cover will increase to such an extent that it will cause subwatershed quality to decline, a watershed manager should consider shifting impervious cover to another watershed or limiting development.

Southeastern Delaware Whole Basin Management

The Delaware Department of Natural Resources and Environmental Control (DNREC) and Sussex County officials developed a phased process to manage the Inland Bays Basin that combines an assessment program with an implementation plan to solve water quality problems affecting Rehoboth, Indian River, and Little Assawoman Bays (Delaware DNREC, 2000). They identified excessive nitrogen and phosphorus as the most pressing water quality problems in the basin. They attributed the elevated nutrient levels to both urban and agricultural sources, including

- Failing or inadequate septic systems.
- Sewage treatment plant effluent.
- Fertilizer application for residential and commercial landscaping.
- Construction site sediment export.
- Exhaust emissions.
- Open burning.
- Field application of manure to crops.

They also assessed biological populations and identified priority communities and species that warrant special protection.

To begin implementing a whole basin management program, the Delaware legislature established the Center for the Inland Bays in 1994. In 1998 the Center initiated a Tributary Strategy Program that organized stakeholders into three Tributary Action Teams, which assist the Center in reducing nutrient inputs to the bays and restoring habitat. They are also assisting DNREC in developing pollution control strategies to meet TMDLs for nutrients. In 1999 the Delaware House of Representatives passed Resolution 32, which established a multijurisdictional committee to

- Assess progress toward implementation of the Land-Use Action Plan of the Inland Bays Comprehensive Conservation and Management Plan.
- To identify areas where implementation has not been achieved.
- To recommend changes to Sussex County's Comprehensive Plan and implement zoning and subdivision ordinances.

Finally, in 1999 the Delaware Legislature passed the Delaware Nutrient Management Law, which established the Delaware Nutrient Management Commission. The purpose of the Commission is to develop a program to address nutrient inputs from both agricultural sources and urban sources such as golf course landscape operations, residential inputs, and residential and commercial fertilizers.

Regardless of the forecasting option chosen to estimate future impervious cover, it is important to verify and adjust the estimate periodically. This adjustment helps ensure that land use planning tools for the watershed result in the desired level of impervious cover needed to maintain the management strategy of each subwatershed.

1.3.2.5 Develop subwatershed plan

Based on the information obtained in the preceding steps, the watershed manager should determine what goals and objectives are appropriate in the watershed and its individual subwatersheds. Goal-setting is among the most important steps in watershed planning, and the management structure should ensure full involvement from stakeholders at this stage.

A subwatershed plan is a detailed blueprint to achieve the established subwatershed objectives. A typical plan may include revised zoning, management practice regulations, proposed management practice locations, description of proposed new programs, estimates of budget and staff needed to implement the plan, stream buffer widths, or monitoring protocols.

The plan should target the subwatershed objectives with the combination of management practices that is most economical, effective, and feasible. Implementing management practices by planning on the subwatershed scale can increase cost-effectiveness and water quality benefits. A combination of nonstructural, on-site, regional, and channel stabilization practices specifically tailored to the subwatershed will help to maximize these benefits. Pollution prevention and nonstructural practices are key, as they can reduce the generation of pollution and its exposure to rainfall and runoff. In addition, implementing site-dispersed, low-impact development practices can help to control both runoff quality and quantity at the site level. Ensuring that drainage channels and floodplains are stable will provide protection against flooding and serve to buffer receiving waters. Finally, regional runoff control and treatment practices are a last line of defense to control flooding and reduce pollution. The following are descriptions of each type of practice and how they can meet water quality objectives in a subwatershed:

- *Nonstructural practices*. Pollution prevention and nonstructural practices are effective in reducing the generation of pollution and its exposure to rainfall and runoff. These practices help to increase public awareness, and can reduce the need for pollutant removal capacity in runoff treatment controls and the burden of maintaining those controls. Used alone, however, nonstructural practices do not provide a comprehensive solution for runoff management. While various techniques have been developed to qualitatively measure the effectiveness of nonstructural practices, it is difficult to gauge their direct water quality benefits.
- *Site-dispersed (on-site) practices*. Site-dispersed, low-impact development practices control runoff quality and quantity at the site level and reduce the flow volume and pollutant load that reaches drainage channels. In addition to these benefits, infiltration practices can be a source of ground water recharge and reduce the frequency of combined sewer overflows (CSOs). They require less land area and can provide aesthetic benefits. These practices can also provide cost savings from both reduced construction costs and lower maintenance requirements. On the other hand, responsibility might fall on the property owner to inspect and maintain the practices. In addition, on-site treatment

practices only treat the first ½ inch to 1 inch of runoff, and the rest is bypassed. They are, however, good first practices in a system of storm water management practices.

- *Regional (off-site) practices*. Regional runoff control and treatment practices act as a last line of defense to control flooding and reduce pollution. The advantages of regional controls are that they are easier to maintain and do not require the actions of the property owner; they can provide aesthetic and recreational benefits; and they can be cost-effective due to the economy of scale. However, a regional pond offers no protection to upstream tributaries, and placement in low-lying areas may hurt natural wetlands. Communities may also have to address safety and liability considerations.
- *Stable drainage channels*. Stable drainage channels and floodplains are important for protection against flooding and as buffers for receiving waters by filtering pollutants and preventing erosion. Riparian areas can provide aesthetic and recreational benefits as well as wildlife habitat. Restoring stream channels and riparian areas can, however, be expensive, and is not feasible when development exists along drainage channels or restoration conflicts with landowner use of streamside property.

Regional vs. On-Site Development Regulations

In anticipation of dramatic growth in the next decade or two, the city of Seattle, Washington is considering the development of an integrated drainage plan to address storm water at the subwatershed level rather than on a project-by-project basis. One of the options being considered is the establishment of off-site mitigation programs in urban jurisdictions. These programs allow developers to meet on-site development requirements relating to storm water by compensating the municipality to provide equivalent mitigation in an off-site public facility. In a case study, Maupin and Wagner (2003) explore the costs and benefits of regional and onsite management practices. The authors determine that an offsite mitigation program might be beneficial if the municipality has storm water management obligations, has the authority to regulate development, requires on-site storm water management on new development or redevelopment projects, and cost, water quality, or community benefits may result from off-site treatment. Because it shifts the maintenance burden to the municipality, it may not be appropriate in all cases (Maupin and Wagner, 2003).

Targeting Runoff Treatment Practices for Temperature Control

In the Token Creek Watershed in Dane County Wisconsin, a proposed 492-acre development for single-family homes posed concern for regulators regarding Token Creek, a cold water stream that is a major tributary to Lake Mendota. Managers identified three major goals for the watershed: reduce overall sediment and nutrient flows to Lake Mendota; protect the water quality in Token Creek, primarily regarding sediment and water temperature; and implement practices that will be aesthetically pleasing and increase property values. Managers recognized that traditional treatment practices such as storm water ponds and wetlands (for more information, see Management Measure 5) would not protect the stream from the potential thermal impacts of runoff from a highly developed area. Instead, the channel was lined with rock to provide infiltration, heat dissipation, and erosion control, and rock-filled gabion dams were installed. The Temperature Urban Runoff Model (TURM) was used to estimate water quality benefits. Modeling results predicted a 10.7 degree Fahrenheit increase in water temperature with the practices installed, as opposed to a predicted 21.6 degree increase without the practices (Dorava et al., 2003).

1.3.2.6 Adopt and implement the watershed plan

The best way to ensure that a plan is implemented is to incorporate the right stakeholders, realistically assess budgetary resources, develop a scientifically and economically sound plan, and mandate the plan's use and implementation. During and after plan development, watershed managers need to ensure that local governments have both the regulatory authority and the resources to implement the plan.

Watershed managers need to identify funding sources to support plan implementation. One of the greatest costs of watershed implementation is the staff resources needed to continue monitoring in the watershed, design and build retrofits and new management practices, and enforce the ordinance and laws called for in the plan.

1.3.2.7 Revisit and update the watershed and subwatershed plan

A one-time watershed study only identifies the problems that exist in a watershed. Many local governments, for one reason or another, take on watershed planning without realizing that it is a process rather than a report. Watershed and subwatershed plans should continue to be updated and revised as the watershed management process evolves and problems are identified.

1.3.3 Provide Adequate Funding and Staffing

Implementing an urban runoff control program requires funding to support programs and provide staff. Local and state governments can provide revenue from the tax base, but environmental programs often come up short when they compete with other municipally funded projects. Alternative borrowing and fundraising techniques can be used to provide additional money for water quality projects.

A variety of resources for financing information are available. The Environmental Finance Center, sponsored by EPA and the University of Maryland Sea Grant College, was created to assist local communities in finding creative ways to pay for environmental projects. The Center promotes alternative and innovative ways to manage the cost of environmental activities, provides training and development opportunities in environmental management, and works to increase awareness of the benefits associated with sound environmental management policies. In addition, the Center serves as a national repository and clearinghouse for environmental finance-related information, including information from EPA, the Environmental Financial Advisory Board (EFAB), and the Environmental Financing Information Network (EFIN), as well as other Environmental Finance Centers (EFCs) across the nation. More information about the technical assistance and support the Center provides, such as workshop and conference sessions, problem-solving roundtables for communities, watershed management training sessions, and utility rate design assistance, is provided at http://www.mdsg.umd.edu/EFC (EFC, 2000).

Another source of financing information is the Florida Stormwater Association (FSA), which was formed to assist professionals in both the public and private sectors who work in the storm water management and finance areas. FSA provides online services to its members, including a newsletter, storm water utility survey, access to local ordinances, and the FSA membership directory. For more information about FSA, refer to http://www.florida-stormwater.org/ (FSA, 2000).

City of Lenexa, Kansas, Sales Tax Increase

The City of Lenexa, Kansas, passed a 1/8-cent sales tax to help fund a new storm water program. The initiative includes the construction of multipurpose lakes and other storm water facilities to reduce flooding, improve water quality, and provide recreation for the citizens of Lenexa. The program differs from conventional storm water programs in that it also focuses on water quality and recreational opportunities. Most storm water programs focus only on preventing flooding. Revenue from the sales tax will be used to

- Construct lakes, detention basins, and sport fields.
- Acquire land in key locations before development occurs.
- Address existing problems in developed areas.

Other sources of revenue for the program include an annual $30 per home utility charge, a new development charge, and existing revenue sources such as a mill levy and Johnson County storm water funds.

The city's watershed management program will be implemented by constructing new facilities, improving the management of existing facilities, establishing development policies and processes, and implementing activities to ensure compliance with new regulations associated with the Clean Water Act. Lenexa has recently inventoried critical natural areas in the city to provide guidance for conserving, protecting, and restoring natural resources. Stream restoration opportunities in developed areas of the city will be identified, along with measures to address flooding. Lenexa encourages citizens to participate in the Watershed Management Program and offers tips for improving the quality of urban storm water runoff.

For more information about the Lenexa Storm Water Management Plan, contact Lenexa Public Works at 913-477-7680 or refer to http://www.ci.lenexa.ks.us/Stormwater/intro.html (Lenexa, No date).

Finally, the Center for Urban Policy and the Environment at Indiana University–Purdue University Indianapolis (2001) developed *An Internet Guide to Financing Stormwater Management*. This guide, located at http://stormwaterfinance.urbancenter.iupui.edu, is designed to help communities find ways to pay for storm water management projects. The site includes an annotated bibliography of existing storm water finance materials, an archive that contains selected previously published materials concerning storm water finance, a manual that discusses the financing options available to communities for storm water management programs, a set of case studies that describe successful finance mechanisms that have been used in seven communities around the country, and a group of links to other useful Web sites about storm water management.

Several mechanisms that watershed managers can use to secure funding for their storm water programs are described below.

1.3.3.1 Taxes and fees

Municipalities often use taxes to fund environmental programs, but the taxes are not dedicated for a specific purpose and may be allocated to other, non-environmental programs. Fees are another method that can generate money for environmental programs. Table 1.4 outlines several kinds of taxes and fees that are appropriate for financing storm water management programs.

Table 1.4: Types of taxes and fees that can be used to raise money for storm water management programs (adapted from USEPA, 1994).

Tax or Fee	Description
Property and sales taxes	Charged as a percentage of property value or gross sales.
Real estate transfer taxes	Assessed as a percentage of property values when property is sold.
Commodity taxes	Charged on specific items such as gasoline and hunting and fishing equipment.
Tax surcharges	Added to established tax rates.
Tax incentives	Offer tax reductions as state tax credits, deductions, or rebates.
Tax disincentives	Fees, taxes, or price increases to discourage the use of an inefficient product.
Tax differentiation	Tax charged on an inefficient product to encourage the use of an efficient substitute.
Selective sales tax	In the form of a retail tax or an inspection fee.
Tax increment	Financing incremental increases in real estate taxes to repay the original investment in improved public facilities that resulted in increased real estate values.
Plan review fees	Collected to conduct development plan reviews to ensure they meet requirements.
Storm water utility fees	Imposed on property owners based on amount of runoff generated, impervious area on the property, or the assessed value of the property.
Impact fees	The cost of infrastructure services is paid up-front by fees collected from developers or property owners.
Inspection fees	Collected to ensure that development plans are properly implemented.
User fees	Directly tied to the use of a resource or facility and especially useful at the local level where user groups are easily identified.
Capacity credits	Private interests guarantee future capacity in a public facility and provide additional funding to local governments for project completion.
Effluent discharge fees	Levied on an industrial facility based on the volume of pollutants discharged. Can be used to meet water quality objectives, to cover costs of pollution abatement, or to meet effluent standards. Provides economic incentive to reduce pollution output and is an equitable method for funding pollution control projects.

1.3.3.2 Bonds

Several kinds of bonds can be used to fund projects over the long or short term. Long-term bonds provide funding for the duration or life expectancy of the project and can be paid back all at once at the end of the project or little by little until the end of the project. Short-term bonds provide interim funding for long-term projects that have not yet been financed. There are also general obligation bonds, which are issued by state or local governments and are repaid using taxes and other revenues. Revenue bonds are also issued by state or local governments, but they are repaid using income or funds generated by the project itself. Finally, state revolving funds, which are long-term, low-interest loans to local governments or individuals for capital investments, can be used to fund storm water projects. Repayment allows the fund to revolve its lending ability continuously. The fund is intended to provide a permanent source of financing for state and local water quality projects and can be used for many different projects, including:

- Construction of wastewater treatment plants
- Implementation of approved state nonpoint source management programs and ground water protection strategies under section 319 of the Clean Water Act

– Development and implementation of estuary comprehensive conservation and management plans under section 320 of the Clean Water Act

1.3.3.3 Leases

A municipal lease grants the lessee the option of applying lease payments to the purchase of the facility. The lessee is responsible for paying taxes on the property. Leases can be used to finance the purchase of environmentally sensitive areas, land for wetland restoration, or other projects. A sale/lease-back arrangement allows the owner of a facility to sell it to another entity and subsequently lease it back from the new owner. This arrangement can provide alternative financing for a facility and may limit a government's liability.

1.3.3.4 Intergovernmental transfers and assistance

Grants are awarded to state or local governments for assistance in meeting national environmental quality goals. EPA establishes the criteria that must be met before receiving funds, while section 319 of the Clean Water Act allocates federal funds to states for implementing approved nonpoint source management programs. The grant money can also be used for postimplementation monitoring and groundwater assessment as part of an approved NPS pollution control program.

The conservation districts in Delaware have a conservation cost-share program that is funded by the state. Each of the three districts currently receives approximately $300,000, plus an additional $175,000 for nutrient management program practices. Most of the urban management practices involve backyard drainage projects, streambank erosion control, rehabilitation of storm water management ponds, urban flood control projects, tree plantings in community open space, conservation windbreaks, and debris pit remediation, and they can include assisting a community with an engineering study to determine solutions for a problem. Each conservation district determines the priority areas for the conservation funding, with the most urban BMPs implemented in New Castle County. Depending on the practice, the landowner pays 25 to 50 percent of the costs (Mickowski, 2004).

Using Clean Water Act Funds for Water Quality Improvements

The Delaware Department of Natural Resources and Environmental Control (DNREC) is using the Clean Water State Revolving Fund to effect water quality improvements. Practices implemented with the funds include wastewater collection to eliminate 300 failing onsite wastewater treatment systems and prevent 594 new systems; replacement of failing onsite wastewater treatment systems; sediment and storm water management practices; water body restoration practices such as stream bank stabilization, wetland restoration, and riparian buffer installations; land purchases and conservation easements for water quality protection; and implementation of Comprehensive Conservation and Management Plans for the Delaware Estuary and Delaware Inland Bays. For more information on the Clean Water State Revolving Fund, see http://www.epa.gov/owmitnet/cwfinance/cwsrf.

1.3.3.5 Public-private partnerships

The private sector can invest in public-sector facilities. This approach reduces the financial burden for the public sector through cost sharing and is especially appropriate when neither the public nor private entities can fund the projects themselves. However, there might be political opposition from government workers or negative public opinion due to private ownership and operation of a public facility, even though private operations are often more cost-efficient, provide a higher level of service, and require less implementation time than public operations.

1.3.4 Foster Input from Technical Experts, Citizens, and Stakeholders

Most runoff management institutions require input from three groups of people—technical experts, citizens, and stakeholders—to plan and implement successful runoff management practices. Technical committees are often set up to provide expertise on scientific issues, while citizen advisory and stakeholder committees afford the public a chance to include their opinions in the management process.

1.3.4.1 Technical committees

The central principle of technical committees is that proactive involvement of all stakeholders will result in greater watershed improvements because actions will have the approval of all interests. Ideally, members of the technical committee are also agency representatives in the larger management institution. Members may include representatives from the state and county natural resources, environment, planning, health, and water resources management entities. In addition, federal agency representatives and individual citizens with expertise in scientific fields or engineering may participate. The technical committee evaluates monitoring data and identifies data gaps, coordinates monitoring efforts within the watershed to obtain missing data, evaluates proposed regulatory or land use changes with respect to their potential impact on the watershed resource, interprets scientific data for the watershed management institution, and assesses and coordinates currently approved implementation projects.

1.3.4.2 Citizen committees

A citizen committee is open to all citizens and provides direct feedback to the management institution on public sentiments regarding the planning process. The review of citizen concerns in a comprehensive process is critical in gaining community support. Some of the possible functions of a citizen committee include organizing public outreach and community awareness projects, such as tree planting days, stream cleanups, storm drain system stenciling, watershed awareness days, and volunteer activities, and exploring funding sources and grant-writing. In addition, such a committee might organize media relations and publicity programs such as press releases, informational flyers, and watershed awareness campaigns; act as a liaison between citizen groups and government agencies; and establish early stakeholder and public involvement.

Creating Quality Places Program, Kansas City, Missouri

The “Creating Quality Places: Successful Communities by Design” is a program of the Mid-America Regional Council (MARC), which represents city and county governments in the bistate Kansas City metropolitan area. The program, which is partially supported with resources from EPA’s Sustainable Communities Challenge Grant Program, is aimed at developing a better quality of life in neighborhoods throughout the Kansas City region. Creating Quality Places is divided into two phases. In the first phase, 20 quality principles were identified to guide future development. These principles offer the best means for the region to grow, while also preserving and enhancing the quality of life enjoyed by residents. The second phase of the program focuses on the means for implementing these principles.

Creating Quality Places was a coordinated effort between multiple stakeholders. In the first phase, a steering committee and three advisory committees were convened by MARC to ensure broad stakeholder representation. The steering committee, which included elected officials, developers, civic leaders, citizens, planners, and representatives of other stakeholder groups, provided input and direction throughout the proceedings. The three advisory committees provided specific and technical input during deliberations. These committees each represented a specific sector of the development arena and included mayors, city council members, county commissioners, planning commissioners, city managers, planning directors, park professionals, public works professionals, developers, builders, architects, and engineers.

The initial quality principles were developed by merging the principles devised by each of the four committees. At a joint session of the four committees, the combined principles were reviewed, strengths and weaknesses of each were identified, and the principles were edited. The edited principles were then reviewed through a questionnaire, which was administered at public forums conducted for each topic area. The steering committee and advisory committees conducted a final review, and the quality principles were finalized. This development and review process allowed stakeholders to be involved throughout the entire process.

MARC also ensured stakeholder involvement by organizing public forums to establish dialogue on quality development issues and to raise awareness about land use and development practices. The forums consisted of two parts. The first part was a session at which national speakers and local panels discussed issues, and the second was a workshop that provided steering and advisory committee members with an opportunity to ask questions and discuss concerns.

For more information about the quality principles, including specifics of the final 20 quality principles, resources for implementing the principles, and case studies of how other communities are using the principles, refer to www.qualityplaces.marc.org (MARC, 2000).

1.3.4.3 Stakeholder committees

Stakeholder committees address the goals and opinions of the agencies, organizations, or individuals directly affected by management activities in the watershed. The incorporation of stakeholder views into the development of the watershed plan is crucial to building consensus and gaining support for future implementation. Typical stakeholders involved in the watershed planning process include:

- Conservation groups (e.g., Trout Unlimited, Save our Streams, Bass Masters)
- Developers
- Homeowners
- Citizen associations

- Farmers
- Industrial and commercial business interests
- Utility companies

Other groups, such as trade associations, research and academic institutions, sporting groups, and individual citizens, might also wish to be involved in the process. When planning occurs at the watershed level or higher, local and regional offices of federal agencies will also often decide to become involved. By placing the emphasis for watershed management on the subwatershed level, the number of stakeholders guiding plan development will be much more manageable.

Early and frequent involvement of stakeholders is a key ingredient in building support for the subwatershed management process. Stakeholders should be given a meaningful and well-defined role in the formulation of management plans. Sharing data and mapping, establishing goals, setting priorities, developing management criteria, measuring success, and reviewing and approving subwatershed plans will strengthen stakeholder ownership in the plan.

1.3.5 Establish Intergovernmental Coordination

The watershed management institution's primary responsibility is to oversee the execution of a watershed management plan. The management institution focuses the diverse stakeholders in a watershed into a viable group capable of guiding implementation. The institution is also responsible for the timely preparation and implementation of the watershed plan and its revision as project goals are achieved or changed. Communities might elect to create a single authority for an entire watershed, or a series of smaller authorities at the subwatershed level. The effectiveness of the management institution is dependent upon its ability to forge all interagency or multi-jurisdictional partnerships and agreements necessary to support the organization over the life of the planning process.

Intergovernmental coordination is essential when establishing a watershed management program, especially when the watershed extends over more than one political jurisdiction. Without the participation of a broad spectrum of local, state, and federal agencies, most watershed planning endeavors will not have the financial or information-gathering resources required to continue beyond initial start-up efforts. Interagency coordination requires sharing of resources and data, joint development and endorsement of a watershed management plan, and continued participation of all agencies. Care must be taken to avoid interagency rivalries or miscommunication.

The first step in fostering interagency coordination is the establishment of a watershed management institution. One instrument that has been used to steer this process is the Memorandum of Understanding (MOU). An MOU is an agreement by government agencies and local stakeholder representatives to work together in the creation of a watershed planning strategy. MOUs are widely used because agencies can enter into these agreements while retaining their jurisdictional and budgetary appropriation authority. MOUs are not legally binding contracts. Instead, the points in an MOU are presented in a broad manner to facilitate consensus. Typically short (one or two pages), these agreements outline the goals and objectives for the watershed management institution. The basic contents of an MOU are:

- Identification of the parties involved in the process
- Vision statement
- Purpose of the MOU (issues to be addressed by the agreement)
- Pact to provide assistance to the partnership for coordination of planning efforts under a central management organization
- Resolution to use the watershed plan as guidance in future land use or water management decisions
- Signatures of all partners involved

Philadelphia's Office of Watersheds

In 1998, the Office of Watersheds was created within the Philadelphia Office of Water. The new department is charged with administering a watershed management program that integrates combined sewer overflow, storm water management, and drinking water source protection. The watershed approach focuses on regional and local partnerships and supports watershed initiatives at the local level through innovations and demonstrations, and by facilitating cooperation between stakeholders. The Office of Water's "watershed technology center" is a central repository of technical support such as Geographic Information Systems, information technology, and model development for the various watershed programs. The office is working with local watershed organizations, academic institutions, and other agencies to pursue funding for demonstration projects, streambank restorations, and information collection for regional watersheds (Neukrug, 2003; WERF, 2000).

1.3.6 Develop Training and Education Programs and Materials

Training programs and educational materials designed for people directly involved in the design and implementation of a runoff management program are essential. Most states and many local governments have developed guidance manuals, workshops, and other educational opportunities to assist developers, site designers, contractors, plan reviewers, consultants, inspectors, and others in understanding and complying with runoff management goals and objectives.

Most states make education and training voluntary. A few states, however, including Delaware, Florida, Maryland, South Carolina, and Virginia, have made professional educational programs mandatory by law or regulation. Delaware, for example, requires that "all responsible personnel involved in a construction project will have a certificate of attendance at a Department-sponsored or approved training course for the control of sediment and storm water before initiation of land disturbing activity." The state provides personnel training and educational opportunities for contractors to meet this requirement, and has delegated program elements to conservation districts, counties, and other agencies.

In addition to professional audiences, the public can greatly benefit from runoff management education and training. Public awareness of program goals leads to greater support. Awareness can be achieved in many ways, including workshops, brochures, meetings, and media campaigns, as well as hands-on projects like storm drain stenciling and stream clean-ups.

Watershed citizens can and do play an important role in controlling nonpoint source pollution. Consequently, they need to acknowledge and be educated on pollution prevention issues and activities. Management practices concerning this topic are discussed in greater detail under the Management Measure 9: Pollution Prevention.

1.4 Information Resources

An Internet Guide to Financing Stormwater Management is a Web site presented by the Center for Urban Policy and the Environment (2001) at Indiana University-Purdue University Indianapolis. The site includes an annotated bibliography of existing storm water finance materials, an archive that contains selected previously published materials concerning storm water finance, a manual that discusses the financing options available to communities for storm water management programs, a set of case studies that describe successful finance mechanisms that have been used in seven communities around the country, and a group of links to other useful Web sites about storm water management. The site can be accessed at http://stormwaterfinance.urbancenter.iupui.edu.

The Center for Watershed Protection's *Rapid Watershed Planning Handbook* (CWP, 1998) describes techniques communities can use to more effectively protect and restore water resources. This document is available for purchase from the Center for Watershed Protection's Web site (http://www.cwp.org).

Framework for a Watershed Management Program (Clements, 1996) develops a specific watershed management protocol to increase the understanding of the critical components in watershed management programs. The publication is available for purchase from the Water Environment Research Foundation by calling 800-666-0206 and specifying publication order number D53016.

Building Local Partnerships, an Internet brochure published by the Conservation Technology Information Center (no date), provides an overview of local partnerships, including the types of partnerships that can be made, a how-to guide for forming partnerships, and caveats, as well as links to other resources pertaining to partnership-building. The publication can be accessed at http://www.ctic.purdue.edu/KYW/Brochures/BuildingLocal.html.

The Environmental Finance Center (2000) was created to assist local communities in finding creative ways to pay for environmental projects. The Center promotes alternative and innovative ways to manage the cost of environmental activities, provides training and development opportunities in environmental management, and works to increase the public and private sector's awareness of the benefits associated with sound environmental management policies. The site includes *Creative Financing Techniques for Establishing Riparian Forest Buffers* (or other land protection efforts), which describes methods such as notification, recognition, and nonbinding agreement programs; management agreements and leases; financing arrangements, such as agreements tied to loans; easements; and land acquisition to encourage conservation and stewardship of ecologically significant properties. The site also includes *Financing Stream Corridor Protection with a Community Quilt*, which describes a method for financing environmental protection and restoration efforts using a "community quilt" of financing techniques that has the potential to cover the variety of activities within the watershed. The Environmental Finance Center is located at http://www.mdsg.umd.edu/EFC.

The Florida Stormwater Association (2000) Web site contains information for storm water managers and stakeholders, including a manual entitled *Establishing a Stormwater Utility in*

Florida, storm water utility surveys, articles, news, and activities, and links to storm water management resources. The site can be accessed at http://www.florida-stormwater.org/.

The National Association of Counties (1999) has assembled a comprehensive kit that provides counties a host of tools for beginning and strengthening programs that favor purchase of products that are energy-efficient, contain recycled materials, and are less hazardous to the environment and human health. The kit includes case studies, a model purchasing resolution, a sample press release, and a comprehensive list of resources. It can be ordered (free for members, $10 for nonmembers) from the National Association of Counties' Web site at http://www.naco.org/Template.cfm?Section=Publications&Template=/cffiles/pubs/publications.cfm&PubCat=EPP.

The *State and Local Government Guide to Environmental Program Funding Alternatives* (USEPA, 1994) provides an overview of traditional (nongovernmental) funding mechanisms and innovative approaches for funding environmental programs. The document can be downloaded from http://www.epa.gov/owow/nps/MMGI/funding.html.

The *Catalog of Federal Funding Sources for Watershed Protection* (USEPA, 1999a) provides a guide for watershed practitioners on federal funds that might be available to support a variety of watershed protection projects. The catalog presents information on 69 federal funding sources (grants and loans) that can be used to fund watershed projects. The information on funding sources is organized into categories including coastal waters, conservation, economic development, education and research, environmental justice, forestry, Indian tribes, mining, pollution prevention, and wetlands. The catalog also includes key words that can be used to search for funding programs for particular subject areas. The document is available in HTML format at http://www.epa.gov/owow/watershed/wacademy/fund.html.

Model Ordinances to Protect Local Resources (USEPA, 1999b), located at http://www.epa.gov/owow/nps/ordinance, is a Web site of model ordinances that can serve as a template for those charged with making decisions concerning growth and environmental protection. For each model ordinance listed, there are several real-life examples of ordinances used by local and state governments around the nation. The ordinances address matters that are often forgotten in many local codes, including aquatic buffers, erosion and sediment control, open space development, storm water control operation and maintenance, illicit discharges, and postconstruction controls. There is also a miscellaneous category containing ordinances that don't fit into these sections. In addition, this Web site has materials that support particular ordinances, such as maintenance agreements and inspection checklists.

EPA's Office of Wastewater Management (USEPA, 2001) has a financing Web site (http://www.epa.gov/OWM/finan.htm) that provides an overview of the many types of assistance they provide to national, state, and local programs to abate and prevent municipal water pollution. Included is guidance information such as *Paying For Water Quality: Managing Funding Programs to Achieve the Greatest Environmental Benefit* and *Guide to Using EPA's Automated Clearing House For the Drinking Water State Revolving Fund Program* as well as information on programs such as the Clean Water State Revolving Fund (SRF), Construction Grants Programs, Section 106 Water Pollution Control Program Grants, Section 104(b)(3) Water Quality Cooperative Agreements, and Indian Set-Aside Grants.

The Watershed Management Institute, Inc. (1997a) printed a book entitled *Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation*. This book presents a comprehensive review of the institutional frameworks of successful urban runoff management programs. It was developed to assist individuals responsible for developing and implementing urban erosion, sediment control, and storm water management programs. The book is available for purchase ($10 for Storm Water Phase II communities, $27 for others) using an order form that can be downloaded at http://www.naco.org/Template.cfm?Section=Publications&Template=/cffiles/pubs/publications.cfm&PubCat=EPP.

The Southeast Michigan Council of Governments (SEMCOG) is a regional planning partnership that supports local planning efforts through technical support, the facilitation of intergovernmental coordination, and the adoption of region-wide plans and policies. SEMCOG partnered with six local communities to assemble a workbook, *Opportunities for Water Resource Protection in Local Plans, Ordinances, and Programs: A Workbook for Local Governments*, which provides guidance on planning to protect water resources. SEMCOG's approach is not prescriptive, but rather provides various options for planners, outlining key programmatic and regulatory components for a range of watershed protection approaches. The workbook emphasizes the need to address the protection of water resources through planning and prevention, and is meant to serve as a basis for local governments to customize their individual plans based on the needs and resources of the community. The book is available for download at http://www.stormwater.ucf.edu/publications/urban_runoff.pdf.

1.5 References

Brewer, K., J. Butcher, M. Clar, T. Clements, J. Doll, K. Marquis, and E. Thirolle. 2000. *City of High Point (NC) Deep River 1 Watershed Assessment and Stormwater Plan*. Prepared by Tetra Tech, Inc., for the City of High Point, NC.

Center for Urban Policy and the Environment. 2001. *An Internet Guide to Financing Stormwater Management.* http://stormwaterfinance.urbancenter.iupui.edu/home.htm. Last updated April 2, 2001. Accessed November 29, 2001.

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

Center for Watershed Protection (CWP). 1998b. *Nutrient Loading from Conventional and Innovative Site Development. Prepared for Chesapeake Research Consortium*. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1998c. *Rapid Watershed Planning Handbook*. Center for Watershed Protection, Ellicott City, MD.

City of Lenexa. No date. *Turning Rain into Recreation: Lenexa's New Approach to Storm Water Management*. http://www.ci.lenexa.ks.us/Stormwater/index.html. Accessed March 19, 2001.

Clements, T., C. Creager, A. Neach, M. Marcus, and T. Schueler. 1996. *Framework for A Watershed Management Program*. Final Report. Project 93-IRM-4. Water Environment Research Foundation, Alexandria, VA.

Conservation Technology Information Center (CTIC). 2000. *Know Your Watershed Home Page*. http://www.ctic.purdue.edu/KYW. Last updated April 19, 2000. Accessed April 24, 2000.

Conservation Technology Information Center (CTIC). No date. *Building Local Partnerships: A Guide to Watershed Partnerships*. http://www.ctic.purdue.edu/KYW/Brochures/BuildingLocal.html. Accessed April 23, 2002.

Cowles, C.D., D. Sheldon, and S. Dietz. 1991. *Guidance on Developing Local Wetlands Projects: A Case Study of Three Counties and Guidelines for Others*. Submitted to the Office of Wetlands Protection, United States Environmental Protection Agency, by the New England Interstate Water Pollution Control Commission. http://www.epa.gov/OWOW/wetlands/initiative/local.html. Last updated January 17, 2003. Accessed August 13, 2003.

Deering, J.W. 1999. *Moving the Earth for Environmental and Financial Success*. John W. Deering, Inc., Bethel, CT.

Delaware Department of Natural Resources and Environmental Control (DNREC). 1997. *Conservation Design for Stormwater Management*. Delaware Department of Natural Resources and Environmental Conservation, Dover, DE.

Delaware Department of Natural Resources and Environmental Control (DNREC). 2000. *Whole Basin Management: Inland Bays Environmental Profile*. Document number 40-01/00/03/14. Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Dorava, J.M., A.R. Espinosa, K. Johnson, and D. Severson. 2003. *Enhancing Storm Water Infiltration to Reduce Water Temperature Downstream*. In Proceedings, National Conference on Urban Storm Water: Enhancing Programs at the Local Level, February 17–20, 2003, Chicago, IL.

Dreher, D.W., and T.H. Price. 1994. *Reducing the Impacts of Urban Runoff: The Advantages of Alternative Site Design Approaches*. Northeastern Illinois Planning Commission, Chicago, IL.

Environmental Finance Center (EFC). 2000. The *Environmental Finance Center*. http://www.mdsg.umd.edu/EFC. Last updated January 2000. Accessed January 25, 2001.

Florida Stormwater Association (FSA). 2000. *The Florida Stormwater Association*. http://www.florida-stormwater.org/. Accessed September 29, 2005.

Illinois-American Water Company. No Date. *Project Description: Alton Water Treatment Facility, Water Treatment Residuals Handling Via Suspended Solids Trading*. Description submitted as a comment to USEPA during public comment period for this document.

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resources management. *Ecological Applications* 1(1): 66–84.

Maupin, M., and T. Wagner. 2003. *Regional Facility vs. On-site Development Regulations: Increasing Flexibility and Effectiveness in Development Regulation Implementation*. In Proceedings, National Conference on Urban Storm Water: Enhancing Programs at the Local Level, February 17–20, 2003, Chicago, IL.

Maurer, G. 1996. *A Better Way to Grow: For More Livable Communities and a Healthier Chesapeake Bay.* Chesapeake Bay Foundation, Annapolis, MD.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, and E.B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound Lowland ecoregion. *Watershed Protection Techniques* 2(4):483–494.

Mickowski, R. 2004. Posting to NPSInfo Listserve, RE: Urban BMP Cost Share Programs, October 18, 2004.

Mid-American Regional Council (MARC). 2000. *Creating Quality Places: Successful Communities by Design*. Mid-American Regional Council, Kansas City, MO.

National Association of Counties. 1999. *Local Government Environmental Purchasing Starter Kit: A Guide to Greening Government through Powerful Purchasing Decisions*. National Association of Counties, Washington, DC.

National Association of Homebuilders (NAHB). 1995. *Storm Water Runoff and Nonpoint Source Pollution Control Guide for Builders and Developers*. National Association of Homebuilders, Washington, DC.

Nemke, J. 1997. August 8. *Recommendations for Watershed Planning and Activities*. Memo from Jim Nemke to Commissioners from the Metropolitan Madison Sewerage District, Madison, WI.

Neukrug, H.M. 2003. *Watersheds and EPA Program Integration*. Presented at USEPA National Water Directors Meeting, January 22, 2003.

Oakland Museum of California. No date. *Guide to San Francisco Bay Area Creeks: Arroyo Viejo Watershed Map*. http://www.museumca.org/creeks/1220-OMAViejo.html. Accessed April 5, 2002.

Patton, C.J., A.H.Windrope, S.S. Beamish, E.C. Shute, Jr., R.B. Hooper, R.S. Taylor, and B.A. Schmidt. 2000. *Protecting Local Wetlands: A Toolbox for Your Community.* Save The Bay and Shute, Mihaly & Weinberger, LLP. http://www.savesfbay.org/atf/cf/%7B2D306CC1-EF35-48CC-B523-32B03A970AE5%7D/ProtectingWetlands.pdf. Accessed August 13, 2003.

Qiu, Z. 2003. *Residents' Willingness to Pay for Adopting Riparian Buffers for Newly Developed Residential Communities*. Presented at the American Water Resources Association 2003 International Congress on Watershed Management for Water Supply Systems. June 29–July 2, 2003, Millenium Hotel, New York, NY.

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

Shaver, E., J. Maxted, G. Curtis, and D. Carter. 1994. Watershed Protection Using an Integrated Approach. In *Stormwater NPDES Related Monitoring Needs*, proceedings of an Engineering Foundation Conference held in Mount Crested Butte, Colorado, August 7–12, 1994.

South Carolina Coastal Conservation League (SCCCL). 1995. Getting a Rein on Runoff: How Sprawl and Traditional Town Compare. *SCCCL Land Development Bulletin*, no. 7. South Carolina Coastal Conservation League, Charleston, SC.

Terrene Institute. 1993. *Clean Water in Your Watershed: A Citizen's Guide to Watershed Protection*. Terrene Institute, Alexandria, VA.

Terrene Institute. 1994. *Pollution Control for Horse Stables and Backyard Livestock*. Prepared for U.S. Environmental Protection Agency, Region 6, Dallas, TX, by Terrene Institute, Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 1992. *Agricultural Waste Management Field Handbook*. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1994. *A State and Local Government Guide to Environmental Program Funding Alternatives*. EPA 841-K-94-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999a. *Catalog of Federal Funding Sources for Watershed Protection.* 2nd ed. EPA 841-B-99-003. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999b. *Model Ordinances to Protect Local Resources*. http://www.epa.gov/owow/nps/ordinance/index.htm. Accessed March 25, 2001. Last updated October 29, 1999.

U.S. Environmental Protection Agency (USEPA). 2001. *Office of Wastewater Management Financial Assistance*. http://www.epa.gov/OWM/finan.htm. Last updated March 22, 2001. Accessed March 30, 2001.

Water Environment Research Foundation (WERF). 2000. Creation of a Philadelphia Office of Watersheds. *Progress Newsletter* 11(1). http://www.werf.org/press/Winter00/philadelphia.cfm. Accessed July 29, 2003.

Watershed Management Institute (WMI). 1997a. *Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation*. Watershed Management Institute, Inc., Ingleside, MD.

Watershed Management Institute (WMI). 1997b. *Operation, Maintenance, and Management of Stormwater Management*. Watershed Management Institute, Inc., Ingleside, MD.

MANAGEMENT MEASURE 2
WATERSHED ASSESSMENT

2.1 Management Measure

Develop and implement a watershed assessment program to:

- Characterize watershed conditions
- Establish a set of watershed indicators

2.2 Management Measure Description and Selection

2.2.1 Description

Watershed assessment and monitoring are tools used to characterize water quality and to identify trends in water quality over time (USEPA, 1998c). This management measure describes methods that can be used to determine the health of water bodies by using watershed indicators that measure physical, chemical, and biological conditions.

2.2.2 Management Measure Selection

2.2.2.1 Overview

Watershed assessment is a critical component of a watershed-based approach to managing receiving waters. Watershed assessment is needed to develop both protection and restoration strategies, identify priorities, and adjust management prescriptions based on trend analyses. Both rapid and extensive assessments can be performed to determine water body status and trends. Numerous metrics, such as EPA's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*; *Lake and Reservoir Bioassessment and Biocriteria*; and *Estuarine and Coastal Marine Waters:Bioassessment and Biocriteria Guidance,* are available for determining water body status. In general, the objectives, available funding, and expertise of the assessors will determine the level of assessment conducted.

An assessment and monitoring program is important for effective watershed management because it provides a basis for decisions and actions, and allows managers to continually reassess progress and redefine goals and priorities. Monitoring enables water quality managers to identify existing or emerging problems. Monitoring also facilitates responses to emergencies such as spills and floods, and helps water quality managers target specific pollution prevention or remediation programs to address these problems. Assessment and monitoring can be used to determine whether program goals, such as compliance with pollution regulations and implementation of effective pollution control actions, are being met. Monitoring programs should be established based on indicators of human health and aquatic life. A large number of documents and case studies are available to use as resources (see Information Resources at the end of this chapter).

2.2.2.2 Examples of monitoring and assessment programs and methodologies

State pollution control agencies, Indian tribes, local governments, and federal agencies typically are responsible for watershed assessment and monitoring activities. These entities monitor water quality and identify waters and watersheds that do not meet clean water goals through various programs, which include the following:

- Unified Watershed Assessments (UWAs), developed by states in 1999 to assess the health of watersheds and identify watersheds in need of restoration (i.e., watersheds that do not currently meet clean water and other natural resource goals). UWAs also identified watersheds that need preventive action to sustain water quality using ongoing state, tribal, and federal programs, as well as pristine or sensitive watersheds on federal lands that need an extra measure of protection. The results of these assessments can be obtained from state environmental protection departments.

- Water Quality Reporting Program, established under CWA section 305(b), which mandates the collection of water quality information and reporting on the condition of waters every two years.

- 303(d) program, established under CWA section 303(d), which mandates the use of monitoring and other water quality information to develop lists of waters that do not meet water quality standards.

- Nonpoint Source Program, established under CWA section 319, which involves identifying waterbodies that are impaired by nonpoint sources.

- Source Water Protection Program, established under the Safe Drinking Water Act, which involves assessments of drinking water sources that form a basis for actions to protect such sources.

- State Revolving Fund (SRF) Program, which involves developing and prioritizing clean water projects.

- Federal Emergency Management Agency's National Flood Insurance Program, which involves conducting floodplain studies and developing mitigation plans.

- Marine pollution control programs, which include identification of coastal water quality problem areas as part of efforts to reduce polluted runoff to coastal waters.

- Wetlands Program, which involves developing assessments of wetland areas that need special attention or protection.

One example of a state assessment program comes from the Commonwealth of Pennsylvania. The state's Act 167 requires that watershed assessments consider the following objectives (Pennsylvania DEP, 1999):

- Implement nonpoint source pollutant removal methodologies
- Maintain ground water recharge
- Reduce channel erosion
- Manage overbank flood events
- Manage extreme flood events

The state established four subtasks to achieve these objectives:

- Determine the water quality design storm
- Determine the runoff capture design storm (recharge/retention)
- Establish streambank erosion requirements
- Establish overbank/extreme event requirements (release rates)

To accomplish these subtasks, Pennsylvania developed a process that will ultimately lead to the development of standards for stream bank erosion, infiltration, water quality, overbank flooding, and extreme storm events. The assessment fits into a larger framework for integrated watershed resource management, which includes the following steps:

- Watershed assessment/prioritization
- Watershed evaluation
- Restoration/protection plan development
- Financial resources secured
- Restoration/protection plan implementation
- Results compared to goals

2.3 Management Practices

2.3.1 Characterize Watershed Conditions

2.3.1.1 Establish a reference condition

It is important to establish a reference that characterizes the relatively unimpaired condition of the water body. The reference condition establishes a basis for making comparisons between sites, and is essential for detecting impairment. Conversely, if a water body is found to be impaired, it is important to have an understanding of natural background concentrations before undergoing costly efforts to mitigate anthropogenic inputs.

There are two types of reference conditions—site-specific and regional. Site-specific reference conditions are determined from one or more sites in a watershed or stream from a point where discharges (nonpoint source, point source, or a combination) are occurring. Regional reference conditions typically are established from a population of relatively unimpaired sites within a relatively homogeneous region and habitat type. An ecoregional framework based on land surface form, soil, potential natural vegetation, and land use has been developed by Omerink (1987) to interpret spatial patterns in data (USEPA, 1999); these ecoregions can be used to help develop a reference condition for a relatively homogeneous region. Regional reference conditions are often preferable to site-specific conditions because they are more widely applicable, they produce a larger sample of unimpaired sites, and they allow more robust statistical comparisons.

The U.S. Geological Survey (USGS) developed a model for determining ecoregional background concentrations of nitrogen and phosphorus as a function of annual runoff, basin size, atmospheric nitrogen deposition rate, and region-specific factors. Background total nitrogen (TN) concentrations ranged from 0.02 mg/L in the western United States to more than 0.5 mg/L in the southeastern United States. Background total phosphorus concentrations ranged from less than 0.0006 mg/L in the western United States to more than 0.08 mg/L in the Great Plains (Smith et al., 2003).

2.3.1.2 Model pollutant sources and loads

Watershed managers can use models to estimate storm water pollutant loads in receiving waterbodies. Modeling of pollutant loadings can help watershed managers target specific areas for nonpoint source control. More specifically, runoff models can accomplish one or more of the following:

- Simulate the generation and movement of water and pollutants from their point of origin to a place of treatment or disposal into receiving waters
- Perform frequency analyses on water quality parameters to determine the return periods of concentrations or loads
- Provide input for an analysis of receiving water quality
- Determine the relative effects of pollution control options
- Determine optimal locations and combinations of management practices
- Provide input to cost-benefit analyses

Selecting the model that is most appropriate to fulfill watershed management goals requires careful consideration of trade-offs with respect to level of detail, data requirements, cost, and accuracy. For example, a high level of detail requires a more complex model. Data requirements are also important: a complex model might require more data than one has or is willing to collect. Sometimes published data can be substituted for field-collected data. The advantage of using published data is avoidance of costly, labor-intensive fieldwork. A major data source is the USEPA National Urban Runoff Program (NURP) database, which contains concentration values measured for 30 cities (USEPA, 1983). Information generally required for models includes the following:

Quantity Parameters

- Rainfall information
- Catchment area

- Imperviousness
- Runoff coefficient

Quality Parameters

- Constant concentrations (event mean concentrations or EMCs)
- Constituent median and coefficient of variation (CV)
- Regression relationships
- Buildup and wash-off parameters

Calibration/Verification Parameters

- Measured rainfall
- Measured runoff
- Water quality samples

While model calibration is beneficial, models generally used for watershed assessments do not strictly require calibration and precision to determine compliance with permit requirements or Clean Water Act requirements. Therefore, these models can be simpler and less expensive, while still providing watershed managers with information on pollutant loadings and sources.

Another consideration when choosing a model is its reputation. Watershed managers should become familiar with the model's concepts, assumptions, and limitations, as well as the experiences of other users. In choosing the most appropriate model, watershed managers should:

- Use the simplest model that will satisfy the project's objectives
- Use a model that is consistent with available data
- Predict only the water quality parameters of interest
- Make predictions over the broadest time scale that will satisfy the objectives
- Become familiar with the characteristics and assumptions of the model

Using pollutant loading models has advantages and disadvantages. Measured data are preferable to simulated data, especially when characterizing the magnitude of a pollution problem, because accurate concentration values are important. Models cannot substitute for good field-sampling programs, but they can be used to extrapolate and to augment field-sampling results.

To ensure quality results from a modeling effort, sensitivity analyses should be performed when uncertainty exists regarding data quality or model assumptions. Also, if possible, models should be calibrated and validated using measured values (field monitoring). This process is labor-intensive and can add to the expense of the modeling effort, but it is worthwhile to ensure accuracy when making management decisions.

A detailed description of water quality models of all types can be found in the *Compendium of Tools for Watershed Assessment and TMDL Development* (USEPA, 1997a). In general, watershed managers can choose from several different methodologies depending on the specific goals of the modeling effort, including the following:

– *Constant concentration or published yield values*. This method involves calculating loads as the product of the proportion of land area in a particular land use and the published loading rates for that land use. A disadvantage is that the catchments from which the published values are derived may not represent the catchment of interest. However, the calculations are very simple and easy to use for general loading assessments. Options include coupling constant concentrations with a hydrologic model so that loading will vary with flow, or calculating a confidence interval for loading to determine the level of uncertainty that can be tolerated before conclusions change. This method might be robust enough to answer straightforward management questions despite assumptions.

– *Unit loads.* This method involves calculation of the mass of the pollutant of interest per area of watershed per unit of time. It is site-specific (demographic and hydrologic factors are important determinants) and is based on average runoff volume (not coupled to a hydrologic model). Also, loading rates are variable and difficult to extrapolate from one area to another. This is a relatively simple method that does not require a great deal of data collection. Published values can be used at the expense of some accuracy.

– *Simple empirical model*. This method uses spreadsheet calculations to combine precipitation data with a runoff coefficient and land use-specific constant concentrations. This method easily simulates a mixture of land uses, allowing the study area to extend over a large area without compromising the quality of results. The model can quantify relative contributions from different land uses, and can be expanded readily to incorporate more complex calculations. The hydrologic modeling is very simple, however, and the model does not necessarily work well for short-term predictions. Also, using published constant concentrations in the model introduces errors; locally measured concentrations would greatly improve the model's performance.

– *Statistical method*. The statistical method uses a derived, usually lognormal frequency distribution of estimated mean concentrations (EMCs) of pollutants. This method is useful for assessing the frequency of exceedance of water quality standards, but it has weak hydrologic assumptions. The model can be coupled with stream flow, storage, and treatment data to improve accuracy and estimate the effects of management practices on water quality. Estimates can be improved by using measured EMC values rather than published ones. EMCs can vary widely because of seasonal and watershed land use variations, and might require at least one year and often two years of field verification to be statistically significant.

– *Regression equations.* Regression equations are published equations from the U.S. Geological Survey (USGS) (Driver and Tasker, 1990) that relate loads and EMCs to catchment, demographic, and hydrologic characteristics. They usually incorporate total storm loads and runoff flows or volumes. They require neither preliminary estimates of EMCs nor local monitoring data, and standard errors are provided for a measure of uncertainty. They are more or less accurate depending on the pollutant of interest and the level of precipitation (arid vs. humid). The equations predict only the mean rather than a frequency distribution of EMCs or loads, and they are subject to error when extrapolating to conditions that are different from those used to derive the equations. A related approach uses rating curves to relate pollutant loads or EMCs to flow rates or volumes, thereby allowing quantification of intra-storm variations in these measures.

- *Buildup and washoff.* This method is used to determine loadings by estimating the buildup of pollutants during dry weather and estimating washoff during rainfall events. This method quantifies intra-storm variations in pollutant loading and is good for comparing the relative effects of management practices. However, processes of sediment transport and erosion that are fundamental to this method are still poorly understood. Moreover, this method requires averaging the extent of pollutant buildup on heterogeneous urban surfaces. This averaging can result in erroneous predictions because actual values vary widely over relatively small areas. Assumptions include linear buildup and generic washoff coefficients that might or might not represent actual conditions. Estimates can be improved by using local monitoring data such as site-specific buildup and washoff estimates for model calibration.

- *Mechanistic models*. Mechanistic models contain hydrologic and water quality components and use mathematical algorithms to represent the mechanisms that generate and transport runoff and contaminants. They are the most comprehensive models in that they incorporate many variables to produce the best estimations of the numerous mechanisms that affect pollutant loading. However, they require substantial local data to set and verify parameters, and they demand both skill and commitment from staff. Users must ensure that the models are documented, supported, and proven through the experience of other users. There are several commercially available mechanistic models, including STORM by the U.S. Army Corps of Engineers and SWMM and HSPF by EPA. (See Web references and resources below.)

The confounding factors for load estimation models are:

- Inputs from atmospheric deposition (H_2SO_4, NO_3, etc.)

- Ground water inputs

- Pervious surfaces that confound runoff estimates

- Sediment transport and erosion

- Pollutants adsorbed to solids. These pollutants, namely metals and organics, can be estimated as a proportion of the total suspended solids concentration or annual load.

- Point sources in the watershed (e.g., industrial and commercial sources and publicly owned treatment works)

All of these factors can be included in the surface runoff model at the expense of time and simplicity and can improve the accuracy of loading estimates. Before they are included, consideration should be given to the level of detail needed for the analysis.

Application of a GIS Decision Support Tool to Urban Watershed Management in Fulton County, Georgia

The high density of development in Sandy Springs, a suburban area northwest of Atlanta, reduces the opportunities for new, areawide management practices such as regional detention ponds. Instead, multiple on-site or local management practices are recommended. In response to the need for developing storm water and water quality plans, a GIS application called LORELEI was developed (Slawecki et al., no date). LORELEI allows users to rapidly develop and compare watershed management alternatives for catchments with hundreds of management practices. It was developed to

- Keep track of hundreds of candidate management practice sites.
- Develop management scenarios using different combinations of management practices.
- Evaluate the practices' impact on water quality.
- Compare scenario results.
- Present the information to a wide range of people.

LORELEI provides decision support through data management, scenario development and evaluation, and enhanced involvement in and understanding of the watershed management process. LORELEI stores data about potential management practice locations and associated costs, practice types, and effectiveness data, as well as standard geographic information such as natural features, watershed delineations, and property ownership. Through scenario development, the program allows for rapid selection of individual projects and entire categories of management practices to build various scenarios. LORELEI then evaluates the scenarios to estimate and compare their costs and benefits. Finally, with enhanced involvement and understanding, LORELEI uses GIS to give decision makers an opportunity to participate directly in the watershed management process and to clearly understand issues, components, and cost and benefit implications of different management scenarios. GIS linkages allow for fine-tuning of the scenarios to determine the cost and performance effects of different suggestions made by participants at public meetings.

2.3.1.3 Model receiving water quality

Receiving water quality models identify impacts from runoff inputs and help watershed managers determine whether receiving waters meet water quality standards. Usually, computer models are used because of the complexity of calculations. Models are available for streams, lakes, reservoirs, estuaries, bays, and coastal segments. Most models couple quantity (hydrodynamic) and quality parameters, but some consider these parameters separately.

A useful water resource impact model is the Long-Term Hydrologic Impact Assessment (L-THIA), which was developed by Purdue University (2000) for land use planners to provide site-specific estimates of changes in runoff, recharge, and nonpoint source pollution resulting from past or proposed land use changes. The model uses regional climate data and user-provided location, land use, and soil group data for up to three different scenarios (past, present, and future). The results are in the form of tables, bar charts, and pie charts. The model is available at http://danpatch.ecn.purdue.edu/~sprawl/LTHIA7.

The best sources of information for receiving water quality models are either government agencies or product vendors. The following is a list of government agencies that can provide the information needed to choose the most appropriate model:

- USEPA Center for Exposure Assessment Modeling, Athens, Georgia
- US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi
- US Army Corps of Engineers, Hydrologic Engineering Center, Davis, California
- USGS, Reston, Virginia
- National Oceanic and Atmospheric Administration (NOAA), Silver Spring, Maryland—estuaries and bays
- Tennessee Valley Authority (TVA), Knoxville, Tennessee—rivers and reservoirs

Additional guidance regarding load estimation and receiving water quality modeling is provided in *Compendium of Tools for Watershed Assessment and TMDL Development* (USEPA, 1997a), which supports the watershed approach by summarizing available techniques and models that assess and predict physical, chemical, and biological conditions in water bodies. This document is intended to provide watershed managers and other users with information helpful for selecting models appropriate to their needs and resources. The *Compendium* includes information on the following:

- A wide range of watershed-scale loading models
- Field-scale loading models
- Receiving water models, including eutrophication/water quality models, toxics models, and hydrodynamic models
- Integrated modeling systems that, for example, link watershed-scale loading with receiving water processes
- Ecological techniques and models that can be used to assess and/or predict the status of habitat, single species, or biological communities

An additional modeling resource is *Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas*, which is a major nonpoint source model review effort published by EPA in 1991. It focuses on nonpoint source assessment procedures and modeling techniques for both urban and non-urban land areas (Donigian and Huber, 1991). The report provides detailed reviews of specific methodologies and models, as well as overview discussions and model comparison tables. Simple procedures, such as regression and loading function approaches, are also described in the report, along with complex models like SWMM, HSPF, STORM, CREAMS/GLEAMS, SWRRB, AGNPS, and others. Brief case studies of modeling efforts are summarized, with emphasis on the use of nonpoint and comprehensive watershed models for watershed management activities. This publication can be found at http://yosemite.epa.gov/water/owrccatalog.nsf/0/b28aec046488178585256fc700700b24?OpenDocument.

EPA has assembled a Web site with information about and links to water quality models. This site includes basic information, EPA-supported models, other federal government-supported models, technical guidance for models, and model training and meetings. The Web site can be accessed at http://www.epa.gov/waterscience/wqm/.

2.3.2 Assess Cumulative Effects

A watershed assessment should include an evaluation of cumulative effects, which are combined effects of multiple activities over space or time. Such effects can be difficult to assess because a large number of resources can be affected and often there are multiple pathways through which these effects can occur. In addition, the appropriate spatial and temporal scales for the analysis usually are uncertain. Because many environmental assessments do not take cumulative effects into account, most likely because there is no explicit process for analyzing them, MacDonald (2000) developed a conceptual process to guide their assessment and management. The process is divided into three phases: the scoping phase, the analysis phase, and the implementation and management phase. Within each phase are a group of interrelated steps that, if followed, typically lead to a complete analysis of the cumulative effects on a watershed. The three phases and their steps are shown in Figure 2.1.

2.3.3 Estimate the Effectiveness of Treatment Programs

A useful tool to estimate the effectiveness of treatment practices on water quality is the Watershed Treatment Model (WTM), which was developed by the Center for Watershed Protection (Caraco, 2001). The WTM is a simple model for rapidly assessing how various management programs influence pollutant loadings and/or habitat quality in urban watersheds. It incorporates many simplifying assumptions that allow watershed managers to assess various programs and sources that are not typically tracked in more complex models. The WTM consists of two basic components: pollutant sources and treatment options. The pollutant sources component estimates the load from a watershed without treatment measures in place. It assesses two broad categories of pollutant sources: primary land uses and secondary sources. The treatment options component estimates the reduction in the uncontrolled load resulting from a wide range of treatment measures. Treatment options are broadly defined in the model as storm water treatment practices and storm water management programs. The most current version of the WTM, version 3.0, can track sediment, nutrients, and bacteria. The WTM can be a useful tool for managers who are analyzing the effectiveness of current watershed restoration programs, preparing Total Maximum Daily Loads (TMDLs), or evaluating the watershed benefit of National Pollutant Discharge Elimination System (NPDES) storm water programs. For more information about the WTM, contact the Center by e-mailing center@cwp.org or visit their Web site at http://www.cwp.org.

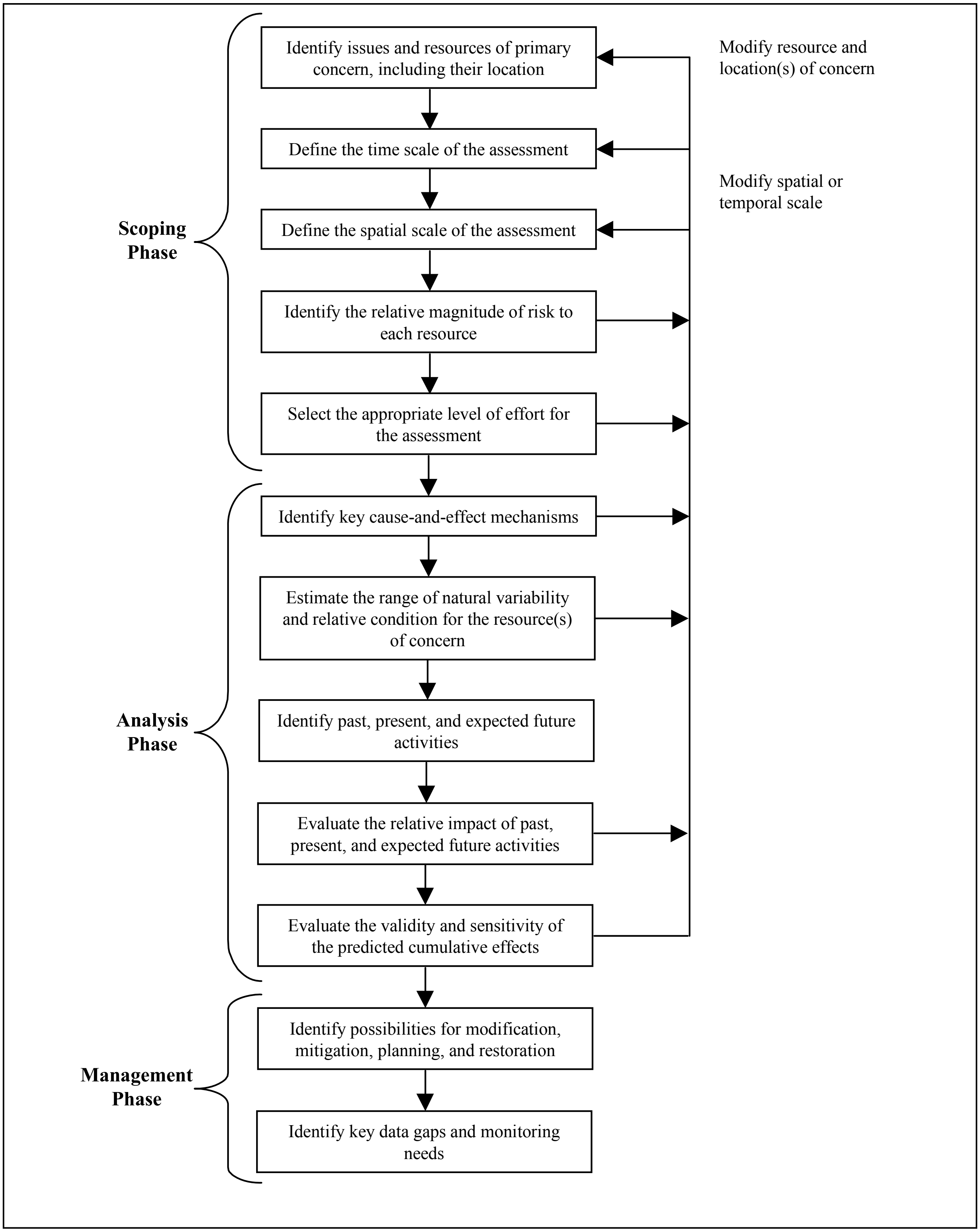


Figure 2.1: Conceptual process for assessing cumulative effects (MacDonald, 2000).

Indicators of Storm Water Program Effectiveness

The Hampton Roads Planning District Commission in Chesapeake, Virginia, has developed a database to track and evaluate various indicators of the effectiveness of the storm water program. The indicators fall into four basic categories: water quality, physical & hydrological, socioeconomic, and programmatic. This database tracks the indicators as listed below (Hillegass, 2003):

- *Water quality*: pollutant loadings for nutrients
- *Physical and hydrological*: acres of open space land protected from development
- *Socioeconomic*: inventory of public education efforts, such as number of publications produced and distributed, Web site hits, media campaigns, stream cleanup activities
- *Programmatic*: the following are programmatic indicators:
  - Number of approved erosion and sediment control plans and disturbed acreage
  - Number of inspections and enforcement actions for erosion and sediment controls
  - Number of citizen calls about flooding and drainage problems, and number of responses
  - Cost and number of flooding and drainage projects
  - Investigative and corrective actions for illicit discharge detection and elimination
  - Operation and maintenance activities
  - Number of approved site and subdivision plans, and acreage served
  - Number and type of BMPs installed, the number of acres served by each BMP, and installation and maintenance information

Under the Phase II Storm Water Rule, communities are required to go beyond chemical pollutant monitoring to track the implementation of storm water management programs. This database can serve as a useful tool in fulfilling this requirement and can be used as a model for the development of varied indicators of program success (Hillegass, 2003).

2.3.4 Establish a Set of Watershed Indicators

Watershed indicators are monitoring parameters or techniques used to measure the effectiveness of management practices in meeting watershed and subwatershed goals and objectives. Indicators range from complex chemical or toxicity testing methods to simple public perception surveys. Watershed managers can choose one or more of these indicators to better focus their monitoring efforts. Regardless of the parameters or technique, to be effective, an indicator must accomplish the following:

- Reflect a measurable attribute of a watershed goal or subwatershed management objective
- Be measured using scientifically valid protocols, quality controls, and assessment techniques to ensure that results are replicable, consistent, compatible with other data collection efforts, and statistically valid
- Be measured at one or more locations that will adequately characterize "typical" conditions in the management unit and establish reference conditions against which future data comparisons can be made

- Be monitored over a long enough period to establish observable trends
- Be compatible with available finances, personnel, and other resources. The cost of implementing the watershed indicator is an important consideration.

The Center for Watershed Protection and EPA published a reference to help municipalities select a suite of indicators that will most effectively measure conditions in their watershed (Claytor and Brown, 1996). This publication, *Environmental Indicators to Assess Stormwater Control Programs and Practices*, presents profiles with information such as advantages, disadvantages, cost, and applicability for 26 indicators, which include water quality, physical/hydrological, biological, social, programmatic, and site indicators. The document is available online at http://www.cwp.org.

2.3.5 Establish Water Quality Indicators

Conduct water quality monitoring. This type of monitoring involves measuring pollutants in both runoff and baseflow conditions. The most commonly measured constituents are oxygen demand, nutrients, metals, pH, temperature, flow or discharge, solids (e.g., total suspended solids or turbidity), fecal coliform, and a measure of oil and hydrocarbons (e.g., total petroleum hydrocarbons [TPH] or polycyclic aromatic hydrocarbons [PAHs]). Measurements can be taken at management facilities or in receiving waters. This method allows for the identification of trends in water quality over time and can identify areas that are degraded relative to low-impact reference sites. Changes in water quality that result from changes in land use or from the implementation of management practices can be detected to prioritize future conservation or restoration efforts. The specific constituents found in receiving waters can aid in identifying the source of the pollution problem and help target management practices effectively. The methodology for water quality monitoring is well-outlined in specific protocols, and results are quantitative and easy to present and compare to other monitoring databases. However, the monitoring effort must be long-term because of the high variability in constituent concentrations, and it might be expensive because of labor requirements or equipment costs for automation. Volunteer monitoring programs can reduce some of the expense of monitoring while providing the additional benefit of educating the public. EPA's Volunteer Monitoring Web site has more information about volunteer monitoring (http://www.epa.gov/owow/monitoring/volunteer).

(1) *Conduct toxicity testing*. These methods, often called whole effluent toxicity (WET) tests, involve exposing standardized freshwater, marine, and estuarine vertebrates, invertebrates, and plants to water samples to directly measure the adverse effects of effluents. Both acute and short-term chronic effects can be assessed. The test organisms can be either resident species or species that will be restocked or reintroduced. Toxicity reduction evaluation (TRE) can be used to identify the agent of toxicity, which helps to identify the pollutant source and indicates which management practices would be appropriate to treat the problem. Although this method allows managers to distinguish among a range of conditions and chemicals, species' responses vary substantially with respect to the choice of species, location (laboratory or in situ), and duration of the test. Also, chronic toxic effects, which may take a long time to manifest, are not measured with this type of testing. The TRE process can be expensive and is often used to specifically identify pollutants when receiving waters have previously been identified as impaired through other, less-expensive methods.

More information on WET methods is available at http://www.epa.gov/OST/WET. Descriptions and guidance on other analytical methods are provided at http://www.epa.gov/ost/methods (USEPA, 2000d).

(2) *Measure the frequency at which water quality standards are exceeded*. This method is usually based on chemical standards and can be derived from existing data or as part of the biennial 305(b) reporting process. It can identify long-term trends in water quality, storm water impacts, and the effectiveness of management practices. However, because the ability to detect exceedances is highly dependent on the frequency and timing of sample collection, brief periods of exceedance might be missed (during storm flow) and long-term conditions inaccurately represented. Also, exceedance frequencies provide little information about causes and sources of pollution. Costs associated with this method are minimal because data are usually collected through other programs. Guidance and information on EPA and state water quality standards and criteria can be found at http://www.epa.gov/ost/standards (USEPA, 2001c).

(3) *Determine sediment pollutant levels*. This type of monitoring involves the determination of pollutant load carried by sediments and deposited in slow-moving receiving waters. Analysis is usually conducted using spectrophotometry and chromatographic tests of samples from natural or artificial water bodies. The extent of toxicity in sediments can be determined by comparing sample results to reference samples that are known to be relatively unimpacted. Measured pollutant levels can also be compared to existing standards for typical contaminants in sediment (USEPA, 2000d). Using sediment contamination as an indicator of water quality is often confounded by uncertainty related to levels of concern and long-term impacts, the inability to identify pollutant sources, and lag time between discharge and settling. However, long-term trends in sediment pollutant loading can be detected if monitoring is conducted over a long period.

(4) *Measure microbial contamination*. This type of monitoring involves measuring concentrations of microbes such as fecal coliform or *Escherichia coli* to ascertain the probable presence of pathogens in the water column. These pathogens result in the closure of beaches, fishing areas, and shellfish beds. Tracking the frequency of such closures may indicate contamination in effluent from industrial or municipal facilities or septic systems, or runoff from agricultural areas. In areas where no treatment facilities or septic systems are present, runoff can be identified as the main source of pathogens. Measuring microbe concentrations can help determine the effectiveness of management practices in removing this type of contamination from receiving waters.

Trends in beach or shellfish closures over time may indicate a developing problem if high concentrations or counts become more frequent, or they may demonstrate the effectiveness of management efforts if decreasing trends occur. However, many of the bacteria measured have a variety of nonhuman sources, making it difficult to identify the source of the pollution. In addition, they are short-lived in the water column, so depending on when samples are collected, the occurrence of high bacterial concentrations may not be detected even though they are present at certain times (e.g., during storm flows).

Bacterial source tracking refers to a family of methods that can be used to distinguish among sources of fecal contamination and can aid in tracking illicit discharges to storm sewer systems. Bacterial source tracking requires development of a database of known sources against which samples can be compared (Zhang et al., 2003). The methods can be molecular (e.g. DNA fingerprinting, or more specifically, ribotyping, pulsed-field gel electrophoresis [PFGE], polymerase chain reaction, terminal restriction fragment length polymorphism) or non-molecular. Non-molecular procedures can be biochemical (e.g., antibiotic resistance analysis, carbon utilization, F-specific coliphage typing, cell wall fatty acid methyl ester) or chemical (e.g., caffeine detection, optical brightener detection). In general, molecular methods can offer the most precise identification of specific types of sources, but they also have the highest unit costs and the most time-consuming procedures. Biochemical procedures are simpler, less expensive, and faster, and allow a larger number of samples to be analyzed in a shorter period of time (USEPA, 2002). The technology in this subject area is constantly evolving and new procedures and more refined methods may be available as research progresses.

Zhang et al. (2003) described the use of the PFGE method of bacterial source tracking analysis on *E. coli* samples from Four Mile Run in Northern Virginia, which is a highly urbanized watershed with approximately 40 percent impervious surface. Four Mile Run is impaired due to bacterial contamination and has a TMDL in place to control bacterial sources. The PFGE analysis identified that waterfowl contribute 38 percent of the bacteria, humans and pets (combined) accounted for 26 percent, and raccoons contributed 25 percent. Deer (9 percent) and rats (11 percent) also contributed bacteria to Four Mile Run.

DNA testing is an expensive but effective molecular method for identifying the primary animal or animals (human, duck, dog, etc.) that contribute microbes to the water column. More information about bacterial source tracking can be found in a two-part article in *Stormwater* available at http://www.forester.net/sw_0105_detecting.html (Hager, 2001).

Antibiotic resistance analysis (ARA) is the most commonly used non-molecular method for tracking sources of bacteria. ARA is used to distinguish among sources by looking at patterns of antibiotic resistance found in bacteria from human and animal sources. Fecal bacteria from humans can exhibit greater resistance to certain antibiotics than bacteria from wildlife feces (Hager, 2001; USEPA, 2002). However, this method may be confounded by the presence of bacteria from agricultural operations such as feedlots or poultry operations where antibiotics are used.

EPA's Office of Research and Development's National Risk Management Research Laboratory (NRMRL) is working to develop an integrated system for screening fecal bacteria contamination from various animal sources. NRMRL is working to match the best molecular method to its target bacteria for rapid screening and identification of sources of fecal contamination in watersheds (Simpson, 2003).

(5) *Measure nonpoint source loadings.* It is possible to estimate the amount of pollutants transported in storm water runoff from various land uses by using empirical monitoring data, land use imperviousness and cover, area, and rainfall volume. Modeling of pollutant loads can establish baselines that can be used to determine whether changes have occurred as a

Maryland's Environmental Indicators

The state of Maryland has compiled several indicators to characterize environmental quality (MDE, 1999). These indicators embody a range of environmental attributes, from air quality to drinking water quality to public understanding and community support. The Non-Tidal Aquatic Systems category, which encompasses the range of plants and animals found in free-flowing rivers, streams, lakes, and most wetlands, includes several indicators that appropriately address Maryland's habitat and land uses and include physical, chemical, and biological measures:

- Miles of Streams Degraded by Abandoned Mine Drainage.
- Stream Miles Open to Migratory Fish.
- Physical Habitat Index (Non-Tidal).
- Benthic Macroinvertebrate Index of Biotic Integrity (Non-Tidal).
- Fish Index of Biotic Integrity (Non-Tidal).
- Riparian Forest Buffers.

The biological indicators consider communities of living organisms as found throughout the water column rather than any individual species, and their values reflect the physical and chemical water quality conditions described by other indicators. The Riparian Forest Buffers indicator was chosen because of its importance to physical and chemical habitat and its contribution in cycling nutrients to aquatic species and because a statewide benchmark had already been established through the Chesapeake Bay Program. More information on Maryland's environmental indicators is available at http://www.mde.state.md.us/enpa/ 2000_enpa/envi_indicators.

result of land use changes or implementation of management practices. Loadings can be calculated for small-scale studies using the Simple Method as described in *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs* (Schueler, 1987), which is available for purchase at http://www.mwcog.org. Alternatively, several computer simulation models are available to model changes in nonpoint source loads under different scenarios.

Another source of information for estimating pollutant releases is the Healthy Community Environmental Mapping program, called HUD E-MAPS (HUD and USEPA, 2000). HUD E-MAPS, which was developed by the Department of Housing and Urban Development (HUD) and EPA, combines EPA environmental data with information on HUD's community development and housing programs. The program provides location, type, and performance information on HUD-funded activities throughout the country, and select EPA pollution release information. The maps help communities to plan by allowing them to identify areas of pollutant releases when planning economic development and housing projects. The HUD E-MAPS program can be accessed at http://www.hud.gov/emaps.

2.3.6 Establish Physical and Hydrological Indicators

EPA's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (USEPA, 1999) and *Volunteer Stream Monitoring: A Methods Manual* (USEPA, 1997c) provide guidance on how to conduct assessments of a water body's physical, habitat, and hydrological characteristics. Both documents are available on the Internet: the former can be found at http://www.epa.gov/owow/monitoring/rbp, and the latter is located at http://www.epa.gov/owow/monitoring/volunteer/stream.

EPA also provides guidance for lake and reservoir monitoring in *Lake and Reservoir Bioassessment and Biocriteria* (USEPA, 1998b), which is available at http://www.epa.gov/owow/monitoring/tech/lakes.html. Monitoring guidance for estuarine and coastal marine waters can be found in *Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Guidance* (USEPA, 2000a), located at http://www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html.

Additional monitoring guidance can also be obtained from EPA's Environmental Monitoring and Assessment Program (EMAP), a research program designed to develop the necessary tools for monitoring and assessing the nation's ecological resources. The objective of the program is to guide national monitoring initiatives and activities with improved scientific understanding of ecosystem integrity and dynamics. Information about the EMAP program is available at http://www.epa.gov/emap.

Methods for characterizing streams are contained in *Applied River Morphology* (Rosgen, 1996). Rosgen discusses geomorphic characterization of streams, which helps to differentiate between degraded and stable stream systems. This book also contains methods used to assess the current conditions of a stream and the departure from its potential. The Bank Erodibility Hazard (BHI) Rating Guide can be used to quickly determine bank erosion potential.

(1) *Measure stream widening/downcutting*. Measurements of stream width, depth, and bank characteristics taken over time can be used to indicate changes in the magnitude and frequency of storm flows caused by land use changes that affect stream geometry. Such measurements are also useful in identifying stream segments that are especially susceptible to erosion and areas where habitat is degraded to target areas for implementation of management practices. Many stream channels are already modified, so baseline conditions need to be established. This method cannot be used to predict changes, but it can help to diagnose a problem after it has occurred. Booth (1994) presents excellent guidance for conducting measurements of stream cross-sectional area.

(2) *Conduct physical habitat monitoring*. Monitoring of physical habitat is used to assess the potential of the stream to support different kinds of biota. Parameters such as weather, stream type and origin, land use, erosion, reach width and depth, canopy, proportion of stream morphological type (pool, riffle, and run), and presence or absence of large woody debris and aquatic vegetation can be measured easily and inexpensively and can provide information about which taxa would likely be found in the stream without water quality impacts (reference condition). If conducted over time, monitoring can provide information about past, present, and future changes in channel morphology. Although this method detects impacts from relatively low levels of development, it is not useful in pinpointing sources of degradation, nor does it offer insight into other water quality impacts.

(3) *Assess dry weather flows*. This method is used to assess the impact of urbanization on base flows, either as compared to a non-urbanized stream in the same ecoregion, or as a change over time. Impacted streams in humid areas show decreased flow, whereas perennial streams in arid regions show increased flow, as a result of urbanization. Evaluating pipe installations and impervious surfaces in humid regions and water use in arid regions allows this method to be used to identify causes of baseflow alteration. This method works well in conjunction

with stream widening/downcutting studies. It cannot be used to distinguish between urbanization and other causes of stream flow alteration such as irrigation, long-term drought, and the like, unless these factors are taken into account explicitly. Also, it is difficult to establish trends without extensive long-term data and knowledge about certain geologic conditions.

(4) *Measure flooding*. It is important to quantify changes in stream morphology over time because alterations in stream size or shape or in floodplain boundaries indicate that hydrologic changes have resulted from development in the watershed. These changes can be identified by comparing historical floodplain records to current floodplain maps, called Flood Hazard Boundary Maps (FHBMs). They are official maps issued by a community administrator that detail the boundaries of the flood, mudslide, and related erosion areas having special hazards that have been designated (FEMA, 2000). The maps can be obtained from local community map repository sites, from the Federal Emergency Management Agency (FEMA) online at http://msc.fema.gov, or through FEMA by phone, fax, or mail from the Map Service Center, P.O. Box 1038, Jessup, Maryland 20794-1038; telephone 800-358-9616; fax 800-358-9620.

(5) *Monitor stream temperature*. This method identifies areas where stream temperature has increased as a result of urbanization and loss of shading and buffers. Stream temperature can be measured over time or compared to other, low-impact watersheds. This monitoring method can be used to identify areas that would potentially benefit from riparian buffer enhancement and to measure the effectiveness of management practices used to regulate stream temperature. Changes in stream temperature can be an early warning sign that sensitive species will be lost without intervention. Climatic conditions can cause variability in stream temperature that is extraneous to trends caused by urbanization and can confound analyses. In addition, in should be noted that some management practices, such as ponds and wetlands, can result in increased temperature.

2.3.7 Establish Biological Indicators

Bioassessments are useful for detecting aquatic life impairments and identifying the causative agents and possible mitigation strategies. Additional bioassessments can indicate whether mitigation was successful and can direct further management activities. Monitoring of biological communities offers the following advantages:

- Biological communities reflect overall ecological integrity and directly relate to the primary goal of the Clean Water Act.
- Biological communities integrate the effects of different stressors and provide a broad measure of their aggregate impact.
- Biological communities provide an ecological measure of changes in environmental conditions.

Development and Evaluation of Ecosystem Indicators for Urbanizing Midwestern Watersheds

Researchers at Purdue University are undertaking a study to develop predictive indicators of urbanization that are applicable to midwestern watersheds (Spacie et al., 2000). The objectives of this study are as follows:

- Quantify impacts on hydrologic regimes, water quality, and habitat structure of stream ecosystems using paired experimental watersheds.
- Develop linked models to accurately predict these impacts.
- Use the models to generate and test indicators of urbanization and hydrologic change with respect to biological responses to these changes.
- Use these indicators with the models to assess biological responses to alternative urbanization scenarios on larger scales.

Data from satellite imagery, intensive water quality and biological sampling, stream cross-section measurements, and physical habitat assessments will be used to develop and test the models. A dynamic hydrology model that can simulate cross-sectional averaged velocities, shear stress velocities, and water depth variability during storm peaks has been developed. Functional biological metrics and habitat quality indices will be correlated not only to land use but also to channel morphometry and flow variability.

For more information contact Anne Spacie, Department of Forestry and Natural Resources, Purdue University, 1159 Forestry Building, West Lafayette, Indiana 47907-1159; telephone 765-494-3621; e-mail aspacie@purdue.edu.

- Routine biological monitoring is inexpensive compared to chemical monitoring and toxicity tests.
- Biological monitoring is useful for evaluating impairment when criteria for specific ambient impacts do not exist.

Bioassessments can include evaluation of fish populations, benthic macroinvertebrate communities, periphyton, and single species monitoring. EPA's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (USEPA, 1999) contains descriptions of various methods for each community type. EPA (2000b) also published the *Stressor Identification Guidance Document*, which outlines a process to identify causes of biological impairment. The stressor identification process is outlined in Figure 2.2 and includes three major steps: (1) listing candidate causes of impairment; (2) analyzing new and existing data to generate evidence for each candidate cause; and (3) producing a causal characterization with the evidence generated in step 2 to draw conclusions about the stressors most likely to have caused the impairment. The *Stressor Identification Guidance Document* is available for download in PDF format at http://www.epa.gov/waterscience/biocriteria/stressors/stressorid.html or can be ordered through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

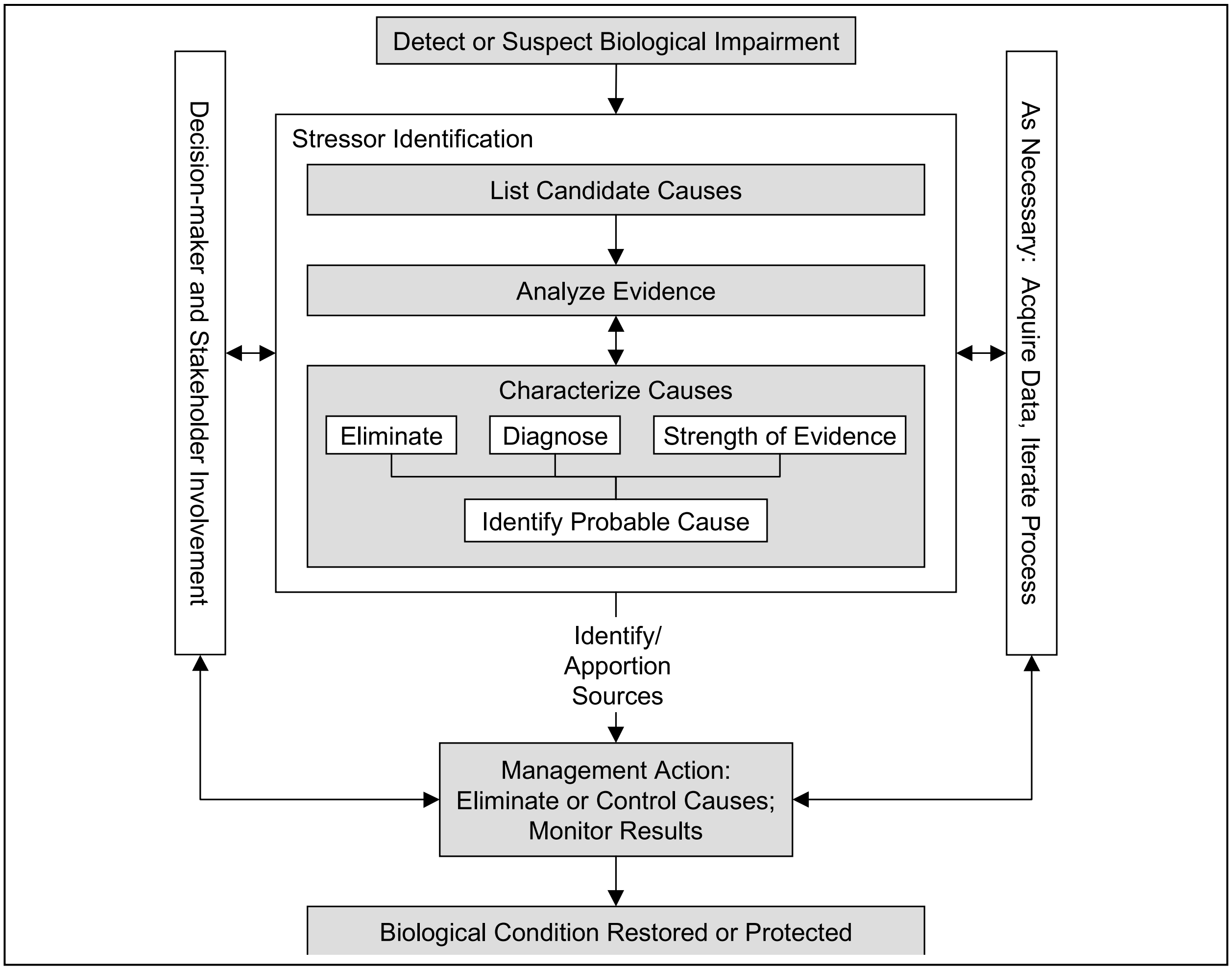


Figure 2.2: Conceptual diagram of the stressor identification process (USEPA, 2000b).

The Biological Assessment of Wetlands Workgroup (BAWWG) (USEPA, 2001b) provides information for establishing monitoring protocols for wetlands through its series of "state of the science" reports. These reports include introductory modules on wetland bioassessments and modules on specific methods, such as bioassessments for macroinvertebrates. Although the reports do not provide specific prescriptive guidance, they summarize current knowledge and provide options and recommendations to states for developing wetland bioassessment methods and programs. The modules also point out limitations of current methods and identify research needs. Information from BAWWG is available at http://www.epa.gov/owow/wetlands/bawwg/index.html.

(1) *Assess periphyton populations*. Changes in periphyton or plankton community structure and distribution patterns can indicate a water quality problem stemming from thermal pollution, toxic chemicals, nutrients, and sedimentation. Because periphyton have a short life cycle, they are especially good indicators of short-term impacts. Measurements of chlorophyll, a chemical common to all periphyton, can also be used as an indicator of eutrophication. Although there are several levels of sampling and analysis of periphyton populations, rapid sampling can be relatively easy and inexpensive and has little impact on the ecosystem.

Also, standardized methods (biomass, chlorophyll) can be used to analyze and interpret algal communities without doing an extensive taxonomic evaluation, which requires specialized training. One problem with these indicators is that plankton populations vary seasonally and are highly transient, making them a poor indicator of site-specific conditions.

(2) *Assess macroinvertebrate assemblages*. Macroinvertebrates are relatively immobile and are good indicators of site-specific effects. They have a short life cycle and therefore are good indicators of short-term stress. Measurements of invertebrate populations are usually compared to populations from a reference condition to determine the severity of pollutant impacts. The presence or absence of particular species can be used to infer poor aquatic integrity because macroinvertebrate assemblages typically cover a broad range of trophic levels and pollution tolerances that allow interpretation of multiple effects. Macroinvertebrate sampling has some drawbacks, including the fact that populations are highly habitat-dependent and vary with season, stream flow, and region, which can confound results. In addition, taxa identification requires training and can be complex and time-consuming. Despite these drawbacks, volunteer monitoring programs can be used to collect macroinvertebrate data. Both *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (USEPA, 1999) and *Volunteer Stream Monitoring: A Methods Manual* (USEPA, 1997c) provide guidance on how to conduct benthic macroinvertebrate assessments.

(3) *Assess fish assemblages*. Measurements of fish diversity, species richness, species pollutant tolerance, disease prevalence, and a variety of other metrics can be used to identify the nature and extent of a pollution or habitat problem. Measurements are taken in several different habitats within the stream or other water body and are usually compared to a regional reference condition to determine the extent of impairment. The methods can also be used to evaluate the success of management practices. Because fish have a relatively long lifespan, they often react to chronic levels of pollutants and long-term impacts. Fish are also easy to collect and identify. However, fish populations are influenced by many other variables, such as stream size, region, season, temperature, and flow conditions, that need to be taken into account when analyzing the data. Also, fish that migrate may be affected by conditions in another area that is not the area of interest. It is sometimes difficult to identify the source of problems in fish populations because of the prevalence of confounding factors that make interpretation of results difficult.

Biodiversity information on the Web via NatureServe

NatureServe, a nonprofit organization, partners with a network of natural heritage programs and conservation data centers to conduct expert local biodiversity inventories and analyze the results both nationally and internationally. Their Web site offers such data products as the NatureServe Explorer, which compiles conservation data on more than 50,000 plants, animals, and ecological communities in the United States and Canada. Users can search the database by any combination of name, location, and conservation status. The Web site also links to online data resources available from natural heritage programs and conservation data centers via the “Local Program Data” link. NatureServe provides links to ecology, animal, and plant data for download and provides links to other biodiversity resources on the Web. The NatureServe Web site can be accessed at http://www.natureserve.org.

(4) *Assess single species indicators*. Trout, salmon, and freshwater mussels are often used for this type of assessment. Some species are popular with the public, and their popularity can help in rallying support for better management. Measuring only one species is relatively easy and inexpensive and might provide early diagnosis of degradation, which can facilitate remediation efforts. However, natural population fluctuations in a single species can skew results, and without corroborating evidence there is no way to prove conclusively that degradation has occurred. It should be noted that focusing on protecting a single species may decrease protection of other threatened species.

(5) *Measure composite indicators*. This method typically involves developing an index that incorporates the results of several different bioindicators. Several metrics can be combined into a single integrity index, such as the number of native fish species or the number of intolerant macroinvertebrate taxa. Composite indicators provide a more comprehensive evaluation of storm water impacts than fish, macroinvertebrate, or single species indicators alone. Both long-term and short-term effects can be evaluated by using this type of metric. As with the other biological methods, populations are dependent on region, season, and flow. Reference site measurements are essential for valid comparisons when determining the extent of storm water impacts. Note: other measurements may be needed to identify sources of degradation.

2.3.8 Establish Programmatic Indicators

It is important to assess the effectiveness of a runoff management program. Claytor and Brown (1996) present several programmatic indicators that can be used to estimate the success of a management program and help to direct future efforts. These include:

- Number of illicit connections identified or corrected
- Number of management practices installed, inspected, and maintained
- Permitting and compliance
- Growth and development

Management Measure 12 discusses other ways to determine the effectiveness of runoff management programs.

2.3.9 Develop a Suite of Social Indicators

Watershed managers can use several methods to gauge public perception of water quality issues and nonpoint source programs. These “social indicators” include:

- Public attitude surveys
- Industrial/commercial pollution prevention
- Public involvement and monitoring
- User perception

More information about these indicators can be found in *Environmental Indicators to Assess Stormwater Control Programs and Practices* (Claytor and Brown, 1996).

2.4 Information Resources

USGS's NAWQA Data Warehouse provides online access for invertebrate community data from 1,700 stream sites in more than 50 major river basins across the nation. Data from more than 5,000 invertebrate community samples that were collected from 1993 through 2002 can be found here. The data warehouse also provides data on fish communities from more than 1,000 stream locations, as well as data from thousands of water quality samples from approximately 6,400 stream sites, 7,000 wells, and streambed sediment and aquatic animal tissue. Samples have been analyzed for a number of constituents. The NAWQA Data Warehouse can be accessed at http://water.usgs.gov/nawqa/data.

The Caltrans *Guidance Manual: Storm Water Monitoring Protocols* (Caltrans, 2000a) provides step-by-step descriptions of the processes used to plan and implement a successful water quality monitoring program specific to runoff from transportation-related facilities. Although the guidance manual emphasizes uniform policies and procedures for monitoring, the *Statewide Storm Water Management Plan* (Caltrans, 2000b) describes minimum procedures and practices Caltrans uses to reduce pollutants discharged from storm water drainage systems. These documents, along with other storm water-related documents, can be downloaded in PDF format http://www.dot.ca.gov/hq/env/stormwater/special/index.htm.

Donigan and Huber (1991), in *Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas*, reviewed nonpoint source assessment procedures and modeling techniques for both urban and non-urban land areas. Detailed reviews of specific methodologies and models are presented, along with overview discussions focusing on both urban and non-urban methods and models. Brief case studies of ongoing and recently completed modeling efforts are described and recommendations for nonpoint runoff quality modeling are presented. This document can be ordered from the National Technical Information Service at *www.ntis.gov* or by calling 800-553-6847.

EPA has assembled a Web site with information about and links to water quality models. This site includes basic information, EPA-supported models, other federal government-supported models, technical guidance for models, and model training and meetings. The Web site can be accessed at http://www.epa.gov/waterscience/wqm/.

Patten et al. (2000) have undertaken a study to develop improved indicators and innovative techniques for assessing and monitoring ecological integrity at the watershed level in the western United States. Their objectives are to develop practical, scientifically valid indicators that span multiple resource categories, are relatively scale-independent, address different levels of biological organization, can be rapidly and cost-effectively monitored by remote sensing, and are sensitive to a broad range of anthropogenic and natural environmental stressors. More information about this project can be found at http://es.epa.gov/ncer_abstracts/grants/99/ecological/patten.html (NCER, 2001).

Compendium of Tools for Watershed Assessment and TMDL Development (USEPA, 1997a) supports the watershed approach by summarizing available techniques and models that assess and predict physical, chemical, and biological conditions in water bodies. The publication contains descriptions of three major categories of models: watershed loading, receiving water, and ecological. Watershed loading models can be used to simulate the generation and movement of pollutants from the source to discharge into receiving waters. Receiving water models can be used to simulate the movement and transformation of pollutants through lakes, streams, and rivers. Ecological models can be used to simulate plant and animal communities and their response to pollutants and habitat modification. This document is available through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

EPA's *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA, 1997b) contains an overview of nonpoint source pollution and covers the development of a monitoring plan, data analysis, quality assurance/quality control, and biological monitoring. The manual was written to assist users in the design of water quality monitoring programs to assess both impacts from nonpoint source pollution and the effectiveness of control practices and management measures. It is available through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

Volunteer Stream Monitoring (USEPA, 1997c) serves as a tool for program managers who want to launch a new stream monitoring program or enhance an existing program. It contains methods that have been adapted from those used successfully by existing volunteer programs. The guidance is available in HTML and PDF formats at http://www.epa.gov/owow/monitoring/volunteer/stream.

The *Lake and Reservoir Bioassessment and Biocriteria* (USEPA, 1998b) guidance was developed through the experience of existing state, regional, and national lake monitoring programs and is oriented toward practical decision-making rather than research. Its primary target audiences are state and tribal natural resource agencies. It is intended to provide managers and field biologists with functional methods and approaches that will facilitate the implementation of viable lake bioassessment and biocriteria programs that meet their needs and resources. The document can be obtained in HTML format at http://www.epa.gov/owow/monitoring/tech/lakes.html.

Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish (USEPA, 1999) is a practical technical reference for conducting cost-effective biological assessments of lotic systems. This guidance is intended to provide basic, cost-effective biological methods for states, tribes, and local agencies that: (1) have no established bioassessment procedures; (2) are looking for alternative methodologies; or (3) may need to supplement their existing programs (not supersede other bioassessment approaches that have already been successfully implemented). The scope of this guidance is considered applicable to a range of planning and management purposes, i.e., the methods may be appropriate for priority-setting, point and nonpoint source evaluations, use-attainability analyses, and trend monitoring, as well as initial screening. The guidance is available in HTML and PDF formats at http://www.epa.gov/owow/monitoring/rbp.

The *Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Guidance* (USEPA, 2000a) provides an extensive collection of methods and protocols for conducting bioassessments in estuarine and coastal marine waters, as well as the procedures for deriving biocriteria from the results. Several case studies illustrate the bioassessment process and biocriteria derivation procedures. This document can be downloaded in PDF format at http://www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html.

The *Stressor Identification Guidance Document* (USEPA, 2000b) leads water resource managers through the process of stressor identification and evidence assembly. The guidance can be used whenever biological impairment is present in an aquatic ecosystem and the cause is unknown. The stressor identification process combines multiple methods to determine the causes of impairment, and the methods are presented in order of the kinds of evidence used, from site-specific to more general information. The *Stressor Identification Guidance Document* is available in PDF format at http://www.epa.gov/waterscience/biocriteria/stressors/stressorid.html.

Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban (USEPA, 2000c) was written to assist local officials in focusing limited resources by using statistical sampling methods to assess, inspect, or evaluate a representative set of management practices, erosion and sediment controls, and onsite wastewater treatment systems. The document can be downloaded in PDF format at http://www.epa.gov/owow/nps/urban.pdf, or it can be ordered through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

EPA's Web site titled "An Introduction to Water Quality Monitoring" contains a wide variety of resources for those interested in learning more about water quality monitoring, automated data management, and geographic information systems (USEPA, 2001). Many EPA guidance documents, fact sheets, and final reports are available from this site, which can be accessed at http://www.epa.gov/owow/monitoring/monitor.html.

EPA's Web site, "Water Quality Criteria and Standards Plan" (USEPA, 1998d), describes six new criteria and standards program initiatives that EPA and the states and tribes will take over during the next decade. The plan presents a "vision" and strategy for meeting these important new initiatives and improvements and will guide EPA, states, and tribes in developing and implementing criteria and standards that provide a basis for enhancements to the TMDL program, NPDES permitting, nonpoint source control, wetlands protection, and other water resource management efforts. The Web site is located at http://www.epa.gov/ost/standards/quality.html.

EPA's Volunteer Monitoring Program provides technical assistance, serves as a regional contact for volunteer programs, manages grants to state agencies that undergo volunteer water monitoring and conduct public participation programs, and provides information exchange services for volunteers. The program's Web site (http://www.epa.gov/owow/monitoring/volunteer) provides a link to a listserver is available for volunteer monitoring program coordinators, as well as a national newsletter for volunteer monitors, a directory of volunteer monitoring programs, and manuals on volunteer monitoring methods and on planning and implementing volunteer programs.

EPA's Watershed and Water Quality Modeling Technical Support Center provides information and services to federal agencies, state and local governments, businesses, and individuals to help support implementation of the Clean Water Act. Support includes reviewing proposed TMDLs, providing oversight to TMDL development nationwide, serving as technical advisors, applying models for TMDL development, assisting in data acquisition and analysis, assisting in TMDL implementation, analyzing BMP design and performance, and researching models for regulatory applications. The center's Web site can be accessed at http://www.epa.gov/athens/wwqtsc/index.html.

The P8—Urban Catchment Model by Walker (2000) is designed to predict the generation and transport of runoff pollutants in urban watersheds. The model was developed to design and evaluate runoff treatment control combinations in developments for pollutant removal efficiency. The most recent version of this DOS-based program (Version 2.4, published in February 2000), as well as data files and program documentation, is available for download from http://wwwalker.net/p8.

A useful water resource impact model is the Long-Term Hydrologic Impact Assessment (L-THIA), which was developed by Purdue University (2000) for land use planners to provide site-specific estimates of changes in runoff, recharge, and nonpoint source pollution resulting from past or proposed land use changes. The model uses regional climate data and user-provided location, land use, and soil group data for up to three different scenarios (past, present, and future). The results are in the form of tables, bar charts, and pie charts. The model is available at http://danpatch.ecn.purdue.edu/~sprawl/LTHIA7.

Vermont's Water Resources Board developed "A Scientifically Based Assessment and Adaptive Management Approach to Stormwater Management" as an appendix to the *Investigation into Developing Cleanup Plans for Stormwater Impaired Waters* (Docket No. INV-03-01). The assessment paper describes a framework for identifying storm water runoff problems and providing adaptive management to address controls for and treatment of runoff in problem areas. The framework represents a balance of the interests of many diverse constituents, focusing on surface water impairments and improvements to identify problems due to runoff and improvements due to runoff controls. The report, part of the Vermont Water Resources Board's Stormwater Docket, can be accessed at http://www.state.vt.us/wtrboard/docs/inv-03-01report.pdf.

NatureServe, a nonprofit organization, partners with a network of natural heritage programs and conservation data centers to conduct expert local biodiversity inventories and analyze the results both nationally and internationally. Its Web site offers such data resources as the NatureServe Explorer, which compiles conservation data on more than 50,000 plants, animals, and ecological communities in the United States and Canada. Users can search the database by any combination of name, location, and conservation status. The Web site also connects to online data resources available from natural heritage programs and conservation data centers via the "Local Program Data" link. NatureServe provides links to ecology, animal, and plant data for download and to other biodiversity resources on the Web. The NatureServe Web site can be accessed at http://www.natureserve.org.

2.5 References

Booth, D.B. 1994. *A Protocol for Rapid Channel Assessment*, Unpublished report. Surface Water Management Division, Water Resources Section, King County, WA.

California Department of Transportation (Caltrans). 2000a. *Guidance Manual: Storm Water Monitoring Protocols*. CTSW-RT-00-005. California Department of Transportation, Sacramento, CA.

California Department of Transportation (Caltrans). 2000b. *Statewide Storm Water Management Plan*. CTSW-RT-01-024. California Department of Transportation, Sacramento, CA.

Caraco, D. 2001. *The Watershed Model, Version 3.0*. Prepared for U.S. Environmental Protection Agency by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1999. Microbes and urban watersheds feature article VI: Resources for detecting bacterial sources. *Watershed Protection Techniques* 3(1):593–596.

Claytor, R., and W. Brown. 1996. *Environmental Indicators to Assess Stormwater Control Programs and Practices*. Prepared for U.S. Environmental Protection Agency, Washington, DC, by Center for Watershed Protection, Ellicott City, MD.

Donigian, A.S., and W.C. Huber. 1991. *Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas*. EPA 600-3-91-039. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

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*. U.S. Geological Survey, Reston, VA.

Federal Emergency Management Agency (FEMA). 2000. *Map Service Center Products*. http://msc.fema.gov. Last updated June 7, 2000. Accessed March 28, 2001.

Hager, M.C. 2001. Detecting Bacteria in Coastal Waters*.* *Stormwater Magazine* 2(3): 16-25. http://www.forester.net/sw_0105_detecting.html. Accessed August 12, 2003.

Hillegass, J.B. 2003. *Using an Indicators Database to Measure Storm Water Program Effectiveness in Hampton Roads.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

MacDonald, L. 2000. Evaluating and managing cumulative effects: Process and constraints. *Environmental Management* 26(3):299–315.

Maryland Department of the Environment (MDE). 1999. *Maryland's Environmental Indicators Status Report Summer 1999.* Maryland Department of the Environment, Annapolis, MD. Last updated December 6, 1999. Accessed February 9, 2000.

National Center for Environmental Research (NCER). 2001. *Developing Effective Ecological Indicators for Watershed Analysis*. http://es.epa.gov/ncer_abstracts/grants/99/ecological/patten.html. Last updated August 13, 2001. Accessed May 3, 2002.

Omerink, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77(1):118–125.

Patten, D.T., W. Minshall, R. Lawrence, and A. Marcus. 2000. Developing effective ecological indicators for watershed analysis. In *2000 STAR Ecosystem Indicators Progress Review Workshop*. Proceedings of National Center for Environmental Research Workshop, Las Vegas, NV, May 8–10, 2000, p. 26.

Pennsylvania Department of Environmental Protection (PDEP). 1999. *Water Quality Initiatives in PA Act 167 Stormwater Planning*. Pennsylvania Department of Environmental Protection, Harrisburg, PA.

Purdue University. 2000. *Impacts of Land Use Change on Water Resources.* http://danpatch.ecn.purdue.edu/~sprawl/LTHIA7. Last updated September 2000. Accessed March 28, 2001.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology books, Pagosa Springs, CO.

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

Simpson, J. 2003. *DNA Based Molecular Methods for Bacterial Source Tracking in Watersheds.* Presented at the EPA Science Forum, May 5-7, 2003, Ronald Reagan Building and International Trade Center, Washington, DC.

Slawecki, T.A.D., R. Copp, and C. Zahorcak. No date. *Application of a GIS Decision Support Tool to Urban Watershed Management in Fulton, County, Georgia*. Limno-Tech, Inc., and Brown and Caldwell, Ann Arbor, MI.

Smith, R.A., R.B. Alexander, and G.E. Schwarz. 2003. Natural Background Concentrations of Nutrients in Streams and Rivers of the Conterminous United States. *Environmental Science and Technology* 37(14): 3039-3047.

Spacie, A., J.M. Harbor, M. Hondzo, and B.A. Engel. 2000. Development and evaluation of ecosystem indicators for urbanizing midwestern watersheds. In *2000 STAR Ecosystem Indicators Progress Review Workshop*. Proceedings of National Center for Environmental Research Workshop, Las Vegas, NV, May 8–10, 2000, p. 49.

U.S. Department of Housing and Urban Development (HUD) and U.S. Environmental Protection Agency (USEPA). 2000. *HUD Environmental Maps E-MAPS.* http://www.hud.gov/emaps. Last updated March 2000. Accessed March 28, 2001.

U.S. Environmental Protection Agency (USEPA). 1983. *Final Report of the Nationwide Urban Runoff Program*. U.S. Environmental Protection Agency, Water Planning Division, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997a. *Compendium of Tools for Watershed Assessment and TMDL Development*. EPA 841-B-97-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997b. *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls*. EPA 841-B-96-004. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997c. *Volunteer Stream Monitoring: A Methods Manual*. EPA 841-B-97-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1998a. *An Introduction to Water Quality Monitoring*. U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://www.epa.gov/owow/monitoring/monintr.html. Last updated December 14, 1998. Accessed February 2, 2000.

U.S. Environmental Protection Agency (USEPA). 1998b. *Lake and Reservoir Bioassessment and Biocriteria*. EPA 841-B-98-007. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1998d. *Water Quality Criteria and Standards Plan*. http://www.epa.gov/ost/standards/quality.html. Last updated July 2, 1998. Accessed May 2, 2002.

U.S. Environmental Protection Agency (USEPA). 1999. *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2000a. *Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Guidance*. EPA 822-B-00-024. U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2000b. *Stressor Identification Guidance Document*. EPA-822-B-00-025. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2000c. *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures—Urban*. EPA 841-B-00-007. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2000d. *Whole Effluent Toxicity (WET) Methods*. http://www.epa.gov/OST/WET. Last updated August 1, 2000. Accessed March 28, 2001.

U.S. Environmental Protection Agency (USEPA). 2001a. *An Introduction to Water Quality Monitoring*. http://www.epa.gov/owow/monitoring/monintr.html. Last updated June 11, 2001. Accessed May 6, 2002.

U.S. Environmental Protection Agency (USEPA). 2001b. *Biological Assessment of Wetlands Workgroup (BAWWG)*. http://www.epa.gov/owow/wetlands/bawwg/index.html. Last updated March 26, 2001. Accessed March 28, 2001.

U.S. Environmental Protection Agency (USEPA). 2001c. *Water Quality Criteria and Standards Program*. http://www.epa.gov/OST/standards. Last updated March 6, 2001. Accessed March 28, 2001.

U.S. Environmental Protection Agency (USEPA). 2002. *Wastewater Technology Fact Sheet: Bacterial Source Tracking.* EPA 832-F-02-010. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Walker, W.W. 2000. P8—Urban Catchment Model: Program For Predicting Polluting Particle Passage Through Pits, Puddles, and Ponds. http://wwwalker.net/p8/. Accessed September 10, 2004.

Zhang, H.X., J.T. Maurao, L.A. Fillmore, and J. Wheeler. 2003. *Bacterial Source Tracking in Watershed Management and Source Water Protection*. Presented at the AWRA 2003 International Congress, June 29-July 2, 2003, New York, NY.

MANAGEMENT MEASURE 3
WATERSHED PROTECTION

3.1 Management Measure

Develop a watershed protection program to:

- Avoid development of areas that are particularly susceptible to erosion and sediment loss.
- Preserve areas that provide important water quality benefits and/or are necessary to maintain riparian vegetation and aquatic biota.
- Site development projects, including roads, highways, and bridges, to protect the natural integrity of water bodies and natural drainage systems.

3.2 Management Measure Description and Selection

3.2.1 Description

The purpose of this management measure is to reduce the generation of nonpoint source pollutants and to mitigate the impacts of urban runoff and associated pollutants from new development and redevelopment, including the construction of new and relocated roads, highways, and bridges. It is intended to provide general goals for local agencies and urban communities in developing comprehensive programs for guiding future development and land use activities in a manner that will prevent and mitigate the effects of nonpoint source pollution.

Although the goals of this management measure and Management Measure 4 (Site Development) are similar, this measure is intended to apply to larger watersheds or regional drainage basins rather than individual sites. The watershed protection and site development management measures are intended to be complementary. They can be used together with the other management measures in a comprehensive framework to control runoff and reduce nonpoint source pollution. (See Chapter 1 for a description of the runoff management program framework.)

Comprehensive planning is an effective nonstructural tool to control nonpoint source pollution. Where possible, growth should be directed toward areas where it can be sustained with minimal impact on the natural environment (Meeks, 1990). Poorly planned growth and development have the potential to degrade and destroy natural drainage systems and surface waters (Mantel et al., 1990). By making proper planning and zoning decisions, water quality managers can direct development and land disturbance away from areas that drain to sensitive waters. Land use designations and zoning laws can also be used to protect environmentally sensitive areas such as riparian corridors and wetlands.

Riparian buffers and wetlands can have the benefit of providing long-term pollutant removal capabilities without the comparatively high costs usually associated with constructing and maintaining structural controls. Conservation or preservation of these areas is important to protect the water quality of streams, wetlands, lakes, and reservoirs. Land acquisition programs help to preserve areas considered critical to maintaining surface water quality. Adequate buffer strips along streambanks provide protection for stream ecosystems, help stabilize the stream, and can prevent streambank erosion (Holler, 1989). Buffer strips can also protect and maintain near-stream vegetation that attenuates the release of sediment into stream channels. Levels of suspended solids have been shown to increase at a slower rate in stream channel sections with well-developed riparian vegetation (Holler, 1989).

3.2.2 Management Measure Selection

This measure was selected for several reasons. First, watershed protection is a technique that provides long-term water quality benefits, and many states and local communities have adopted this practice. Numerous state and local governments have already legislated and implemented detailed watershed planning programs that are consistent with this management measure. For example, Oregon, New Jersey, Delaware, and Florida have passed legislation that requires county and municipal governments to adopt comprehensive plans, including requirements to direct future development away from sensitive areas. Many municipalities and regions have adopted land use and growth controls, including the towns of Amherst and Norwood and the Cape Cod region of Massachusetts; Narragansett, Rhode Island; King County, Washington; and many others.

Second, there is general recognition that the protection of sensitive areas and areas that provide water quality benefits is integral to maintaining or minimizing the impacts of development on receiving waters and associated habitat. Without a comprehensive planning approach that includes the use of riparian buffers, open space, bioretention, and structural controls to maintain the predevelopment hydrologic characteristics of the site, significant water quality and habitat impacts are likely. The experience of communities across the country has shown that the use of structural controls without adequate local land use planning and zoning often does not adequately protect water quality and might even cause detrimental effects such as increased temperature.

Third, this measure is effective in producing long-term water quality benefits without the high operation and maintenance costs associated with structural controls. The Michigan Department of Environmental Quality (no date) compared the costs of two nonpoint source projects. One involved preserving an urbanizing watershed, and the other entailed restoring an urban watershed. Table 3.1 is a side-by-side cost comparison demonstrating that it is generally less costly to protect high-quality streams than to restore them.

Table 3.1: Cost comparison of stream preservation vs. stream restoration (Michigan Department of Environmental Quality, no date).

	Bear Creek	York Creek
Type of nonpoint source project	Preservation	Restoration
Setting	Grand Rapids, MI, area stream	Grand Rapids, MI, area stream
Size	20,096 acres	2,110 acres
Level of urbanization	9.5% (1991)	19% (1993)
Stream category	High-quality trout stream	Former trout stream
Storm water ordinance	$10,000	$10,000
Decision-making GIS	$10,000	$10,000
Information/education program	$100,000	$80,000
Streambank stabilization	$15,000	$130,000
Storm water basin retrofits	–	$180,000
Additional storm water basins	–	$75,000
Other practices (habitat improvement, repairing road crossings, etc.)	$75,000	$190,000
Total cost	$210,000[a]	$675,000

[a] Total cost does not take into account the purchase cost or opportunity cost for not developing the land

3.3 Management Practices

A comprehensive watershed approach requires constant adjustments based on development patterns, population increases, changing land uses, the state of the resources, and the institutional capacity of the community to manage its resources. The practices listed below provide an overview of the approaches communities around the country are adopting or experimenting with to protect their water resources in a cost-effective way.

3.3.1 Resource Inventory and Information Analysis

Before a comprehensive program can be developed, communities should define the watershed boundaries, target areas, and pollutants of concern, and conduct resource inventory and information analysis. These activities can be done by using the best available information or collecting primary data, depending on funding availability and the quality of available data. Activities pursued under this process include assessment of ground water and surface water hydrology; evaluation of soil type and ground cover; identification of areas with water quality impairments; and identification of environmentally sensitive areas, such as steep or erodible uplands, wetlands, riparian areas, floodplains, aquifer recharge areas, drainageways, and unique geologic formations. Once environmentally sensitive areas are identified, those that are integral to the protection of surface waters and the prevention of nonpoint source pollution can be protected.

The City of Virginia Beach, Virginia, conducted a three-phase inventory of natural areas to help planners and public officials develop practices for resource protection. The data collection phase cost $13,867 (1991 dollars); the field inventory (Phase II), cost $54,624; and Phase III, preparation of a final report, cost $15,255 (Jenkins, 1991).

Richmond County, Virginia, developed the Richmond County Resource Information System (RIS) to provide a basis for responsible planning and development of shoreline areas. The

Watershed Approach to Storm Water and Flood Management

The Planning Department of Delaware County, New York, is leading the effort to develop long-term solutions to water quality impairment from urban runoff. The county's Stormwater and Flood Management program uses a two-phase approach: (1) inventorying and assessing sources of urban runoff and storm water infrastructure, and (2) local implementation and municipal plan development.

The inventory and assessment component involves a detailed evaluation of point and nonpoint sources of pollution in the Cannonsville Basin. Locations of potential sources were documented using a Global Positioning System and site characteristics such as soil type and land use were recorded. A GIS database was used to store this information along with existing infrastructure, topographic maps ,and planimetric maps.

The local implementation and municipal plan development component involves working with local municipalities as part of its Town Planning Advisory Service (TPAS) to develop local initiatives for water quality protection and to demonstrate the role of water quality in community economic development. The municipal plans help local officials integrate wellhead protection into water quality planning, prioritize management needs, establish maintenance programs, and incorporate runoff management into capital planning (Delaware County Departments of Planning and Public Works, 2003).

compilation and mapping of resource information are part of the county's planning and zoning program. In 1990, the program was supported by a $39,000 Federal Coastal Zone Management Grant, $45,000 from the Chesapeake Bay Foundation through a Virginia Environmental Endowment Grant, and $96,000 from the county's comprehensive plan budget (Jenkins, 1991).

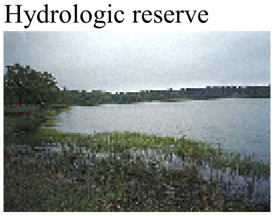
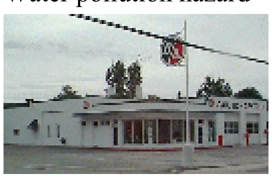
3.3.1.1 Identify environmentally sensitive, critical conservation areas

The identification of environmentally sensitive areas, also referred to as critical conservation areas, is an essential component of a watershed protection program. These areas need to be identified to: (1) avoid developing areas susceptible to erosion and sediment loss; and (2) preserve areas that provide important water quality benefits, such as wetlands, permeable soils, forested buffers, and riparian areas. These types of lands are described in Table 3.2. Inventories of these areas can be developed using wetland inventories, soil maps, maps of critical habitat for endangered species, GIS tools, remote sensing, vegetative cover inventories/maps, and forest inventories, among other sources.

GIS Mapping for Open Space and Water Resource Protection

The towns of Westford, Littleton, Chelmsford, and Boxborough, located in the Merrimack River Watershed north of Boston, Massachusetts, are using GIS as a tool to guide efforts to protect critical open space lands and aquifers. The effort is part of Massachusetts' Community Preservation Initiative, which helps local officials address the tradeoff between environmental planning issues, such as habitat and watershed protection, and the growing needs of the community in terms of economic development, housing, and transportation. GIS provides local officials with the capability of identifying open space lands that are critical to protecting water resources and exploring the implications of various build-out scenarios, land preservation strategies, land uses, and densities (NALGEP, 2003).

Table 3.2: Types of lands that should be preserved for watershed protection (adapted from Caraco et al., 1998).

Conservation Area	Description	Examples
Critical habitat 	Essential spaces for plant and animal communities or populations	Tidal wetlands, freshwater wetlands, large forest clumps, springs, spawning areas in streams, habitat for rare or endangered species, potential restoration areas, native vegetation areas, coves
Aquatic corridor 	Areas where land and water interact	Floodplains, stream channels, springs and seeps, steep slopes, small estuarine coves, littoral areas, stream crossings, shorelines, riparian forest, caves, and sinkholes
Hydrologic reserve 	Undeveloped areas responsible for maintaining the predevelopment hydrologic response of a subwatershed	Forest, meadow, prairie, wetland, cropland, pasture, or managed forest
Water pollution hazard  Source: Stapleton, 1999.	Any land use or activity that is expected to create a relatively high risk of water pollution	Septic systems, landfills, hazardous water generators, aboveground or underground tanks, impervious cover, surface or subsurface discharge of wastewater effluent, land application sites, storm water "hot spots," pesticide application, industrial discharges, and road salt storage areas
Cultural and historic sites  Source: NPS, 2001.	Areas that provide a sense of place in the landscape and are important habitats for people	Historic or archaeological sites, trails, parkland, scenic views, water access, bridges, and recreational areas

3.3.1.2 Identify and protect drinking water sources

All drinking water sources, including surface and ground waters, should be considered for protection, and unfiltered sources will require the most stringent protection. More than 200 cities, towns, and tribes protect ground water public drinking water systems from contamination using a variety of local government tools such as zoning, subdivision controls, and transfer of development rights. The ordinances implementing these tools are varied and include measures such as regulating onsite wastewater treatment systems and limiting nitrogen loading within wellhead protection areas (see section 1.3.1.2 in Management Measure 1, which describes different types of ordinances, including source water protection ordinances). This section introduces several tools to protect surface and ground water sources. Also, more information about identifying and protecting drinking water sources can be found at EPA's Office of Ground Water and Drinking Water Web site at http://www.epa.gov/ogwdw.

(1) *Delineate a Source Water Protection Area.* Delineation of a Source Water Protection Area requires identifying the boundaries of the area from which drinking water supplies are drawn. This information can be obtained from states, which are required to conduct an assessment of all public water systems. These assessments include a delineation, contaminant inventory, and susceptibility determination (see http://www.epa.gov/safewater/protect/swap.html for more information about state Source Water Assessment Programs). Local governments may choose to elaborate on the state's assessment before planning management activities.

(2) *Protect Sole Source Aquifers.* Sole Source Aquifer (SSA) designations are one tool to protect drinking water supplies in areas with few or no alternative sources. These areas are of special significance because if contamination occurred, using an alternative source would be prohibitively expensive. The designation protects an area's ground water resource by requiring EPA review of any proposed projects within the designated area that are receiving federal financial assistance. All proposed projects receiving federal funds are subject to a review to ensure they do not endanger the water source. Between January 1997 and January 1999, EPA reviewed 439 projects, 60 of which required modifications that were deemed necessary to protect the Sole Source Aquifers. Examples of federally funded projects that have been reviewed by EPA under the SSA protection program include highway improvements and new road construction, public water supply wells and transmission lines, wastewater treatment facilities, construction projects that involve disposal of storm water, agricultural projects that involve management of animal waste, and projects funded through Community Development Block Grants.

EPA has developed Memoranda of Understanding (MOU) with other agencies to help establish review responsibilities under the Sole Source Aquifer Protection Program and to clarify what types of projects should or should not be referred to EPA. If you have questions about whether EPA needs to review a project in a particular Sole Source Aquifer, please contact the Sole Source Aquifer Coordinator for your state or territory (see http://www.epa.gov/safewater/swp/sumssa.html for lists and maps of Sole Source Aquifers in each of the EPA regions along with contact information for Sole Source Aquifer Coordinators).

(3) *Develop a local wellhead protection ordinance.* Wellhead protection refers to implementing pollution prevention and source controls to protect underground sources of drinking water. The Safe Drinking Water Act requires that State Wellhead Protection Programs be approved by EPA and incorporate delineation, contaminant source inventory, and source management. Local governments can also develop local wellhead protection ordinances to further protect drinking water supplies from contamination.

(4) *Purchase property or development rights*. This practice is meant to guarantee community control over the activities conducted on lands that contribute to aquifers or surface waters. This may involve outright purchase of the land or just surface-use rights (see section 3.3.5 for a discussion of land acquisition options). New funds from the Safe Drinking Water Act allow land trusts and other local organizations to work with state agencies and water suppliers to identify and acquire critical lands and conservation easements.

3.3.2 Development of Watershed Management Plan

The resource inventory and information analysis component provides the basis for a watershed management plan, which is a comprehensive approach to addressing the needs of a watershed, including land use, urban runoff control practices, pollutant reduction strategies, and pollution prevention techniques.

For a watershed management plan to be effective, it should have measurable goals describing desired outcomes and methods for achieving the goals. Goals, such as reducing pollutant loads to surface water by 25 percent, can be articulated in a watershed management plan. Development and implementation of urban runoff practices, both structural and nonstructural, can be incorporated as methods for achieving the goal. The following describes the general steps for developing a watershed management plan (Livingston and McCarron, 1992):

1. Delineate and map watershed boundaries and subbasins within the watershed.
2. Inventory and map natural runoff conveyance and storage systems.
3. Inventory and map the manmade storm water conveyance and storage system.
4. Inventory and map land use by subbasin.
5. Inventory and map detailed soils by subbasin.
6. Establish a clear understanding of water resources in the watershed. Analyze water quality, sediment, and biological data. Analyze subjective information on problems such as citizen complaints. Evaluate water body use impairment, including the frequency, timing, and seasonality of the problem. Conduct a water quantity assessment (e.g., low flows, seasonality).
7. Inventory pollution sources in the watershed, including point sources (location, pollutants, loadings, flow capacity, etc.) and nonpoint sources (type, location, pollutants, loading, etc.). Include a land use/loading rate analysis for storm water, a sanitary survey for septic tanks, and dry weather flow monitoring to locate illicit discharges.
8. Identify and map future land use by subbasin. Conduct land use loading rate analyses to assess potential effects of various land use scenarios.
9. Identify planned short-term (five years) and long-term (20 years) infrastructure improvements. Runoff management deficiencies should be coordinated and scheduled with other infrastructure or development projects.
10. Determine infrastructure and natural resource management needs within each watershed.

11. Set resource management goals and objectives. Before corrective actions can be taken, a resource management target must be set. The target can be defined in terms of water quality standards, attainment of beneficial uses, or other local resource management objectives.
12. Determine pollutant reduction for existing and future land uses needed to achieve water quality goals.
13. Select appropriate management practices for both point and nonpoint sources that can be used to achieve the goal. Evaluate pollutant removal effectiveness, landowner acceptance, financial incentives and costs, availability of land operation and maintenance needs, feasibility, and availability of technical assistance.
14. Develop a watershed management plan. Since the problems in each watershed will be unique, each watershed management plan will be specific. However, all watershed plans will include elements such as an existing and future land use plan; a master storm water management plan that addresses existing and future needs; a wastewater management plan, including septic tank maintenance programs; and an infrastructure and capital improvements plan.

Development of a watershed management plan may involve establishing general land use designations that define allowable activities on a parcel of land. For example, land designated for low-density residential use would be limited to a density of two houses per acre, provided that all other regulations and requirements are met. All development activities allowed in a use category should be defined. By guiding uses within the planning areas, impacts to surface waters from urban runoff can be controlled. Those areas identified in the resource inventory and information analysis phase as environmentally sensitive and important to maintaining water quality can be preserved through various measures supported by state or local goals, objectives, and policies.

In Florida, local governments (counties and incorporated municipalities) were required to develop comprehensive plans based on existing information to guide short-term (five years) and long-term (20 to 25 years) growth and development. Local plans were required to be consistent with the state plan and the state growth management law and needed to identify environmentally sensitive areas and areas with water quality problems.

The Environmental Quality Corridor (EQC) System was established in Fairfax County, Virginia, to preserve floodplains, wetlands, shoreline areas, and steep valley slopes. EQCs were defined in the county's comprehensive plan and identified on the county land use map. If a parcel of land subject to a zoning or land use designation change contained an EQC, it was required to be set aside by the developer as part of development approval. Since its initiation, tens of thousands of acres have been set aside through the EQC program. The cost of implementing the program is part of the operating budget of the county planning department.

Howard County, Maryland, developed a Land Preservation and Recreation Plan as part of the county comprehensive plan. Under this plan, open space resources are purchased for preservation and recreation. The annual cost to update the plan, $25,000 (in 1991 dollars), is funded by the state. In FY 1990, the county received $1.14 million in state funds to update the plan and acquire land (Jenkins, 1991).

3.3.3 Implement the Plan

Once critical areas have been identified, land use designations have been defined, and goals have been established to guide activities in the watershed, implementation strategies can be developed. At this point, the requirements of future development are defined. These requirements include, but are not limited to, permitted uses, construction techniques, and protective maintenance measures. Land development regulations may also prescribe natural performance standards, such as "rates of runoff or soil loss should be no greater than predevelopment conditions."

A useful planning tool is the Long-Term Hydrologic Impact Assessment (L-THIA), which was developed by Purdue University (2000) for land use planners to provide site-specific estimates of changes in runoff, recharge, and nonpoint source pollution resulting from past or proposed land use changes. The model uses regional climate data and user-provided location, land use, and soil group data for up to three different scenarios (past, present, and future). The results are in the form of tables, bar charts, and pie charts. The model is available at http://danpatch.ecn.purdue.edu/~sprawl/LTHIA7.

Listed below are examples of the types of development regulations and other implementation tools that have been successful at controlling nonpoint source pollution.

3.3.3.1 Develop ordinances or regulations requiring nonpoint source pollution controls for new development and redevelopment

These ordinances or regulations should address, at a minimum:

- Control of off-site urban runoff discharges (to control potential impacts of flooding);
- The use of source control BMPs and treatment BMPs;
- The performance expectations of BMPs, specifying design storm size, frequency, and minimum removal effectiveness, as specified by the state or local government;
- The protection of stream channels, natural drainageways, and wetlands;
- Erosion and sediment control requirements for new construction and redevelopment; and
- Treatment BMP operation and maintenance requirements and designation of responsible parties.

3.3.3.2 Plan infrastructure

Infrastructure planning is the multiyear scheduling and implementation of infrastructure improvements, such as roads, sewers, potable water delivery, landfills, public transportation, and urban runoff management facilities. Infrastructure planning can be an effective practice to help guide development patterns away from areas that provide water quality benefits, are susceptible to erosion, or are sensitive to disturbance or pollutant loadings. Where possible, long-term comprehensive plans to prevent the conversion of these areas to more intensive land uses should be drafted and adopted. Infrastructure should be planned for and sited in areas that have the capacity to sustain environmentally sound development. Development tends to occur in response to infrastructure availability, both existing and planned. New development should be targeted for areas that have adequate infrastructure to support growth in order to promote infill development, prevent urban sprawl, and discourage the use of septic tanks where they are inappropriate (International City/County Management Association, 1979). Infill development may have the added advantage of municipal cost savings.

To discourage development in the environmentally sensitive East Everglades area, Dade County, Florida, has developed an urban services boundary (USB). In areas outside the USB, the county will not provide infrastructure and has kept land use densities very low. This strategy was selected to prevent urban sprawl, protect the Everglades wetlands (outside of Everglades National Park), and minimize the costs of providing services countywide. The area is defined in the county comprehensive plan, and restrictions have been implemented through the land development regulations (Metro-Dade Planning Department, 1988).

Congress has enacted similar legislation for the protection of coastal barrier islands. In 1981, the availability of federal flood insurance for new construction on barrier islands was discontinued. In 1982, Congress passed the Coastal Barriers Resources Act, establishing the Coastal Barrier Resource System (CBRS), and terminated a variety of federal assistance programs for designated coastal barriers, including grants for new water, sewage, and transportation systems. In 1988, similar legislation was passed for the Great Lakes area, adding 112 Great Lakes barrier islands. Additions to the CBRS in 1990 included parts of the Florida Keys, the U.S. Virgin Islands, Puerto Rico, and the Great Lakes (Simmons, 1991).

The result of the legislation and subsequent additions to the CBRS has been the establishment of approximately 1,326,000 acres of barriers that are ineligible for federal assistance for infrastructure and flood insurance (U.S. Fish and Wildlife Service (USFWS), 2002). This act has helped to guide development away from these sensitive coastal areas to more suitable locations. USFWS (2002) estimates that more than a billion dollars may be saved between 1983 and 2010 due to reduction of disaster relief and infrastructure construction costs.

3.3.3.3 Revise local zoning ordinances

Zoning is the division of a municipality or county into districts for the purpose of regulating land use. Usually defined on a map, the allowable uses within each zone are described in an official document, such as a zoning ordinance. Zoning is enacted for a variety of reasons, including preservation of areas that are environmentally sensitive or necessary to maintain environmental integrity (International City/County Management Association, 1979).

Within zoning ordinances, subdivision regulations govern the process by which individual lots are created out of larger tracts of land. Subdivision regulations are intended to ensure that subdivisions are appropriately related to their surroundings. General site design standards, such as preservation of environmentally sensitive areas, are one example of subdivision regulations (International City/County Management Association, 1979).

There are specific types of zoning ordinances that can be particularly useful in protecting water resources, including performance-based zoning, overlay zones, bonus or incentive zoning, large-lot zoning, agricultural protection zoning, watershed-based zoning, and urban growth boundaries. The following provides an overview of each of these types of zoning:

3.3.3.3.1 Performance-based zoning

In performance-based zoning, developers are allowed flexibility in planning and designing the development as long as they meet minimum requirements set by the local government. These minimum requirements vary based on the particular resource protection objectives of the community but might include limiting the amount of impervious surfaces or preserving sensitive features such as wetlands or steep slopes with high erosion potential. Developers can choose lot sizes, building types, site layouts, and other development characteristics as long as they meet the minimum criteria. Performance-based zoning offers protection of natural resources for the community and increased flexibility for the developer. It requires greater effort on the part of the local government, however, to carefully tailor the language of the ordinance to ensure that resources are adequately protected, and to carefully review development proposals to ensure that performance criteria are met.

Officials in Columbia, Missouri, were interested in developing a uniform policy to deal with storm water pollution (Tritto, 2000). This effort was initiated in response to a recent back-and-forth battle between a developer and the Columbia City Council. Officials are reviewing a report developed by Missouri University researchers that evaluated the environmental sensitivity of 13 watersheds in the Columbia area using 12 criteria focused on human health and environmental protection. The report recommended limits on the percentage of impervious surfaces for developments based on categories of watershed sensitivity. Developers would be allowed to exceed these limits only by taking additional steps to control storm water pollution through the use of management practices. The approach recommended in the report would provide a financial incentive for developers to direct high-density developments to less-sensitive watersheds because tougher standards on impervious areas and the costs of storm water controls would make it more expensive to develop in environmentally sensitive watersheds. City officials are also reviewing storm water management policies in other cities to develop uniform guidelines so that developers are better-informed about what is expected of them.

3.3.3.3.2 Overlay zones

Overlay zones superimpose additional restrictions on existing zoning categories to provide extra protection for a particular natural resource. For example, if a wetland or endangered species habitat crosses the boundaries of several development zones, an overlay zone can be established to limit development in areas that affect the wetland. Overlay zones can also be used to limit development in areas with highly permeable soils to protect an underground drinking water source from contamination. The overlay zones would maintain the general land use category, such as residential or commercial, but would require additional protection, such as greater limits on impervious area or special vegetation protection requirements.

3.3.3.3.3 Bonus or incentive zoning

Bonus or incentive zoning is another method to allow developers greater flexibility in return for preservation of open space and sensitive or environmentally significant features. With incentive zoning, a developer might be allowed to develop at a higher density than normally allowed if in return he or she preserves additional open space, creates a wetland, or reduces the site’s overall impervious area with underground parking, transportation modifications, or innovative site layouts. The success of bonus or incentive zoning is highly dependent on an individual developer’s perception of the economic benefits of additional density credits; therefore, this type of zoning cannot be relied upon to protect natural resources. However, bonus or incentive zoning can encourage voluntary and economically beneficial protection for open space and sensitive features.

3.3.3.3.4 Large-lot zoning

Large-lot zoning establishes a very low density of development; individual dwellings are built on lots of 5 acres or more. Large-lot zoning is most effective when lots are very large (5 to 20 acres) (Caraco et al., 1998). The purpose of large-lot zoning is to spread development thinly, thereby conserving a large proportion of open space on each lot and reducing impacts on water resources. This method can produce undesirable results, however, including

- Promoting sprawl;
- Fragmenting habitats with more extensive infrastructure and lawns;
- Increasing reliance on automobile transportation; and
- Excluding lower-income residents who cannot afford to purchase large parcels of land.

One approach to minimizing the negative impacts of large-lot zoning is to combine it with cluster zoning. In this way, a large area of open space can be protected, while accommodating new development in a more concentrated manner. Although used in many areas, large-lot zoning is not considered to be any more protective than other zoning tools.

3.3.3.3.5 Farmland preservation zoning

Farmland preservation ordinances are another type of measure to provide open space retention, habitat protection, and watershed protection. Farmland protection may be a less-costly means of controlling pollutant loadings than the implementation of urban runoff structural control practices. Much of the farmland currently being converted has soils that are stable and not highly erodible. Conversion of these farmlands often displaces farming activities to less-productive, more-erodible areas that may require increased nutrient and pesticide applications.

Many communities consider both agriculture and forestry to be an integral part of rural heritage and strive to preserve these industries and the open space associated with them. According to the 1997 National Resources Inventory, nearly 16 million acres of forest, cropland, and open space were converted to urban and other uses from 1992 to 1997. The average rate for those five years—3.2 million acres per year—is more than twice the conversion rate of 1.4 million acres per year recorded from 1982 to 1992 (USDA-NRCS, 2000).

Agricultural lands can be protected by implementing a modified large-lot zoning ordinance that makes residential development less economically attractive. Alternatively, a cluster development ordinance can be established that specifies a density for an agricultural development and also requires that dwellings be built on small lots, leaving the remainder of the site as agricultural open space. The ordinance can also specify that development must occur on the least-productive part of the lot so the richest soils can be reserved for cultivation.

Agricultural zoning ordinances can be combined with other initiatives to promote farming and forestry and to protect rural areas from being overtaken by urban sprawl (Sims, 2000b). The King County, Washington, executive official has undertaken several initiatives to promote diversity in lifestyle choices, encourage the continuation of farming and forestry, protect environmental quality and wildlife habitat, and maintain a link to the county's heritage by preserving rural areas. So far the county has reduced its development rate in rural areas from 15 percent in 1980 to 6 percent at present. The target is to further reduce the development rate to 4 percent. The county issued orders to close loopholes in subdivision and land segregation regulations, and it tightened subdivision requirements for rural lands. These efforts will ensure that new development is consistent with current environmental and development standards.

The county's initiatives include maintaining an agricultural district as an "unincorporated urban area" to permanently protect this area from development pressures, establishing the Puget Sound Fresh program to promote locally grown and produced products, establishing a Farm Link program to connect farmers with land to sell or lease with those wishing to farm, and providing improved services for rural community centers. The county also established a Rural Forest Commission to encourage forestry and maintain the forest land base in the county's rural areas. The county implemented a Farmlands Preservation Program, which has preserved 12,793 acres of agricultural lands through purchase or donation of development rights. Additionally, the county is able to preserve hundreds more acres of rural land each year through incentive-based taxation programs. Finally, King County's 2000 Comprehensive Plan includes the following goals and initiatives:

- Ensure that zoning complies with goals to reduce the rate of growth and protect the environment;
- Ensure that the types and scale of development in the rural area blend with traditional rural development;
- Implement recommendations from the forest commission to bolster King County's forest and farming economies; and
- Consider alternative uses of agricultural land, such as for wetland mitigation or recreation, such that these uses will not harm the integrity of agriculture in the county.

More information about King County's growth management initiatives can be found on the SmartGrowth Rural Legacy Web site at http://www.metrokc.gov/smartgrowth/rural.htm.

3.3.3.3.6 Watershed-based zoning

Historically, zoning has been used to establish limits on building density and to separate uses believed to be inherently incompatible (Arendt, 1997). Watershed-based zoning, in contrast, uses watershed and subwatershed boundaries as the basis for making land use decisions. Typically, zoning objectives focus on maintaining or reducing impervious cover in sensitive subwatersheds and redirecting development to subwatersheds that are better able to absorb their influence (Caraco et al., 1998).

Local, state, and federal officials recently approved the Riverside County (California) Plan, which involved multi-agency cooperation in identifying where development may occur and where land should be preserved (Verden, 2000). Over the next 50 years, the Riverside County Plan will serve as a blueprint for building new roads, shopping centers, and homes, while also preserving rapidly disappearing habitat. The plan is designed to avoid costly delays and confrontations between regulators and developers. With the population of Riverside County expected to double in 20 years, the plan will help developers accommodate growth while it also protects rare plants and animals. State and federal land, transportation, and wildlife managers hope the Riverside County Plan will be a model for other communities struggling to balance development and preservation.

In 1992 Maryland enacted the Economic Growth, Resource Protection, and Planning Act to organize and direct comprehensive planning, regulating, and funding by state, county, and municipal governments in furtherance of a specific economic growth and resource protection policy (Maryland Department of Planning, no date). The policy is organized around seven statutory vision statements that must be pursued in county and municipal comprehensive plans where priorities for land use, economic growth, and resource protection are established. The seven statutory vision statements are:

- Development is concentrated in suitable areas.
- Sensitive areas are protected.
- In rural areas, growth is directed to existing population centers and resource areas are protected.
- Stewardship of the Chesapeake Bay and the land is a universal ethic.
- Conservation of resources, including a reduction in resource consumption, is practiced.
- To assure the achievement of the above, economic growth is encouraged and regulatory mechanisms are streamlined.
- Funding mechanisms are addressed to achieve these visions.

The visions must also be followed by the state in undertaking its various programs. Both state and local funding decisions on public construction projects must adhere to the visions. The Act also established an Economic Growth, Resource Protection, and Planning Commission to oversee, study, and report on progress towards implementation of the visions. More information about the act can be found at http://www.mdp.state.md.us/planningact.htm.

3.3.3.3.7 Urban growth boundaries

Urban growth boundaries are lines drawn around metropolitan areas to delineate where urban development can take place (inside the boundary) and where it may not (outside the boundary). Outside of urban growth boundaries, land use is restricted to agriculture, forestry, and open space (Nelson and Moore, 1993). The boundaries encourage more compact (i.e., infill) development, control urban sprawl, and help protect rural heritage. The approval process for new development can be streamlined within the growth boundary to further encourage development in these areas.

The duration or lifespan of growth boundaries is normally related to planning periods or cycles, typically 10 to 20 years. Boundaries should be examined at regular planning intervals, however, to assess whether conditions have changed since they were established.

Establishing the location of urban growth boundaries sometimes requires complex decision-making. Officials should be reasonably sure that there is sufficient land within the boundary to meet projected growth over the planning period and that public facilities and services can be provided at reasonable cost in a timely fashion. The potential impact of growth within the boundary on existing natural resources also needs to be determined. In the context of watershed planning, it is advantageous to use watershed boundaries or other natural features as urban growth boundaries. In this manner, key or sensitive watersheds can be protected from the impacts of development.

In Arizona, the 1998 Growing Smarter Act and its 2000 addendum, Growing Smarter Plus, were signed into law by Governor Jane Hull (Morrison, 2000). This legislation addresses the issue of development by strengthening the ability of communities in Arizona to plan for growth and to acquire and preserve open space. The Growing Smarter legislation requires communities to address growth and growth-related pressures by mandating general plans that identify growth areas, establish policies and strategies for new growth, identify open space needs, regionally plan for interconnected open space, and analyze the environmental impacts of the development anticipated by the general plan (City of Tucson, no date).

3.3.3.4 Establish limits on impervious surfaces, encourage open space, and promote cluster development

As described earlier, urban runoff contains high concentrations of pollutants washed off impervious surfaces (roadways, parking lots, loading docks, etc.). By retaining the greatest area of pervious surface and maximizing open space, nonpoint source pollution due to runoff from impervious surfaces can be kept to a minimum. Refer to section 4.3.2 for a detailed discussion of site design practices to reduce impervious surfaces in new developments.

The following are examples of successful implementation of open space requirements and cluster development:

- Brunswick, Maine, recently adopted an allowable impervious area threshold of 5 percent of any site to be developed in the defined coastal protection zone. The remaining 95 percent is required to be left natural or landscaped. The threshold was developed and adopted using a $28,000 grant.

- Virginia provides general guidance with regard to minimum open space and maximum impervious areas to local governments within the Chesapeake Bay watershed. While specific requirements are not associated with the guidance, local plans are required to contain criteria and must be approved by the Chesapeake Bay Local Assistance Board.

- Carroll County, Maryland, is a community with substantial farmland and open space. Because it is located close to both Baltimore and Washington, DC, the county amended its zoning ordinance to encourage cluster development and preserve open space. This and land protection efforts by Carroll County have resulted in protection of 33,000 acres by agricultural easements (Maryland Environmental Trust Land Conservation Center, 2002).

- Maryland adopted the Forest Conservation Act of 1991, which requires all public agencies and private landowners submitting a subdivision plan or application for a sediment control permit for an area greater than 40,000 square feet to develop a plan for retention of existing forest cover on-site. The act allows clearing that is essential to site development, and it established a forest conservation fund for reforestation projects. In the first five years of implementation, the Forest Conservation Act has produced 22,508 acres of retained forest and 4,313 planted acres, while 12,210 acres of existing forest have been cleared (Honeczy, 2000).

- Broward County, Florida, has an open space program and encourages cluster development to reduce impervious surface area, protect water quality, and enhance aquifer recharge (Broward County, Florida, 1990).

- New Hampshire has a model shoreland protection ordinance that encourages grouping of residential units, provided a minimum of 50 percent of the total parcel remains as open space.

One way to increase open space while allowing reasonable development of land is to encourage cluster development. Clustering entails decreasing the allowable lot size while maintaining the number of allowable units on a site. Such policies provide planners the flexibility to site buildings on more suitable areas of the property and leave environmentally sensitive areas, such as wetlands or steep slopes, undeveloped. Criteria can vary. Advantages of cluster development include:

- Reducing the costs of infrastructure;
- Preserving sensitive areas;
- Increasing property values with proximity to open space; and
- Preserving ecological, aesthetic, and recreational values.

Planned unit development is a type of zoning that encourages the use of cluster development but does not require it. For example, a set number of units could be spread across the site under typical residential zoning, but under cluster zoning, the same number of units could be concentrated on smaller lots on only a portion of the site, preserving the other portion for common open space to protect sensitive features or for use as a recreation area.

3.3.3.5 Revitalize existing developed areas

Redeveloping existing areas can alleviate water quality impacts by reducing the strain of development on open space land and minimizing the amount of impervious surface added to the watershed. Existing impervious surfaces, such as declining shopping malls and retail centers, can provide large tracts of developable land and are a prime opportunity for mixed-use infill development. For additional discussion of options for revitalizing urban areas, see Management Measure 10—Existing Development.

3.3.3.6 Establish setback (buffer zone) standards

In coastal areas, setbacks or buffer zones adjacent to surface water bodies, such as rivers, estuaries, or wetlands, provide a transition between upland development and these water bodies. The use of setbacks or buffer zones may prevent direct flow of urban runoff from impervious areas into adjoining surface waters and provide pollutant removal, sediment attenuation, and infiltration. Riparian forest buffers function as filters to remove sediment and attached pollutants, as transformers that alter the chemical composition of compounds, as sinks that store nutrients for an extended period of time, and as a source of energy for aquatic life (USEPA, 1992). Setbacks or buffer zones are commonly used to protect coastal vegetation and wildlife corridors, reduce exposure to flood hazards, and protect surface waters by reducing and cleansing urban runoff (Mantel et al., 1990). The types of development allowed in these areas are usually limited to non-habitable structures and those necessary to allow reasonable use of the property, such as docks and unenclosed gazebos.

Factors for delineating setbacks and buffer zones vary with location and environment and include:

- Seasonal water levels;
- Nature and extent of wetlands and floodplains;
- Steepness of adjacent topography;
- Type of riparian vegetation;
- Quantity and velocity of runoff entering the buffer;
- Soil types and infiltration capacity;
- Density of development adjacent to the riparian corridor; and
- Wildlife values.

It is important that sheet flow, not concentrated flow, be directed to the buffer. High-velocity runoff from steeply sloped or highly impervious areas can promote excessive erosion and decreased pollutant removal. A flat, grassy area or a level spreader can be installed at the upland part of the buffer to slow the velocity of runoff and promote sheet flow. It is also important to consider that the pollutant removal capacity of a buffer is finite and can be exceeded in areas with high concentrations of pollutants in runoff.

Buffer width is an important measure of pollutant removal effectiveness. Buffers typically range from 20 to 200 feet wide and should include the 100-year floodplain, riparian areas including adjacent wetlands, steep slopes, or critical habitat areas (Schueler, 1995). A buffer at least 100 feet wide is recommended for water quality protection, and a 300-foot buffer is recommended to maintain a wildlife habitat corridor. Wider buffers offer increased detention times, infiltration rates, and diversity of soil, vegetation, and wildlife.

According to Herson-Jones et al. (1995), forested buffers achieve 50 percent TSS removal; 23 to 96 percent phosphorus removal depending on the extent of TSS removal; greater than 40 percent lead removal; more than 60 percent copper, zinc, aluminum, and iron removal; and more than 70 percent oil and grease removal.

Overall, aquatic buffers are highly effective at removing particulate pollutants, but less effective in removing soluble pollutants (such as nitrogen, for which documented removal rates range from -15 to 99 percent). Proper siting and design and regular maintenance enhance removal efficiency.

In general, EPA recommends that no habitat-disturbing activities should occur within tidal or non-tidal wetlands. In addition, a buffer area should be adequate to protect the identified wetland values. Minimum widths for buffers should be 50 feet for low-order headwater streams, with expansion to as much as 200 feet or more for larger streams. In coastal areas, a 100-foot minimum buffer of natural vegetation landward from the mean high tide line helps to remove or reduce sediment, nutrients, and toxic substances entering surface waters.

3.3.3.6.1 Buffer ordinance

Buffer ordinances provide guidelines for buffer creation and maintenance. They should include the following provisions:

- Buffer boundaries to be clearly marked on local planning maps;
- Maintenance language that restricts vegetation and soil disturbance;
- Tables that illustrate buffer width adjustment by percent slope and type of stream; and
- Direction on allowable uses and public education.

A model ordinance and examples of buffer ordinances from across the country can be found at http://www.epa.gov/owow/nps/ordinance. Buffer ordinances and other water resource-related ordinances are also described in section 1.3.1.2.

The following are examples of setback or buffer requirements:

- Town commissioners in Apex and Cary, North Carolina, have agreed to set wider buffers between development and streams (Price, 2000). Under the new ordinance, buffers must be at least 50 feet wide along intermittent streams and must average 100 feet wide along perennial streams. The towns chose to use an average rather than a strict 100-foot minimum to allow landowners flexibility. In addition to the buffer ordinance, Apex and Cary halved the limit of impervious surfaces on a given tract of land over which retention ponds are required to control runoff (from 24 percent to 12 percent). Town officials will hold a public hearing to vote on the new regulations.

- Monroe County, Florida, requires a setback of 20 feet from high water on man-made or lawfully altered shorelines for all enclosed structures and 50 feet from the landward extent of mangroves or mean high tide line for natural water bodies with unaltered shorelines (Monroe County, Florida, Code, Section 9.5-286).

- Brunswick, Maine requires a buffer of 125 to 300 feet from mean high water within the Coastal Protection Zone (Section 315 of the Brunswick Zoning Ordinance), depending on the slope of the buffer, as designated on the town's land use map.

- Queen Anne's County, Maryland, established a standard shore buffer of 300 feet from the edge of tidal water or wetland, 50 percent of which must be forested.

- Maryland's Critical Area Act requires the establishment of a minimum buffer of 100 feet of natural vegetation landward from the mean high-water line of tidal waters or the edge of tidal wetlands and tributary streams. Unless a property owner can demonstrate unwarranted hardship and prove no negative impact to water quality, plant, fish or wildlife habitat, the local jurisdiction will not permit disturbance or new development within the buffer except for access or water-dependent facilities. Any clearing that occurs for access or water-dependent facilities must be mitigated through a buffer management plan approved by the local jurisdiction (Critical Area Commission for the Chesapeake and Atlantic Coastal Bays, no date).

3.3.3.6.2 Vegetative and use strategies within management zones

Buffers can be divided into three zones—the streamside, middle, and upland zones (Herson-Jones et al., 1995). Dense vegetation in the streamside zone (recommended to be approximately 25 feet wide) prevents excessive activity in this sensitive area, maintains the physical integrity of the stream, and provides shade, litter, debris, and erosion protection. The width of a grassed or mostly forested middle zone (minimum of 50 feet) depends on the size of the stream and its floodplain and the location of protected areas such as wetlands or steep slopes. The upland zone, typically 25 feet wide, is an additional setback from the buffer and usually consists of lawn or turf. Zones in the buffer should be delineated to determine the types of vegetation that should be maintained or established.

Allowable land uses in the three zones vary. The streamside zone is limited to footpaths, runoff channels, and utility or roadway crossings. The middle zone may be used for recreation and runoff control practices. The upland zone may be used for many purposes, with the exception of septic systems, permanent structures, or impervious covers. A depression incorporated into the design of the upland zone can detain runoff during storms. This runoff is released slowly to the middle zone as sheet flow, which is then transferred to the dense streamside zone, designed to have minimal to no discharge of surface water to the stream.

3.3.3.6.3 Provisions for buffer crossings

Stream crossings should minimize impacts on buffer integrity while providing crossing points for linear forms of development such as roads, bridges, golf course fairways, underground utilities, enclosed storm drains, and outfall channels (Schueler, 1995). They should also be designed to provide fish passage and to withstand overbank flows from the 100-year storm event. Design considerations for buffer crossings include: minimizing the width of the crossing; orienting the crossing at a right angle to the stream; limiting the total number of crossings; ensuring that outfalls discharge at the invert elevation of the stream channel; and burying utility crossings at least 3 feet below the channel’s invert elevation. An outfall should not be placed directly in the main channel. Energy-dissipating devices can be installed in outfalls to protect the streambed and adjacent banks.

3.3.3.6.4 Integration of structural runoff management practices where appropriate

Depressions can be incorporated into the upland part of a stream buffer to provide runoff detention during storms and to promote sheet flow over the middle zone of the buffer. A flat, grassed area or level spreader can also be used in the upland part of the buffer to create sheet flow and to promote infiltration over the rest of the buffer.

Storm water ponds and wetlands can be located inside or outside the buffer. According to Schueler (1995), ponds inside the buffer should be used only for runoff quantity control. Although ponds in the buffer treat the greatest possible drainage area, are more likely to maintain their water level during dry periods, provide a diversity of aquatic habitats, and can increase the total width of the buffer, they displace vegetation and might cause barriers to fish migration, modification of existing wetlands, and stream warming.

3.3.3.6.5 Development of buffer education and awareness programs

Buffer education efforts should foster community awareness and encourage stewardship. These objectives can be met by posting signs along the buffer boundaries that describe allowable activities in different parts of the buffer. Buffer owners can be educated by distributing pamphlets, hosting stream walks, and holding meetings. New owners should be made aware of buffer limits and allowable uses when the property is transferred. Buffer stewardship can be encouraged through reforestation and “bufferscaping” programs. Annual inspections can be done with “buffer walks” to determine the extent of encroachment, devegetation, erosion, or excessive sediment deposition.

3.3.3.7 Establish slope restrictions

Slope restrictions can be effective tools to control erosion and sediment transport. Erosion rates depend on several site-specific factors including soil type, vegetative cover, and rainfall intensity. In general, as slope increases, there is a corresponding increase in runoff water velocity, which may result in increased erosion and sediment transport to surface waters (Dunn and Leopold, 1978).

3.3.3.8 Promote urban forestry

Urban forestry is an effective tool for protecting watersheds because it can provide some of the storm water management required in urban areas. Trees decrease runoff by intercepting rain and promoting infiltration. This reduces the peak runoff flow and the total runoff volume that communities must manage, which can be financially beneficial to communities that have to build and maintain sewer and drainage systems (ENN, 2001). Also, trees provide shade, which lowers the temperature of urban heat islands and runoff. Erosion and leaf litter in forested areas can contribute sediment and nutrients to receiving waters; therefore, an effort should be made to establish and maintain stable vegetation and to keep leaf litter on-site.

Several organizations dedicated to promoting urban forestry can provide information and other resources to interested groups or individuals. For example, American Forests (http://www.americanforests.org) is a conservation organization that is working to improve the environment with trees and forests. The organization’s Urban Forest Center offers tools to measure the environmental benefits of trees, such as pollution reduction and storm water management. These tools include the Regional Ecosystem Analysis (REA) and CITYgreen software packages. REA uses a combination of satellite data, field surveys, CITYgreen software, and other GIS technology to measure a region's or city's tree canopy and calculate its dollar value. CITYgreen allows users to compare the economic benefits of various planning scenarios by testing landscape ordinances, evaluating site plans, and modeling development scenarios that capture the benefits of trees. An application of this tool in Fayetteville, Arkansas, found that increasing the city’s tree cover from 27 to 40 percent could result in cost savings from runoff reduction of up to $135 million (NALGEP, 2003). Information about the software is available at http://www.americanforests.org/productsandpubs/citygreen/.

TreePeople is another forestry organization. It works with the U.S. Forest Service and has enlisted the help of thousands of students and volunteers to plant seedlings in the mountains around Southern California. Its mission is to inspire people to take responsibility for improving their immediate environment. Information about TreePeople is available at http://www.treepeople.org/.

Houston's Urban Forests

American Forests conducted a study of a 3.2 million-acre area in Houston to document urban forest cover (ENN, 2001). They also analyzed 25 individual sites with aerial photography using CITYgreen to map and measure tree cover and to calculate the benefits of Houston's trees. Study results show that trees provide significant benefits in storm water runoff reduction, energy savings, and pollutant removal. The study found that Houston's tree cover reduces the need for storm water management by 2.4 billion cubic feet per peak storm event, saving $1.33 billion in one-time construction costs. As a result, American Forests made the following recommendations to the city of Houston:

- Improve green infrastructure by using tree cover data in land-use planning; growth management; and all transportation, public works, and development decision-making.
- Encourage the use of increased tree cover to met storm water needs.
- Work to increase tree cover in the metropolitan area.

3.3.3.9 Use site plan reviews and approval

A site plan review involves review of specific development proposals for consistency with the laws and regulations of the local government of jurisdiction. Potential development sites should be inspected to ensure that natural resources necessary for protecting surface water quality are preserved. Inspection ensures that the information presented in any application for development is accurate and that sensitive areas are noted for preservation. Inspections should also be conducted during and after development to ensure compliance with development conditions. Depending on the size of the local government and the amount of new development, this inspection could be incorporated into the duties of existing staff at minimal additional cost to the local government, or the inspection could require the addition of staff to conduct onsite inspections and monitoring. The effectiveness of such a program depends on the ability of the inspectors to evaluate property for its natural resource value and the practices used to protect areas necessary for the preservation of water quality.

Development approvals should contain conditions requiring maintenance of the area's environmental integrity and prevention of degradation from nonpoint source pollution, consistent with the goals, objectives, and policies of the comprehensive program and the requirements of the land development regulations. The criteria for new development are outlined as part of a development permit. Examples include the following:

- Areas for preservation or mitigation may be identified, similar to the Fairfax County Environmental Quality Corridor System (see section 3.3.2).

- The use of nonstructural and structural management practices described in this chapter for controlling nonpoint source pollution may be a condition of development approval.

- Setbacks and limits on impervious areas may be clearly defined in a condition for development approval, as is being done in the programs discussed above.

- Reduction in the use of pesticides and fertilizers on landscaped areas by encouraging the use of vegetation that is adaptable to the environment and requires minimal maintenance. (Xeriscaping techniques are described in Management Measure 4 and lawn and garden activities are described in Management Measure 9.)

3.3.3.10 Designate an entity or individual responsible for maintaining the infrastructure, including urban runoff management systems

The responsible party should be trained in the maintenance and management of urban runoff management systems. If desired, the local government could be designated to maintain urban runoff systems, with financial compensation from the developer. Because they are not usually trained in infrastructure maintenance, homeowners groups are not the best entity for monitoring infrastructure for adequacy, especially urban runoff management systems. This responsibility should belong to a responsible party that understands the complexity of urban runoff management systems, can determine when such systems are not functioning properly, and has the resources to correct the problem. Again, this is a duty that the local government can assume, with either existing staff or additional staff, depending on the size of the local government and the amount of new development occurring. The amount of funding needed depends on the size of the local government.

3.3.3.11 Use official mapping

Official maps can be used to designate and/or protect environmentally sensitive areas, zoning districts, identified land uses, or other areas that provide water quality benefits. When approved by the local governing body, these maps can be used as legal instruments to make land use decisions related to nonpoint source pollution.

3.3.3.12 Require environmental impact assessment statements

To evaluate the impact that proposed development may have on the natural resources of an area, some counties and municipalities require an environmental assessment as part of the development approval processes. These assessments can be incorporated into the land development regulation process. Areas to be covered include geology, slopes, vegetation, historical features, wildlife, and infrastructure needs (International City/County Management Association, 1979).

3.3.4 Cost of Planning Programs

The cost of planning programs depends on a variety of factors, including the level of effort needed to complete and implement a program. Many of the practices described in this section can be incorporated into ongoing activities of a state or local government.

The Florida legislature funded the development of comprehensive programs and land development regulations required by the Local Government Comprehensive Planning and Land Development Regulation Act (1985). Distribution of funds was based on population according to formulas used for determining funding for the plan and land development regulations. A base amount was given to all counties that requested it. The balance of the monies was allocated to each county in an amount proportionate to its share of the total unincorporated population of all the counties. A similar distribution process was used for local governments. A total of $2.1 million was allocated for plan development; however, not all components of the plans address nonpoint source issues.

The effect of planning programs depends on many variables, including implementation of programs and monitoring of conformance with conditions of development approval.

3.3.5 Land or Development Rights Acquisition Practices

An effective way to preserve land necessary for protecting the environmental integrity of an area is to acquire it outright or to limit development rights. Land conservation includes more than simply preserving land in its current state. It also means taking responsibility for restoration of areas of the property that might already have been affected by urban runoff. Stewardship activities for land conservation might include:

- Resource monitoring
- General maintenance
- Control of exotic species
- Installation of structural runoff management practices

A government agency or a nonprofit organization, such as a land trust, often has a greater capacity to take on the responsibility of stewardship than do private owners. Consequently, many of the practices discussed below focus on how conservation lands, or at least property rights to those lands, can be transferred to such entities. In many instances, however, private owners successfully accomplish stewardship without any formal or binding relationship with a public or private conservation agency or organization.

Several organizations provide educational materials and training to help landowners learn to manage conservation areas for the benefit of water quality, wildlife, and other purposes. For example, the Land Trust Alliance, an organization that "promotes voluntary land conservation and strengthens the land trust movement by providing the leadership, information, skills, and resources land trusts need to conserve land for the benefit of communities and natural systems," has compiled a list of links to local land trust organizations. This list can be accessed at http://www.lta.org/resources/links (Land Trust Alliance, 2001). Other information on land conservation policy, news, success stories, training opportunities, and technical guidance is provided on the Land Trust Alliance's Web site at http://www.lta.org.

Additionally, The Conservation Fund Web site, at http://www.conservationfund.org, provides information on land acquisition, community initiatives, leadership training, and sustainable conservation solutions emphasizing the integration of economic and environmental goals.

Another resource is the Natural Lands Trust whose Web site, at http://www.natlands.org, provides information and resources pertaining to land preservation and land use planning.

The practices described below can be used to protect beneficial uses.

3.3.5.1 Fee simple acquisition/conservation easements

The most direct way to protect land for preservation purposes and associated nonpoint source control functions is fee simple acquisition, through either purchase or donation. Once a suitable area is identified for preservation, the area may be acquired along with the development rights. The more development rights that are associated with a piece of property, the more expensive it will be. Many state and local governments and private organizations have programs for purchasing land.

Conservation easements are legal restrictions on the present and future use of land. For preservation purposes, the easement holder, who is usually not the owner of the property, is able to control the rights of the property when the landowner might adversely impact resources on the property. In effect, the property owner gives up development rights within the easement while retaining fee ownership of the property (Mantel et al., 1990; Barrett and Livermore, 1983). The agreement between the easement holder and property owner is permanent, legally enforceable, and not subject to alteration unless permission is received in writing by the easement holder and all other cosigners (Arendt, 1997).

A conservation easement is a flexible tool that can be customized to set different levels of restrictions among different types of conservation areas in a parcel. In addition to protecting and maintaining environmental benefits in perpetuity, landowners who donate conservation easements to a government agency or nonprofit group typically realize substantial income, property, and estate tax benefits resulting from the charitable donations. Their property value might be lowered, however, because the development rights were removed. Consequently, tax and estate planning professionals need to be consulted when a conservation easement is being contemplated.

As an alternative, agricultural and forestry easements are specific types of conservation easements that allow continued use of land as farms or forests and prevent the land from being sold for commercial or residential development. The USDA Natural Resource Conservation Service currently manages the Farm and Ranch Lands Protection Program (FRPP), a voluntary program that provides matching funds to state, tribal, or local governments and non-governmental organizations with existing farm and ranch land protection programs to purchase conservation easements. FRPP is reauthorized in the Farm Security and Rural Investment Act of 2002, also known as the Farm Bill (NRCS, 2003).

3.3.5.2 Leases, deed restrictions, and covenants

Even though government agencies, land trusts, and other nonprofit organizations would prefer that conservation lands be acquired by donation or that conservation easements be placed on the property, some lands hold so much value as conservation areas that leasing is worth the expense and effort. Leasing a property allows the agency, trust, or organization to actively manage the land for conservation.

Deed restrictions are included in deeds for the purpose of constraining use of the land. In theory, deed restrictions are designed to perform functions similar to those of conservation easements. In practice, however, deed restrictions have proven to be much weaker substitutes because unlike conservation easements, they do not necessarily designate or convey oversight responsibilities to a particular agency or organization to enforce protection and maintenance provisions. Also, deed restrictions can be relatively easy to modify or vacate through litigation. Modifying or nullifying an easement is difficult, especially if tax benefits have already been realized. For these reasons, conservation easements are generally preferred over deed restrictions.

A covenant is similar to a deed restriction in that it restricts activities on a property, but it is in the form of a contract between the landowner and another party. The term *mutual covenants* is used to describe a situation where one or more nearby or adjacent landowners are contracted and covered by the same restrictions.

3.3.5.3 Transfer of development rights

The principle of transfer of development rights (TDR) is based on the concept that ownership of real property includes the ownership of a bundle of rights that goes with it. These rights may include densities granted by a certain use designation, environmental permits, zoning approvals, and others. Certain properties have a bigger bundle of rights than others, depending on what approvals have been received by the owner. The TDR system takes all or some of the rights on one piece of property and moves them to another parcel. The purpose of TDRs is to shift future development potential from an area that is determined to be unsuitable for development (sending site) to an area deemed more suitable (receiving site). The development potential can be measured in a variety of ways, including number of dwelling units, square footage, acres, or number of parking spaces. Most TDR systems require a legal restriction for future development on the sending site. TDR programs can be either fixed so that there are only a certain number of sending and receiving sites in an area, or flexible so that a sender and receiver can be matched as the situation allows (Mantel et al., 1990; Barrett and Livermore, 1983).

This system is useful for the preservation of those areas considered necessary for maintaining the quality of surface waters, in that development rights associated with the environmentally sensitive areas can be transferred to less-sensitive areas. There are several examples of TDR use in the United States. The more successful projects include preservation of the New Jersey Pine Barrens and the Santa Monica Mountains in California. For the TDR concept to work, receiving and sending sites should be identified and evaluated, a simple, flexible program should be developed, and the use of the program should be promoted and facilitated (Mantel et al., 1990).

In contrast to a conventional down-zoning approach, which withholds from landowners the value associated with the right to develop, TDR systems allow a landowner to be compensated for that value by developing at another site.

Most TDR systems require a legal restriction to ensure that future development will not occur on the “sending” site. Also, TDR programs can be fixed so that there are only a certain number of sending and receiving sites in an area, or they can be flexible so that a sender and receiver can be matched as the situation allows. The following are general steps for setting up a TDR program (Redman/Johnston Associates, 1997):

- *Provide education and outreach*. The public should be familiar with the overall objectives of the program. Landowners and developers also need to be educated on how they will be affected.

- *Conduct an analysis of market conditions*. A successful program requires a market for TDR transfers.

- *Identify and designate TDR "receiving areas."* Receiving areas should be capable of supporting growth. Factors include adequate land area, infrastructure, public services, and consideration of environmental constraints.

- *Identify and designate TDR "sending areas."* Sending areas should support preservation and protection goals. Specific areas should be delineated to the parcel level.

- *Determine the nature of program*. Programs can be voluntary or mandatory. If mandatory, sending areas should be down-zoned to control growth.

- *Determine development potential and allocate TDRs*. Compute current allowable densities in both receiving and sending areas, and then allocate TDRs from sending areas based on desired densities. For example, down-zoning from a yield of 1 lot per 5 acres to 1 lot per 25 acres equates to 4 TDRs.

- *Consider a TDR Bank*. A TDR bank buys, holds, and sells TDRs. The bank can be either a government organization or a quasi-governmental entity.

Transfer of Development Credits Pilot Program, King County, Washington

King County, Washington's Transfer of Development Credits (TDC) Pilot Program is a voluntary initiative that allows residential densities to be transferred from rural areas to urban areas better suited to absorb additional density (King County Office of Regional Policy and Planning, 2001). The following provisions were made:

- A $1.5 million TDC bank was established to purchase and sell density credits.

- $500,000 was appropriated for urban amenities to improve neighborhoods that will receive increased density.

- An extensive outreach effort has been launched to inform stakeholders about the program and identify potential receiving sites.

- The Rural Forest Commission has reviewed and approved sending site criteria to be used by the TDC bank.

The first successful TDC was finalized in 2000 (Sims, 2000a). Forest land totaling 313 acres was protected from development. The density credits were transferred to a developer to add 500,000 square feet of commercial space in the nearby city of Issaquah.

More information about this TDC is presented at ww.metrokc.gov/exec/news/2000/032800.htm. More information about the King County TDC Pilot Program can be obtained from the program's Web site at http://www.metrokc.gov/exec/orpp/tdc or by contacting Mark Sollitto at 206-205-0705.

– *Provide adequate resources*. A TDR program does not run itself. It needs staff and resources to administer and manage the program.

3.3.5.4 Purchase of development rights

In this process, the rights of development are purchased while the remaining rights remain with the fee title holder. Restrictions in the deed make it clear that the land cannot be developed based on the rights that have been purchased (Mantel et al., 1990).

Howard County, Maryland, has the goal of preserving 20,000 acres of farmland. Development rights are acquired in perpetuity with $\frac{1}{4}^{th}$ of 1 percent of the local land transfer tax used as funding. There is no cap on the percentage of assessed value that may be considered development value, and payment for development rights may be spread over 30 years to ease the capital gains tax burden on the landowner (Jenkins, 1991).

3.3.5.5 Land trusts

Land trusts may be established as publicly or privately sponsored nonprofit organizations with the goal of holding lands or conservation easements for the protection of habitat, water quality, recreation, or scenic value, or for agricultural preservation. A land trust may also pre-acquire properties that are conservation priorities if it enters the development market when government funds are not immediately available by securing bank funding with the government as guarantor (Jenkins, 1991).

3.3.5.6 Agricultural and forest districts

Agricultural or forest districting is an alternative to acquisition of land or development rights. Jurisdictions may choose to allow landowners to apply for designation of land as an agricultural or forest district. Tax benefits are received in exchange for a commitment to maintain the land in agriculture, forest, or open space.

Fairfax County, Virginia, taxes land designated as an agricultural or forest district based on the present use valuation rather than the usual potential use valuation. A commitment to agricultural or forestry activities must be shown, and sound land management practices must be used. The districts are established and renewed for eight-year periods (Jenkins, 1991).

3.3.5.7 Cost and effectiveness of land acquisition programs

The costs associated with land acquisition programs vary depending on the desired outcome. If land is to be purchased, the cost depend on the value of the land. An additional cost to be considered is the maintenance of the property once it is in public ownership. Easements and development rights are less expensive, and maintenance responsibility is retained by the owner. Depending on the size of the local government, implementation of these programs is usually part of the operating budget of the appropriate agency (planning department or parks and recreation department, for example).

The effectiveness of a land acquisition program is determined by the size of the parcel and the difference between predevelopment and potential postdevelopment pollutant loading rates. In addition, wetlands and riparian areas have been shown to reduce pollutant loadings. The acquisition and preservation of these areas can be extremely important to water quality protection and decrease the cost of implementing structural BMPs. However, the use of wetlands for urban runoff treatment, in general, should be discouraged. Where no other alternative exists, states and local governments can target upland areas for acquisition to minimize the impacts to and preserve the function of wetlands. One option for acquiring land is a public/private partnership. For example, Harford County, Maryland, has targeted areas for purchase of conservation easements. The county staff is working jointly with a local land trust to acquire conservation easements and to educate people in environmentally sound land-use practices. The estimated cost for the program is $60,000 per year (Jenkins, 1991). To aid in the establishment of two local land trusts, Anne Arundel County, Maryland, provided $350,000 in seed money for capital expenditures such as land and easement procurement. The county also gives staff assistance to volunteers; additional support comes from contributions of money or land, grants, and fundraisers (Jenkins 1991).

3.4 Information Resources

The Center for Watershed Protection's *Rapid Watershed Planning Handbook*, published in 1998, describes techniques communities can use to more effectively protect and restore water resources. This document is available for purchase from the Center for Watershed Protection's Web site (http://www.cwp.org).

The Chesapeake Bay Program's (1997) *Protecting Wetlands: Tools for Local Governments in the Chesapeake Bay Region* is available from the Chesapeake Bay Program's Web site at http://www.chesapeakebay.net.

The Conservation Fund's Web site, located at http://www.conservationfund.org, provides information on land acquisition, community initiatives, leadership training, and sustainable conservation solutions emphasizing the integration of economic and environmental goals.

Correll's (2000) Web site, entitled *Vegetated Stream Riparian Zones: Their Effects on Stream Nutrients, Sediments, and Toxic Substances*, presents an annotated and indexed bibliography of buffer strip literature. See http://www.unl.edu/nac/ripzone03.htm.

Eco-Compass (Island Press, 2000) is an information resource for urban sprawl issues. Developed by Island Press, Eco-Compass is an Internet guide to a wide range of environmental information, including ecosystems, communities, global change, and economics. The urban sprawl feature of Eco-Compass provides a summary of the major issues relating to sprawl as well as an examination of the lessons that can be learned from Atlanta, a city that has experienced tremendous growth in the past decade. The site also includes links to more than 50 of the best sprawl-related Web sites and publications. More information about Eco-Compass is available at http://www.islandpress.org/.

The Natural Lands Trust's 1997 publication, *Growing Greener: Putting Conservation into Local Codes,* is available from Natural Land Trust, 1031 Palmers Mill Road, Media, PA 19063; telephone 610-353-5587; e-mail planning@natlands.org. Other information and resources pertaining to land preservation and land use planning can be found at the Natural Lands Trust's Web site at http://www.natlands.org.

Schueler's (1995) manual, *Site Planning for Urban Stream Protection*, is available for download from the Center for Watershed Protection's Web site at http://www.cwp.org/SPSP/TOC.htm.

Based on the Local Government Commission's research of more than 150 "smart growth" zoning codes from across the nation, *Smart Growth Zoning Codes: A Resource Guide* will help planners design a zoning code that encourages the construction of walkable, mixed use neighborhoods and the revitalization of existing places. Each chapter analyzes a critical issue, such as design, streets, and parking, and highlights exemplary codes from across the country. The guidebook comes with a CD-ROM that contains copies of some of the best zoning codes in the United States and other resources. The guide is available for purchase ($25) from the LGC bookstore at http://www2.lgc.org/bookstore/detail.cfm?itemId=34.

The Smart Growth Network is a nationwide effort coordinated by EPA's Urban and Economic Development Division (International City/County Management Association, 2000). Through cooperative partnerships with a diverse network of organizations, EPA is working to encourage development that better serves the economic, environmental, and social needs of communities. The network provides a forum for information sharing, education, tool development and application, and collaboration on smart growth issues. Smart growth approaches focus on flexible zoning, preventive planning, intelligent management of natural resources and water quality, and implementation of treatment and control technologies at multiple scales from development sites to watershed planning. For more information about the Smart Growth Network, visit http://www.smartgrowth.org or contact ICMA—Smart Growth Network, 777 North Capitol St., NE, Suite 500, Washington, DC 20002-4201; telephone 202-962-3591; e-mail nsimon@icma.org.

The Mid-America Regional Council (MARC) initiated a project to raise awareness of the relationship between land development and transportation systems. In *Principles of Transit Supportive Development*, MARC (no date) presents alternative approaches to land development that encourage a more sustainable and balanced transportation system. The organization promotes community designs that enable citizens to walk, bike, ride transit, and drive from home to shops, schools, and services. For more information about the potential of transit supportive development, contact MARC at 816-474-4240 or visit their Web site at http://www.marc.org/transportation.

The Local Government Commission (http://www.lgc.org) is a nonprofit organization that provides peer networking opportunities, acts as an interface between city and county officials, and provides practical policy ideas for addressing serious environmental and social problems. The commission provides guidelines and resources for communities to improve their design, transportation, economic development, environment, energy, and waste prevention. A list of publications can be found at http://www2.lgc.org/bookstore/list.cfm?categoryId=1.

The Northeastern Illinois Planning Commission published *Model Stream and Wetland Protection Ordinance for the Creation of a Lowland Conservancy Overlay District: A Guide for Local Officials*, which can be ordered from its Web site at http://www.nipc.org/pubs-services/.

The National Association of Conservation Districts' Web site (http://www.nacdnet.org) contains a list of conservation districts across the country as well as conservation resources for districts, educators, and the public.

In July 2001 the National Governors' Association Center for Best Practices published *New Community Design to the Rescue: Fulfilling Another American Dream* (Hirschhorn and Souza, 2001), which provides alternatives to sprawl through "new community design." The book includes a checklist for local governments to evaluate communities and development projects for consistency with smart growth principles and provides examples of infill, suburban redevelopment, and greenfields projects that have successfully incorporated new community design principles. Innovative policies and actions taken by states to encourage new community design are also included. This publication can be purchased at the National Governors' Association Web site at http://www.nga.org or downloaded in PDF format at http://www.nga.org/cda/files/072001NCDFull.pdf.

"Protecting Water Resources with Smart Growth" is intended for audiences such as communities, local governments, state and regional planners already familiar with smart growth who are now seeking additional ideas on how to protect their water resources. The document is a compilation of 75 policies designed to protect water resources and implement smart growth. The majority of these policies (46) are oriented to the watershed, or regional level; the other 29 are targeted for specific development sites. The document is available for download in PDF format at http://www.epa.gov/smartgrowth/water_resource.htm.

Getting to Smart Growth: 100 Policies for Implementation was produced by the Smart Growth Network. The document highlights and describes techniques to help policymakers put smart growth principles into practice. The policies and guidelines, which have proven successful in communities across the U.S., range from formal legislative or regulatory efforts to informal approaches, plans, and programs. The primer describes 10 smart growth principles, specific policies for each principle, illustrations of their application in a community, and additional resources to aid communities in implementation. The document is available online in PDF format at http://www.smartgrowth.org/pdf/gettosg.pdf.

The concept of creating and maintaining an interconnected network of protected land and water, called "Green Infrastructure," is presented at http://www.greeninfrastructure.net. Green Infrastructure supports native species, maintains natural ecological processes, sustains air and water resources, and contributes to health and quality of life. This Web site, developed by The Conservation Fund with support from USDA Cooperative Forestry, contains information to aid in implementing a comprehensive conservation program and includes resources such as searchable profiles, training information, events, and references databases.

The Southeast Michigan Council of Governments (SEMCOG) published *Opportunities for Water Resource Protection in Local Plans, Ordinances and Programs: A Workbook for Local Governments*, which is a guide for local communities to protect water resources. The workbook provides checklists that guide users through the process of establishing a water resource protection program. It covers a wide range of topics, including land conservation, erosion and sediment control, public education, and pollution prevention. For each of these topics, case studies and checklists guide users through basic tools available for master planning, regulatory controls, and design standards. The document can be downloaded from http://www.semcog.org or ordered by calling 313-961-4266.

EPA's Green Communities Program encourages successful community-based environmental protection and sustainable community development. The Green Communities Assistance Kit provides technical assistance and training for planning green communities. Information about the Green Communities Program can be found at http://www.epa.gov/greenkit.

Other useful EPA publications:

> U.S. Environmental Protection Agency (USEPA). 1996. *Green Development: Literature Summary and Benefits Associated with Alternative Development Approaches*. EPA841-B-97-001. U.S. Environmental Protection Agency, Washington, DC. Available through EPA's National Service Center for Environmental Publications (NSCEP) at http://www.epa.gov/ncepihom or by calling 800-490-9198.

U.S. Environmental Protection Agency (USEPA). 1998. *The Volunteer Monitor*. U.S. Environmental Protection Agency, Washington DC. Available in HTML format at http://www.epa.gov/owow/monitoring/volunteer/vm_index.html.

U.S. Environmental Protection Agency (USEPA). 1999. *Model Ordinances to Protect Local Resources*. U.S. Environmental Protection Agency, Washington DC. Available in HTML format at http://www.epa.gov/owow/nps/ordinance.

U.S. Environmental Protection Agency (USEPA). 2001. *Monitoring Water Quality: Volunteer Monitoring*. U.S. Environmental Protection Agency, Washington DC. Available in HTML format at http://www.epa.gov/volunteer.

3.5 References

Arendt, R.G. 1997. *Growing Greener: Putting Conservation into Local Codes*. Natural Lands Trust, Inc., Media, PA.

Barrett, T.S., and P. Livermore. 1983. *The Conservation Easement in California*. Island Press, Covelo, CA.

Broward County, Florida. 1990. Land Development Code. Ft. Lauderdale, FL.

Caraco, D., R. Claytor, P. Hinkle, H.Y. Kwon, T. Schueler, C. Swann, S. Vysotsky, and J. Zielinski. 1998. *Rapid Watershed Planning Handbook.* Center for Watershed Protection, Ellicott City, MD.

City of Tucson. No date. *Summary of Growing Smarter and Growing Smarter Plus Legislation.* http://www.ci.tucson.az.us/planning/grosmart/gsovervu.pdf. Accessed August 21, 2003.

Correll, D. 2000. *Vegetated Stream Riparian Zones: Their Effects on Stream Nutrients, Sediments, and Toxic Substances*. http://www.unl.edu/nac/ripzone03.htm. Last updated September 2001. Accessed May 28, 2002.

Critical Area Commission for the Chesapeake and Atlantic Coastal Bays. No date. *Frequently Asked Questions*. http://www.dnr.state.md.us/criticalarea/faq.html#14. Accessed March 3, 2005.

Delaware County Departments of Planning and Public Works. 2003. *Stormwater Management: Delaware County Action Plan.* Version 1.

Dunn, T., and L.B. Leopold. 1978. *Water in Environmental Planning*. W.H. Freeman and Company, San Francisco, CA.

Environmental News Network (ENN). 2001, January 10. *Calculating the Benefits of Houston's Urban Trees*. http://www.dnr.state.md.us/criticalarea/faq.html. Last updated January 10, 2001. Accessed April 6, 2001.

Herson-Jones, L.M., M. Hearty, and B. Jordan. 1995. *Riparian Buffer Strategies for Urban Watersheds.* Metropolitan Washington Council of Governments, Washington, DC.

Hirschhorn, J.S., and P. Souza. 2001. *New Community Design to the Rescue: Fulfilling Another American Dream*. National Governors' Association, Washington, DC.

Holler, S. 1989. Buffer Strips in Watershed Management. In *Watershed Management Strategies for New Jersey*, Cook College Department of Environmental Resources and New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, NJ, pp. 69–116.

Honeczy, M.R. 2000. *The Maryland Forest Conservation Act—A 5-Year Review*. Presented at the 2000 APA National Planning Conference, New York, New York, April 16, 2000.

http://www.asu.edu/caed/proceedings00/FOREST3/honeczy.htm. Accessed March 3, 2005.

International City/County Management Association. 1979. *The Practice of Local Government Planning.* American Planning Association, Chicago, IL.

International City/County Management Association. 2000. *Smart Growth Network.* www.smartgrowth.org. Last updated June 17, 2000. Accessed June 21, 2000.

Island Press. 2000. *Eco-Compass: Sprawl Cities*. www.islandpress.org/ecocompass/ community/sprawl.html. Accessed April 4, 2001.

Jenkins. 1991. *Chesapeake Bay Restoration: Innovations at the Local Level. A Compilation of Local Government Programs*. The Chesapeake Bay Local Government Advisory Committee and the U.S. Environmental Protection Agency, Annapolis, MD.

King County Office of Regional Policy and Planning. 2001. *Transfer of Development Credits (TDC) Program.* Last updated April 23, 2001. Accessed May 1, 2001.

Land Trust Alliance. 2001. Links to Web Sites of Sponsor Members of the Land Trust Alliance. www.lta.org/resources/links. Last updated February 16, 2001. Accessed May 1, 2001

Livingston, E.H., and E. McCarron. 1992. *Stormwater Management: A Guide for Floridians*. Florida Department of Environmental Regulation, Tallahassee, FL.

Mantel, M.A., S.F. Harper, and L. Propst. 1990. *Creating Successful Communities: A Guidebook to Growth Management Strategies*. Island Press, Washington, DC.

Maryland Department of Planning. No date. *The Economic Growth, Resource Protection, and Planning Act of 1992*. http://www.mdp.state.md.us/planningact.htm. Accessed March 3, 2005.

Maryland Environmental Trust Land Conservation Center. 2002. *Local County Purchase of Development Rights (PDR) Programs*. http://www.conservemd.org/purchased/pdr. Accessed March 3, 2005.

Meeks, G. 1990. *State Land Conservation and Growth Management Policy: A Legislator's Guide*. National Conference of State Legislators, Washington, DC.

Metro-Dade Planning Department. 1988. *Comprehensive Development Master Plan.* Miami, FL.

Michigan Department of Environmental Quality. No date. *Into Every Life a Little Rain Must Fall.* Michigan Department of Environmental Quality, Madison, WI.

Mid-America Regional Council (MARC). No date. *Principles of Transit Supportive Development.* Mid-America Regional Council, Kansas City, MO.

Morrison, M. 2000, June 5. A sudden oasis, or just sprawl? Phoenix exurb sharpens growth debate. *The Washington Post*, p. A3.

National Association of Local Government Environmental Professionals (NALGEP). 2003. *Smart Growth for Clean Water: Helping Communities Address the Water Quality Impacts of Sprawl.* National Association of Local Government Environmental Professionals, Trust for Public Land, ERG. http://www.resourcesaver.com/file/toolmanager/CustomO93C337F42157.pdf. Accessed June 30, 2003.

National Park Service (NPS). 2001. *Colonial National Historical Park.* http://www.nps.gov/colo/. Last updated May 2, 2001. Accessed May 2, 2001.

Natural Resource Conservation Service (NRCS). 2003. *Farm Bill 2002: Farm and Ranch Lands Protection Program.* Natural Resource Conservation Service, U.S. Department of Agriculture. http://www.nrcs.usda.gov/programs/farmbill/2002/pdf/FRPPFct.pdf.

Nelson, A.C. and T. Moore. 1993. Assessing urban growth management: The case of Portland, Oregon, the USA's largest urban growth boundary. *Land Use Policy* 10(4): 293-302.

Price, J. 2000, December 7. Apex leaders agree to beef up their stream-protection measures: New rules call for larger buffers. *The Raleigh News and Observer*.

Redman/Johnson Associates. 1997. *Beyond Sprawl—Land Management Techniques for the Chesapeake Bay: A Handbook for Local Governments*. EPA 903-B-97-005. U.S. Environmental Protection Agency, Region 3, Chesapeake Bay Program Office, Annapolis, MD.

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

Simmons, M.M. 1991. *Coastal Barriers Protection Issues in the 101st Congress*. Congressional Reporting Service, Environment and Natural Resource Policy Division, Washington, DC.

Sims, R. 2000a. *First Transfer of Development Credits in NW Celebrated.* www.metrokc.gov/exec/news/2000/032800.htm. Last updated March 28, 2000. Accessed May 4, 2001.

Sims, R. 2000b. *SmartGrowth: Rural Legacy.* www.metrokc.gov/smartgrowth/rural.htm. Last updated May 31, 2000. Accessed May 1, 2001.

Stapleton, B. 1999. Old B/A Gas Station Finds New Life. http://www.oldgas.com/info/banewtonville.html. Last updated September 11, 1999. Accessed February 21, 2000.

Tritto, C. 2000, November 13. City seeks policy on storm water. *Missourian*, p. 9.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 2000. *1997 National Resources Inventory*. http://www.nrcs.usda.gov/technical/NRI/1997/index.html. Accessed June 5, 2000.

U.S. Environmental Protection Agency (USEPA). 1992. Notes of Riparian and Forestry Management. In *U.S. EPA, Nonpoint Source News Notes.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. March 1992, pp. 10–11.

U.S. Fish and Wildlife Service. 2002. *The Coastal Barrier Resources Act: Harnessing the Power of Market Forces to Conserve America's Coasts and Save Taxpayers' Money*. http://www.fws.gov/habitatconservation/TaxpayerSavingsfromCBRA.pdf. Last updated August 2002. Accessed March 3, 2005.

University of Oregon. 1995. *What is an Urban Growth Boundary?* darkwing.uoregon.edu/~pppm/landuse/UGB.html. Last updated May 10, 1995. Accessed April 5, 2001.

Verden, T. 2000, September 25. Officials sign pact to balance development with preservation. *The Sacramento Bee*, p. N10.

MANAGEMENT MEASURE 4
SITE DEVELOPMENT

4.1 Management Measure

Plan, design, and develop sites to:

- Maintain predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, or detain runoff;
- Protect areas that provide important water quality benefits or are particularly susceptible to erosion and sediment loss;
- Limit effective impervious area[a] by design and the use of management practices;
- Limit land disturbance activities, such as clearing and grading and cut-and-fill, to reduce erosion, sediment loss, and soil compaction; and
- Preserve natural drainage features and vegetation to the extent possible.

4.2 Management Measure Description and Selection

4.2.1 Description

The goals of this management measure are to reduce the generation of nonpoint source pollution, maintain predevelopment hydrology, and mitigate the impacts of urban runoff and associated pollutants from all site development, including activities associated with roads, highways, and bridges. Included in this section are management practices that can be applied during the site planning and review process to ensure that nonpoint source pollution and increases in the volume and rate of runoff are appropriately managed before, during, and after construction.

Although the goals of Management Measure 3 (watershed protection) are similar, this measure is intended to apply to individual sites at the catchment level (see Figure 1.3) rather than larger watersheds or regional drainage basins. The site development and watershed protection management measures are intended to complement each other and be used together within a comprehensive framework to control runoff and reduce nonpoint source pollution.

---

[a] Effective impervious area is the portion of total impervious cover that is directly connected to the storm drain network (Sutherland, 1995). These surfaces usually include street surfaces and paved driveways and sidewalks connected to or immediately adjacent to them, parking lots, and rooftops that are hydraulically connected to the drainage network (e.g., downspouts run directly to gutters or driveways).

Programs designed to control increased runoff and nonpoint source pollution resulting from site development should include:

- Predevelopment planning and review processes to ensure watershed/subwatershed and site-level natural resource and performance goals are achieved;
- Guidance on assessing and designing sites to maintain predevelopment site hydrology;
- Appropriate pollution prevention practices to be incorporated into site development and use.
- Site plan review and conditional approval processes to ensure the preservation of environmentally sensitive areas and areas necessary for maintaining natural hydrology and water quality; and
- Requirements for erosion and sediment control plan review and approval prior to issuance of appropriate development permits.

In addition to the preceding provisions, the following objectives should be incorporated into the site development process:

- During site development, disturb only the smallest area necessary to perform current activities to reduce erosion and off-site transport of sediment.
- Avoid disturbance of unstable soils or soils particularly susceptible to erosion and sediment loss.
- Favor sites where development will conserve natural drainage areas and sensitive environmental features, and minimize erosion, sediment loss, and soil compaction.
- Revegetate the site as soon as possible after disturbance, preferably with native vegetation.
- Protect and retain existing vegetation to decrease concentrated flows, maintain site hydrology, and control erosion.
- Minimize imperviousness to the extent practicable.
- Develop and implement inspection and maintenance procedures to ensure that landscapes are maintained to avoid water quality impacts.
- Use natural hydrology as a design element, and avoid alteration, modification, or destruction of natural drainage features.
- Design sites to preserve vegetated or natural buffers adjacent to receiving waters.

– Reforest areas within the same watershed in proportion to the acreage cleared of trees.

– Use porous pavements for areas of infrequent use (see section 5.3.2.3 in Management Measure 5).

The use of site planning and evaluation can significantly reduce the size of controls required to retain runoff and sediment on-site. Long-term maintenance burdens can also be reduced. Good site planning can attenuate runoff from development and can improve the effectiveness of the conveyance and treatment components of an urban runoff management system (Anacostia Restoration Team, 1992).

4.2.2 Management Measure Selection

This management measure was selected because the practices associated with it have been shown to be effective in protecting natural drainage features, reducing runoff quantity, and improving runoff quality. Site evaluation and protection of features that promote infiltration, filtration, and on-site detention will protect receiving water quality, maintain baseflow in receiving waters, and prevent or reduce further degradation of stream channels. Development in and around urban areas is inevitable as population growth puts pressure on suburbs and rural areas. This management measure recommends standards for new development that reduce environmental damage caused by development.

4.3 Management Practices

Many of the management practices in this section are considered “better site design techniques,” planning techniques that are intended to be used to guide the layout of new developments to reduce the total effective impervious area, conserve natural habitats, and better distribute and infiltrate runoff. All aspects of an individual site, including soil types, slopes, and the location of environmentally sensitive features such as wetlands, forests, and meadows, should be examined to identify areas that should be preserved or restored. Better site design techniques can be used to identify the most efficient building and infrastructure layouts. It can also be used to develop a comprehensive strategy to reduce the quantity of runoff leaving the site and minimize the amount of pollutants generated on-site.

There are many advantages to better site design. Environmentally friendly site designs are more likely to be accepted by local governments and the community, thereby speeding plan approval. Site designs that preserve community open space also reduce the burden on the local government to provide recreational areas. In addition, better site design techniques reduce the amount and cost of infrastructure, which also in turn reduce engineering and maintenance costs. For example, runoff storage requirements for a low-impact development neighborhood in Pierce County, Washington, were reduced by more than 75 percent and the cost was 20 percent less than for conventional designs. These cost savings resulted primarily from the reduced size of runoff detention structures and the elimination of catch basins and pipes (Zickler, 2002).

Low-impact development practices can provide substantial benefits in terms of reducing the occurrence of combined sewer overflows (CSOs). Temporarily storing runoff in urban areas can greatly reduce the peak flow into storm water systems and provide a cost-effective way to mitigate basement flooding and CSOs (USEPA, 1999). Two communities in Indiana successfully implemented street surface storage of runoff to reduce the occurrence of CSOs in a cost effective manner while also reducing peak flows to wastewater treatment plants. The distributed storage controls also offered some water quality benefits by temporarily detaining runoff during storms (USEPA, 1999).

From a marketing perspective, studies have shown that lots abutting forested or other open space are initially valued higher than lots with no adjacent open space, and over time they appreciate more than lots in conventional subdivisions (Arendt, 1996). For example, lots in an open space subdivision in Amherst, Massachusetts, experienced a 13 percent greater appreciation in value compared to a conventional development after 20 years, even though the lots in the conventional development were twice as large (Arendt, 1996).

From a quality-of-life standpoint, site designs that incorporate pedestrian paths and common open space foster a greater sense of community among residents. House lots are closer together, encouraging communication among neighbors. Additionally, common open space provides recreational opportunities that further encourage community interaction.

Finally, better site design offers environmental benefits, including protection of ecologically significant natural resources, reduction of runoff, and preservation of open space and wildlife habitat. Maintaining open space also increases the opportunity for alternative sewage and wastewater disposal and treatment practices such as land treatment, spray irrigation, and reclamation and reuse. In addition, the flexibility of better site design allows designers to site these wastewater treatment systems in the areas of the development best suited for them.

Overall, the practices presented in this management measure provide many advantages over conventional developments and can be implemented in most communities. In some cases, however, outdated development rules can discourage or prohibit some of these practices. Watershed managers should review the local building codes and regulations that govern new developments to determine whether better site design techniques are allowed or encouraged and work with the appropriate authorities to remove these impediments.

The second edition of the Bay Area Stormwater Management Agencies Association's *Start at the Source*, which was originally published in 1997, is an excellent resource on site design issues for watershed managers. This publication emphasizes the importance of considering runoff quality in the early stages of land planning and design. The new edition has been updated and expanded to include commercial, industrial, and institutional development, as well as a technical section that provides more detailed information on the characteristics, applications, design criteria, maintenance, and economics of the practices discussed in the document. More information about ordering this publication when it becomes available is provided on the Bay Area Stormwater Management Agencies Association's Web site at http://www.basmaa.org/ (BASMAA, no date).

Pembroke Woods Subdivision, Emmittsburg, Maryland

Pembroke Woods is a 43-acre low impact development residential subdivision that the designers hail as the first subdivision designed and under construction using the *Low-Impact Development Design Strategies: An Integrated Design Approach* manual developed by Prince George's County, Maryland (2000a). The designers have identified significant cost savings for this development compared to the traditional development plan created in the 1990s. These include

- Eliminating the need for 2 storm water management ponds that had been envisioned in a prior concept plan for the site, yielding construction cost savings of $200,000.
- In place of those 2 storm water management ponds, 2.5 acres of undisturbed open space and wetlands were conserved, with cost savings realized in eliminating wetland mitigation costs.
- An additional 2 lots were created by revising the site plan, increasing the site yield from 68 to 70 lots and adding $90,000 to the project value.
- Approximately 3,000 linear feet of roads were converted from urban road to rural road, replacing curb & gutter with grass bioswales, yielding a savings of $60,000 in construction costs. Also, reducing the road with from 36 feet to 30 feet in the rural road section of the development reduced paving costs by 17 percent.

A brief project overview and contact information can be found at http://www.buckeyedevelopment.net/lowimpactdevelopment.htm.

4.3.1 Site Planning Practices

4.3.1.1 Select site designs that preserve or minimize impacts to predevelopment site hydrology and topography

Retaining the existing topography of a development site assists in maintaining natural drainage features and depressional storage areas that help infiltrate and attenuate flows and filter pollutants. Depressional storage areas, commonly found as ponded areas after storms or during the wet season, aid in reducing runoff volumes and trapping pollutants. To help preserve natural drainage, a developer can (Goldman et al., 1986):

- Construct buildings and parking areas on existing flat terrain;
- Locate buildings and roads along existing contours;
- Orient long buildings with the major portion parallel to contours;
- Stagger floor levels to adjust to gradient changes; and
- Fit the development to the topography.

4.3.1.2 Protect environmentally sensitive areas

Sites should be developed to avoid destroying wetlands, seeps, bogs, fens, springs, surface water bodies, and catchment areas that are important for sustaining the hydrology of the land. In addition, riparian buffers, both forested and covered with grasses, should be preserved to protect surface water bodies. Steep slopes and highly erodible areas need to be protected to avoid landslides and soil movement into water bodies.

The increase in storm water runoff that results from urban development can dramatically impact the ecology of wetlands and other areas by altering characteristics of hydrology, water quality, and soil (USEPA, 1996). Urban development can also result in ecological changes due to fragmentation and habitat destruction. If the development of a site changes runoff characteristics, measures should be taken to prevent negative impacts to wetlands and other features. For example, Pohlig Builders of Malvern, Pennsylvania, incorporated measures to protect wetlands into its building plan after homeowners opposed the construction of seven high-end homes adjacent to a wetland area. Pohlig designed a vegetative filter strip to buffer runoff from the homes and provide treatment before runoff reached the wetlands. The filter strip was designed to eventually grow into a wooded area to enhance aesthetics and benefit water quality. A level spreader was added to convert concentrated runoff to sheet flow that can be more effectively treated, and extra erosion and sediment control measures were used during construction. The total additional cost of these measures was $30,000 (NAHB, 2003).

4.3.1.3 Practice site fingerprinting

The total amount of disturbed area in a site can be reduced by "fingerprinting" development, i.e., placing development in the most environmentally sound locations on the site and minimizing the size of the disturbed area and ultimate development footprint. Fingerprinting places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces and restoration areas, areas with trees to be saved, and temporary and permanent vegetative forest buffer zones. At a subdivision or lot level, ground disturbance is confined to areas where structures, roads, and rights-of-way will exist after construction is complete. Other site-level fingerprinting practices include reducing paving and compaction of highly permeable soils, minimizing the size of construction easements and material storage areas, minimizing impervious areas in the site design, clearly demarcating the disturbance area, maintaining existing topography and drainage divide, and disconnecting impervious areas (Prince George's County, Maryland, Department of Environmental Resources, 2000a).

4.3.1.4 Use cluster development

Cluster development is used to concentrate development and construction activity on a limited portion of a site, leaving the remainder undisturbed. Figures 4.1 and 4.2 show schematics of a residential cluster development and a rural cluster development. Clustering allows the design of more effective urban runoff management systems and reduces overall site-level erosion and sediment impacts. It also provides a mechanism to preserve environmentally sensitive areas and reduce infrastructure such as wastewater treatment systems, roads, sidewalks, and parking areas.

In addition to its environmental benefits, clustering can result in cost savings for municipalities because clustering and infill development typically require less new infrastructure, such as urban runoff treatment systems. The imposition of density controls may preclude clustering. Although minimum lot size requirements are useful in some instances, such as farmland preservation (see

Management Measure 3), zoning ordinances should not preclude the implementation of clustered development as an alternative to conventional suburban development.

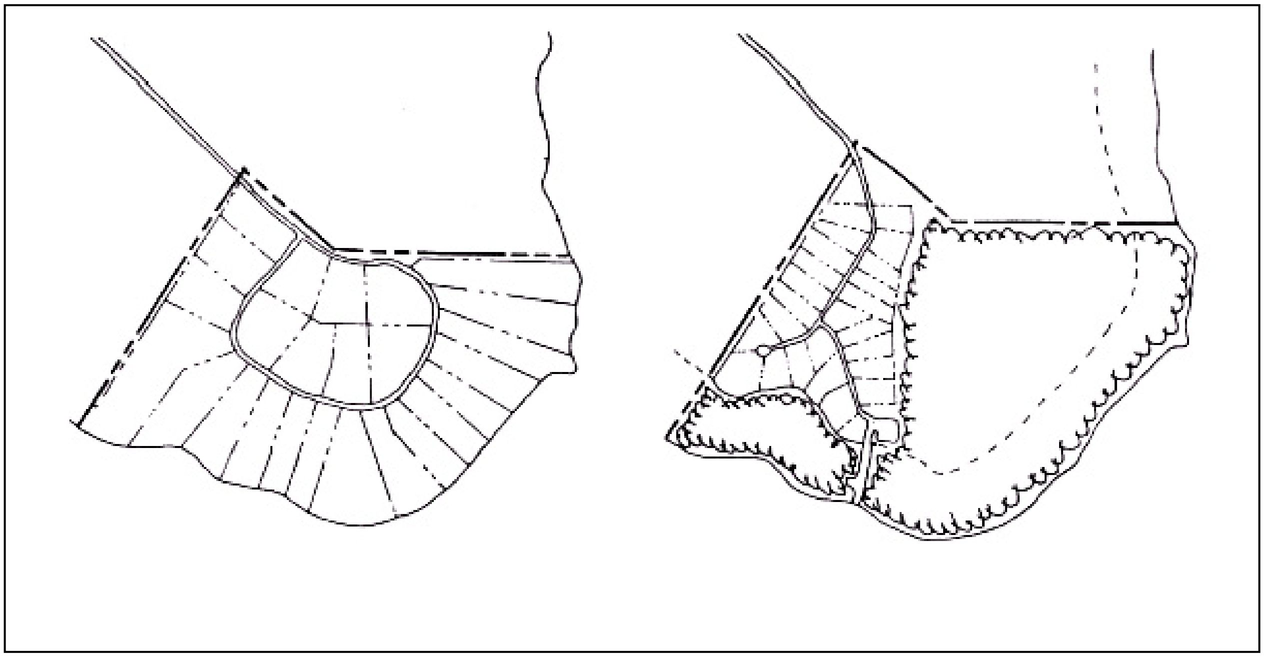


Figure 4.1: Schematic of a residential cluster development (Schueler, 1995).

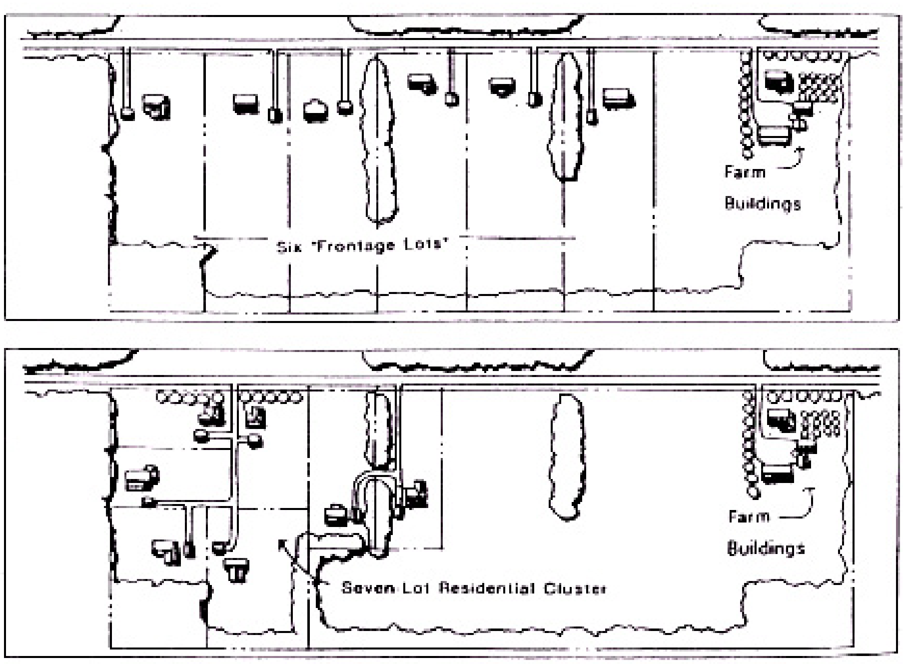


Figure 4.2: Schematic of a rural cluster development (Schueler, 1995).

4.3.1.5 Create open space

Open space development is a technique that concentrates development on one area of a site in exchange for open space in another area. Benefits associated with open space design include:

- A 40- to 60-percent reduction in impervious cover compared to conventional development designs;
- Increased property values;
- Reduced construction and development costs;
- Common recreational facilities (i.e., pedestrian paths, picnic areas, and athletic fields);
- Reduced infrastructure;
- Improved quality of life; and
- The use of community onsite/decentralized systems (see Nutrient Export case study below).

The following are some techniques for conserving open space:

- *By-right open space development*. This technique allows increased density on one portion of a site in exchange for open space on another portion. A large percentage of this open space can be dedicated as conservation land. To encourage open space development, municipalities can draft ordinances so that this is a "by-right" option, as opposed to a special exception or variance.
- *Density compensation*. This technique allows developers to increase housing density to offset potential housing lots lost to on-site buffers or other conservation lands.
- *Storm water credits*. Credit is given for implementation of source controls that reduce runoff volumes and pollutant concentrations before the remaining runoff reaches structural controls. Because performance is typically measured by comparing influent runoff to effluent runoff, storm water credits benefit operators of structural controls because credit for pollutant removal occurs before treatment.
- *Property tax credit*. The property tax credit is a technique for reducing, deferring, or exempting property taxes on conservation land. Typically, conservation easements are exchanged for the property tax credit.
- *Density bonus*. This bonus allows developers to increase density above base zoning density in exchange for conserving natural areas.
- *Off-site mitigation*. This term refers to the restoration or creation of wetlands in a designated off-site area if on-site wetlands are adversely affected and on-site mitigation is not feasible.

Randall Arendt (1996), in his book, *Conservation Design for Subdivisions: A Practical Guide for Creating Open Space Networks*, presents a plain-language, illustrated guide for designing open space subdivisions. This publication is available from Natural Lands Trust, Inc., 1031 Palmers Mill Road, Media, PA 19063; phone 610-353-5587. The following topics are covered:

- Open space vs. conventional developments;
- Economic, social, and environmental benefits of open space designs;
- Roles and responsibilities of stakeholders in site development;
- A stepwise approach to designing an open space subdivision (discussed below);
- Ideas for creating an interconnected open space network;
- Seven case studies;
- Methods to modify existing regulations to encourage open space design;
- Management techniques for conservation lands;
- Sample house plans for open space subdivisions;
- Sample advertisements for developers to capitalize on open space design benefits; and
- Model ordinance provisions.

Arendt's multi-step process for creating conservation subdivisions involves two stages. The first, called the background stage, involves identifying the characteristics of the surrounding landscape and existing development and analyzing and delineating significant features of the site. The second stage involves integrating the site's feature information into a map and prioritizing conservation lands based on the features deemed most important, while maintaining the quantity of land necessary to develop the site to the desired density.

The background stage involves examining the surrounding landscape and existing development to identify conservation areas. It includes the following practices:

(1) *Understanding the locational context*. The layout of new development should consider proximity to traditional small towns or villages; if existing development is nearby, the design of the new community should reflect and extend the historical streetscape and pattern. In rural areas located away from existing development, informal, irregular, "organic" layouts can be used successfully without detracting from the surrounding landscape.

(2) *Mapping natural, cultural, and historic features.* A thorough analysis of a site's special features that may enhance or constrain development is an important step in planning a new development. Special features might already have been identified in a natural resources inventory conducted by local government or land trust organizations. The site analysis should include site visits and identify the conservation areas described in this section.

The following conservation areas are legally or logistically unbuildable and therefore must be avoided:

- *Wetlands*. Tidal and non-tidal saltwater and freshwater wetlands and the dry upland buffers surrounding them should be identified as areas to be conserved because they filter runoff, provide critical habitat at the land-water interface, and offer opportunities for recreation and environmental education. Soil survey maps, National

Wetlands Inventory maps, state or environmental agency wetland maps, or on-site delineations can be used to determine the extent of wetland habitat on the site.

- *Floodplains*. The 100-year floodplain, which can be determined from floodplain maps published by the Federal Emergency Management Agency (FEMA) (see Management Measure 2), should be left undeveloped to preserve a continuous riparian greenway and to prevent damage to property from flooding. To preserve views of the water on wooded sites, lower tree limbs can be removed. (This may be a reasonable alternative to developing closer to the water's edge.) Zoning requirements might dictate an additional 50- to 100-foot setback from the 100-year floodplain.

- *Slopes*. Slopes of more than 25 percent should not be developed because of their high potential for erosion. Slopes between 15 and 20 percent can be developed using special site planning but should be avoided when possible. Slope maps can be prepared from USGS topographic maps by an engineer, planner, or landscape architect, but site visits should confirm these conditions.

The following conservation areas typically are legally buildable but are historically or ecologically significant or desirable, and therefore they should be avoided when other land is available for development.

- *Soils*. Soil surveys, whether they are based on existing maps produced by NRCS or data gleaned from on-site testing, identify well-drained soils suitable for treating wastewater, poorly drained soils that might result in leaky basements or wetland conditions, and steep or stony soils that would be difficult to build on. Existing soil survey data might not be detailed enough to characterize site conditions, depending on the spatial variability of soil types in the region. High-intensity soil surveys and site surveys that are accurate to 0.1 acre should be used in highly variable circumstances.

- *Significant wildlife habitats*. Habitat for threatened or endangered wildlife, including travel corridors to food sources, homes, and breeding grounds, should be conserved. An additional buffer of open space is recommended. These habitat locations might have been officially documented already by state or local agencies. Habitat for wildlife species that are not threatened or endangered should also be considered for conservation areas where possible. Continuity in habitat areas is important; land that connects two isolated habitat areas provides a valuable corridor that extends the usable habitat for the species of concern.

- *Woodlands*. Woodlands often provide valuable wildlife habitat and contribute to the aesthetic value of a property. Where areas are mostly forested and clearing is required for site development, however, areas of mature forest or areas with unique species composition should be of higher conservation priority. In areas where woodland is not the predominant land use, as much of the existing tree cover as possible should be conserved on the property. An effort should be made to maintain corridors that connect forested areas to provide as much continuous forested habitat as possible.

- *Farmland*. Agricultural lands can be conserved as open space if desired, although relatively small fields might not be lucrative and could pose a more significant water quality risk compared to residential development due to specific land management practices (tilling, fertilizer application) associated with agriculture. Another option for agricultural fields is to let them succeed to a more natural meadow state with grasses, wildflowers, and shrubs that could provide habitat for many birds and small mammals.

- *Historic, archaeological, and cultural features*. Areas with historic significance can be identified from official lists such as the National Register of Historic Places and state and local inventories of historic and cultural resources. Landowners and local historians should also be consulted for detailed information about a site's history. Although historic areas are not always protected from demolition, if other areas of the property are equally suitable for development, historic resources should be preserved.

- *Views into and out from the site*. Development should be designed to blend well with the surrounding landscape. Because developers typically want to site buildings to take advantage of attractive views, they often build in areas where structures are highly visible. Siting buildings away from the pinnacles of ridges and hills, designing buildings with lower profiles, and preserving or planting trees to shield buildings from view are all techniques that can be used to reduce the visual impact of development on the landscape. Views can be created by cutting a limited number of trees to create "view tunnels," or trimming lower limbs to create "view holes" through the foliage.

- *Aquifers and their recharge areas.* An aquifer recharge area is where water moves downward to the water table. In other words, recharge areas replenish groundwater. Unconfined aquifers are not covered by a layer of impermeable rock and are open to receive water from the land surface. Unconfined aquifers are typically recharged in topographically high areas or through sandy or gravelly soils. These areas should be conserved as open space to maintain ground water recharge. They should also be buffered with vegetation to filter solids and associated pollutants from runoff.

After background information has been obtained, the next step is to integrate the information and prioritize conservation areas. Typically, all of the features mentioned above are drawn onto overlay sheets or entered into a geographic information system (GIS). Once the significant features are shown together, areas most suitable for development become obvious. Where some conservation areas need to be sacrificed to achieve the development objectives, decisions must be made regarding ranking the conservation areas based on how special, unique, irreplaceable, environmentally valuable, historic, or scenic they are. Figure 4.3 shows an example site before development, developed with a conventional strategy, and developed with consideration of locational context and conservation areas (Arendt, 1996).

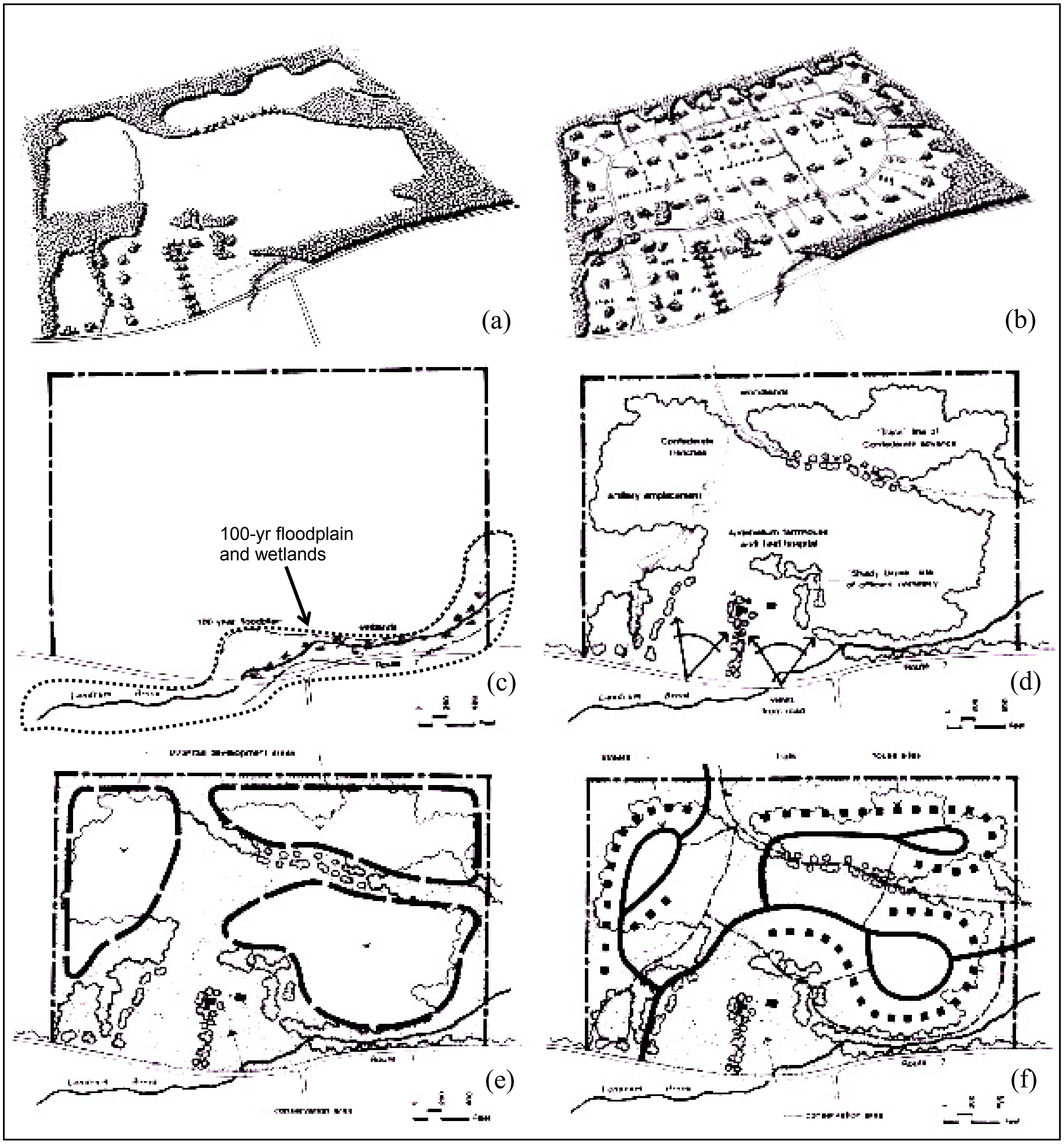


Figure 4.3: Development of a conservation subdivision. The site before development (a) and as designed with conventional development (b); identification of legally unbuildable (c) and legally buildable (d) conservation areas with features to be protected; and delineation of potential development areas (e and f) (adapted from Arendt, 1996).

Comparison of Traditional and Low Impact Development Scenarios in Delaware

The Brandywine Conservancy and the Delaware Department of Natural Resources and Environmental Control presented a case study in *Conservation Design for Stormwater Management* (Delaware DNREC and the Brandywine Conservancy, 1997). The case study compares conventional site development to several alternative, low impact development scenarios at Chapel Run, a 96-acre site in Sussex County, Delaware. The Chapel Run site is located in a rural area and is categorized by Sussex County as a primarily agricultural area where low-density residential development is permitted. Conservation areas that were identified through a site investigation include a large area of woodland, much of which is on well-drained soils that generate little or no runoff, and a small area with steep slopes.

The proposed conventional design dictates dividing the site into 142 lots ½ acre in size. The conventional design does not take into consideration the sensitive areas identified in the site assessment and results in a site with 100 percent of the area disturbed after clearing and grading. Overall site imperviousness under conventional development would be 29 percent, assuming conventional road widths. On-site runoff management would be accomplished by a curb and gutter system that conveys runoff to two detention basins.

Two alternative designs were developed for the Chapel Run site: the parkway design and the village cluster design. Figure 4.4 shows lot layouts for the conventional and conservation designs. Table 4.1 shows a theoretical side-by-side comparison of the three types of developments with respect to lot size and layout, amount of disturbed and impervious area, hydrology, and costs. Table 4.2 shows differences in itemized costs for infrastructure and management practices between conventional and low impact alternative designs.

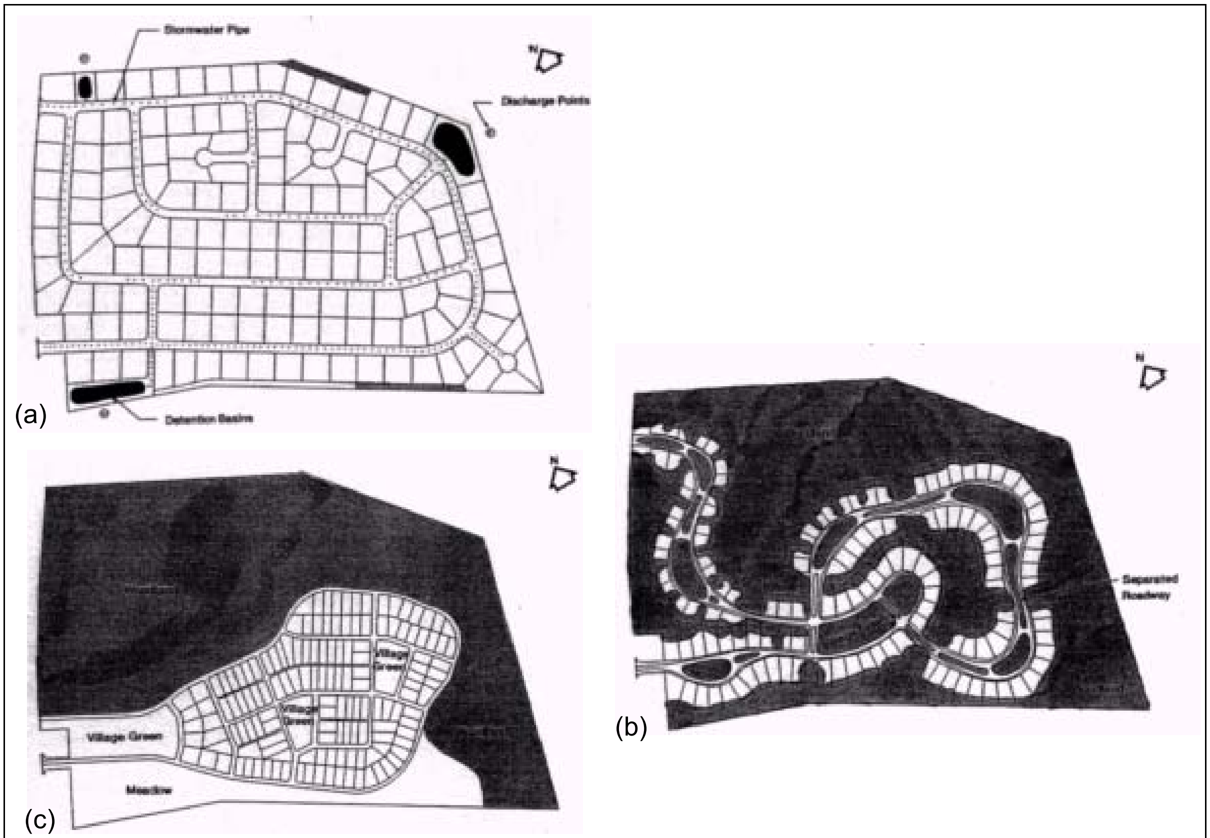


Figure 4.4: Schematic drawings of conventional (a), parkway (b), and clustered (c) development scenarios for the Chapel Run subdivision (Delaware DNREC and the Brandywine Conservancy, 1997).

Comparison of Traditional and Low-Impact Development Scenarios in Delaware (continued)

Table 4.1: Theoretical comparison of conventional and low-impact alternative designs for the Chapel Run site (DE DNREC and the Brandywine Conservancy, 1997). (Reductions are compared to the conventional design.)

Name	Conventional	Village	Parkway
Layout type	Conventional	Condensed cluster	Lots configured along curving road
Number of lots	142	142	142
Lot size	1/2-acre	1/8-acre	1/4-acre
Areas conserved	None	Woodland and high recharge areas	Woodland and high recharge areas
Percent of site in open space	0%	72.7%	49.7%
Impervious cover	29%	17.7%	14.9%
Impervious cover reduction	—	38%	48%
Street width	28 feet	20 feet	Two one-way lanes 12 feet wide with a pervious median
Undisturbed areas	0%	67.5%	59.6%
Runoff management system	Curb and gutter system that conveys runoff underground to two detention basins.	Swale conveyance system along roads that directs runoff to retention/ infiltration areas with level-spreading devices and low berms. These retention/infiltration areas are located throughout the site. Several village greens established on well-drained soils function as both recreation and infiltration areas.	Infiltration of runoff into depressed median (swales) along streets. Wide oval parkway centers used for retention/infiltration. These areas are designed with overflow piping to prevent flooding.
Average curve number[a]	78	66	65
Peak runoff rate for a 10-yr storm[a]	—	53 cfs	51 cfs
Water budget (gal) Precipitation Runoff Recharge Evapotranspiration	 114,082,682 31,584,217 31,280,103 51,223,261	 114,082,682 21,812,868 34,001,079 58,208,796	 114,082,682 17,782,776 35,502,938 60,802,278
Costs [b] Total Per lot	 $2,460,200 $17,325	 $1,174,716 $8,273	 $887,705 $6,259

[a] From USDA-NRCS's TR-55 model.
[b] Total cost for the Parkway design shown here differs from total cost published in DE DNREC and the Brandywine Conservancy (1997). Total cost shown here is based on itemized costs, provided in Table 4.2. These are conservative estimates, as in most cases additional costs such as grading have not been taken into account.

Comparison of Traditional and Low-Impact Development Scenarios in Delaware (continued)

Table 4.2: Theoretical comparison of itemized costs for conventional and low-impact alternative designs for the Chapel Run site (DE DNREC and the Brandywine Conservancy, 1997).

Name	Conventional	Village	Parkway
Street			
Length installed	13,388 ft	11,828 ft	7,800 ft
Unit cost	$150/linear ft	$85/linear ft	$85/linear ft
Total cost	**$2,008,200**	**$1,005,380**	**$663,000**
Storm water detention ponds			
Number installed	3	0	0
Unit cost	$16,000 per pond		
Total Cost	**$48,000**	**$0**	**$0**
Storm water pipe			
Length installed	16,000 ft	2,000 ft	3,000 ft
Unit cost	$22/linear ft	$22/linear ft	$22/linear ft
Total cost	**$352,000**	**$44,000**	**$66,000**
Endwalls/inlets			
Number installed	40	5	10
Unit cost	$1,300 each	$1,300 each	$1,300 each
Total cost	**$52,000**	**$6500**	**$13,000**
Berms			
Length installed	0	1050 ft	1000 ft
Unit cost		$10/linear ft	$10/linear ft
Total cost	**$0**	**$10,500**	**$10,000**
Swales			
Length installed	0	22,570 ft	20,600 ft
Unit cost		$4.50/linear ft	$4.50/linear ft
Total cost	**$0**	**$101,565**	**$92,700**
Check dams			
Number installed	0	90	82
Unit cost		$75 each	$75 each
Total cost	**$0**	**$6771**	**$6150**
Reforestation			
Acres reforested	0	0	12.8
Unit cost			$2,925/ac
Total cost	**$0**	**$0**	**$36,855**
Total [a]	**$2,460,200**	**$1,174,716**	**$887,705**

[a] Total cost for the Parkway design shown here differs from total cost published in DE DNREC and the Brandywine Conservancy (1997). Total cost shown here is based on itemized costs. These are conservative estimates, as in most cases additional costs such as grading have not been taken into account.

4.3.2 On-Lot Impervious Surfaces

4.3.2.1 Reduce the hydraulic connectivity of impervious surfaces

Pollutant loading from impervious surfaces can be reduced by preventing the direct connection of the impervious area to an impervious conveyance system. This can be done in a number of ways, including:

(1) Routing runoff over lawn areas to increase infiltration;

(2) Discouraging the direct connection of downspouts to storm sewers, or the discharge of rooftop downspouts to driveways, parking lots, and gutters;

(3) Substituting swale and pond systems for curbs and gutters to increase infiltration; or

(4) Reducing the use of storm sewers to drain streets, parking lots, and backyards by routing runoff overland using curbless systems, curb cuts, sloped sidewalks, and bioretention cells.

If runoff is directed over lawns, care should be taken to alleviate soil compaction. Urban lawns that are highly disturbed and compacted do not necessarily function as pervious surfaces (for more information on managing runoff from lawns and landscaping, see Management Measure 9).

Figure 4.5 shows schematic representations of impervious areas that are directly connected and not directly connected (BASMAA, 1997).

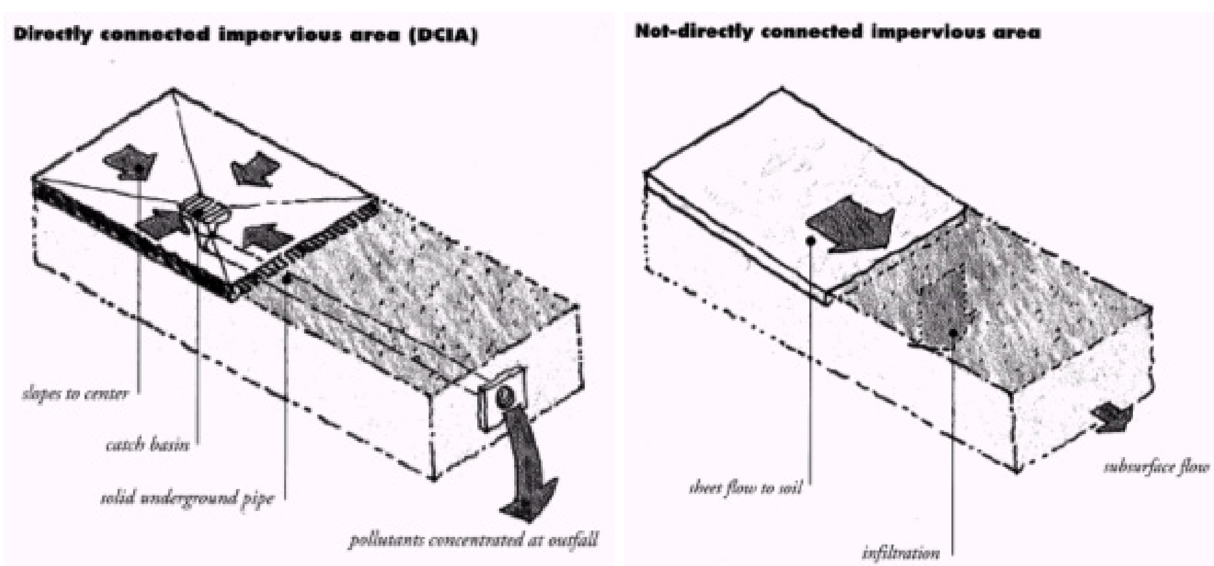


Figure 4.5: Schematic representation of directly connected and not-directly connected impervious areas (BASMAA, 1997).

The Urban Runoff Pollution Mitigation ordinance passed by the City of Santa Monica, California, requires new developments to implement management practices to collect precipitation, increase infiltration, and manage urban runoff on-site rather than after it enters the storm drain system. Infiltration trenches are the most common on-site practices for single-family homes in the city, but biofilters, swales, and porous pavement are also used. Since 1995, when the ordinance came into effect, 600 new developments have implemented management practices, resulting in a 1.2 million-gallon decrease in storm water runoff for each storm of 0.1-inch rainfall or greater (Shapiro, 2003).

In Prince George's County, Maryland, Cheng et al. (no date) measured runoff from adjacent watersheds to compare the effects of conventional versus low-impact subdivision design. One watershed was developed using conventional subdivision design (curb, gutter, and pipe storm drainage), while the other watershed was developed using low-impact development (LID) techniques, including curbless roads, networks of grassy swales to convey runoff, and bioretention areas (with drop inlet structures where necessary to convey concentrated flows during larger storms). After two years of monitoring, the researchers found that the average peak flow rate of the LID site was 56 percent of that of the conventional site, and surface runoff volume for the LID site was 60 percent of that of the conventional site. Only 15 percent of rainfall was converted to runoff in the LID watershed compared to 19 percent in the conventional watershed, and the LID site had delayed runoff hydrographs and a higher frequency of small flow rates compared to the conventional site, which had a higher frequency of larger flow rates.

Gap Creek Low Impact Development Subdivision, Sherwood, Arkansas

The Gap Creek subdivision in Sherwood, Arkansas, was designed using a low impact development approach that involved implementing such practices as street designs that flow with the existing landscape, minimal site disturbance and preservation of native vegetation, preservation of natural drainage features, and a network of buffers and greenbelts that protect sensitive areas. The approach resulted in significant economic benefits arising from lower development costs, higher lot yield, and greater lot values (NRDC, 1999).

The developer took advantage of the open space that was preserved to maximize the number of lots that were adjacent to the uncleared areas, enhancing their marketability and increasing the value of those properties. The LID plan reduced the amount of site clearing and grading, yielding lower site preparation costs.

Additionally, enhancing natural drainage features resulted in less money spent on drainage infrastructure such as piping, curbs, gutters, and other runoff conveyance features. An additional cost savings was realized with shorter and narrower streets, which also reduced imperviousness. For example, the developer reduced street width from 36 to 27 feet and retained trees close to the curb line, resulting in savings of nearly $4,800 per lot.

The greater lot yield and high aesthetic curb appeal also resulted in larger profits. The developer was able to sell lots for $3,000 more than larger lots in competing areas and sold nearly 80 percent of the lots within the first year. Additional benefits can be found in 23.5 acres of green space and parks (Toolbase Services, no date).

The economic benefits are expected to exceed $2 million over original projected profits. Additional benefits of the LID design include lower landscaping and maintenance costs and more common open space and recreational areas.

4.3.2.2 Practice rooftop greening

Rooftop greening has become an increasingly common practice in Europe and other parts of the world. This practice involves growing vegetation on the roofs of businesses and homes to intercept rainfall and promote evaporation rather than runoff (Natural Carpets, 1998). Rooftop mats are typically multilayered and include prevegetated coir fiber mats, a mineral-based substrate, and a synthetic matrix (see Figure 4.6). The coir fiber mat absorbs rainfall; the mineral substrate provides the plants with nutrients; and the synthetic matrix promotes drainage. Mats can be used on roofs with slopes of up to 30 degrees and are capable of reducing runoff by two-thirds (see Figure 4.7). These mats provide benefits other than runoff reduction, including:

- Visual aesthetics
- Protection of roofs from damaging solar radiation, wind, and precipitation
- Insulation
- Noise reduction
- Habitat for wildlife

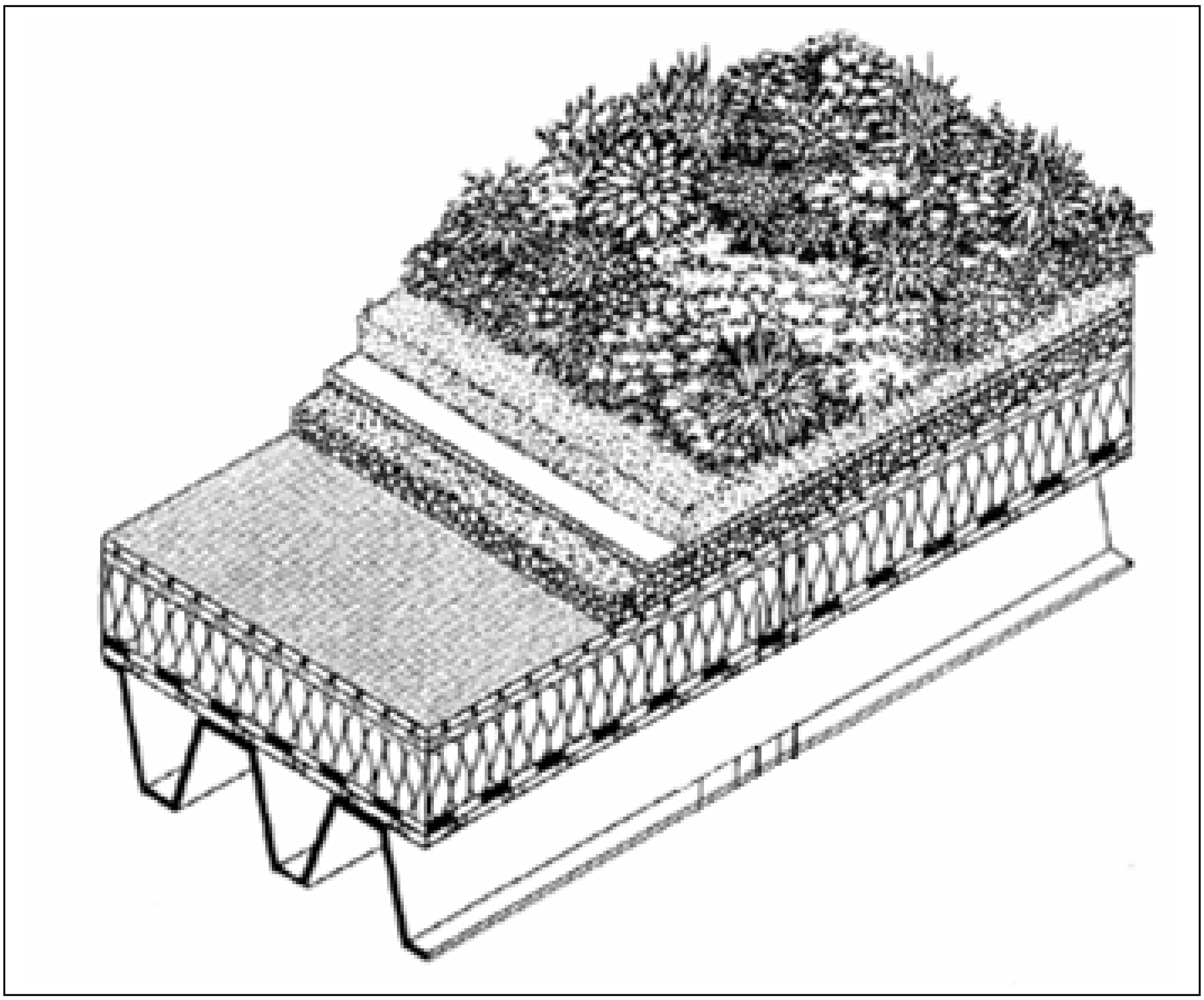


Figure 4.6: Components of the vegetated roof cover (USEPA, 2000).

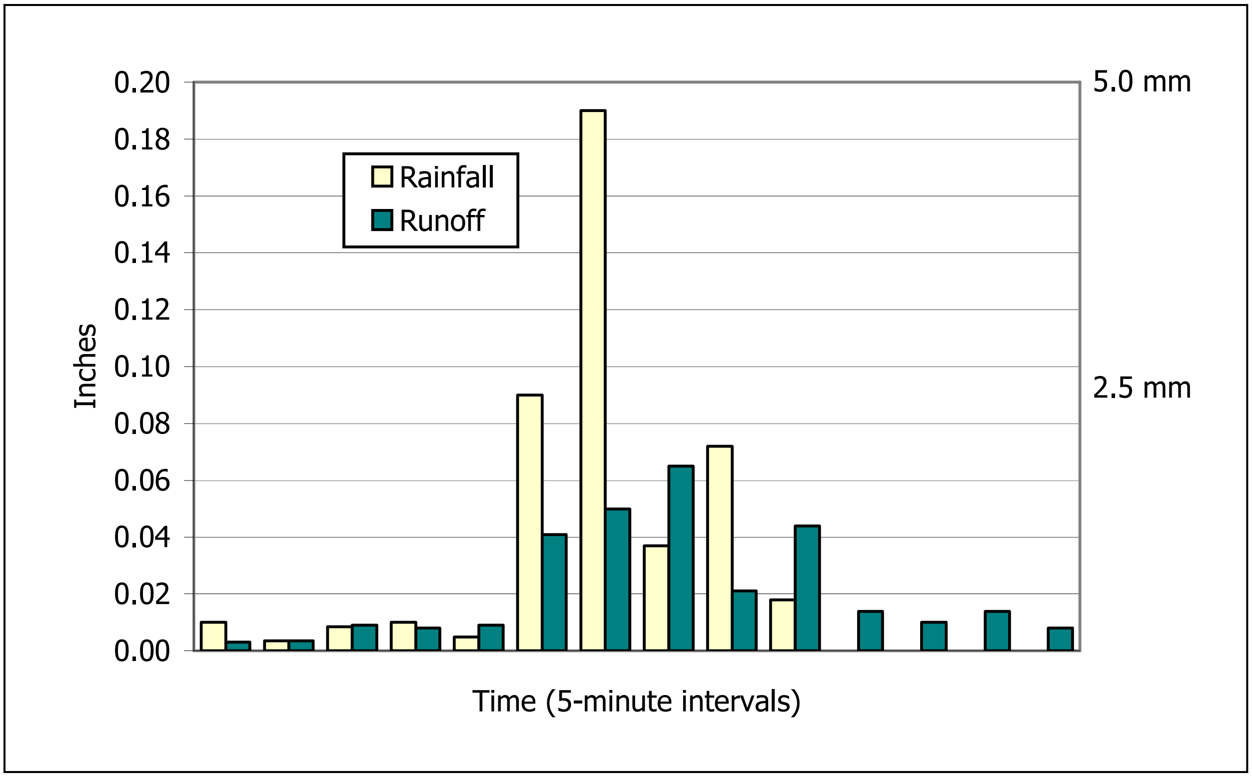


Figure 4.7: Runoff attenuation efficiency for a 0.4-inch rainfall event with saturated media (USEPA, 2000).

- Dust-trapping
- Evaporation and ambient cooling

Vegetation should be well-adapted to the growing conditions of the area where it is installed. Maintenance includes a limited amount of irrigation on steep slopes and periodic fertilization and weeding. Additional roof support might be necessary because the mats, when saturated with water, can add 5 to 17 pounds per square foot.

In response to a court order requiring $3 billion in storm water improvements, Atlanta is targeting commercial buildings for the installation of green roofs, with the anticipation that the resulting decrease in storm water runoff volume will provide water quality benefits. Commercial buildings are being targeted because commercial rooftops cover a huge amount of surface area in the city (Copeland, 2002).

Moran et al. (2004) studied runoff quality from two green roofs installed in North Carolina. They found that each green roof retained approximately 60 percent of the total recorded rainfall during a nine-month observation period. The green roofs reduced average peak flow by approximately 85 percent. Water quality data indicated higher concentrations of total nitrogen and total phosphorus were present in the green roof runoff than in the control roof runoff and in the rainfall at each green roof site. The researchers attribute this to nitrogen and phosphorus leaching from the soil media, which was composed of 15 percent compost. A soil column test of three different green roof soil media indicated that reducing organic matter in the soil media will

Rooftop Meadow Demonstration Project, Philadelphia, Pennsylvania

Rooftop meadows typically use foliage and a lightweight soil mixture to either absorb or filter and detain rainfall (Miller, 1998). Roof meadows are designed to control low-intensity storms by intercepting and retaining or storing water until the peak storm event has passed, while allowing the runoff from higher-intensity storm events to be safely conveyed away from the building. The plants help retain the hydrologic function of intercepting and delaying rainfall runoff by capturing and holding precipitation in the foliage, absorbing water in the root zone, and slowing the velocity of direct runoff by extending the flowpath through the vegetation.

A rooftop meadow demonstration project in Philadelphia, Pennsylvania, consists of a 3,000-ft^2 roof installed and monitored on top of an existing structure. The roof system was intended to mimic natural hydrologic processes of interception, storage, and detention to control the 2-year, 24-hour storm event. There are several distinguishing features of this rooftop meadow: (1) a synthetic underdrain layer that promotes rapid drainage of water from the surface of the roof deck; (2) a thin, lightweight growth medium that permits installation on existing conventional roofs without the need for structural reinforcement; and (3) a meadow-like setting of perennial *Sedum* varieties that have been selected to withstand the range of seasonal conditions typical of the Mid-Atlantic region without the need for regular maintenance.

The installed roof meadow is 3.4 inches thick, including the drainage layer, and weighs less than 5 lb/ft^2 when dry and less than 17 lb/ft^2 when saturated. The moisture content of the medium at field capacity is 45 percent of the volume. The saturated infiltration capacity is 3.5 inches per hour.

The runoff characteristics of the roof were simulated using rainfall records for 1994 from eastern Pennsylvania. The model predicted a 54 percent reduction in annual runoff volume and attenuation of 54 percent and 38 percent, respectively, for the 2- and 10-year, 24-hour Type II storm events. Monitoring of the pilot project for real and synthetic storm events was also conducted for a period of 9 months at 28- and 14-ft^2 trays. The most intense storm monitored was a 0.4-inch, 20-minute thunderstorm. The storm event occurred after an extended period of rainfall had fully saturated the medium. Although 44 inches of rainfall were recorded during this period, only 15.5 inches of runoff were generated from the trays. Runoff was negligible for storm events with less than 0.6 inch of rainfall. This demonstration project shows the advantages of reducing peak runoff rates on overloaded systems for a majority of the storm events and shows that some existing structures can be retrofitted to reduce runoff.

reduce the amount of nutrient leaching. Based on the results of this study, caution should be used when implementing green roofs in nutrient-sensitive watersheds; green roof components such as soil media composition should be selected with consideration of receiving water limitations.

Dunnett and Kingsbury (2004) describe examples of both large-scale and residential applications of green roofs and living walls, and they include technical information about constructing these structures in *Planting Green Roofs and Living Walls.* The authors cover structural engineering concerns as well as factors such as plant selection and environmental considerations that are important for the success of green roofs and living walls. The book is available for purchase at the Timber Press Web site at http://www.timberpress.com.

Another resource for information about green roofs is the proceedings of a conference entitled Green Roofs for Healthy Cities. A CD-ROM of the proceedings can be purchased from http://www.greenroofs.org/portland/proceedings.php and includes information on green roof design and implementation, technical research, and policy developments.

A Better Site Design Approach to Runoff Management: Low Impact Development

The goal of low impact development (LID) is to maintain and enhance the predevelopment hydrologic regime of urban and developing watersheds. LID focuses on managing runoff in small, cost-effective landscape features on each lot rather than conveying runoff to large, costly storm water ponds located at the bottom of large drainage areas. Hydrologic functions such as infiltration, ground water recharge, and depressional storage are maintained using simple, small-scale practices such as bioretention facilities. A key objective of LID is to reduce the hydraulic connectivity of impervious surfaces. For example, instead of allowing storm water to run from a downspout down a driveway and into a storm sewer, direct the runoff onto a lawn or other pervious area. By disconnecting rooftop runoff from the storm drainage system, a community can decrease the volume of water conveyed to a storm drain by as much as 50 percent (Pitt, 1986) and avoid treatment and storage costs, decrease system maintenance costs, and reduce instream impacts. To avoid soggy areas in lawns, water can be directed to specially designed depression storage areas such as bioretention or infiltration areas.

The following is a list of fundamental practices of the LID approach that can be included in runoff management plans. These practices are presented in two publications by the Department of Environmental Resources of Prince George's County, Maryland: *Low-Impact Development Design Strategies: An Integrated Design Approach* (2000a) and *Low Impact Development Hydrologic Analysis* (2000b).

– *Use hydrology as the integrating framework.* Hydrology is used as the key feature when designing a development. Areas that play a critical role in the movement of water (e.g., streams, riparian and buffer areas, floodplains, wetlands, and ground water recharge sites) are identified first. Alternative layout schemes are then evaluated in terms of their impact on site hydrology. Key objectives are to minimize the amount of impervious cover created and to make created impervious areas function as "ineffective" impervious areas that are not directly connected to a storm drain network.

– *Think micromanagement.* Site hydrology is analyzed and dealt with at small scales. Using natural drainage as a design element, integrated management practices are scattered throughout the site, allowing for runoff distribution and the retention of natural hydrologic functions such as infiltration, depressional storage, and interception.

– *Control runoff at the source.* Management of runoff at or near the sources eliminates the need for large-scale runoff management practices such as concrete conveyance systems and storm water ponds.

– *Incorporate safety features into the design of management practices*. LID practices can require diversions or drainage to allow for overflow of runoff from large storms and storm events that occur during saturated conditions. This emergency drainage will protect the longevity of the structural practice against damage from high runoff volumes and flow velocities and enhance the acceptance of LID in the community.

– *Use simple, nonstructural methods.* Natural hydrologic functions rely on simple processes that promote infiltration, depressional storage, and interception of storm water. These characteristics can be implemented throughout the site using simple methods that incorporate native plants, soil, and gravel.

– *Create a multifunctional landscape.* A goal of the LID approach is to create a landscape where runoff is micromanaged and controlled at the source. Runoff management practices and natural landscape features can be used in tandem to reduce postdevelopment runoff volume and maintain the predevelopment time of concentration.

The Prince George's County LID publications can be ordered through the Internet at EPA's National Service Center for Environmental Publications Web site at http://www.epa.gov/ncepihom. They can also be ordered by phone, fax, or mail from USEPA/NSCEP, P.O. Box 42419, Cincinnati, Ohio 45242-2419, toll-free 800-490-9198, fax 513-489-8695.

4.3.2.3 Relax frontage and setback requirements

Developers interested in increasing open space or conservation areas typically increase housing density by creating smaller lots or clustered developments and pool the space “savings” in a large open area accessible to all. This can be accomplished by reducing front, side, and rear yard setbacks and decreasing frontage distances. In addition to increasing housing density for open space development designs, relaxing frontage and setback requirements also decreases impervious cover. This occurs because narrower side yards mean narrower lots, which can in turn lead to shorter subdivision streets; shorter front yard setbacks lead to shorter driveways and sidewalks.

Frontage distance can be reduced by providing garage access through rear alleys. This approach eliminates driveways and allows homes to be sited on narrower lots. This helps reduce road frontage requirements and accommodate more homes on a given amount of road. Because of their limited traffic, the alleys can be paved with alternative treatments to retain more pervious area.

Areas with high potential for significant storm damage, earthquakes, or other catastrophes should take into consideration the appropriate setback distance to ensure emergency access in case of building collapse.

4.3.2.4 Modify sidewalk standards

Many conventional subdivision codes require paved sidewalks on both sides of the street in widths that range from 4 to 6 feet. Communities that want to reduce impervious cover and increase the use of pervious areas for runoff treatment should consider the following (always considering public safety first):

- Allowing sidewalks on only one side of the street or building them only where there is pedestrian demand;

- Increasing the distance between sidewalks and the street so sidewalk runoff has a better chance of infiltrating into the grass border area and not becoming street runoff. This will provide water quality as well as safety benefits;

- Grading sidewalks so that runoff drains into the yard rather than toward the street;

- Reducing the width of very wide sidewalks. Communities should consider the implications of reducing sidewalk widths, including pedestrian demand and wheelchair access, on a case-by-case basis. Three feet will typically allow passage for one wheelchair. Sidewalks in highly commercial areas and government centers should accommodate two wheelchairs abreast, but it may be appropriate for some residential areas to reduce sidewalk width to three feet.

- Maintain sidewalk widths but use porous pavement (see Management Measure 5).

4.3.2.5 Modify driveway standards

In a sense, driveways are small-scale parking lots that are designed to accommodate two to four cars. Typical residential driveways and parking pads often total 400 to 800 square feet. Communities that want to reduce driveway impervious cover should consider:

- Shortening driveway length by shortening front yard setback requirements;
- Narrowing driveway widths;
- Encouraging the use of driveways that are shared by two or more homes; and
- Providing incentives for use of alternative driveway surfaces that allow for infiltration, such as porous pavers, gravel, or a two-track surface with grass in between.

4.3.3 Residential Street and Right-of-Way Impervious Surfaces

The largest percentage of impervious cover in residential neighborhoods is typically associated with the streets, driveways, and sidewalks that together aid in the transport of people to and from their various destinations. Management practices associated with residential streets and their rights-of-way typically are focused on minimizing impervious cover or treating runoff. In general, these objectives can be achieved by developing, updating, or revising codes, ordinances, and standards that determine the size, shape, and construction of residential streets and their rights-of-way.

4.3.3.1 Decrease street pavement width and length

Streets typically make up the largest percentage of transport system impervious cover in residential neighborhoods. Communities can significantly reduce this type of cover in new developments by revising street standards so that street pavement widths are based on traffic volume, on-street parking needs, and other variables rather than requiring all streets to have one universal width. Additionally, communities can encourage developers to design street networks that minimize the total length of pavement. The length of residential streets can be reduced by altering the design and placement of new development. Techniques include:

- Reducing frontage distances and side yard setbacks;
- Allowing narrower lots;
- Clustering smaller lots;
- Reducing the number of non-frontage roads; and
- Eliminating long streets that serve only a small number of homes.

4.3.3.2 Decrease street right-of-way width

A street right-of-way is a public easement corridor through which people, vehicles, runoff, utility services, and other items and materials move in, out, and around the development. A right-of-way usually includes the street itself, its gutters and curbs, and some amount of land on either side of the street, which might contain sidewalks, utility easements, or other components. Options for minimizing right-of-way widths include:

- Eliminating some right-of-way components;
- Placing sidewalks on only one side of the street;
- Running utility pipes, cables, and other infrastructure underneath street pavement (this can result in traffic congestion from road construction if the infrastructure needs to be repaired or replaced); or
- Reducing street and sidewalk widths where appropriate.

On-street parking is a variable that should be closely examined in communities where reducing impervious cover is a goal. Some communities have implemented a concept known as "queuing streets." Queuing streets generally have one travel lane and one or two parking lanes. Cars wait between parked cars until approaching traffic passes before proceeding to the travel lane. This approach also helps slow traffic, which can improve safety.

Street width must provide for utility work (common utilities include water, sewer, gas, cable, phone, power, and fiber optics). If the street width is reduced, utilities can be installed together in a concrete trench with a removable top for maintenance access (Matsuno, 2003).

When considering these options, it is important to remember that public safety should not be compromised and traffic engineering principles must still be a significant design factor. In addition, areas with high potential for significant storm damage, earthquakes, or other catastrophes should take into consideration the appropriate right-of-way width to enable passage of emergency vehicles.

The Headwaters Project: A Sustainable Community

In 1998 the Department of Planning and Development in Surrey, British Columbia, initiated the Headwaters Project to develop a real example of a sustainable community. Part of this project is the *East Clayton Neighbourhood Concept Plan* (The Headwaters Project, 2000), a green infrastructure plan that is an integrated system of "green" streets and affordable housing sites. It has narrow streets that use one-third less blacktop than typical roadways. Storm water management is achieved through natural infiltration, which minimizes runoff and avoids downstream flooding events. Information about East Clayton and a copy of the concept plan are available at http://www.sustainable-communities.agsci.ubc.ca/projects/Headwaters/PDF/toc.pdf

4.3.3.3 Use alternative cul-de-sac designs

Cul-de-sacs (roads with one open and one closed end) are a popular design element in community road networks. The intent of cul-de-sacs is to provide more homebuyers with premium, "end-of-the-road" lots. The typical "bulb" found at the closed end of a cul-de-sac, however, represents a particularly large concentration of impervious cover. Communities can reduce the amount of impervious cover created by bulb-ending cul-de-sacs by

- Eliminating cul-de-sac streets altogether;
- Using alternative designs for turnarounds, such as a T-shaped turnaround or a looped road;
- Reducing the radius of the turnaround bulb; or
- Incorporating a pervious cover island in the center of the turnaround bulb that accepts runoff.

As with modifications of street right-of-way width, public safety should not be compromised and traffic engineering principles must still be a significant design factor for this practice. Existing fire codes may dictate cul-de-sac width. Figures 4.8 and 4.9 show five turnaround options at the end of a residential street and the amount of impervious cover created by each option (Schueler, 1995).

4.3.4 Parking Lot Impervious Surfaces

Parking lots are considered by some to be one of the most damaging land uses in the urban landscape (CWP, 2000). Not only are parking lots very efficient at concentrating and delivering a large amount of runoff to receiving waters, thus exacerbating erosion problems, but they also act as a repository for pollutants associated with automobiles, which include nutrients, trace metals, and hydrocarbons.

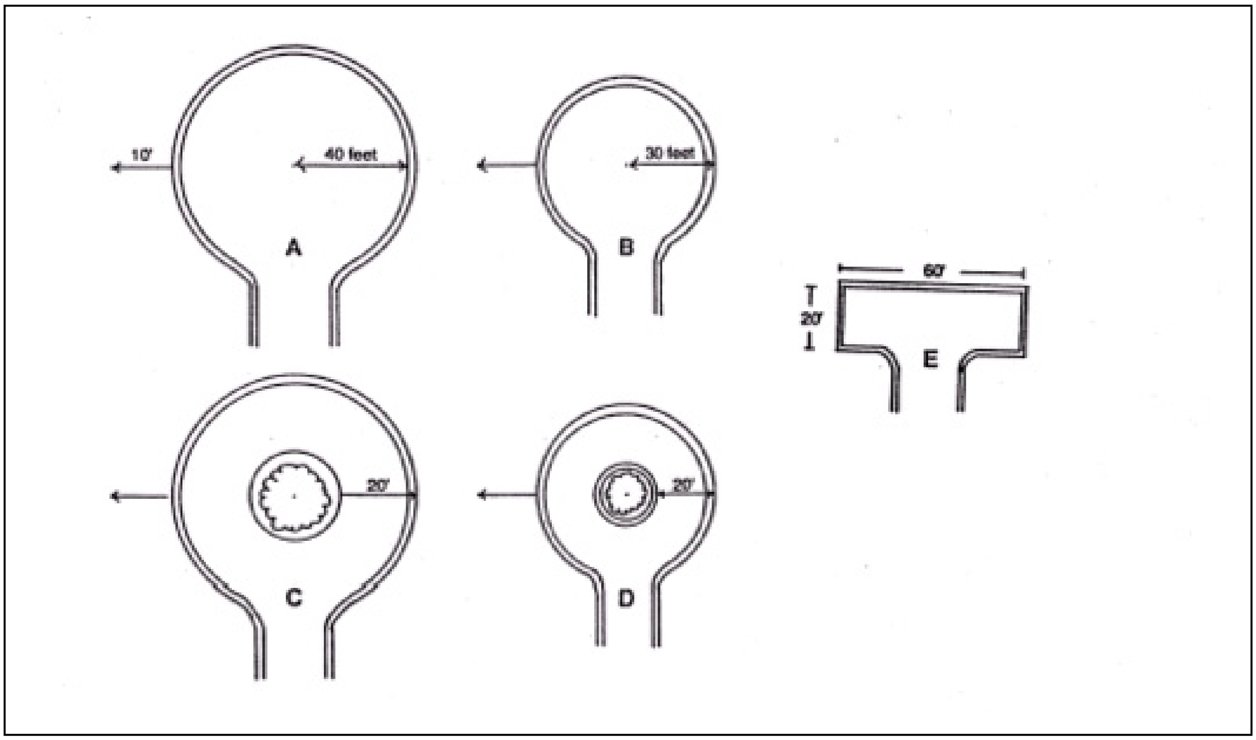


Figure 4.8: Five turnaround options at the end of a residential street (Schueler, 1995).

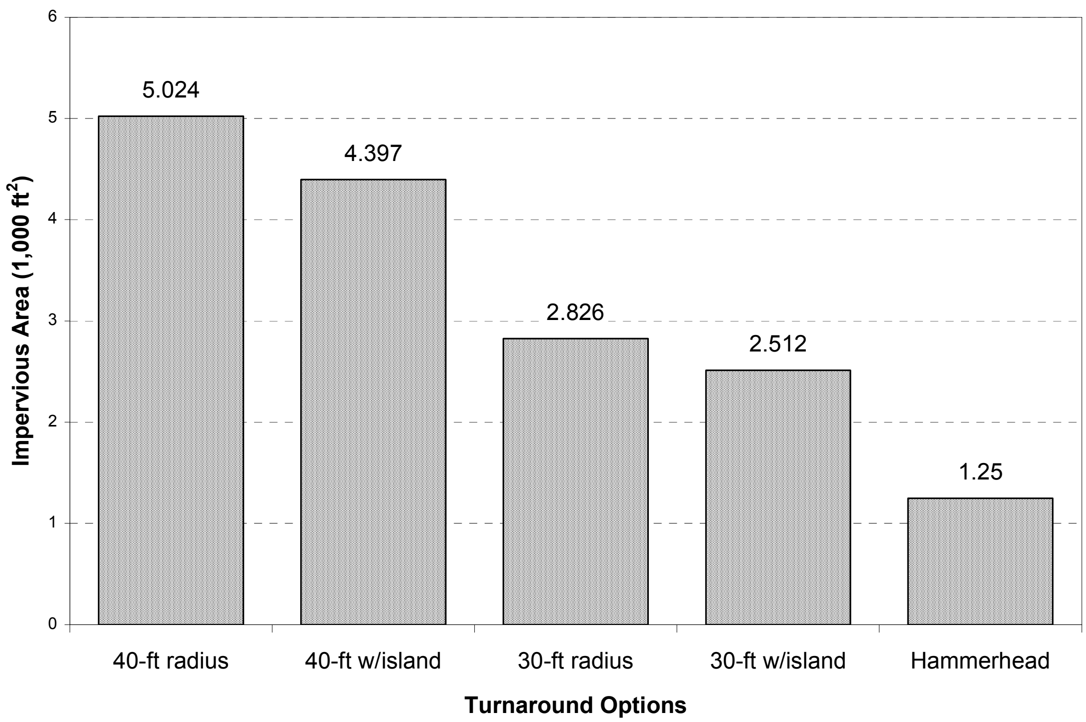


Figure 4.9: Impervious cover created by each turnaround option shown in Figure 4.8 (Schueler, 1995).

Innovative Turf Parking Lot Installation at a Connecticut Shopping Mall

The owners of Westfarms Mall, in the suburbs of Hartford, Connecticut, planned a 310,000-ft^2 expansion that required an additional 4 acres of overflow parking (Wilson et al., 1998). Local zoning boards and members of the community balked at this proposal because of the high ratio of impervious-to-pervious surfaces and concern for the quality and quantity of runoff generated by the new additions.

The traditional solution for handling the increased runoff was to install a large runoff detention pond, which would have cost $1million and was looked upon unfavorably by both the community and the mall owner. A 4-acre turf parking lot was implemented as an alternative and allows rainfall to infiltrate and recharge the ground water supply. To better support automobile traffic, the lot consists of a plastic honeycomb grid filled with sand and soil and laid atop a bed of crushed stone. Additionally, rooftop runoff is diverted to a tank located under the lot and the collected runoff is used to irrigate the turf. The turf would not hold up to everyday traffic, but overflow parking is needed only during the Christmas shopping season when the grass is dormant.

The cost of installing the turf lot was $500,000, which is half the cost of installing a pond. Even though the turf installation was more expensive than traditional pavement installation, the mall owner estimated that the installation would break even within 5 years because of lower maintenance requirements. An additional benefit of this innovative design was for the mall owner to gain the support of community members and local planning commissions.

Traditionally, developers have provided an overabundance of parking as a convenience for shoppers, workers, and landowners. A goal of watershed managers should be to reduce the surface area of parking lots and integrate runoff treatment practices to reduce adverse impacts, while still providing enough spaces to meet the expected parking demand. This reduction can be accomplished by implementing better site design practices, such as:

- Redesigning building and parking area layouts to reduce walking distances and provide more efficient layouts.

- Ensuring that the number of spaces built reflects actual demand. Site planners should design the lot size to correspond to minimum local parking requirements and consider ways in which this requirement can be reduced. For example, less parking is needed if access to public transportation is provided. Also, a parking area can be shared if localities in close proximity have different peak parking times. For instance, a retail establishment with peak demand during weekdays can share parking with a church whose peak demand is on the weekend.

- Sizing parking lot dimensions to meet everyday demand and designating additional “spillover” parking areas to handle peak demand. Because these spillover areas will receive less traffic, alternative paving techniques (see Management Measure 5) can be used to increase infiltration.

- Reducing the dimensions of the normal parking spaces if allowable. Also, developers can designate a percentage of the available parking spaces for use by compact cars and reduce their dimensions correspondingly.

- Building multilevel parking structures when feasible. (Parking structures can sometimes be impractical from a cost standpoint.) Green roofs can be used on these parking garages to reduce imperviousness.

- Converting parking lot islands to bioretention areas (see Management Measure 5).

- Building below-grade parking where it does not affect groundwater or other subsurface resources.

- Working with municipalities to regulate the maximum number of parking spaces allowed in development, rather than a minimum.

When parking area is reduced, functional landscaping can be used to improve the aesthetics of the site and to allow room for the installation of runoff treatment practices such as infiltration basins, filter strips, and dry swales or detention practices like those described in Management Measure 5.

4.3.5 Xeriscaping Techniques

Xeriscaping is a landscaping concept that maximizes water conservation by using site-appropriate plants and an efficient watering system. It involves the use of landscaping plants that need minimal watering, fertilization, and pesticide application, and practices that reduce water demand. For instance, mulching can help retain water and humidity and reduce the need for irrigation. Shading and windbreaks can reduce evaporation, particularly from young plants. In contrast to overhead sprinklers, drip irrigation waters plants directly on the roots without wetting plant leaves, helping to reduce evaporation and control disease. Timers are available that allow automatic watering with drip irrigation systems. Watering early in the morning can also reduce evaporation, and prevent the propagation of disease that often results from leaving foliage wet overnight (Relf, 1996). Xeriscaping can reduce the contribution of landscaped areas to nonpoint source pollution, and it can reduce landscape maintenance by as much as 50 percent, primarily as a result of the following (Clemson University Cooperative Extension Service, 1991):

- Reduction of water loss and soil erosion through careful planning, design, and implementation;
- Reduction of mowing by limiting lawn areas and using proper fertilization techniques; and
- Reduction of fertilization through soil preparation.

The specific benefits resulting from xeriscaping will vary based on the local climate and site conditions.

In 1991 the Florida legislature adopted a xeriscape law that requires state agencies to adopt and implement xeriscaping programs. The law requires that rules and guidelines be adopted for the implementation of xeriscaping along highway rights-of-way and on public property associated with publicly owned buildings constructed after July 1, 1992. Local governments are tasked with determining whether xeriscaping is a cost-effective measure for conserving water. If so, local governments are to work with the state water management districts in developing their xeriscape guidelines. Water management districts will provide financial incentives to local governments for developing xeriscape plans and ordinances. These plans must include:

- Landscape design, installation, and maintenance standards;
- Identification of prohibited plant species (invasive exotic plants);
- Identification of controlled plant species and conditions for their use;
- Specifications for maximum percentage of turf and impervious surfaces allowed in a xeriscaped area;
- Specifications for land clearing and requirements for the conservation of existing native vegetation; and
- Monitoring programs for ordinance implementation and compliance.

The law also includes a provision requiring local governments and water management districts to promote the use of xeriscape practices in existing developed areas through public education programs. California has passed a law requiring all municipalities to consider enacting water-efficient landscape requirements.

Water Conservation and Xeriscaping in Albuquerque, New Mexico

The City of Albuquerque, New Mexico, recently adopted a new strategy to encourage water conservation and to ensure a lasting water supply for years to come (Bennett, 1999). The strategy includes

- Reducing per capita water consumption by 30 percent.
- Developing facilities to treat and distribute city-owned surface water in combination with more limited use of the aquifer.
- Developing systems to use reclaimed wastewater and low-quality shallow ground water to irrigate landscaped areas in specific corridors of the community.
- Aggressive preservation of ground water quality.

The city also developed a new ordinance, the Water Conservation Landscaping and Water Waste Ordinance, that includes the following provisions:

- Prohibits irrigation water from flowing or spraying into streets, storm drains, or adjoining property.
- Limits high-water-use turf to 20 percent of the total landscape for all new developments.
- Establishes design requirements to discourage turf on steep slopes or adjacent to streets.
- Establishes water budget goals for parks and golf courses.
- Requires that new sprinkler systems on large turf areas meet minimum uniformity standards.
- Requires spray irrigation to occur between 6:00 p.m. and 10:00 a.m. from April to September.

The full text of the ordinance can be found at *www.cabq.gov/resources*.

As a result of these changes in Albuquerque's water conservation policy, the city's water consumption has decreased by 24 percent and its irrigation professionals have experienced a substantial increase in business as landowners seek smarter solutions to irrigation problems. Improvements in irrigation technology and increased public awareness are likely to further decrease water consumption.

4.4 Information Resources

In 1991 the Center for Watershed Protection published the *Consensus Agreement on Model Development Principles to Protect Our Streams, Lakes, and Wetlands*, which outlines the series of 22 nationally endorsed principles developed by the Site Planning Roundtable, a national cross-section of diverse planning, environmental, homebuilder, fire, safety, public works, and local government personnel, and details the basic rationale for their implementation. The *Consensus Agreement* can be purchased at http://www.cwp.org/.

The Center for Watershed Protection also published *Better Site Design: A Handbook for Changing Development Rules in Your Community* in 1998. This document outlines 22 guidelines for better developments and provides a detailed rationale for each principle. *Better Site Design* also examines current practices in local communities, details the economic and environmental benefits of better site designs, and presents case studies from across the country. It can be purchased at http://www.cwp.org/.

Wildlife Reserves and Corridors in the Urban Environment: A Guide to Ecological Landscape Planning and Resource Conservation, by Lowell Adams and Louise Dove (1989) reviews the knowledge base regarding wildlife habitat reserves and corridors in urban and urbanizing areas, and it provides guidelines and approaches to ecological landscape planning and wildlife conservation in such areas. It can be purchased from the Urban Wildlife Resources Bookstore at http://users.erols.com/urbanwildlife/bookstor.htm.

In 1997 Randall Arendt of the Natural Lands Trust, Inc., published *Growing Greener: Putting Conservation into Local Codes*. *Growing Greener* is a statewide community planning initiative designed to help communities use the development regulation process to their advantage to protect interconnected networks of greenways and permanent open space. The booklet can be downloaded in PDF format at http://www.dcnr.state.pa.us/growinggreener/growing.pdf.

The Low Impact Development Center was established to develop and provide information to individuals and organizations dedicated to protecting the environment and our water resources through proper site design techniques that replicate preexisting hydrologic site conditions. More information about this organization can be found on the Low Impact Development Center Web site at http://www.lowimpactdevelopment.org/ or by contacting the Center at 301-345-0440.

The Prince George's County, Maryland, Department of Environmental Resources produced two documents, *Low-Impact Development Design Strategies: An Integrated Design Approach* (EPA-841-B-00-003) and *Low-Impact Development Hydrologic Analysis* (EPA-841-B-00-002), that discuss site planning, hydrology, distributed integrated management practice technologies, erosion and sediment control, and public outreach techniques that can reduce storm water runoff from new and existing developments. Both publications can be ordered free of charge through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

Residential Streets, prepared by the American Society of Civil Engineers, the National Association of Home Builders, and the Urban Land Institute (1990), discusses design considerations for residential streets based on their function and their place in the neighborhood.

The publication presents guidance on street widths, speeds, pavement types, streetscapes, rights-of-way, intersections, and drainage systems.

The Institute of Transportation Engineers (ITE) published *Traditional Neighborhood Development—Street Design Guidelines* (1997), in which traditional neighborhood designs that support pedestrian movement over automobile traffic are discussed, and design concepts such as on-street parking, street width, and sight distances are presented. The publication also includes a practical discussion of the time needed for community acceptance and travel behavior changes. ITE also published *Guidelines for Residential Subdivision Street Design* (1993), which presents a discussion of the overall design of a residential subdivision with respect to the adequacy of vehicular and pedestrian access, minimizing excessive vehicular travel, and reducing reliance on extensive traffic regulations. It also provides design considerations for local and collector streets and intersections, including such topics as terrain classifications, rights-of-way, pavements, curb types, and cul-de-sacs. These publications are available through the Institute of Transportation Engineers, 525 School Street, SW, Suite 410, Washington, DC 20024-2797, (202) 863-5486.

Street Design Guidelines for Healthy Neighborhoods is a guidebook intended to help communities implement designs for streets that are safe, efficient, and aesthetically pleasing. This publication can be purchased from the Local Government Commission's Center for Liveable Communities Web site at http://www2.lgc.org/bookstore/topic.cfm?topicId=11.

The Congress for the New Urbanism has compiled a database of jurisdictions across the country that have adopted reduced-width street standards (Cohen, 2000). The database also includes resources related to neighborhood design and transportation. The database can be viewed at http://www.sonic.net/abcaia/narrow.htm.

EPA has compiled a number of resources on its *Low Impact Development (LID)* Web page, with links to Web sites, a literature review, fact sheets, and technical guidance. The Web site is accessible at http://www.epa.gov/owow/nps/lid/.

The Local Government Commission has published a guidebook to assist local communities in overcoming regulatory obstacles to smart growth. *Smart Growth Zoning Codes: A Resource Guide* helps planners design zoning codes that encourage the construction of walkable, mixed-use neighborhoods. The guidebook comes with a CD-ROM containing examples of the best U.S. zoning codes and other resources. The book can be purchased for $25 from http://www2.lgc.org/bookstore/topic.cfm?topicId=1.

Dunnett and Kingsbury (2004) describe examples of both large-scale and residential applications of green roofs and living walls and include technical information about constructing these structures in *Planting Green Roofs and Living Walls.* The authors cover structural engineering concerns as well as factors such as plant selection and environmental considerations that are important for the success of green roofs and living walls. The book is available for purchase at the Timber Press Web site at http://www.timberpress.com.

4.5 References

Adams, L.W. 1999. Metropolitan greenways for recreation. *The Urban Open Space Manager* 4(4): 1.

American Society of Civil Engineers, National Association of Home Builders, and Urban Land Institute. 1990. *Residential Streets*. American Society of Civil Engineers, Reston, VA; National Association of Home Builders, Washington, DC; and Urban Land Institute, Washington, DC.

Anacostia Restoration Team. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone*. Anacostia Restoration Team, Department of Environmental Programs, Metropolitan Council of Governments, Washington, DC.

Arendt, R. 1996. *Conservation Design for Subdivisions: A Practical Guide to Creating Open Space Networks*. Island Press, Washington, DC.

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

Bay Area Stormwater Management Agencies Association (BASMAA). No date. *Web & Flow*. http://www.basmaa.org/. Accessed June 21, 2000.

Bennett, D. 1999. Albuquerque reduces water consumption by 24 percent. *Irrigation Business and Technology* 7(6): 22–28.

Buckeye Development LLC. No date. *Pembroke Woods Low Impact Development (LID) Residential Subdivision, Emmittsburg, MD*. http://www.buckeyedevelopment.net/lowimpactdevelopment.htm. Accessed September 10, 2003.

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

Center for Watershed Protection (CWP). 2000. The benefits of better site design in commercial development. *Watershed Protection Techniques* 3(2): 647–656.

Cheng, M., L.S. Coffman, Y. Zhang, and Z.J. Licsko. No date. *Comparison of Hydrological Responses from Low Impact Development with Conventional Development*. Prince George’s County Department of Environmental Resources, Largo, MD.

Clemson University Cooperative Extension Service. 1991. *Xeriscape: Landscape Water Conservation in the Southeast*. Clemson University, Clemson, SC.

Cohen, A.B. 2000. *Narrow Streets Database: A Congress for the New Urbanism Transportation Task Force Initiative*. http://www.sonic.net/abcaia/narrow.htm. Last updated June 2000. Accessed May 10, 2001.

Copeland, L. 2002. "Ecoroof" lures urbanites, planners back to garden. *USA Today*. December 13, 2002. http://www.usatoday.com/news/nation/2002-12-03-roofs-usat_x.htm. Accessed June 27, 2003.

Cote, M., J. Clausen, B. Morton, P. Stacey, and S. Zaremba. 2000. Jordan Cove Urban Watershed National Monitoring Project. In *National Conference on Tools for Urban Water Resource Management and Protection*, February 7–10, 2000, Chicago, IL. EPA-625-R-00-001. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, pp. 1–14.

Delaware DNREC and the Brandywine Conservancy. 1997. *Conservation Design for Stormwater Management: A Design Approach to Reduce Stormwater Impacts from Land Development and Achieve Multiple Objectives Related to Land Use*. Delaware Department of Natural Resources and Environmental Control, Dover, DE, and the Environmental Management Center of the Brandywine Conservancy, Chadds Ford, PA.

Dunnett, N., and N. Kingsbury. 2004. *Planting Green Roofs and Living Walls*. Timber Press, Portland, OR.

Goldman, S.J., K. Jackson, and T.A. Borstztynksy. 1986. *Erosion and Sediment Control Handbook*. McGraw-Hill, Inc., New York, NY.

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

Institute for Transportation Engineers. 1997. *Traditional Neighborhood Development—Street Design Guidelines.* Institute for Transportation Engineers, Washington, DC.

Kiesling, M. 1999. Pedestrian paths. *Progress* 9(3): 10–11.

Laquatra, J., and G.L. Potter. 2000. Building a balance: Housing affordability and environmental protection in the USA. *Electronic Green Journal.* http://egj.lib.uidaho.edu/egj12/laquatra1.html. Last updated April 22, 2000. Accessed June26, 2001.

Lehner, P., G. P. Aponte Clark, D.M.Cameron and A.G. Frank. 1999. *Stormwater Strategies: Community Responses to Runoff Pollution*. Natural Resources Defense Council, Washington, DC.

Matsuno, R. 2003. *Comments on the Draft National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. King County Department of Transportation. King County, WA.

Miller, C. 1998. Vegetated roof covers: A new method for controlling runoff in urbanized areas. In *Proceedings of the 1998 Stormwater Management Symposium*, Villanova University, Philadelphia, PA.

Moran, A., B. Hunt, and G. Jennings. 2004. *A North Carolina Field Study to Evaluate Greenroof Runoff Quantity, Runoff Quality, and Plant Growth*. http://www.bae.ncsu.edu/greenroofs/GRHC2004paper.pdf. Accessed March 19, 2005.

National Association of Home Builders (NAHB). 2003. *Smart Growth Case Study: Abraham's Landing*. http://www.nahb.org/generic.aspx?genericContentID=508. Accessed June 27, 2003.

Natural Carpets. 1998. Natural carpets protect roof and soil. *Erosion Control* November/December: 25–26.

Phillips, R.A., J.C. Clausen, M.E. Dietz, J.J. Engdahl, J. Alexopoulos, M.P. Cote, S. Zaremba, and B.L. Morton. 2000. Effectiveness of Construction BMPs on Water Quality in a Low-Impact Subdivision. In *8th National Nonpoint Source Monitoring Workshop Field Trip*, September 10–14, 2000, Hartford, CT.

Pitt, R. 1986. Runoff controls in Wisconsin's priority watersheds. In *Urban Runoff Quality: Proceedings of an Engineering Foundation Conference*, June 23–27, 1986, Henniker, NH. American Society of Civil Engineers, Reston, VA, pp. 290–313.

Prince George's County, Maryland, Department of Environmental Resources. 2000a. *Low-Impact Development Design Strategies: An Integrated Design Approach.* Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, Largo, MD.

Prince George's County. 2000b. *Low-Impact Development Hydrologic Analysis*. Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, Largo, MD.

Relf, D. 1996. *Irrigating the Home Garden*. Virginia Cooperative Extension. http://www.ext.vt.edu/pubs/envirohort/426-322/426-322.html. Accessed June 12, 2003.

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

Shapiro, N. 2003. *The Stranger Among Us: Urban Runoff, the Forgotten Local Water Resource.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

Sutherland, R.C. 1995. Methodology for Estimating the Effective Impervious Area of Urban Watersheds. Technical Note 58. *Watershed Protection Techniques* 2(1): 282–283.

Toolbase Services. No date. Low Impact Development (LID) Practices for Storm Water Management. http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1325&DocumentID=2007. Accessed March 23, 2005.

U.S. Environmental Protection Agency (USEPA). 1996. *Protecting Natural Wetlands: A Guide to Stormwater Best Management Practices.* EPA-843-B-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://www.epa.gov/owow/wetlands/pdf/protecti.pdf. Accessed June 27, 2003.

U.S. Environmental Protection Agency (USEPA). 1999. *Street Storage System for Control of Combined Sewer Surcharge: Retrofitting Stormwater Storage into Combined Sewer Systems.* EPA-600-R-00-065. U.S. Environmental Protection Agency, Office of Research and Development, Urban Watershed Management Branch, Cincinnati, OH. http://www.epa.gov/ednnrmrl/publications/reports/epa600r00065/epa600r00065.htm.

U.S. Environmental Protection Agency (USEPA). 2000. *Vegetated Roof Cover*. EPA-841-B-00-005D. http://www.epa.gov/owow/nps/roofcover.pdf. Accessed September 19, 2005.

Wilson, A., J.L. Uncapher, L. McManigal, L.H. Lovins, M. Cureton, and W.D. Browning. 1998. *Green Development: Integrating Ecology and Real Estate*. Rocky Mountain Institute, Snowmass, CO, p. 144.

Zickler, L. 2002, July 25. Managing stormwater in Pierce County: Kensington Estates case study sheds light on low impact development. *Seattle Daily Journal.* http://www.djc.com/news/en/11135654.html. Last updated July 25, 2002. Accessed April 14, 2004.

Zielinski, J., D. Caraco, and R. Claytor. 2000. Comparative nutrient export and economic benefits of conventional and better site design techniques. In *National Conference on Tools for Urban Water Resource Management and Protection*, February 7–10, 2000, Chicago, IL. EPA-625-R-00-001. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, pp. 280–289.

MANAGEMENT MEASURE 5
NEW DEVELOPMENT RUNOFF TREATMENT

5.1 Management Measure

By design or performance (a) reduce the postdevelopment loadings of total suspended solids (TSS) so that the average annual TSS loadings[a] are no greater than the predevelopment loadings, or (b) reduce the average annual TSS loadings by a minimum of 80 percent of the influent concentration of TSS[b].

Maintain the postdevelopment average volume and peak runoff rates at levels that are similar to predevelopment[c] levels or, through planning and/or design, control offsite discharges of runoff to prevent erosive impacts to downstream channels or shorelines.

Maintain discharge temperatures in runoff at levels similar to predevelopment levels or at levels that will protect aquatic communities from the thermal impacts of runoff.

---

[a] In general, calculations of average annual TSS loadings will be based on TSS loadings from all storms below or equal to a predetermined maximum storm size. The most commonly used upper threshold that states use to calculate annual average TSS loadings is the 2-year, 24-hour storm. However, some states have recently reevaluated the benefits of controlling the 2-year versus the 1-year, 24-hour storm and, as a result, have adopted standards that require the control of all storms less than or equal to the 1-year, 24-hour storm.

EPA interprets predevelopment conditions to mean those conditions that exist prior to the current land use. In situations where the previous land use has resulted in unacceptable erosion and significant sediment movement offsite, a baseline reference condition can be used (e.g., the typical TSS loading rates from forested sites or meadows in the area). Average annual TSS loading calculations also should be based on the TSS discharge concentrations that occur after the site has been permanently stabilized.

[b] It is anticipated that the total TSS reductions will be calculated based on all reductions achieved through a system of structural and nonstructural management practices. The intent of this guidance is to promote the implementation of runoff management programs that protect receiving waters from increases of suspended solids that may, on an individual or cumulative basis, threaten or impair surface waters. Management practices and systems of practices should be selected based on achievement of water quality standards throughout the receiving watershed. TSS loading reduction goals therefore should be determined by assessing the capacity of the receiving water body to assimilate TSS from all contributing sources. EPA acknowledges that, in some jurisdictions, reducing 80 percent of the influent TSS concentration is not reasonable due to the presence of significant concentrations of colloidal particles. EPA also understands that treatment of these particles in many cases is not necessary to protect receiving waters and meet state or local water quality standards. In such cases, design or performance requirements should protect receiving waters from impairment from TSS loadings above the ambient TSS in receiving waters that are not due to anthropogenic sources.

[c] As with the TSS element of the measure, term *predevelopment* refers to runoff rates and volumes that exist on-site immediately before the planned land disturbance and development activities occur. Predevelopment is not intended to be interpreted as that period before any human-induced land disturbance activity has occurred. Watershed managers need to determine an appropriate reference or management condition as an objective to achieve. Also, for the purposes of this element of the management measure, the term *similar* is defined as “resembling though not completely identical.”

5.2 Management Measure Description and Selection

5.2.1 Description

During the development process, both the existing landscape and hydrology are altered. As development occurs, the following changes are likely to occur:

- Soil porosity decreases due to removal of vegetation and compaction of topsoil by construction equipment;
- Impermeable surfaces (paving and rooftops) increase (see Introduction);
- Artificial conveyances such as pipes and concrete channels are constructed;
- Slope angles become less acute;
- Vegetative cover decreases; and
- Surface roughness decreases.

These changes result in increased runoff volume and velocity, which may lead to accelerated erosion of streambanks, steep slopes, and unvegetated areas (Novotny, 1991). The grading of urbanized areas can increase the downward slope to a water body and destroy riparian buffer zones, or developers may level a site to facilitate construction activities. Destruction of in-stream and riparian habitat, increases in water temperature, streambed scouring, and downstream sedimentation of streambed substrates, riparian areas, and estuarine habitats may occur.

Everyday activities that occur after development may cause the discharge of pollutants in runoff that can have harmful effects on waters and habitat. Pollutants related to vehicle petroleum and coolant leaks and overflows, tire and brake wear, pet waste, pesticides, and fertilizers can be carried into estuaries, streams, rivers, and lakes through runoff. Soils and sediment can constitute a significant fraction of the solids on urban surfaces. Weather related erosion and transport of eroded soil (e.g., by wind and rain) increases solids in urban areas. Other sources of solids on urban surfaces are wear of automotive parts (brake pads, tires), combustion products from diesel- and gasoline-fueled engines, fireplaces, construction sites, and industrial facilities. An extensive discussion of these pollutants is presented in Chapter 1.

The goals of the new development runoff treatment management measure are to:

- Retain the predevelopment or pre-disturbance hydrological conditions of both surface and ground water;
- Remove suspended solids and associated pollutants entrained in runoff that result from activities occurring during and after development;
- Decrease the erosive potential of increased runoff volumes and velocities associated with development-induced changes in hydrology;

- Preserve natural systems, including in-stream habitat, riparian areas, and wetlands; and
- Reduce the thermal impacts that result from impervious surfaces and treatment devices with large amounts of surface exposed to sunlight such as wet ponds.

Several issues require clarification to fully understand the scope and intent of this management measure. The watershed protection (3), site development (4), and new development runoff treatment (5) management measures are intended to be used together within a comprehensive framework to reduce nonpoint source pollution. Applied on-site and throughout watersheds, these three management measures can be used together to provide increased watershed protection and help prevent erosion, flooding, and increased pollutant loads generally associated with poorly planned development. Implementation of the watershed protection and site development management measures can help achieve the goals of the new development runoff treatment management measure.

5.2.1.1 Pollutants and total suspended solids

Many pollutants bind to and are entrained in sediment or particulate loadings. Particulates include suspended, settleable, and bedload solids. Metals, phosphorus, nitrogen, hydrocarbons, and pesticides are commonly found in urban sediments. The correlation between total suspended solids (TSS) and specific pollutants may vary (URS Greiner Woodward Clyde, 1999).

TSS is a measure of the concentrations of sediment and other solid particles suspended in the water column of a stream, lake, or other water resource. TSS is an important parameter because it quantifies the amount of sediment entrained in runoff. This information can be used to link sources of sediments to the resulting sedimentation in a stream, lake, wetland, or other water resources. As shown previously, TSS is also an indirect measure of other pollutants carried by runoff, because nutrients (phosphorus), metals, and organic compounds are typically attached to sediment particles. For these reasons TSS was selected as the prime or sole parameter associated with the first element of this management measure.

Sansalone and Buchberger (1997) found that the relative proportional mass of heavy metals (Zn, Cu, Pb) in highway runoff and snowbank samples increased with decreasing particle size. This effect was attributed to the increase in surface area binding sites that were present with smaller particles. In another study, Sansalone et al. (1998) observed that the greatest mass of contaminants in highway runoff is found on particles in the 425 to 850 micron (μm) range. Because average particle size varies across the U.S., it makes sense to address the particle size that most effectively captures the highest percentage of associated pollutants.

The quantity and size range of the suspended particles measured and reported as TSS at any given time depends on many factors including:

- The composition and extent of the sources of suspended solids in the watershed;
- The magnitude and duration of storms or dry weather periods preceding the sampling;

- Flow velocity, turbulence, and other conditions that promote the suspension of solids in the water column; and
- The sampling techniques employed.

Generally, individual particles found in a TSS sample are 62 µm (0.062 µm) or less in diameter and classified as either silts or clays (Table 5.1). Solids greater than 62 µm can also be found in the water column if conditions are turbulent enough to keep them in suspension.

Table 5.1: Sediment particle size distribution (shaded classes are found in a typical urban TSS sample).

General Class	Class Name	Diameter (µm)
Sand	Very coarse sand	2000–1000
	Coarse sand	1000–500
	Medium sand	500–250
	Fine sand	250–125
	Very fine sand	125–62
Silt	Coarse silt	62–31
	Medium silt	31–16
	Fine silt	16–8
	Very fine silt	8–4
Clay	Coarse clay	4–2
	Medium clay	2–1
	Fine clay	1–0.5
	Very fine clay	0.5–0.24
	Colloids	< 0.24

Erosion and entrainment of solids in runoff occur primarily during rainfall. Rainfall varies in magnitude through time, with large rainstorms occurring less frequently than small showers. Collectively, all the rainfall occurring during the year contributes to the annual sediment yield from a site. In order to focus on typical annual yields, however, the management measure states that yield calculations are to be based on the average annual TSS loadings from all storms less than or equal to the two-year, 24-hour storm. Setting this threshold eliminates the need to calculate or integrate the impacts of larger infrequent storms into the average annual sediment yield calculation.

The annual TSS loadings can be calculated by adding the TSS loadings that can be expected during an average one-year period from precipitation events less than or equal to the two-year, 24-hour storm. Removal of 80 percent of TSS can be achieved by reducing, over the course of the year, 80 percent of these loadings.

Critics of the TSS standard suggest that the sampling and analysis protocols employed for this measure do not fully capture the entire range of particle sizes found in some kind of samples. More specifically, TSS protocols tend to under-sample larger solids and therefore yield lower-than-actual values for management practice pollutant removal efficiency. However, under-sampling the larger particles that would easily settle out in a runoff treatment control results in higher overall removal rates of solids and fewer solids discharged to surface waters.

There are alternatives to the TSS method, including turbidity and suspended sediment concentration (SSC). Monitoring turbidity in urban runoff is advantageous because the measurements can be conducted in situ using continuous methods (e.g., Secchi disk). It should be noted, however, that using turbidity as a surrogate for TSS may be appropriate only in instances where a strong statistical correlation has been established, such as in low-energy environments like lakes and estuaries. This correlation should be established on a case-by-case basis if turbidity is to be used as a surrogate.

The SSC method is used by the U.S. Geological Survey (USGS) as the standard for determining concentrations of suspended material in surface water samples (USGS, 2000). Gray et al. (2000) examined the comparability of SSC and TSS measurements. SSC and TSS are the predominant analytical methods used to quantify concentrations of solid-phase material in surface waters. SSC values are obtained by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture. TSS data are produced by several methods, most of which involve measuring the dry weight of sediment from a known volume of a subsample of the original. Analysis of paired SSC and TSS data showed bias in the relationship between SSC and TSS. In samples where sand-size material was greater than nearly a quarter of the dry sediment mass, SSC values tended to be higher than corresponding paired TSS values.

According to Gray, the SSC method produces relatively reliable results for natural water samples, regardless of the amount or percentage of sand-size material in the samples. SSC and TSS are not comparable and should not be used interchangeably. Rather, the authors suggest using the SSC analytical method to enhance the accuracy and comparability of suspended solid-phase concentrations of natural waters (Gray et al., 2000). More information about the SSC analytical method can be found at http://www.astm.org/ by searching for standard number ASTM D 3977-97, *Standard Test Method for Determining Sediment Concentration in Water Samples* (ASTM International, 2002).

5.2.1.2 Runoff

Runoff management programs have traditionally focused on reducing or preventing induced flooding from new development. Performance standards were typically developed to control large storms, e.g., 50- or 100-year storms. Although the control of these large storms is still essential, it has become apparent in the last 20 years that a broad range of storms must be managed to prevent streambed and streambank erosion. Recent research points to the need to control total discharge volumes and rates so that they do not result in stream channel degradation. As a result, some states and local governments have developed performance requirements that are intended to prevent stream channel erosion as well as flooding of downstream properties.

This management measure was written to address the control of both peak runoff rates and average runoff volumes with the intent to maintain postdevelopment runoff characteristics at predevelopment levels. Even though EPA recommends that structural runoff controls be designed to control all storms less than or equal to the two-year, 24 hour storm, state and local governments should determine the locally appropriate storm size threshold to control based on local hydraulics, hydrology, meteorology and other regional and local factors. Watershed managers also should consider the development and implementation of volume and peak discharge performance standards to address problems associated with the frequency and duration of erosive flows (MacRae and Rowney, no date). The use of low-impact development (LID) techniques may be one way to achieve these goals (Prince Georges' County, Maryland, Department of Environmental Resources, 2000a, 2000b).

5.2.2 Management Measure Selection

This management measure was selected because of the following factors:

- Removal of 80 percent of TSS is assumed to control heavy metals, phosphorus, and other pollutants.

- Several states and local governments have implemented a TSS removal treatment standard of at least 80 percent. Table 5.2 presents TSS reduction standards and design criteria for select state and local runoff management programs.

- Analysis has shown that constructed wetlands, wet ponds, and infiltration basins can remove 80 percent of TSS, provided they are designed and maintained properly. Other practices or combinations of practices can also be used to achieve the goal.

- A number of flood control practices can control postdevelopment volume and peak runoff rates and maintain predevelopment hydrological conditions, which will reduce or prevent streambank erosion and stream scouring. Table 5.3 presents peak discharge and volume standards and design criteria for select local runoff management programs.

- Urban streams often experience elevated temperatures due to an increase in impervious areas and a decrease in vegetative cover that would normally provide shading for wetlands and stream channels. Many of the practices presented in this management measure and throughout this guidance, such as infiltration practices, riparian buffers, and urban forestry, help to lower stream temperatures. Practices such as retention ponds may contribute to temperature elevation and should not be used in areas with temperature-sensitive fish or macroinvertebrates unless the other measures are taken to counteract this effect (i.e., plant vegetation to shade ponds, wetlands, or channels).

Table 5.2: Select local and state programs with TSS performance standards (adapted from Watershed Management Institute [WMI], 1997a).

Community/State	Standard	Criteria
Olympia, WA	80 percent removal of suspended solids.	Treat runoff volume of six-month, 24 hr storm
Orlando, FL	Reduce average annual TSS loading by 80 percent.	Treat first half-inch of runoff or the runoff from the first inch of rainfall, whichever is greater.
Winter Park, FL	Reduce average annual TSS loading by 80 percent.	Treat the first inch of runoff by retention.
Baltimore Co., MD	Remove at least 80 percent of the average annual TSS loading.	Treat the first half-inch of runoff from the site's impervious area.
South Florida Water Management District	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 1.0 to 2.5 inches times percent impervious area.

Table 5.2 (continued).

Community/State	Standard	Criteria
Delaware	Remove at least 80 percent of the annual TSS loading.	Treat the first inch of runoff by approved management practices.
Florida	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 0.5 to 1.5 inches depending on the practice.
New Jersey	80 percent reduction in TSS.	Treat runoff volume of a storm of >1.25inches in two hours or the one-yr, 24-hr storm.
South Carolina	Remove at least 80 percent of the average annual TSS loading.	Treatment volume varies from 0.5 to 1.0 inch depending on the practice.

Table 5.3: Select local programs with peak discharge and/or runoff volume performance standards (adapted from WMI, 1997a).

Community/State	Peak discharge	Volume
Alexandria, VA	Postdevelopment rate cannot exceed predevelopment rate for two-yr and 10-yr, two-hr storm.	None
Austin, TX	Postdevelopment rate cannot exceed predevelopment rate for two-, 10-, 25-, and 100-yr, 24-hr storm.	None
Bellevue, WA	Postdevelopment rate cannot exceed predevelopment rate for two- and 10-yr, two-hr storm.	Multiple release rates for detention systems.
Olympia, WA	Postdevelopment rate cannot exceed predevelopment rate for two-yr and 100-yr, 24-hr storm.	Must infiltrate all of the 100-yr vol. on-site if percolation rate greater than 6 inches per hr.
Orlando, FL	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	In closed basins, retain runoff from 100-yr, 24-hr storm.
Washington, DC	Postdevelopment rate cannot exceed predevelopment rate for two-, 10-, and 100-yr, 24-hr storm.	None
Clark Co., WA	Postdevelopment rate cannot exceed predevelopment rate for two-, 10- and 100-yr, 24-hr storm.	Post-development vol. cannot exceed predevelopment vol. for two-yr, 24-hr storm.
SW Florida Water Management District	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	Post-development vol. cannot exceed predevelopment vol. for 25-yr, 24-hr storm.

General Performance Standards for Storm Water Management in Maryland

To prevent adverse impacts from runoff, the Maryland Department of the Environment (MDE, 2000) developed 14 performance standards for development sites. These standards apply to any construction activity disturbing 5,000 or more square feet of land. The following standards are required at all sites where runoff management is necessary:

- Site designs shall minimize runoff generation and maximize pervious areas for runoff treatment.
- Runoff generated from development and discharged directly into a jurisdictional wetland or waters of the State of Maryland shall be adequately treated.
- Annual ground water recharge rates shall be maintained by promoting infiltration through the use of structural and nonstructural methods. At a minimum, the annual recharge from postdevelopment site conditions shall mimic the annual recharge from predevelopment site conditions.
- Water quality management shall be provided through the use of structural and nonstructural controls.
- Structural management practices for new development shall be designed to remove 80 percent and 40 percent of the average annual postdevelopment TSS and total phosphorus loads, respectively. It is presumed that a management practice complies with this performance standard if it is sized to capture the prescribed water quality volume, designed according to the specific performance criteria outlined in the Maryland Stormwater Design Manual (MDE, 2000), constructed properly, and maintained regularly.
- On the Eastern Shore, the postdevelopment peak discharge rate shall not exceed the predevelopment peak discharge rate for the 2-year frequency storm event. On the Western Shore, local authorities may require that the postdevelopment 10-year peak discharge not exceed the predevelopment peak discharge if the channel protection storage volume (Cp_v) is provided. In addition, safe conveyance of the 100-year storm event runoff control practices shall be provided.
- To protect stream channels from degradation, Cp_v shall be provided by 12 to 24 hours of extended detention storage for the 1-year storm event. Cp_v shall not be provided on the Eastern Shore unless the appropriate approval authority deems it necessary on a case-by-case basis.
- Runoff to critical areas with sensitive resources may be subject to additional performance criteria or may need to use or restrict certain management practices.
- All management practices shall have an enforceable operation and maintenance agreement to ensure the system functions as designed.
- Every management practice shall have an acceptable form of water quality pretreatment.
- Redevelopment, defined as any construction, alteration, or improvement exceeding 5,000 square feet of land disturbance on sites where existing land use is commercial, industrial, institutional, or multi-family residential, is governed by special sizing criteria depending on the increase or decrease in impervious area created by the redevelopment.
- Certain industrial sites are required to prepare and implement a storm water pollution prevention plan (SWPPP) and file a notice of intent (NOI) under the provisions of Maryland's Storm Water NPDES general permit. The SWPPP requirement applies to both existing and new industrial sites.
- Runoff from land uses or activities with higher potential for pollutant loadings, sometimes referred to as hotspots, may require the use of specific structural runoff control and pollution prevention practices. In addition, runoff from a hotspot land use may not be infiltrated without proper pretreatment.
- In Maryland, local governments are usually responsible for storm water management review authority. Prior to design, applicants should always consult with their local reviewing agency to determine if they are subject to additional storm water design requirements. In addition, certain earth disturbances may require NPDES construction general permit coverage from MDE.

Delaware Urban Runoff Management Model

The Delaware Department of Natural Resources and Environmental Conservation (2005) developed the Delaware Urban Runoff Management Model (DURMM) to quantitatively estimate how "green technology" management practice designs achieve pollutant removal and flow reductions. Green technology includes the following management practices:

- Conservation site design
- Source area disconnection
- Biofiltration swales/grassed swales
- Terraces
- Bioretention structures
- Infiltration practices

These green technologies address some of the drawbacks of traditional runoff controls, including the following:

- Ponds and wetlands do not necessarily protect against streambank erosion
- Ponds and wetlands do not recharge groundwater.
- Ponds and wetlands require substantial land area
- Ponds and wetlands require significant maintenance.
- Discharges from multiple structural practices can overlap, resulting in downstream flooding.
- Discharges can elevate stream temperatures and sometimes contain high levels of algae.

DURMM provides a quantitative approach to define the benefits of conservation design and quantifies runoff reductions and pollutant reductions from filter strips, biofiltration and grassed swales, terraces, bioretention structures, and infiltration trenches. It also quantifies runoff reductions from source area disconnection. The Delaware Department of Natural Resources and Environmental Conservation is also developing a companion document specifically focused on riparian buffer system design.

Additional information on green technology BMPs or DURMM can be obtained by contacting Delaware's Division of Soil & Water Conservation at 302-739-4411.

5.2.3 General Categories of Urban Runoff Control

Structural practices to control urban runoff rely on several basic mechanisms:

- Infiltration;
- Filtration;
- Detention/retention; and
- Evaporation.

5.2.3.1 Infiltration practices

Infiltration facilities are designed to capture a treatment volume of runoff and percolate it through surface soils into the ground water system. This process:

- Reduces the total volume of runoff discharged from the site, which, in turn, decreases peak flows in storm sewers and downstream waters;

- Filters out sediment and other pollutants by various chemical, physical, and biological processes as runoff water moves through the bottom of the infiltration structure and into the underlying soil; and

- Augments ground water reserves by facilitating aquifer recharge. Groundwater recharge is vital to maintain stream and wetland hydrology. During dry weather, ground water recharge helps to assure baseflow necessary for survival of biota in wetlands and streams.

Treatment effectiveness depends on whether the facility is sited on-line or off-line, and on the sizing criteria used to design the facilities. Online systems receive all of the runoff from an area. Off-line practices receive diverted runoff for treatment and isolate it from the remaining fraction of runoff, which must still be controlled to prevent flooding. Off-line infiltration practices prevent all of the TSS and other pollutants contained in the volume of runoff infiltrated from exiting the site. Thus, the total annual load reduction depends on how much of the annual volume of runoff is diverted to the infiltration structure. On-line infiltration practices, on the other hand, have lower treatment effectiveness, averaging approximately 75 percent removal of TSS (WMI, 1997b).

The overall hydrologic benefits of infiltration practices may also vary depending on site characteristics and the frequency and intensity of storms. Holman-Dodds et al. (2003) modeled the potential for infiltration techniques to reduce the adverse hydrologic effects of urbanization. The study indicated that the greatest reductions in flow are achievable when rainfall is limited and relatively frequent, and when soils are relatively porous.

Infiltration facilities require porous soils (i.e., sands and gravels) to function properly. Generally, they are not suitable in soils with 30 percent or greater clay content or 40 percent or greater silt/clay content (WMI, 1997b). They are also not suitable:

- In areas with high water tables;
- In areas with shallow depth to impermeable soil layers;
- On fill sites, which have low permeability, or on steep slopes;
- In areas where infiltration of runoff would likely contaminate ground water;
- In areas where there is a high risk of hazardous material spills; or

- Where additional groundwater could form sinkholes.

Special protection for ground water is needed when runoff is used as a drinking water source in urban areas (see Management Measure 3—Watershed Protection). Certain types of infiltration facilities, called Class V injection wells, may be regulated as part of the federal Underground Injection Control (UIC) Program, authorized by the Safe Drinking Water Act. Class V wells discharge fluids underground. Class V wells include French drains, tile drains, infiltration sumps, and percolation areas with vertical drainage. Dry wells, bored wells, and infiltration galleries are all Class V wells. Class V wells do not include infiltration trenches filled with stone (with no piping), or excavated ponds, lagoons, and ditches (lined or unlined, without piping or drain tile) with an open surface. Compliance with federal regulations may include submitting basic inventory information about the drainage wells to the state or EPA and complying with specific construction, operation, permitting, and closure requirements (USEPA, 2003). Any questions regarding the applicability of the UIC regulations to a storm water facility should be directed to federal or state UIC contacts. This information is available at http://www.epa.gov/safewater/uic.html.

The effect of infiltration practices on ground water quality is unclear, but a few studies exist that indicate potential ground water quality concerns from infiltrating urban runoff (Pitt, et al., 1994; Fischer, no date; Ging et al., 1997, Morrow, 1999). For example, Fischer (no date) studied the effects of infiltration of urban runoff on ground water quality in the New Jersey Coastal Plain. He found that although many pollutants were removed from runoff before reaching the water table, elevated concentrations and occurrences of certain compounds and ions indicated contributions from urban runoff, implying that infiltration practices could have a detrimental effect on ground water quality. Conversely, Fischer hypothesized that infiltrating runoff would have the beneficial effect of diluting other compounds frequently present in ground water.

Pitt et al. (1994) summarized the potential for 25 pollutants to contaminate ground water, categorizing each as low, low/moderate, moderate, or high. Of these 25 pollutants, only one, chloride, has a high potential, and only fluoranthene and pyrene have a moderate potential. Nitrate, a highly soluble and mobile contaminant, was categorized as having a low/moderate potential for contamination, and the other 21 pollutants had low potential.

Heavy metals and hydrocarbons may pose a low risk of contamination, but several studies have indicated that concentrations of these pollutants decrease rapidly with depth (Barraud et al., 1999; Legret et al. 1999). Similarly, Dierkes and Geiger (1999) found that polycyclic aromatic hydrocarbons (PAHs) in highway runoff were removed in the top four inches of soil.

The presence of volatile organic compounds (VOCs) in ground water is another concern. A USGS study (Ging et al., 1997) analyzed the occurrence and distribution of VOCs in ground water in south-central Texas. Although less than 50 percent of the samples taken had VOC detections, 28 VOCs were detected in samples from 89 wells. Based on the results of this study, VOC contamination in ground water appears to be associated with urban development (Ging et al., 1997).

VOC contamination has also been detected in the ground water of the Lower Illinois River Basin. In 1996, water samples collected from 60 wells in the basin were sampled and analyzed for VOCs. There were only six VOC detections in more than 4,300 analyses of the ground water samples (although at least three of these detections may have been caused by well disinfection practices). Additionally, a VOC was detected in one sample from deep glacial drift, indicating that shallow aquifers may be more susceptible to VOC contamination than deep aquifers. Based on these results, the authors concluded that VOC contamination does not appear to be a major concern for ground water quality in rural areas of the Lower Illinois River Basin (Morrow, 1999).

Several studies have found that the potential for ground water contamination, particularly from heavy metals and hydrocarbons, is low when porous pavement and stone-filled subsurface infiltration beds are used. These systems provide treatment through adsorption, filtration, sedimentation, and biodegradation before runoff reaches the underlying soil (Balades et al., 1995; Legret and Colandini, 1999; Newman et al., 2002; Pratt et al., 1999; Swisher, 2002).

5.2.3.2 Filtration practices

Filtration practices are so named because they filter particulate matter from runoff. The most common filtering medium is sand, but other materials, including peat/sand combinations and leaf compost material, have been used. Filtration systems provide only limited flood storage; therefore, they are most often implemented in conjunction with other types of quantity control management practices. Most filtration techniques require a forebay or clarifier to remove larger particles in runoff from clogging the filter media.

Biofiltration refers to practices that use vegetation and amended soils to retain and treat runoff from impervious areas. Treatment is through filtration, infiltration, adsorption, ion exchange, and biological uptake of pollutants.

5.2.3.3 Detention/retention practices

Runoff *detention* facilities provide pollutant removal by temporarily capturing runoff and allowing particulate matter to settle prior to release to surface waters. Dry detention runoff management ponds are one type of detention facility. Peak flows are reduced in drainage systems/receiving waters downstream of detention facilities.

Runoff *retention* facilities are used to capture runoff, which is subsequently withdrawn or evaporated. Therefore, peak flows and total flow volume can be reduced in downstream drainage systems/receiving waters. Wet runoff management ponds are one type of retention facility. These retention facilities can be designed to accept flow from receiving streams/drainage systems offline.

Both detention and retention facilities can use biological uptake as a mechanism for pollutant removal. Runoff management ponds can be designed to control the peak discharge rates, thereby reducing excessive flooding and downstream erosion in reaches of the drainage system/receiving stream immediately downstream. At some point downstream, however, runoff flow that is not retained will increase the volume of total flow, thereby increasing the risk of flooding and erosion if the receiving stream at that point does not have a stable channel and riparian area or floodplain.

Constructed wetlands are engineered systems designed to employ the water quality improvement functions of natural wetlands to treat and contain surface water runoff pollution and decrease pollutant loadings to surface waters. They can be designed with extended detention to control runoff peak flow and volume. Where site-specific conditions allow, constructed wetlands and retention basins should be located to minimize the impact on the surrounding areas (e.g., in upland areas of the watershed). Ponds, constructed wetlands, and other structural management practices degrade the functions of natural buffer areas and natural wetlands, and they may also interrupt surface water and ground water flow when soils are disturbed for installation. Therefore, the placement of structural management practices in natural buffers and natural wetlands should be avoided where possible.

5.2.3.4 Evaporation practices

Runoff detention and retention facilities and other practices that temporarily store runoff can also evaporate it. Evaporation from runoff detention and retention areas such as rooftops, streets, basins, and ponds can be an important mechanism for runoff management in warm, dry climates.

5.3 Management Practices

Management practices to control urban runoff can be classified in seven categories. The following practices are described for illustrative purposes only. EPA has found these practices to be representative of the types of practices that can be applied successfully to achieve the new development runoff treatment management measure. As a practical matter, EPA anticipates that the management measure can be achieved by applying one or more management practices appropriate to the source(s), location, and climate. Thus, practices that by themselves do not achieve 80 percent TSS removal can be combined with other practices to achieve 80 percent removal (such that x + y + z = 80 percent). This is the "treatment train" approach, in which several types of practices are used together and integrated into a comprehensive runoff management system (WMI, 1997b). The seven categories include:

- Infiltration practices;
- Vegetated open channel practices;
- Filtering practices;
- Detention ponds or vaults;
- Retention ponds;
- Wetlands; and
- Other practices such as water quality inlets.

5.3.1 Infiltration Practices

These practices capture and temporarily store runoff before allowing it to infiltrate into the soil over several days. Design variants include:

- Infiltration basins;
- Infiltration trenches; and
- Pervious or porous pavements.

To prevent premature clogging, these practices must not receive drainage from a construction activity or site. Infiltration practices can be placed in service after the construction activity is complete or the site is stabilized.

5.3.1.1 Infiltration basins

Infiltration basins (Figure 5.1) are impoundments created by excavation or creation of berms or small dams. They are typically flat-bottomed with no outlet and are designed to temporarily store runoff generated from adjacent drainage areas (from 2 to 50 acres, depending on local conditions). Runoff gradually infiltrates through the bed and sides of the basin, ideally within 72 hours, to maintain aerobic conditions and ensure that the basin is ready to receive runoff from the next storm. Infiltration basins are often used as an off-line system for treating the first flush of runoff flows or the peak discharges of the two-year storm.

The key to successful operation is keeping the soils on the floor and side slopes of the basin unclogged to maintain the rate of percolation. This is usually much easier said than done. For example, Schueler (1992) reported infiltration basin failure rates ranging from 60 to 100 percent

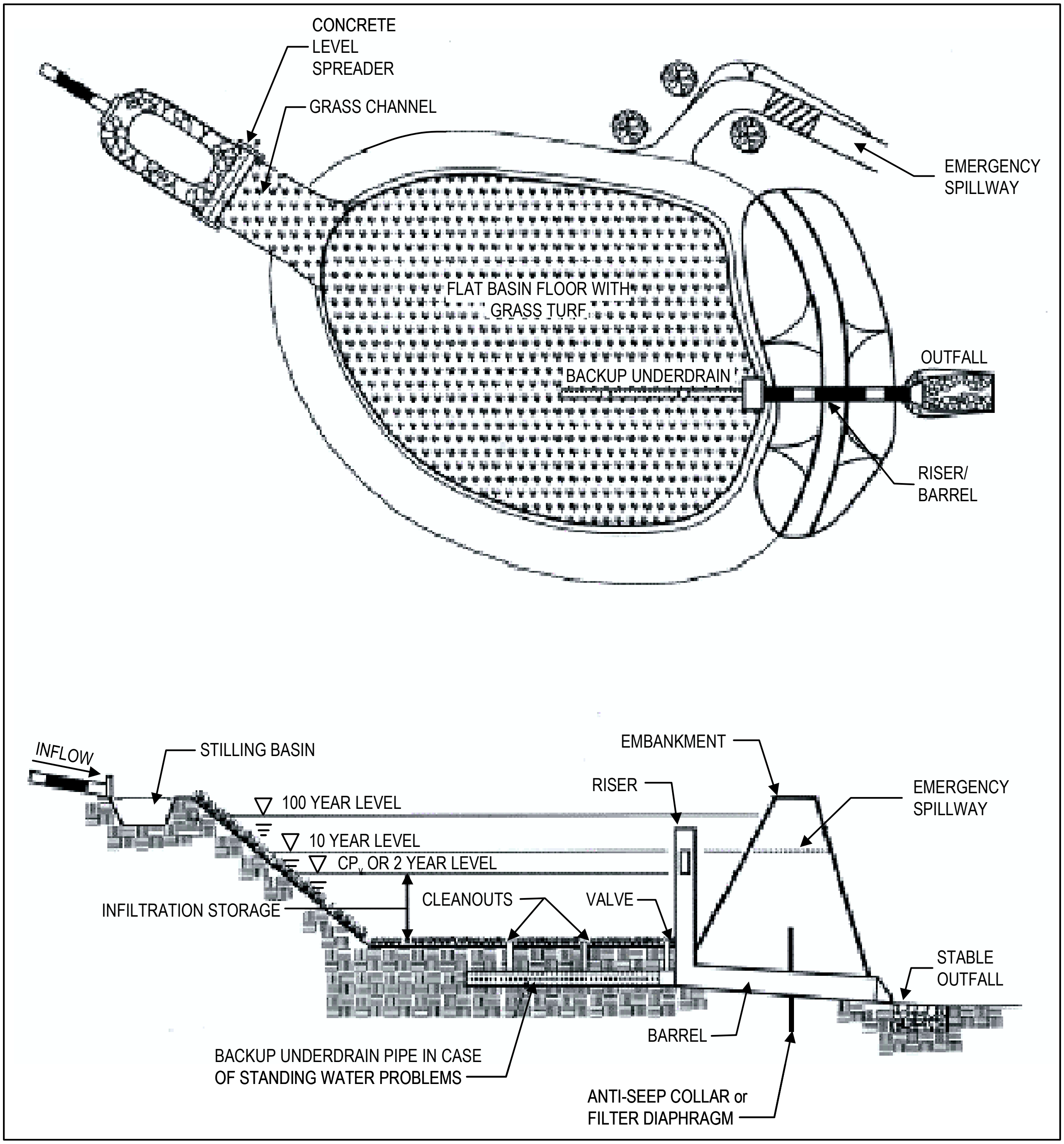


Figure 5.1: Schematic of an infiltration basin (MDE, 2000).

in the mid-Atlantic region. To help keep sediment out of the basin, incoming runoff should be pretreated using vegetated filter strips, a settling forebay, or other techniques. Grasses or other vegetation should also be planted and maintained in the basin. If soil pores become clogged, the basin bottom should be roughened or replaced to restore percolation rates.

5.3.1.2 Infiltration trenches

Infiltration trenches (Figure 5.2) are shallow (2- to 10-feet deep) excavated ditches with relatively permeable soils that have been backfilled with stone to form an underground reservoir. The trench surface can be covered with a grating or can consist of stone, gabion, sand, or a grass-covered area with a surface inlet. Runoff diverted into the trench gradually infiltrates into the subsoil and, eventually, into the ground water. Trenches can be used on small, individual sites or for multi-site runoff treatment. Pretreatment controls such as vegetated filter strips should be incorporated into the design to remove sediment and reduce clogging of soil pores. More expensive than pond systems in terms of cost per volume of runoff treated, infiltration trenches are best-suited for drainage areas of less than 5 to 10 acres, or where ponds cannot be used.

Variations in the design of infiltration trenches include dry wells, which are pits designed to control small volumes of runoff (such as rooftop runoff) and exfiltration trenches. A typical dry well design includes a perforated pipe 3 to 4 feet in diameter that is installed vertically in deposits of gravely/sandy soil. Rock is then backfilled around the base of the well. An exfiltration trench is an infiltration trench that stores runoff water in a perforated or slotted pipe and percolates it out into a surrounding gravel envelope and filter fabric. Dry wells and other infiltration practices that involve subsurface drainage may be regulated by EPA's Underground Injection Control Program. See the EPA's Underground Injection Control Program Web site at http://www.epa.gov/safewater/uic.html for more information.

5.3.1.3 Pervious or porous pavements

Pervious pavement has the approximate strength characteristics of traditional pavement but allows rainfall and runoff to percolate through it. The key to the design of these pavements is the elimination of most of the fine aggregate found in conventional paving materials. There are two types of pervious pavement, porous asphalt and pervious concrete (WMI, 1997b). Porous asphalt has coarse aggregate held together in the asphalt with sufficient interconnected voids to yield high permeability. Pervious concrete, in contrast, is a discontinuous mixture of Portland cement, coarse aggregate, admixtures, and water that also yields interconnected voids for the passage of air and water. Underlying the pervious pavement are a filter layer, a stone reservoir, and a filter fabric. Stored runoff gradually drains out of the stone reservoir into the subsoil. Figure 5.3 shows several types of porous pavement. More information about pervious pavement can be found at http://www.gcpa.org/pervious_concrete_pavement.htm (Georgia Concrete & Products Association, 2003).

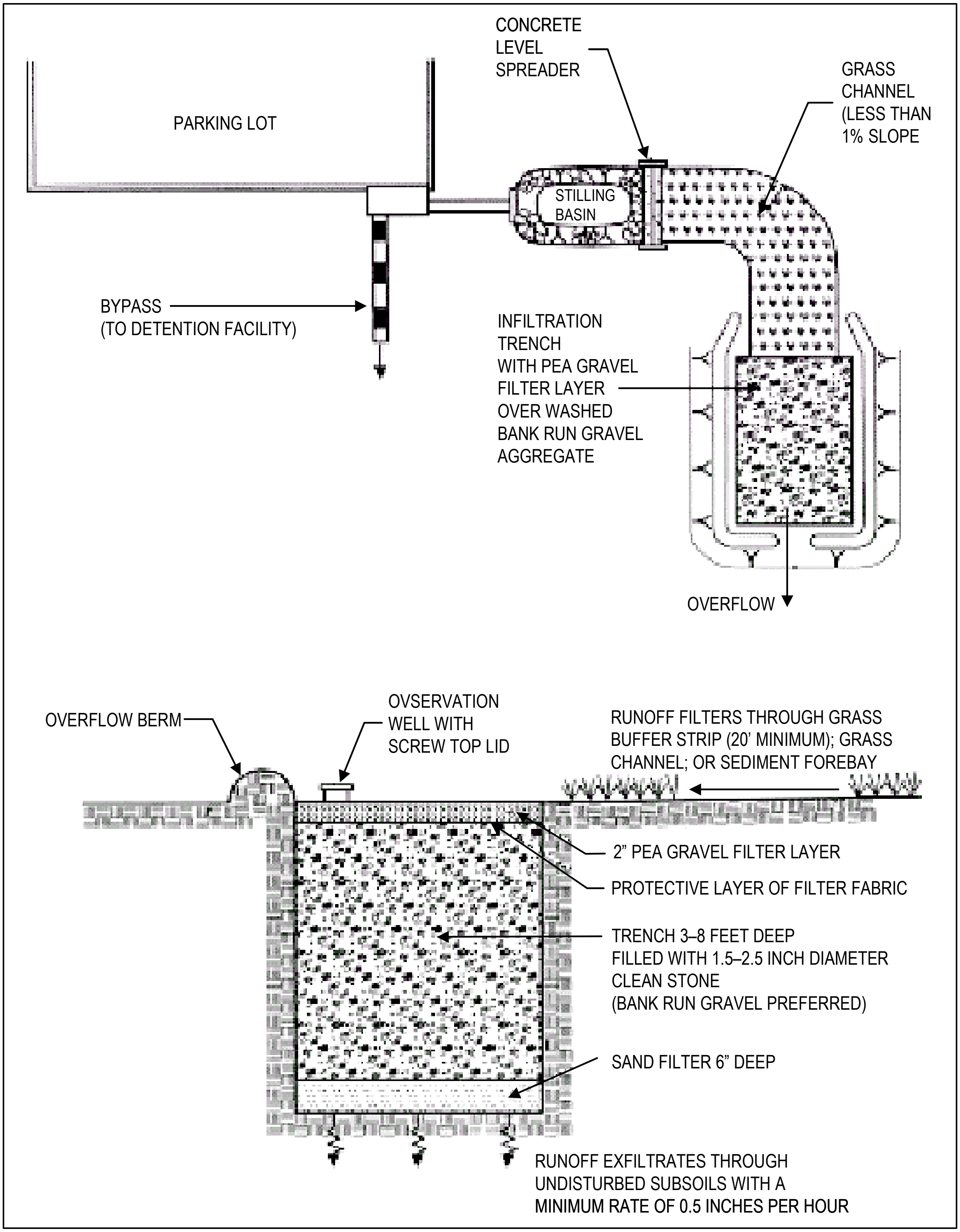


Figure 5.2: Schematic of an infiltration trench (MDE, 2000).

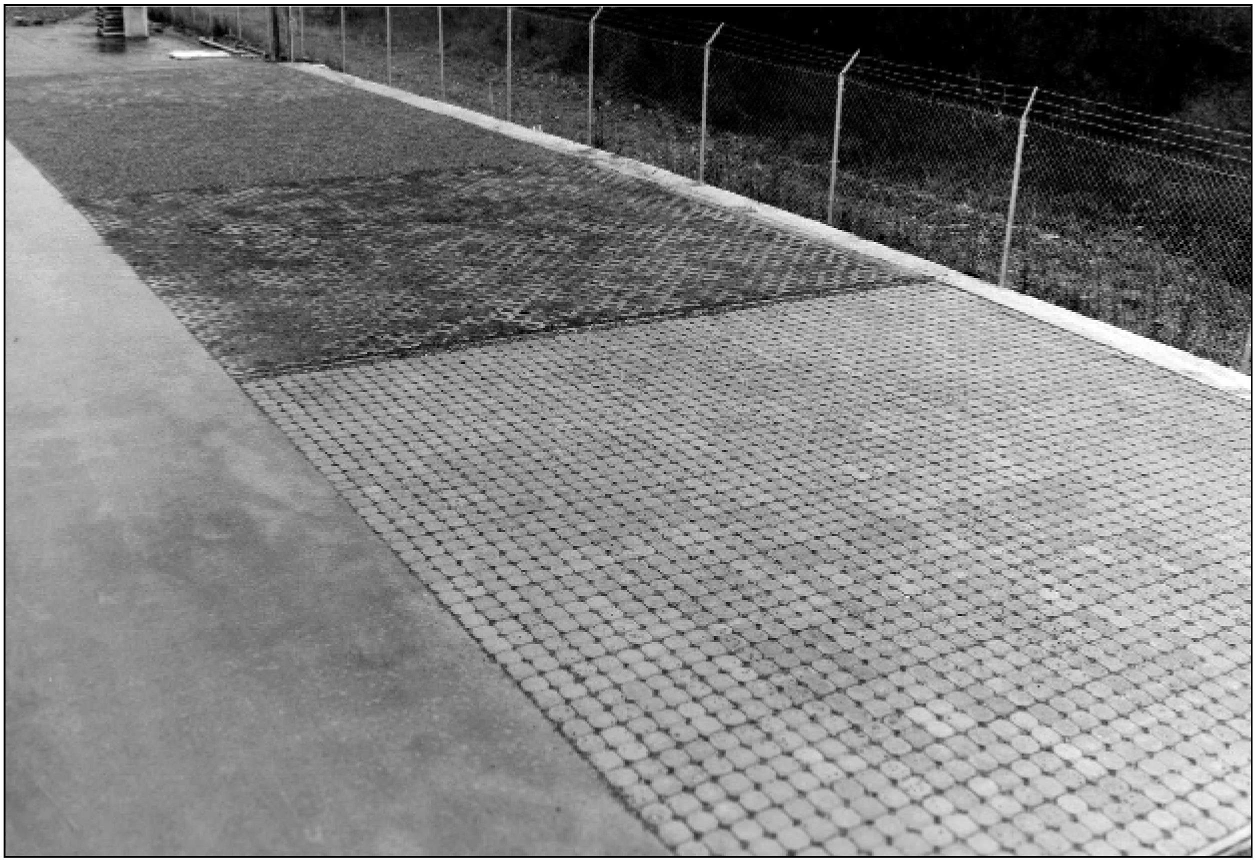


Figure 5.3: Photo showing several types of pervious modular pavement installations.

Modular pavement consists of individual blocks made of pervious material such as sand, gravel, or sod interspersed with strong structural material such as concrete. The blocks are typically placed on a sand or gravel base and designed to provide a load-bearing surface that is adequate to support personal vehicles, while allowing infiltration of surface water into the underlying soils. They usually are used in low-volume traffic areas such as overflow parking lots and lightly used access roads. An alternative to pervious and modular pavement for parking areas is a geotextile material installed as a framework to provide structural strength. Filled with sand and sodded, it provides a completely grassed parking area. More information about concrete pavers can be found at http://www.concretenetwork.com/concrete/porous_concrete_pavers/ (Concretenetwork.com, 2003).

Some states no longer promote the use of porous pavement because it tends to easily clog with fine sediments (Washington Department of Ecology, 1991). If this type of pavement is installed, a vacuum-type street sweeper should be used regularly to maintain porosity. Frequent washing with a high-pressure jet of water can also keep pores clear of clogging sediments. Sites where pervious pavement is to be installed must have deep, permeable soils, slopes of less than 5 percent, and no heavy vehicle traffic.

The City of Kinston, North Carolina, installed a permeable pavement parking lot as a demonstration and research project and to meet the daily parking needs of city employees (Hunt and Stevens, 2001). The final parking lot design included 26 stalls; 20 of the stalls were

The Bath Club Concourse Storm Water Rehabilitation Project, Florida

The Bath Club Concourse is located on a small barrier island community in North Redington Beach, Florida. A combination roadway and parking area, which connects Bath Club Circle and Gulf Boulevard, was previously an impervious slab of concrete pavement. The concourse could not absorb falling rain, which caused runoff to flow directly into a single storm sewer. The sewer would then carry pollutants directly to Boca Ciega Bay. In August 1990, the Water Management District and the town agreed to construct a stormwater rehabilitation project using pervious concrete pavement at the Bath Club Concourse (USEPA, 1999).

The main objective of the rehabilitation project was to reduce nonpoint source pollutant loading by reducing the volume of runoff discharging directly into Boca Ciega Bay. A second objective was to demonstrate an innovative way to treat or improve the quality of runoff in highly urbanized areas, where it can sometimes be difficult or expensive to manage runoff because of land constraints.

To maximize infiltration of runoff and reduce the amount of untreated runoff discharged directly into storm sewers, drainage was directed toward two pervious concrete parking areas. These areas were separated by an unpaved island in the center of the concourse, which also provides infiltration. Engineers installed two 150-foot under-drains to maximize infiltration by allowing subsurface soils to drain beneath the parking areas.

The rehabilitation project resulted in a significant reduction of direct discharge of runoff from the site. Estimates indicate that these improvements resulted in a 33 percent reduction in total on-site runoff volume. Additionally, the volume of surface runoff discharging directly to Boca Ciega Bay was reduced by nearly 75 percent. Overall removal efficiencies for the project, which are based on the pollutant removal efficiency of the under-drain/filter system, indicate that the project can remove 73 percent of lead (Bateman et al., no date). Other removal efficiencies and additional information about the project are available at http://www.stormwaterauthority.org/assets/103BFloridaRetrofits.pdf.

constructed using a concrete block paver filled with and overlaying sand, while the other six were constructed using a plastic grid paver with sandy soil and Bermuda grass. Monitoring results from a two-year study showed a 3- to 5-time reduction in peak runoff for storms greater than 0.5 inches based on calculated runoff coefficients (using the rational method). Of 48 rainstorms, only 11 (less than 25 percent) resulted in runoff generated from the parking lot The researchers found that annual maintenance to scarify the surface of the lot with a street sweeper helps to maximize permeability of the pavement. More information about the study, including several design recommendations, can be found at http://www5.bae.ncsu.edu/programs/extension/wqg/issues/101.pdf.

Brattebo and Booth (2003) examined the long-term effectiveness of permeable pavement by testing four commercially available permeable pavement systems for six years of regular parking use. The systems included the following:

- A flexible plastic grid system with virtually no impervious area, filled with sand and planted with grass;
- An equivalent plastic grid, filled with gravel;
- A concrete block lattice with approximately 60 percent impervious coverage, filled with soil and planted with grass; and

- Small concrete blocks with approximately 90 percent impervious coverage, with the spaces between blocks filled with gravel.

At the end of the study, none of the systems showed major signs of wear. The pavements infiltrated nearly all rainwater, generating almost no surface runoff. The researchers compared the quality of infiltrated water to surface runoff from an asphalt area and found significantly lower levels of copper and zinc in the infiltrated water. Motor oil was not detected in infiltrated water but was detected in 89 percent of samples of surface runoff from asphalt. Measurements of infiltrated rainwater from five years earlier showed significantly higher concentrations of zinc and lower concentrations of copper and lead.

5.3.2 Vegetated Open Channel Practices

Vegetated open channels are explicitly designed to capture and treat runoff through infiltration, filtration, or temporary storage.

A vegetated swale is an infiltration practice that usually functions as a runoff conveyance channel and a filtration practice. It is lined with grass or another erosion-resistant plant species that serves to reduce flow velocity and allow runoff to infiltrate into ground water. The vegetation or turf also prevents erosion, filters sediment, and provides some nutrient uptake benefits. These practices are also known as biofiltration swales. Check dams are often used to reduce flow velocity. When used, sediment that collects behind check dams should be removed regularly.

Two types of channels are typically used in residential landscapes:

- *Grass channels*. These have dense vegetation, a wide bottom, and gentle slopes (Figure 5.4). Usually they are intended to detain flows for 10 to 20 minutes, allowing sediments to filter out.

- *Dry swales*. As with grass channels, runoff flows into the channel and is subsequently filtered by surface vegetation (Figure 5.5). From there, runoff moves downward through a bed of sandy loam soil and is collected by an underdrain pipe system. The treated water is delivered to a receiving water or another structural control. Dry swales are used in large-lot, single-family developments and on campus-type office or industrial sites. They are applicable in all areas where dense vegetative cover can be maintained. Because of a limited ability to control runoff from large storms, they are often combined with other structural practices. They should not be used in areas where flow rates exceed 1.5 feet per second unless additional erosion control measures, such as turf reinforcement mats, are used.

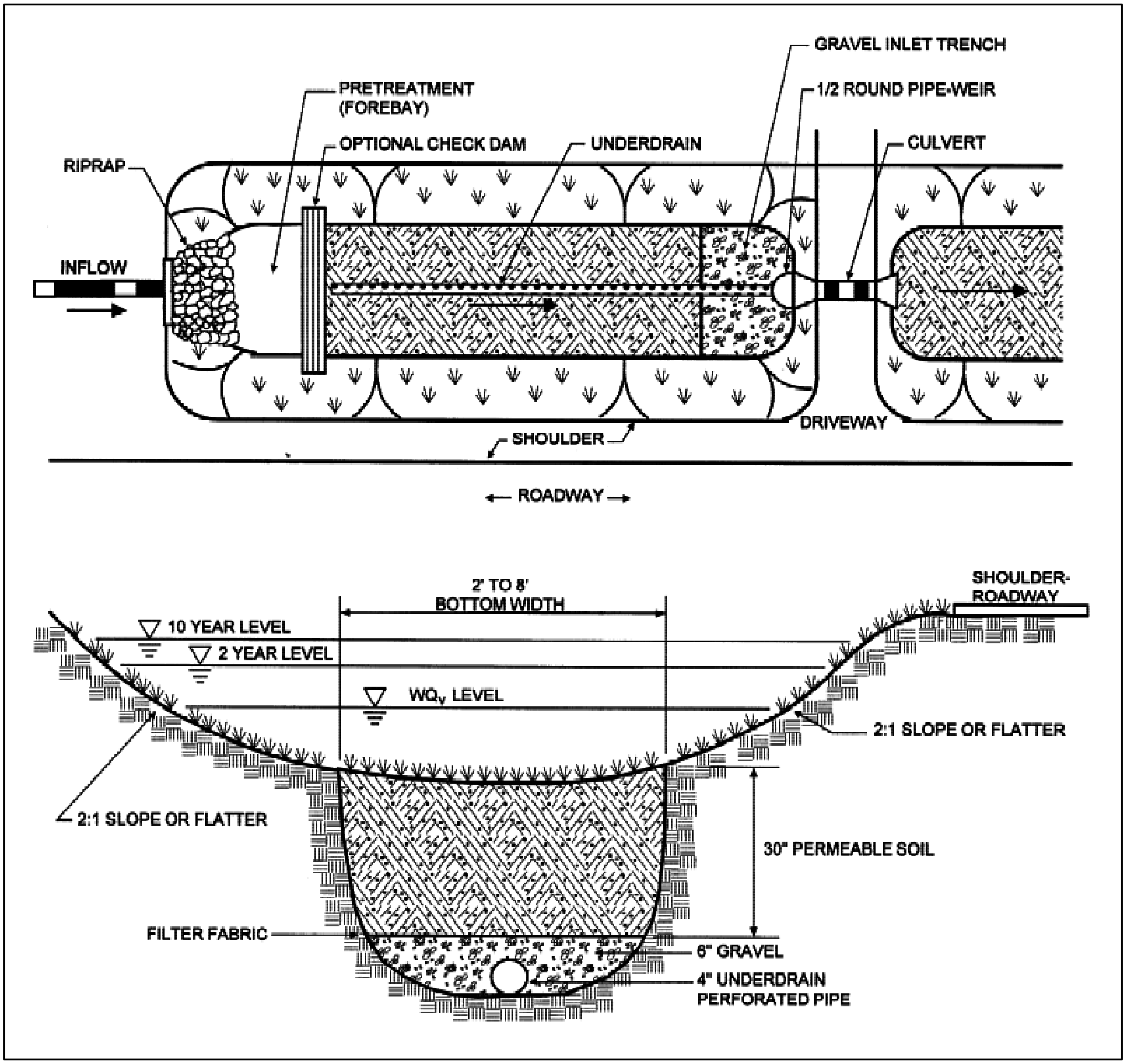


Figure 5.4: Schematic of a grass channel (Claytor and Schueler, 1996).

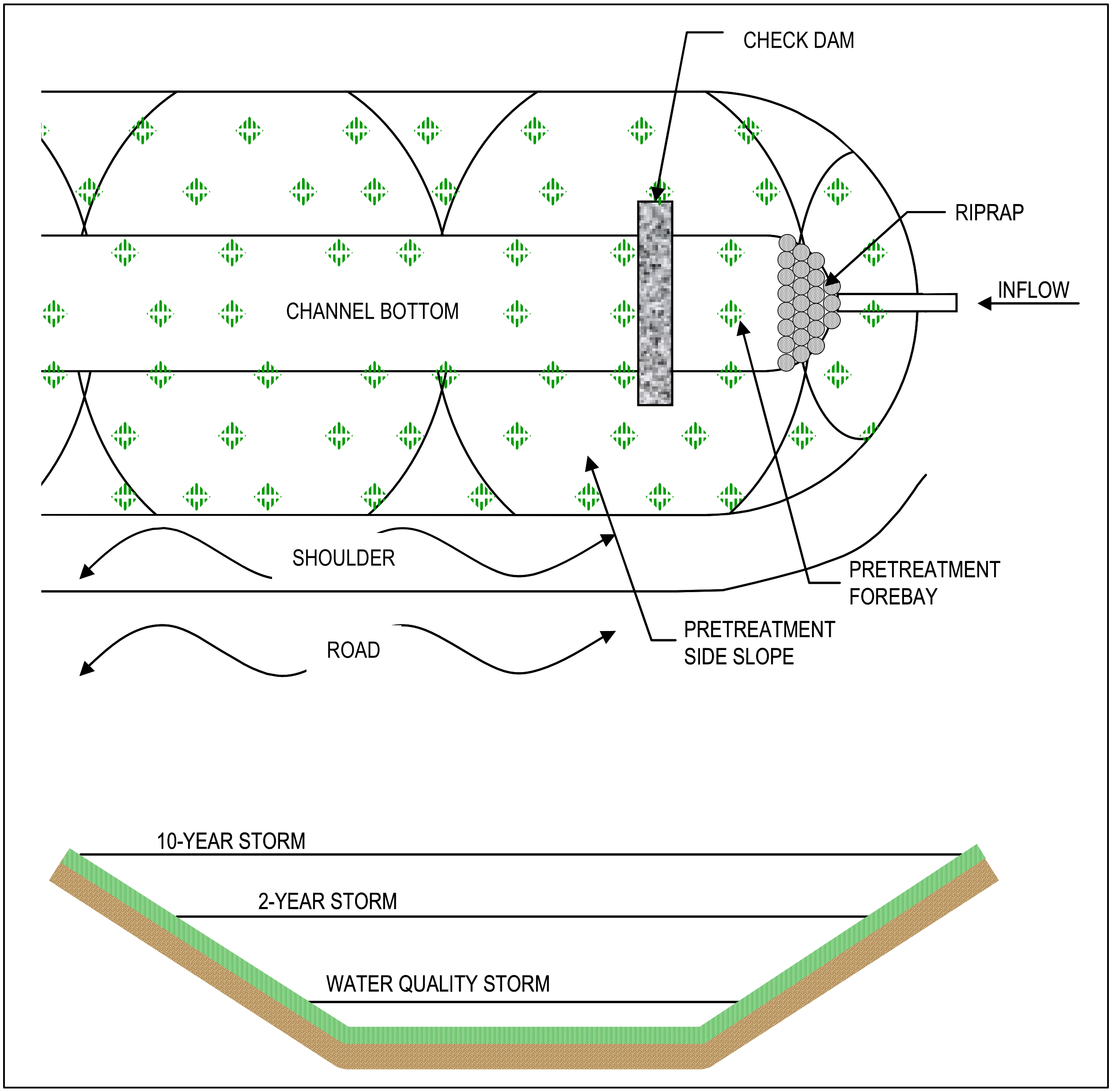


Figure 5.5: Schematic of a dry swale (adapted from MDE, 2000).

In a research study conducted by J.F. Sabourin and Associates (1999), two grass swale/perforated pipe systems and one conventional curb-and-gutter system were compared. Flow monitoring results indicate that much less water reached the outlet of the perforated pipe systems than the conventional system. Peak flows and total runoff volumes from the outlet of the perforated pipe/grass swale system were 2 to 6 percent of those of the conventional system, and total runoff volumes were 6 to 30 percent of conventional system volumes. Water quality monitoring results indicate that for most elements, concentrations measured in the perforated pipes were the same or lower than in the conventional system. Chloride concentrations were found to be higher in the perforated pipe system, most likely from the use of road salt. However, a loading analysis indicated that the perforated pipes released significantly fewer pollutants than the conventional system.

The authors also performed video inspections of the swale/perforated pipe sewershed. These inspections revealed a few interesting issues that can affect the performance of perforated pipe systems. Several unauthorized sanitary sewer connections had been made by some residents, and several raccoons were found living inside the pipes. Both can contribute to nutrient and pathogen problems in receiving waters.

J.F. Sabourin and Associates concluded that infiltration capacities of grass swales are optimum when they allow for proper drainage and hold enough moisture for sustaining grass and plant life. Exfiltration tests indicated that runoff volumes can be reduced by 40 to 60 percent by grass swales and perforated pipe drainage systems. With a direct connection, peak outflows can be 45 percent of the inflow.

5.3.3 Filtering Practices

Filtering practices capture and temporarily store runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff may be collected and returned to the conveyance system, or allowed to exfiltrate into the soil. Design variants include:

- Surface sand filter;
- Underground sand filter;
- Organic filter;
- Pocket sand filter; and
- Bioretention areas.

5.3.3.1 Filtration basins and sand filters

Filtration basins are impoundments lined with a filter medium such as sand or gravel. Runoff drains through the filter medium and through perforated pipes into the subsoil. Detention time is typically four to six hours. Sediment-trapping structures are often used to prevent premature clogging of the filter medium (NVPDC, 1980; Schueler et al., 1992).

Sand filters are usually two-chambered practices: the first is a settling chamber and the second is a filter bed filled with sand or another filtering medium. As runoff flows into the first chamber, large particles settle out and finer particles and other pollutants are removed as runoff flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chambered treatment train (Robertson et al., 1995). All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging site designs (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter). The following are design variations for sand filtration devices:

(1) *Surface sand filter*. The surface sand filter (Figure 5.6) is an aboveground filter design. Both the filter bed and the sediment chamber are aboveground. The surface sand filter is designed as an off-line practice; only the water quality volume is directed to the filter. The surface sand filter is the least-expensive filter option and has been the most widely used.

(2) *Underground sand filter*. The underground sand filter (Figure 5.7) is a modification of the surface sand filter, where all of the filter components are underground. Like the surface sand filter, this practice is an off-line system that receives only flows from small rainstorms. Underground sand filters are expensive to construct but consume very little space. They are well-suited to highly urbanized areas, and often included in groups of practices known as "ultra-urban BMPs."

(3) *Perimeter sand filter*. The perimeter sand filter (Figure 5.8) also includes the basic design elements of a sediment chamber and a filter bed. In this design, however, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is the only filtering option that is on-line; all flow enters the system, but a bypass to an overflow chamber prevents system flooding. One major advantage of the perimeter sand filter design is that it requires little hydraulic head and thus is a good option in areas of low relief.

(4) Organic media filter. Organic media filters (Figure 5.9) are essentially the same as surface filters, with the sand replaced with or supplemented by another medium. Two examples are the peat/sand filter (Galli, 1990) and the compost filter system. It is assumed that these systems will provide enhanced pollutant removal for many compounds because of the increased cation exchange capacity achieved by increasing organic matter content.

(5) *Multi-chambered treatment train*. The multi-chambered treatment train (Figure 5.10) is essentially a "deluxe sand filter" (Robertson et al., 1995). This underground system consists of three chambers. Runoff enters into the first chamber where screening occurs, trapping large sediments and releasing highly volatile materials. The second chamber provides settling of fine sediments and further removal of volatile compounds and floatable hydrocarbons through the use of fine bubble diffusers and sorbent pads. The final chamber provides filtration by using a sand and peat mixed medium for reduction of the remaining pollutants. The top of the filter is covered by a filter fabric that evenly distributes the water volume and prevents channelization. Although this practice can achieve very high pollutant removal rates, it might be prohibitively expensive in many areas. It has been implemented only on an experimental basis.

(6) *Exfiltration/partial exfiltration.* In exfiltration designs, all or part of the underdrain system is replaced with an open bottom that allows infiltration to the ground water. When the underdrain is present, it is used as an overflow device in case the filter becomes clogged. These designs are best applied in the same soils where infiltration practices are used.

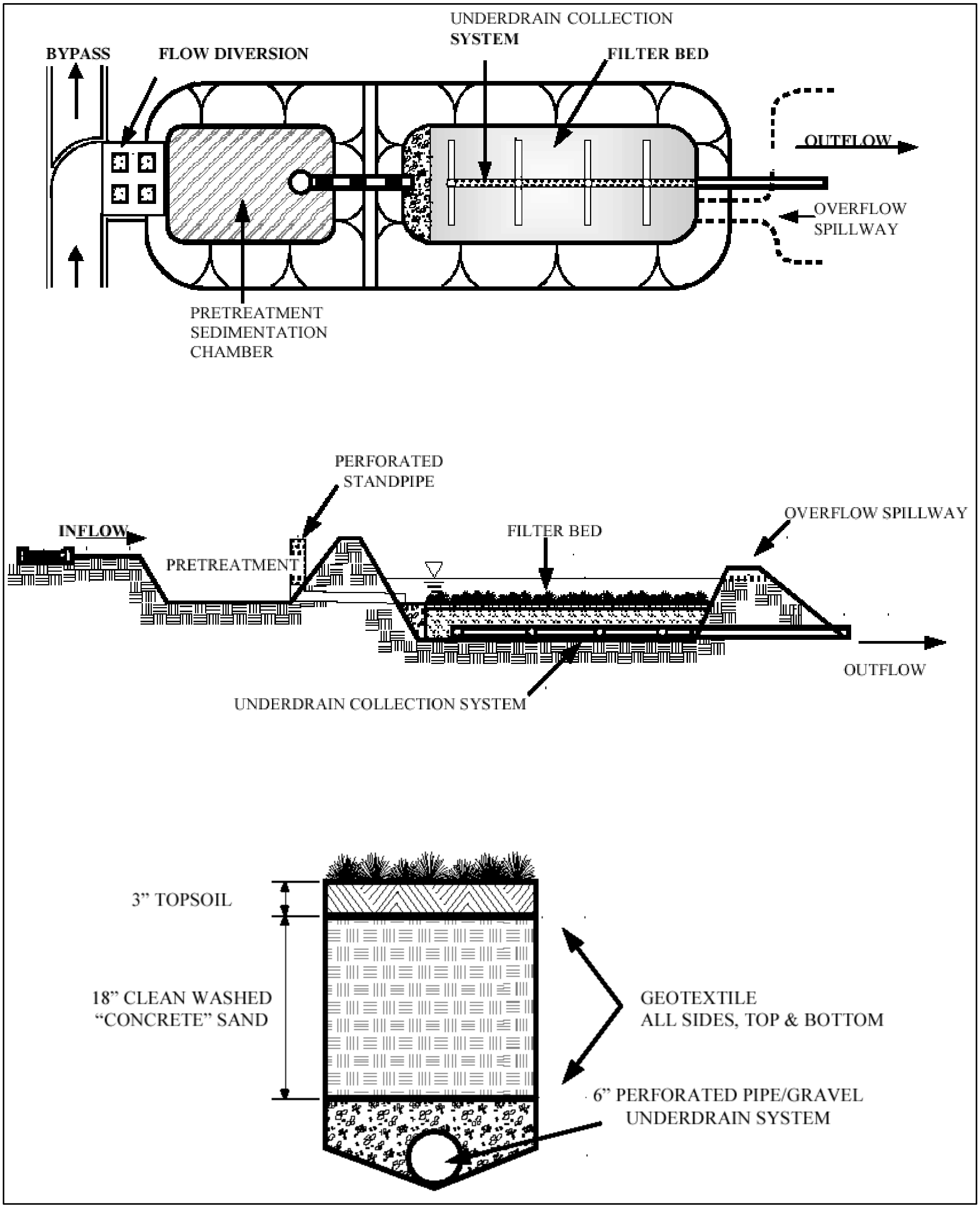


Figure 5.6: Schematic of a surface sand filter (MDE, 2000).

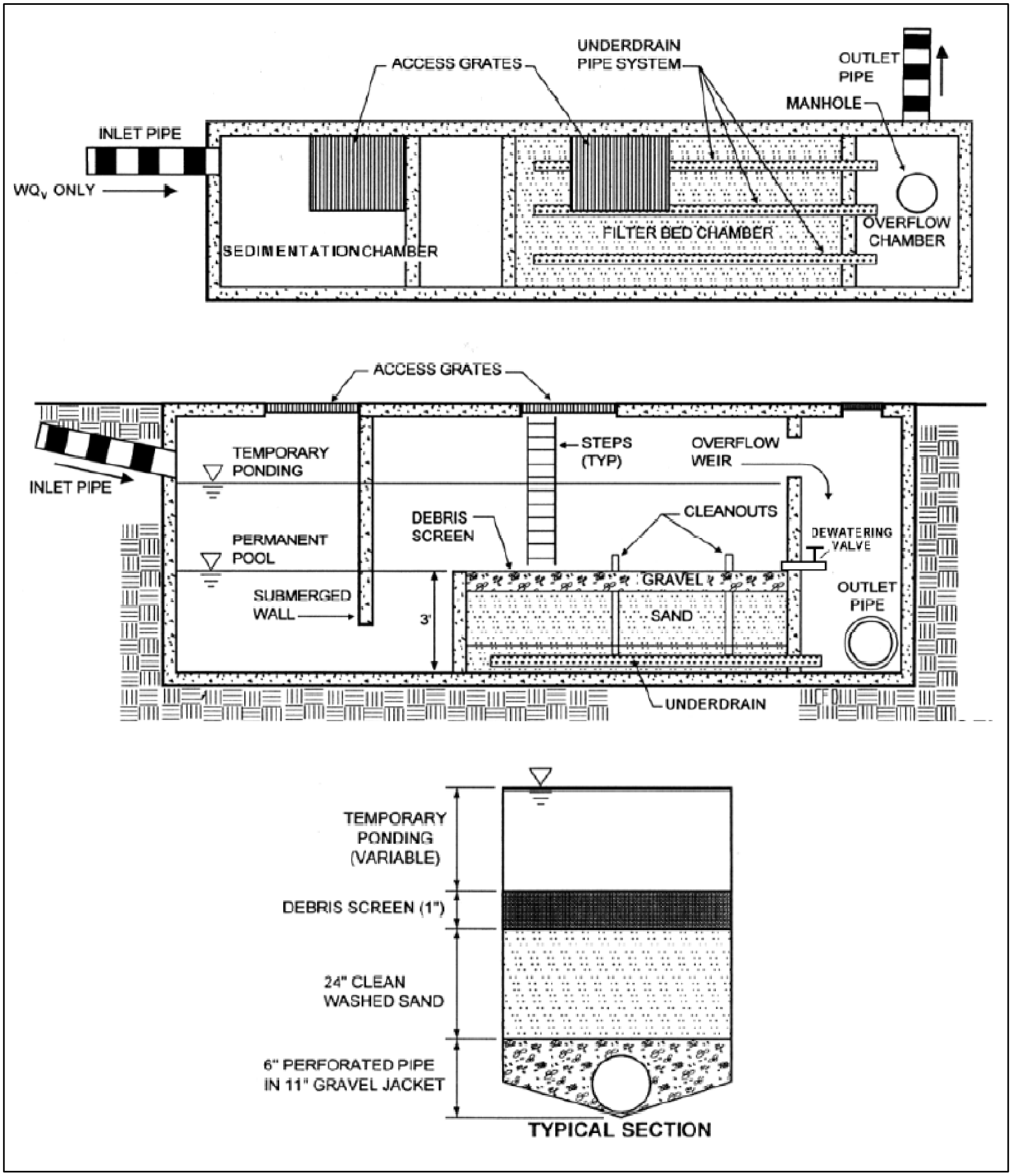


Figure 5.7: Schematic of an underground sand filter (MDE, 2000).

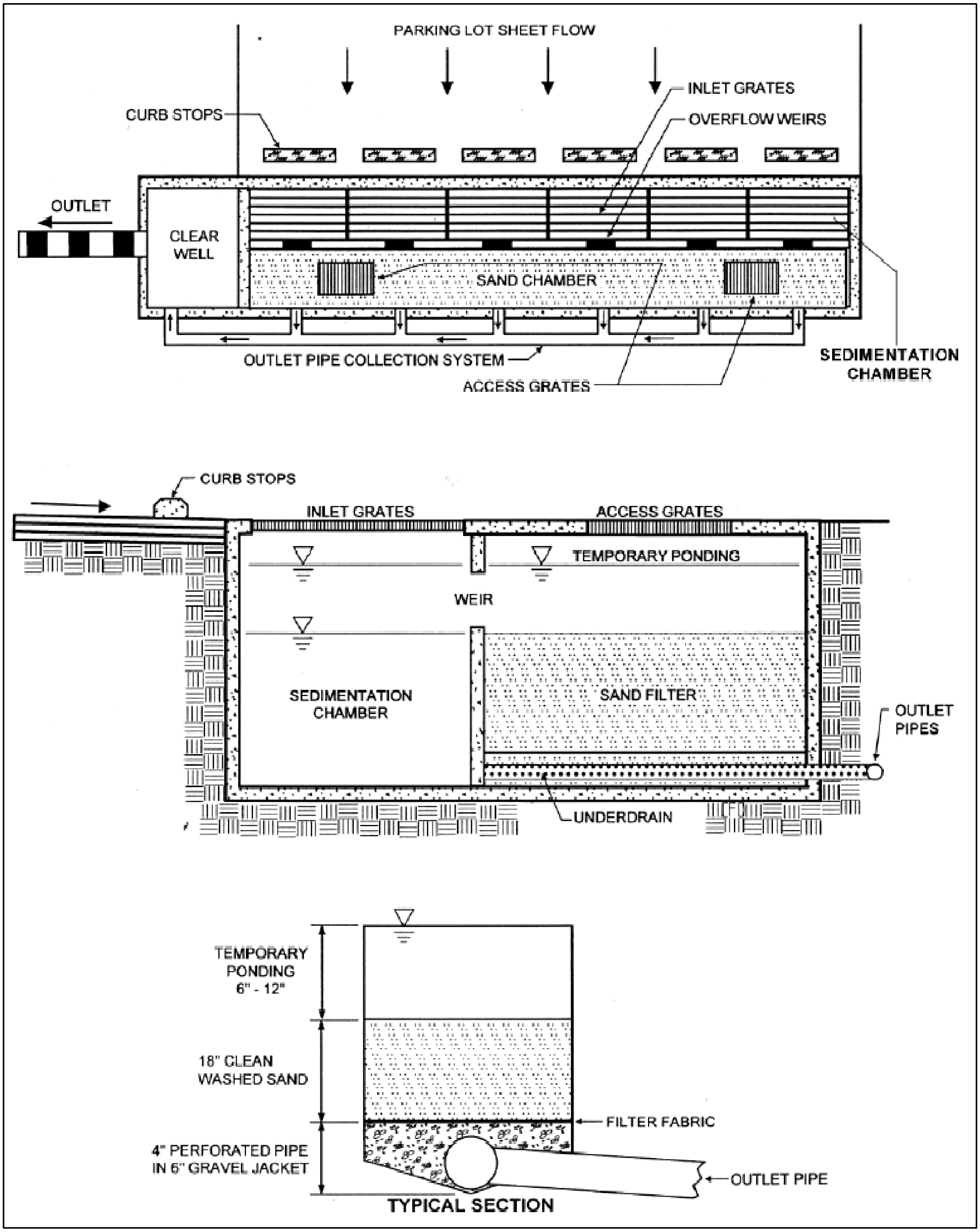


Figure 5.8: Schematic of a perimeter sand filter (MDE, 2000).

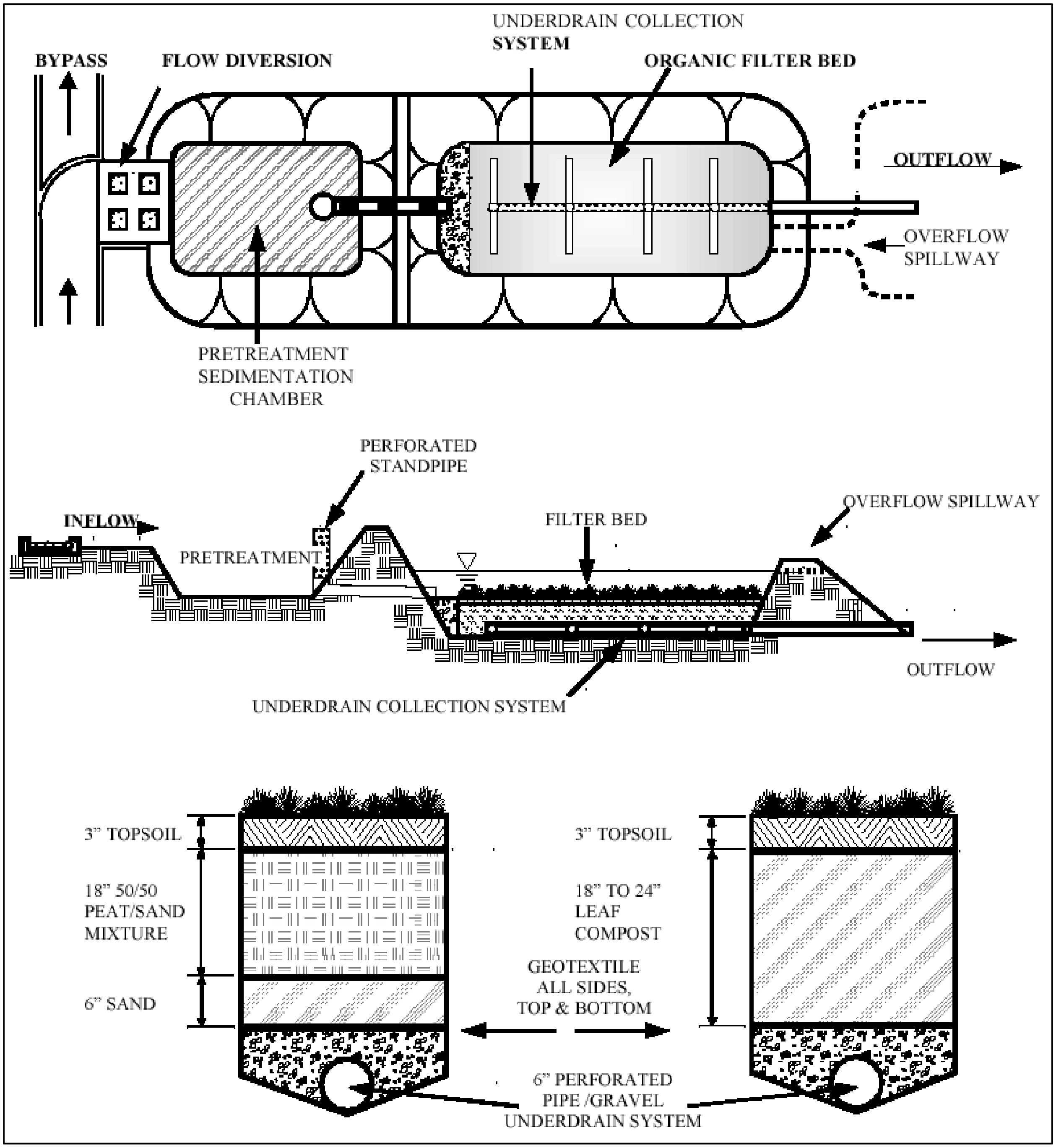


Figure 5.9: Schematic of an organic media filter (MDE, 2000).

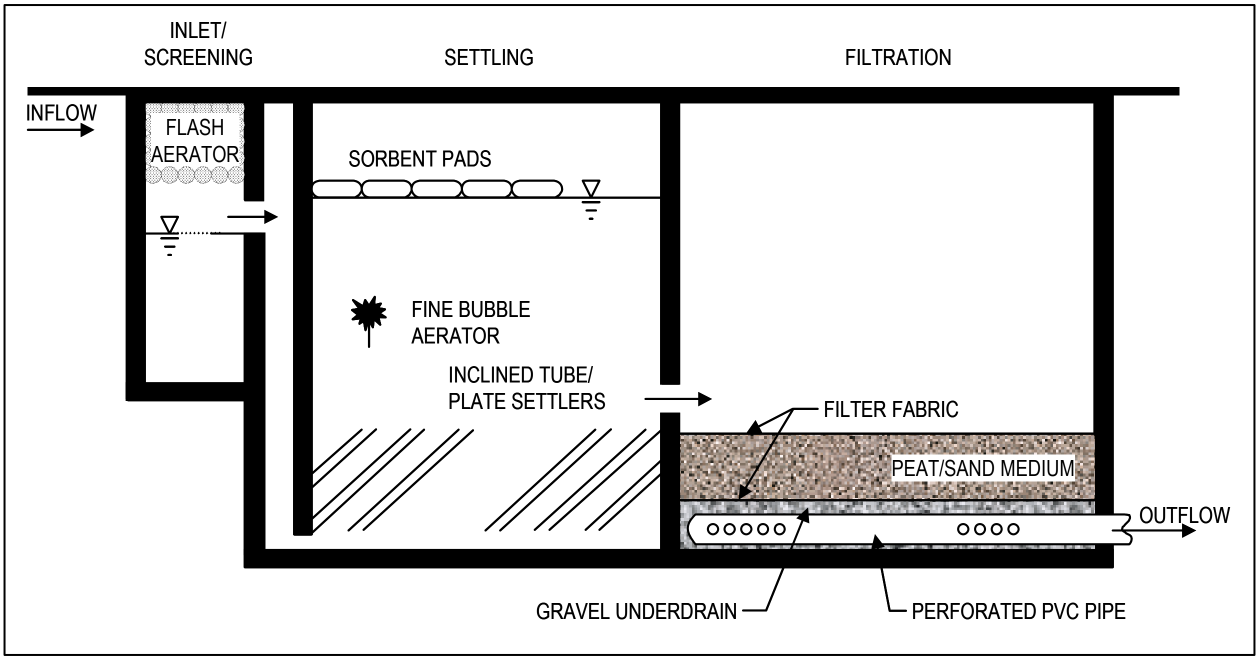


Figure 5.10: Schematic of a multi-chambered treatment train (Pitt, 1996).

5.3.3.2 Media filtration units

Similar to wastewater treatment technology, passive filtration units can be used to capture pollutants from runoff. Media filtration practices commonly use trenches filled with sand or peat. Other media, including types of crushed rock and composted leaves, can also be used. A basin collects the runoff and gradually routes discharge through cartridges filled with filter media. An emergency bypass prevents system flooding during large rainstorms. According to the Unified Sewerage Agency of Washington County in Oregon (WEF, 1998), composted leaf media trap particulates, adsorb organic chemicals, and remove 90 percent of solids, 85 percent of oil and grease, and 82 to 98 percent of heavy metals through cation exchange from leaf decomposition. Similar types of systems with various filter media are available commercially.

Performance of a Compost Storm Water Treatment System in Hillsboro, Oregon

A compost storm water treatment facility was constructed to treat runoff from 3.9 acres of 5-lane arterial road and 70.1 acres of mixed residential land use in Hillsboro, Oregon (FHWA, no date). The system consists of a discharge pipe that conveys runoff from the drainage area into a forebay. Runoff then flows over a wooden baffle into two consecutive cells filled with Portland leaf compost material. After runoff filters through the compost medium, it is discharged to a rock drainbed separated from the compost by a layer of filter fabric.

Monitoring of the effluent between 1991 and 1994 showed average mass balance pollutant removals of 81 percent for oils and grease, 84 percent for petroleum hydrocarbons, 58 percent to 94 percent for nutrients, and 68 percent to 93 percent for metals. See Table 5.4 for additional pollutant removal results. More details on the design and performance of this study are available at http://www.fhwa.dot.gov/environment/ultraurb/5mcs5.htm.

Table 5.4: Pollutant removal efficiencies for the compost storm water treatment facility from 1991 to 1994.

Parameter		1991-1992	1992-1993	1993-1994
Turbidity	Combined	84.2 %	78.4 %	78.4 %
	First Flush	93.4 %	85.3 %	81.4 %
Total Suspended Solids	Combined	94.8 %	88.5 %	86.0 %
	First Flush	98.3 %	91.4 %	89.0 %
Chemical Oxygen Demand	Combined	66.9 %	76.3 %	74.0 %
	First Flush	89.5 %	82.1 %	79.8 %
Total Phosphorus	Combined	40.5 %	53.2 %	65.5 %
	First Flush	67.3 %	68.9 %	72.9 %
Total Kjeldhal Nitrogen	Combined	55.9 %	50.5 %	66.7 %
	First Flush	84 %	60.8 %	69.0 %
Iron	Combined	89 %	95.5 %	79.6 %
	First Flush	94 %	97.5 %	82.9 %
Chromium	Combined	61.2 %	74.5 %	64.3 %
	First Flush	92.4 %	80.8 %	72.8 %
Copper	Combined	66.7 %	63.5 %	64.1 %
	First Flush	83.7 %	73.9 %	70.7 %
Lead	Combined	N/A	85.1 %	81.4 %
	First Flush	N/A	89.0 %	84.0 %
Zinc	Combined	88.3 %	75.8 %	79.9 %
	First Flush	92.8 %	83.1 %	83.1 %

5.3.3.3 Bioretention systems

Bioretention systems (Figure 5.11 and Figure 5.12) are suitable to treat runoff on sites where there is adequate soil infiltration capacity and where the runoff volumes that are not infiltrated do not present a safety or flooding hazard. Typical applications for bioretention include parking areas with or without curbs, traffic islands, and swales or depressed areas that receive runoff from impervious areas.

Bioretention system designs are very flexible, can be adapted to a wide range of commercial, industrial, and residential settings, and can be linked in series or combined with structural devices to provide the necessary level of treatment depending on expected runoff volumes and pollutant loading. A common technique is to use bioretention areas to pre-treat sheet flow before it is channelized or collected in an inlet structure.

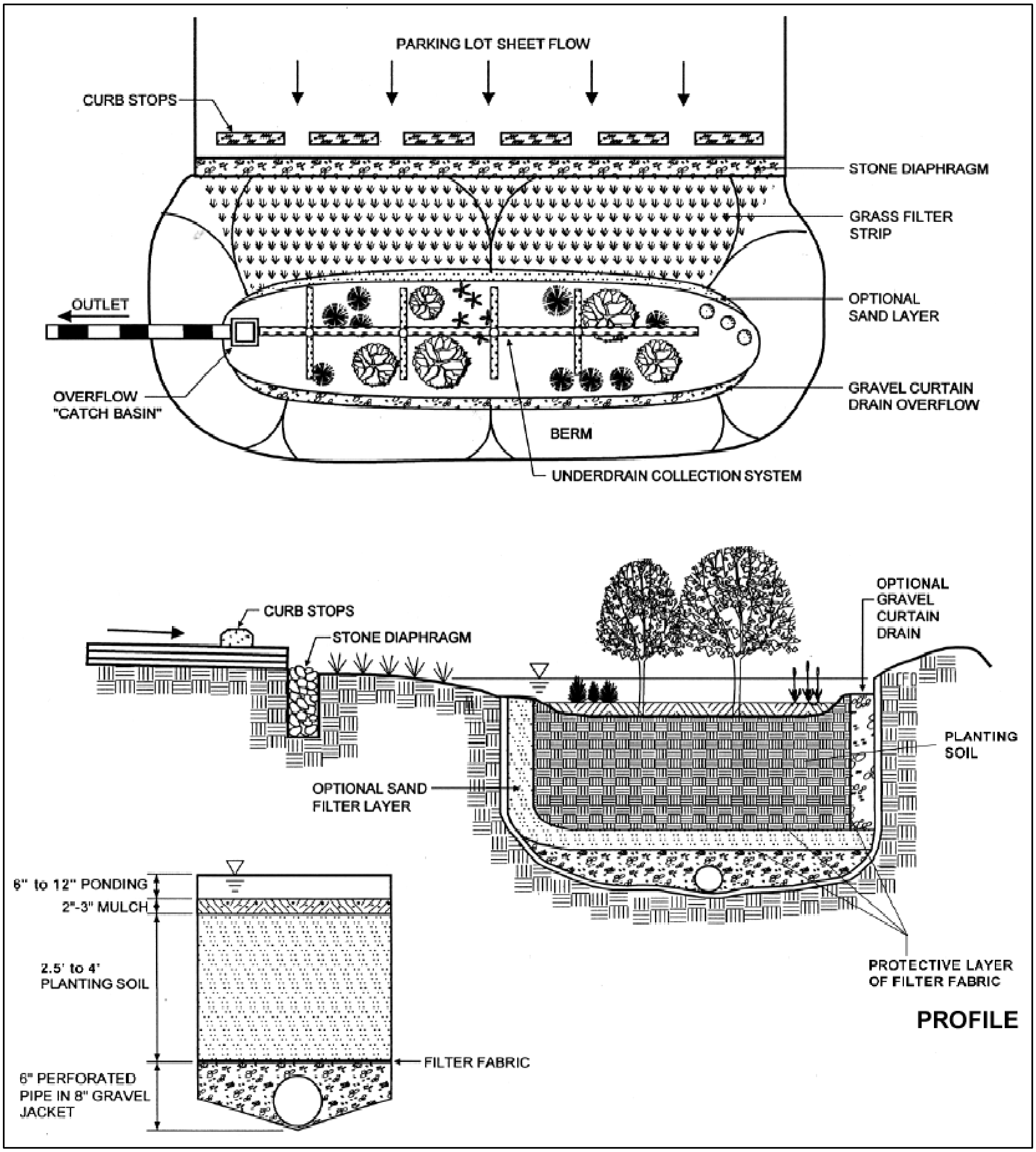


Figure 5.11: Schematic of a bioretention system (MDE, 2000).

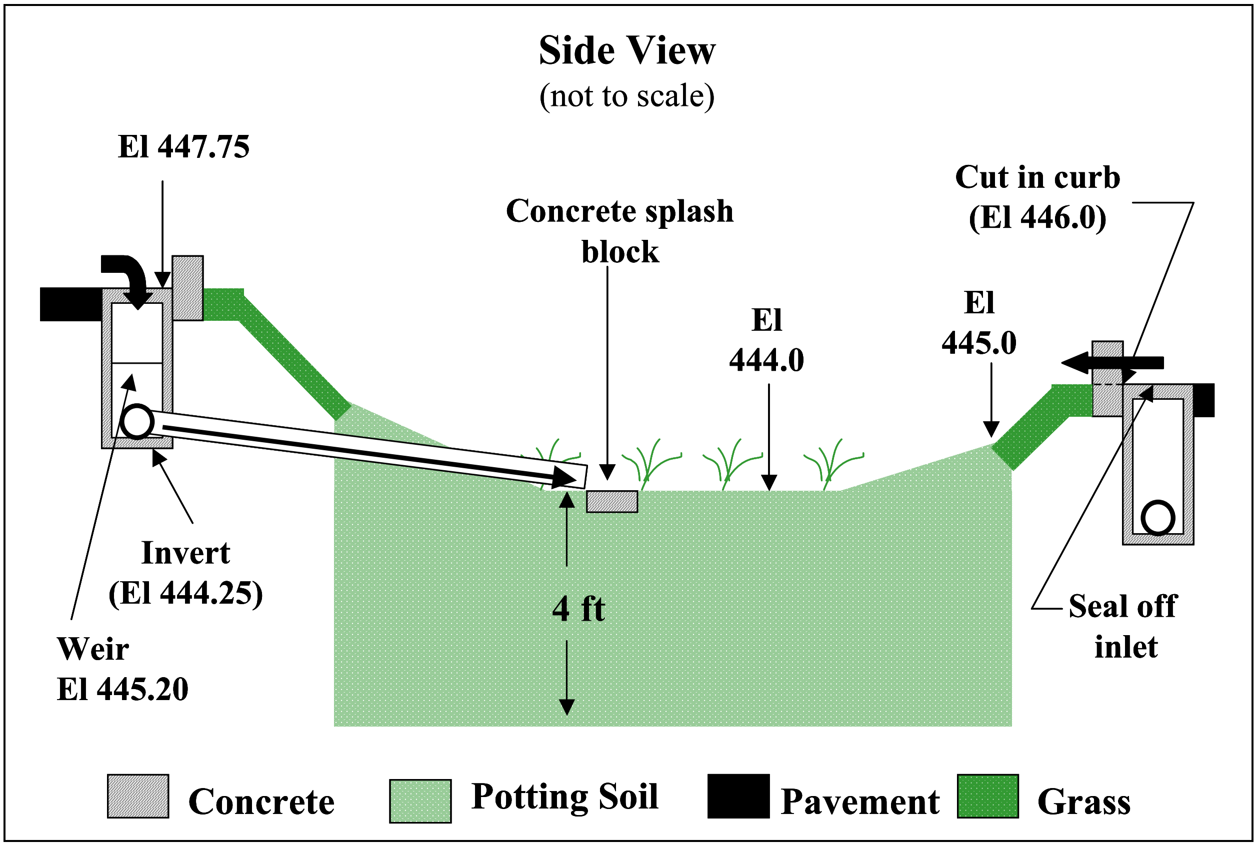


Figure 5.12: Schematic of a bioretention parking lot island (Traver, 2003).

Bioretention should not be used in areas:

- With mature trees;
- With slopes greater than 20 percent;
- With a water table within 6 feet of the land surface;
- With easily erodible soils;
- Below outfalls;
- Where concentrated flows are discharged; or
- Where excavation or cutting will occur.

To determine the appropriate design of the bioretention area with respect to the amount of runoff it receives, Prince George's County, Maryland, Department of Environmental Resources (1993), suggests a design based on a four-day maximum ponding period (appropriate for the Mid-Atlantic region). This four-day period is based on hydrologic, horticultural, and maintenance constraints such as plant tolerance of flooded conditions and mosquito-breeding concerns. Other considerations include infiltration rates for the root zone, sand layer, and in-situ material.

There is some flexibility with respect to size, shape, and placement of vegetation within the bioretention area. Other elements that should be incorporated into the design of the bioretention system include curb openings, a ponding area suitable to handle runoff from larger storms, amended planting soil that provides the desired infiltration rate, and an under-layer sand or gravel bed or underground perforated pipe that facilitates infiltration.

Regular maintenance, including soil pH testing, mulching and repairing eroded areas, inspecting vegetation, ensuring that runoff is infiltrating as designed, and checking for damage caused by large storms, will help to ensure the longevity of bioretention areas. More information about the design, operation, and maintenance of bioretention systems can be found in Coffman and Winogradoff (1999) or Prince George's County, Maryland, Department of Environmental Resources (1993).

As for the performance of bioretention areas, in one research study, simulated runoff was pumped continuously into an area of 5.3 m^2 in six bioretention cells, and effluent samples were collected from the perforated drainpipes underlying the bioretention media. All six bioretention facilities showed greater than 99 percent removal efficiency for oil and grease. Total lead removal efficiency decreased when the TSS level in the effluent increased because lead was adsorbed onto the surface of the solids. TSS removal ranged from 72 to 99 percent, and lead removal rates ranged from 80 to 100 percent. For total phosphorus, the removal efficiency was found to be highly variable, ranging from 37 to 99 percent. Nitrate-nitrogen and ammonium-nitrogen removal efficiencies ranged from 2 to 7 percent and 5 to 49 percent, respectively. Overall, the bioretention cells contributed significantly to water quality improvement (Hsieh and Davis, 2003).

The developer of Somerset Community, a typical suburban development in Prince George's County, Maryland, incorporated bioretention areas into each lot to control runoff quantity and quality. The bioretention areas eliminated the need for a wet pond, allowed the development of six extra lots, and resulted in a cost savings of more than $4,000 per lot. Somerset residents have enthusiastically accepted their bioretention areas, are actively maintaining them, and have lodged few complaints. Safety issues and mosquitoes have not been a problem (Daniels, 1995, and Curry and Wynkoop, 1995).

The Inglewood Demonstration Project in Largo, Maryland, involved retrofitting an existing parking facility with bioretention areas and comparing the pollutant removal efficiency of a bioretention cell in a laboratory setting to that of a comparable facility constructed in a parking lot. This study showed the feasibility of retrofitting an existing parking facility and demonstrated the consistency of laboratory and field pollutant removal performance. Results showed that the runoff temperature was lowered 12 degrees Celsius, lead levels were lowered 79 percent, zinc levels were lowered 78 percent, and numerous other pollutant levels were also considerably reduced. The retrofit cost $4,500 to construct, while usual methods would have cost $15,000 to $20,000 and involved fewer environmental benefits and higher maintenance costs. Also, bioretention areas offer the ancillary benefit of aesthetic enhancement. It is interesting to note that a drought occurred after the installation of the plants, and although many of the other plants in the parking lot died or experienced severe drought stress, those in the bioretention facility survived because of the retained water supply (USEPA, 2000a).

Using Landscaped Rain Gardens to Control Runoff

The city of Maplewood, Minnesota is seeking to improve drainage in its older neighborhoods through the use of rain gardens. A successful pilot project, which was implemented in 1995, was the starting point for the current citywide rain garden initiative. Rain gardens from the pilot project have prevented runoff from flowing out of the area, containing 100 percent of the flow. City officials decided to expand the project when they recognized the aesthetic and environmental benefits resulting from the pilot project rain gardens.

The city is focusing on demonstration, education, and outreach to convey the benefits of using rain gardens for runoff management, rather than requiring homeowners to participate. Although rain gardens can be a solution for people who are opposed to adding curbs and gutters to their streets, some are concerned that rain gardens may attract and breed mosquitoes. Before beginning a street improvement project for a specific neighborhood, the city holds neighborhood meetings and distributes a comprehensive educational mailing and questionnaire to homeowners. These materials contain a fact sheet that explains the purpose of rain gardens, how they are designed, how they work, their benefits, and the plants best suited for a variety of hydrologic conditions. A questionnaire is also included to ascertain existing drainage problems and to determine whether the homeowner would be willing to agree to use a rain garden.

Once a homeowner has decided that they want a rain garden, they choose the location and size. The city works with homeowners to make these types of decisions and to help them comply with restrictions on garden placement caused by existing trees, natural drainage, or the presence of gas and water mains and other utilities. Homeowners may choose from three standard rain garden sizes (12-foot by 24-foot, 10-foot by 20-foot, and 8-foot by 16-foot) and from one of six different garden themes, including an easy shrub garden, easy daylily garden, sunny garden, sunny border garden, butterflies and friends garden, Minnesota prairie garden, and shady garden.

To begin construction, the city's contractor excavates a gently sloping depression to collect the water. Rain garden depths vary depending on garden size and topography. The contractor digs a sump 42 inches wide and 3 feet deep at the deepest part of the garden to accommodate a geotextile filter fabric bag, which is filled with clean crushed rock. The sump promotes rapid infiltration to reduce the standing time of water in the rain garden. After the infiltration sump is in place, the contractor adds at least 8 inches of bedding material (typically a mixture of salvaged topsoil and clean organic compost) and covers the area with 3 to 4 inches of shredded wood mulch. Residents are provided with all necessary plants and a landscape plan at no additional cost. However, many Minnesota municipalities charge residents a street assessment to cover a percentage of the project cost.

The city's rain garden street improvement project typically costs 75 to 85 percent of a traditional curb and gutter project. Costs are kept low because most of the existing street material is recycled to use as the base aggregate. Additionally, plants are obtained at a reasonable cost and residents are responsible for the planting. Other long-term savings, which are difficult to quantify, result from the reduced demand on the city's downstream sewer infrastructure, which is not characteristic of conventional storm systems. The city may also be able to reduce the need for downstream storm sewer system upgrades and construction, including detention and treatment facilities designed to prevent pollution, erosion, and flooding problems.

More information about Maplewood's rain garden project is available from Chris Cavett, Assistant City Engineer, at 651-770-4554 or chris.cavett@ci.maplewood.mn.us (Terrene Institute, 2001).

5.3.4 Detention and Retention Practices

5.3.4.1 Detention ponds and vaults

These practices temporarily detain runoff to ensure that the postdevelopment peak discharge rate is equal to the predevelopment rate for the desired design storm (e.g. two-, 10-, or 25-year). These practices may also be used to provide temporary extended detention to protect downstream channels from erosion (e.g., 24-hour extended detention for a one-year storm).

Extended detention (ED) ponds (Figure 5.13) are an example of this type of facility. ED ponds temporarily detain a portion of urban runoff for up to 24 hours after a storm, using a fixed orifice to regulate outflow at a specified rate and allowing solids and associated pollutants time to settle out. ED ponds are normally dry between storm events and do not have any permanent standing water. These basins are typically composed of two stages: an upper stage, which remains dry except after larger storms, and a lower stage, which is designed for typical storms. Enhanced ED ponds are equipped with plunge pools or forebays near the inlet, a micropool at the outlet, and an adjustable reverse-sloped pipe as the ED control device (NVPDC, 1980; Schueler et al., 1992). Most ED ponds use a riser with an anti-vortex trash rack on top to control large floating solids.

Detention tanks and vaults are underground structures used to control peak runoff flows. They are usually constructed out of concrete (vaults) or corrugated metal pipe (tanks). Underground detention can also be achieved by retrofitting the over-capacity storm drain pipes with baffles. The baffles allow water to be stored in the pipes so it can be released at a slower rate. Pretreatment structures such as water quality inlets and sand filters can be used to treat runoff and remove trash and debris.

These systems are primarily applicable where space is limited and there are no other practical alternatives. Concrete vaults are relatively expensive and are often used to control small flows where system replacement costs are high. Corrugated metal pipe systems are less expensive and are often used to control larger volumes of runoff in parking lots, adjacent to rights-of-way, and in medians. These systems should be located where maintenance can be conducted with minimal disturbance.

Underground detention structures provide runoff quantity control but do not provide significant water quality control without modifications. Corrugated metal pipe systems can work in conjunction with infiltration to provide additional runoff treatment. This is accomplished by adding perforations to the pipe to allow it to store the water until it can be released into the soil (FHWA, no date).

5.3.4.2 Retention ponds

These practices use a permanent pool, extended detention basin, or shallow marsh to remove pollutants and can include:

- Micropool extended detention ponds;
- Wet ponds;
- Wet extended detention ponds; and
- Multiple pond systems.

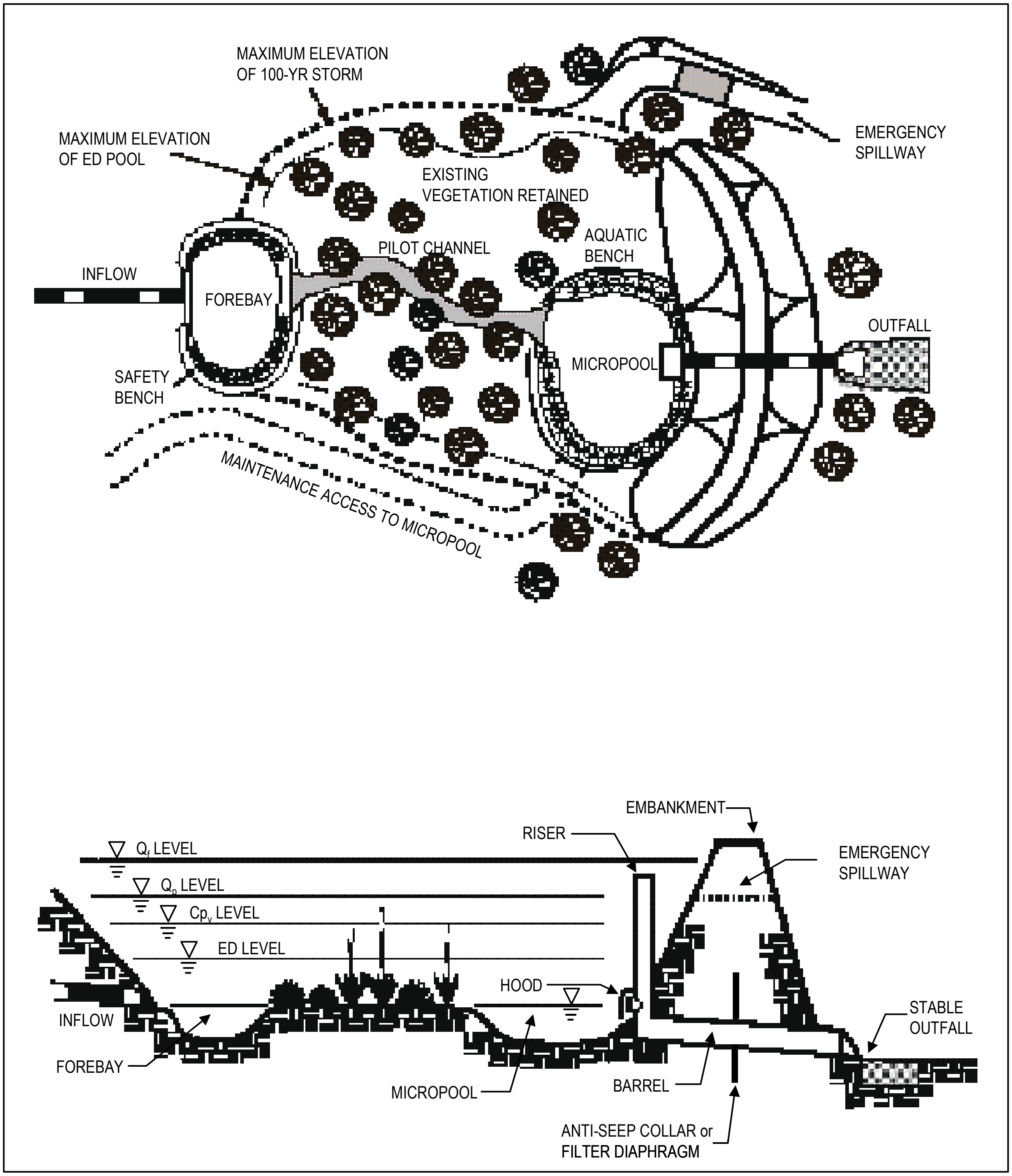


Figure 5.13: Schematic of a dry extended detention pond (MDE, 2000).

Ponds (Figure 5.14) are basins designed to maintain a permanent pool of water and temporarily store runoff (ED wet pond), which is released at a controlled rate. Ponds allow particulates to settle and can provide biological uptake of pollutants such as nitrogen or phosphorus. Enhanced designs include a forebay to trap incoming sediment where it can easily be removed. Often, a

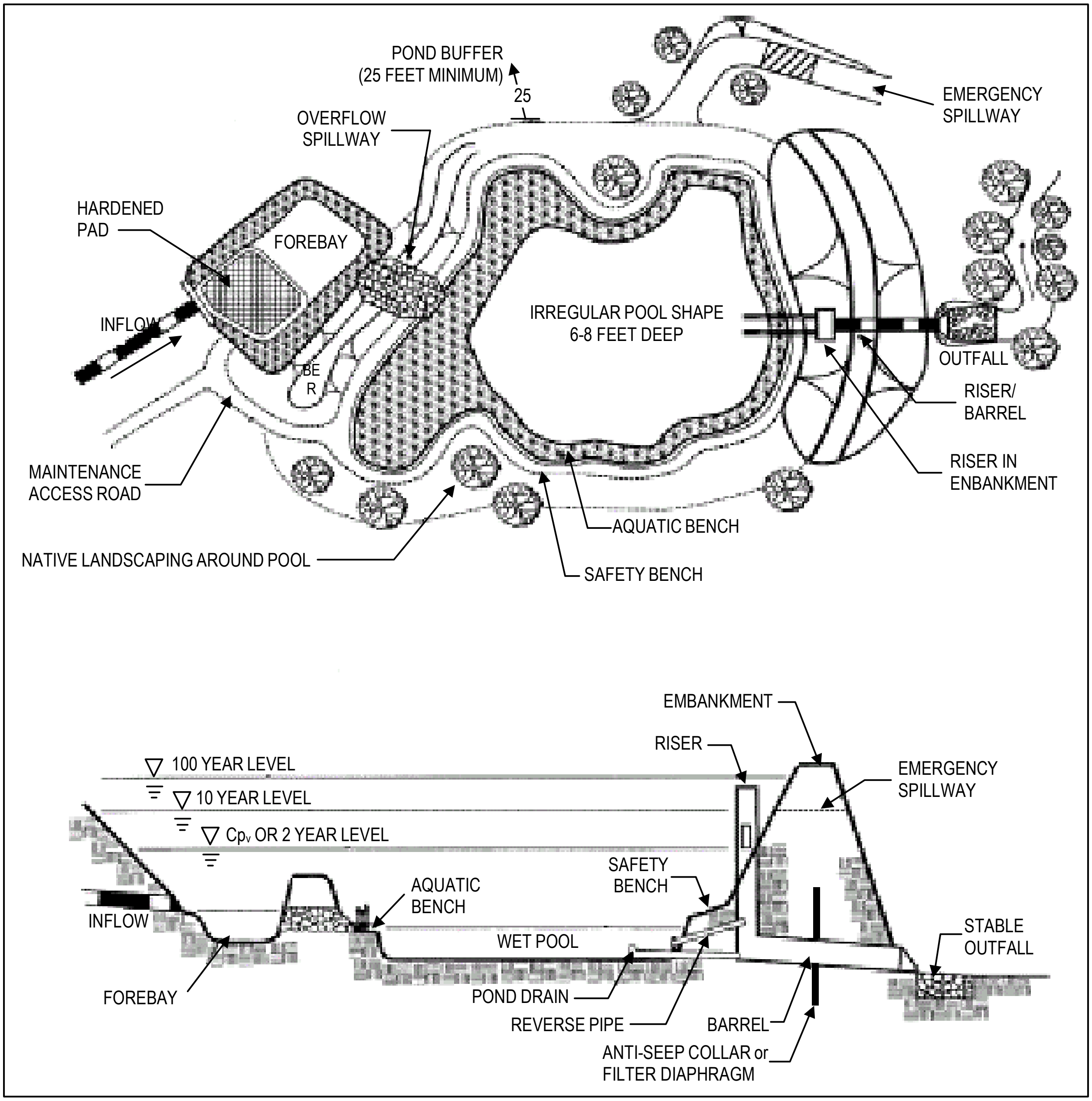


Figure 5.14: Schematic of a wet pond (MDE, 2000).

fringe wetland is installed around the perimeter of the pond to increase the habitat, aesthetic, and pollutant removal values of the facility. An outlet riser, sometimes combined with an anti-vortex trash device, is a common design modification. The design of wet ponds should account for the infiltration of ground water when the wet pond intercepts the water table. Table 5.5 presents several design considerations for ponds.

Table 5.5: Design considerations for ponds and wetlands (MDE, 2000).

Design Consideration	Ponds	Wetlands
Watershed Design Requirements		
Streams in intensely developed areas	Drainage area may limit the applicability of ponds except for pocket ponds.	Drainage area may limit the applicability of ponds except for pocket wetlands.
Cold-water streams	An offline design is recommended. Maximize shading of open pool areas.	An off-line design is recommended. Maximize shading of open pool areas.
Streams in sparsely developed areas	Require additional storage to ensure adequate downstream channel protection.	Require additional storage to ensure adequate downstream channel protection.
Aquifer protection	May require a liner depending on soil type.	May require a liner depending on soil type.
Reservoir protection	Require additional storage to ensure adequate downstream channel protection.	Require additional storage to ensure adequate downstream channel protection.
Shellfish beach located downstream	Provide moderate bacteria removal. Should be designed to prevent geese problems. Should provide permanent pools.	Provide 48-hr extended detention for maximum bacterial die-off.
Terrain Factors		
Low relief	The maximum normal pool depth should be 4 feet (dugout).	Wetlands are suitable for low-relief areas.
Karst	Require a poly or clay liner and geotechnical tests.	Require a poly or clay liner and geotechnical tests.
Mountainous	Embankment heights are restricted.	Embankment heights are restricted.
Physical Feasibility		
Soils	Depending on pond type, they may or may not require a liner or testing.	Certain soils may require a liner.
Water table	Must be at least 2 feet above water table if near a potentially contaminated "hotspot" or if underlain by an aquifer. Pocket ponds by definition are below the water table.	Must be at least 2 feet above water table if near a potentially contaminated "hotspot" or if underlain by an aquifer.
Drainage area	Minimum drainage area is 10 to 25 acres depending on type of pond. Pocket pond has a 5-acre maximum.	Minimum of 25 acres except pocket wetlands, which have a 5-acre maximum.
Site slope	Slopes should always be less than 15%	Slopes should be less than 8%.
Head	A 6- to 8-foot head is needed for all ponds except pocket ponds, which require a 4-foot head.	A 3- to 5-foot head is needed for most wetlands except pocket wetlands, which require a 2- to 3-foot head.
Ultra urban	Only pocket ponds are practical.	Pocket wetlands are sometimes practical; all others impractical.
Runoff Treatment Suitability		
Ground water recharge	No	No
Channel protection	Yes	Yes
Runoff Treatment Suitability (continued)		
Ground water recharge	No	No
Channel protection	Yes	Yes
Water quantity control	Yes	Yes
Large space requirements	Less space	More space
Community and Environmental Factors		
Maintenance	Easier	More difficult
Community acceptance	More acceptable	Less acceptable
Affordability	More affordable	Less affordable
Wildlife habitat	Yes	Yes

Used in combination with on-site and nonstructural practices, regional ponds are an important component of a runoff management program. The costs and benefits of regional, or off-site, practices compared to on-site practices should be considered as part of a comprehensive management program. For example, regional ponds can be located to treat runoff from existing development, and will result in overall net reductions on pollutant loads for the watershed (Fairfax County Environmental Coordinating Committee, 2002). Regional facilities can incorporate more advanced treatment technologies than on-site facilities (Maupin and Wagner, 2003). They can also provide community recreation and wildlife benefits, reduce peak and total flow, and be easier to maintain than dispersed controls. The City of Fairfax, Virginia, found that maintenance costs for a regional pond were about one-sixth those of on-site ponds (Fairfax County Environmental Coordinating Committee, 2002). Maintenance responsibilities and liability for regional runoff facilities belong to the municipality (Maupin and Wagner, 2003).

A study of 43 wadeable streams in Austin, Texas, showed that several indicators of stream health (ephemeroptera-plecoptera-trichoptera (EPT) richness and percent EPT abundance) were higher in streams with storm water ponds protecting 60 to 95 percent of their catchments than in streams with no storm water controls (Maxted and Scoggins, 2004). This trend was only significant in fully developed watersheds (having greater than 40 percent impervious cover). In watersheds with less than 40 percent impervious cover, storm water ponds had no significant impact on EPT richness or percent EPT abundance. The researchers attributed the lack of effects of storm water ponds to urban development in the reference watersheds and to the nature of the biological index used to gauge stream health, which was not tailored to the specific environmental conditions of the Austin area.

Research has shown that storm water ponds can increase property values. A survey in Columbia, Maryland, found that 75 percent of homeowners felt that permanent bodies of water such as storm water ponds added to real estate values. Seventy-three percent were willing to pay more for property located in a neighborhood with storm water control basins designed to enhance fish or wildlife uses (Adams et al., 1984; Tourbier and Westmacott, 1992; USEPA, 1995). Residents of a Champaign-Urbana, Illinois, neighborhood with storm water ponds stated that lots adjacent to a wet pond were worth an average of 21.9 percent more than comparable non-adjacent lots in the same subdivision. The same survey revealed that 82 percent would in the future be willing to pay a premium for a lot adjacent to a wet pond (Emmerling-DiNovo, 1995). In Alexandria, Virginia, condominiums alongside a 14-acre runoff detention pond sold for $7,500 more than comparable units not adjacent to the pond (USEPA, 1995).

Regional ponds do not, however, provide protection in contributing drainage systems, including upstream tributaries. These can experience damage from increased peak flow and flow volume. In addition, placement of regional ponds in low-lying areas may harm natural wetlands, and the ponds may create safety and liability issues. Siting ponds or other structural management practices within natural buffer areas and wetlands degrades their functions and may interrupt surface water and ground water flow when soils are disturbed for installation.

5.3.4.3 Constructed wetlands

Constructed wetlands (Figure 5.15) are engineered systems designed to treat runoff. They are typically designed to provide some of the functions of natural wetlands, e.g., wildlife habitat, in

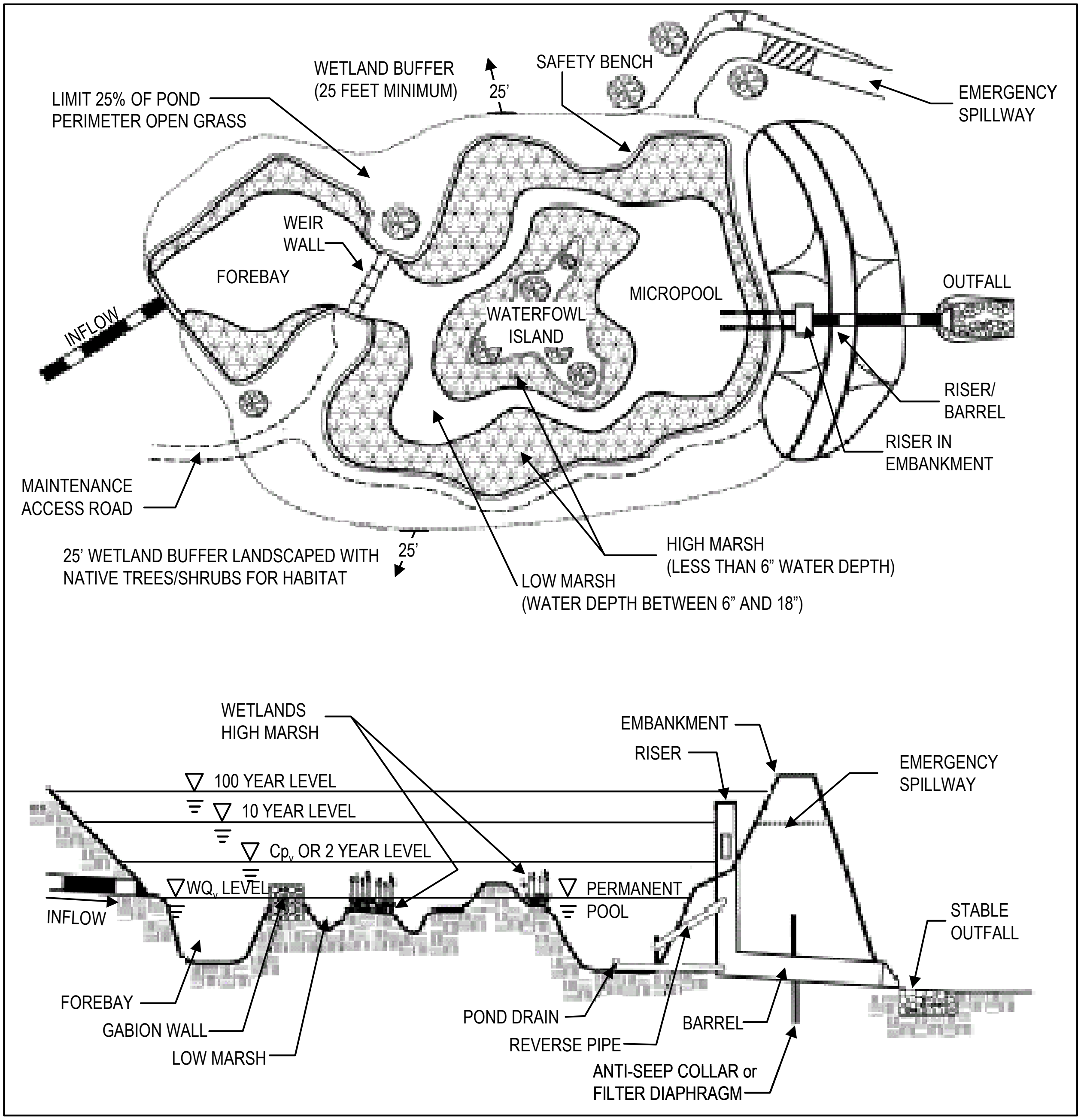


Figure 5.15: Schematic of a shallow wetland (MDE, 2000).

addition to controlling runoff volumes and pollutant loadings. There are many variations of constructed wetlands, such as shallow wetlands, extended detention wetlands, pond/wetland systems, and small isolated "pocket" wetlands. Constructed wetlands may contain some or all of the following elements: shallow vegetated areas, permanent pools, sediment forebays, transition areas, and weirs. Designs are intended to slow flow through the wetlands and provide maximum contact with wetland vegetation.

It should be noted, however, that constructed wetlands rarely replicate the functions of natural wetlands and should not be used for compensatory mitigation of natural wetlands and buffers.

Furthermore, constructed wetlands should be designed to receive periodic maintenance to ensure the wetland continues to function as designed.

Constructed wetlands are feasible at most sites and drainage areas where there is enough rainfall and/or snowmelt to maintain a permanent pool. In areas with highly permeable soils, other impermeable barriers, such as synthetic liners or clay, sometimes can be used to maintain enough water or moisture to support the wetland. Constructed wetlands should be located contiguous to existing wetlands wherever possible, unless there is concern about contaminants that may pose a threat to wildlife. Although it is technically feasible to construct a wetland on a small site (less than 1 acre), alternative control strategies should be considered when land constraints are present.

Constructed wetland systems can take several forms, including wet ponds with a wetland fringe, swale/ditch wetland depressions, and large-scale constructed wetlands used as mitigation wetlands or treatment wetlands. The choice of wetland designs depends on watershed characteristics, spatial and geomorphic constraints, runoff treatment requirements, and community and environmental factors. These considerations are outlined in Table 5.5.

In the San Diego Creek Watershed in southern California, constructed wetlands are being used as a regional runoff control technique. This approach, called the Natural Treatment System (NTS) Plan, is part of a watershed-wide management effort to meet total maximum daily load (TMDL) requirements for the San Diego Creek, which is impaired by sediment, nutrients, pathogens, heavy metals, and pesticides. The results of water quality modeling that accounted for the combined effects of the 44 planned facilities indicated that the TMDL for total nitrogen in base flows would be achieved, total phosphorus targets would be met in all but the wettest years and the fecal coliform target would be met in the dry season. While the NTS Plan is not meant to meet the TMDL for sediment, it will capture 1,900 tons annually, and the wetlands are estimated to remove 18 percent of the total zinc and 11 percent of the total copper and lead in runoff (Strecker et al., 2003).

New York City Bluebelt

The New York City Department of Environmental Protection (NYCDEP) has taken an innovative approach to solving drainage problems that have long plagued southern Staten Island. Instead of installing a conventional piped storm sewer system that would destroy the existing wetlands through drainage or filling, NYCDEP proposed to use a natural drainage system to convey, store, and filter runoff. The plan involves both preserving and restoring wetlands. In 1991, the agency began purchasing land along wetland corridors, and soon this network of property was termed the Bluebelt, because it mirrors the role a Greenbelt plays for open space areas by protecting water resources. The Bluebelt area is a total of 10,000 acres and includes 16 watersheds.

The constructed wetlands in the Bluebelt range from 0.5 to 2 acres in area and have a permanent pool that ranges from 12 to 24 inches deep. The wetlands are intended to provide water quality, flood control, and flow attenuation benefits for the region. More than 100 management practices were screened for their applicability, and in addition to constructed wetlands, meandering streams and outlet stilling basins were installed. Meandering streams convey runoff in open channels, providing a basis for the establishment and preservation of riparian areas. Outlet stilling basins mitigate the high velocities of runoff exiting conventional pipes. In the past 12 years, approximately half of the 89 planned management practices have been designed (Vokral et al, 2003).

Desert Wetlands

A constructed wetland demonstration project is being tested in the Sonoran Desert to improve the New River, which consists primarily of wastewater from Mexico and agricultural drain water from California's Imperial Valley (Fortner, 2000). Without these two sources of water, the New River would run dry. Near Imperial, California, about halfway along the New River, 68 acres of wetlands were constructed as a demonstration project. These wetlands use a series of six cells to remove sediments and other pollutants from irrigation drain water. A few miles downstream, in Brawley, California, a similar project will treat water that is diverted directly from the New River. The site for this project consists of 7 acres and three cells. The two sites are collectively referred to as the Brawley Constructed Wetlands Demonstration Project.

The project is described as one of the most challenging constructed wetlands projects in the United States and will help researchers determine the best design for treating river and agricultural drain water. Scientists are aware that it will be challenging to construct a wetland to treat a severely impaired waterbody in a desert area. They will monitor the performance of the test sites before additional wetlands are built. Once the data is obtained, the Citizens' Congressional Task Force for the New River (comprised of citizens and representatives from environmental groups, local community organizations, and state and federal agencies) will decide whether to expand the project.

Wetlands and other runoff control systems should not be sited in areas where they disrupt or significantly alter the predevelopment hydrology unless restoration objectives apply. When designing the wetland, a variety of physical characteristics should be used to promote multiple wildlife and habitat functions. For example, an irregular shape increases the perimeter of the system and provides a greater variety of microhabitats along the shoreline. Also, an irregular shoreline can extend the perimeter of a constructed wetland by 10 to 20 percent with no increase in land requirements.

Shallow-water wetlands do not contain a large volume of water per surface area as would a typical wet pond. In general, the wetland should have a shallow slope with a permanent pool in the middle. To enable growth of emergent vegetation, static water depths should not exceed 2 to 3 feet. Depths greater than 2 to 3 feet are conducive to the growth of submerged aquatic vegetation. The use of deeper water (>3 feet) in an area that is easily accessible for small children should be discouraged. No area of the pond should have a depth greater than four feet. In general, 50 percent of the pond should have depths less than one foot, 30 percent should be 1 foot to 2 feet deep, and 20 percent should be 2 to 4 feet deep. Greater depths are allowable for the inflow forebay and around the outlet structure.

The Maryland Department of the Environment (2000) requires that the first inch of runoff from the site must be controlled and released over a 24-hour period to provide water quality treatment, while peak discharge control of the two- and 10-year storms must be provided for water quantity control. Local requirements should be used when designing the treatment capacity of a constructed wetland. Other factors such as steep slopes may necessitate deeper ponds to obtain adequate runoff control.

Individual soil analyses should be done during the site design phase to determine if a clay or plastic liner is needed to maintain a wetland environment. Wetland vegetation cannot usually survive unless a base flow is available to provide a permanent pool to keep plants wet. Rapid infiltration will remove this needed pool. If a liner is needed, it should have at least 1 foot of

The Use of Wetlands to Reduce Fecal Coliform

Unusually high levels of fecal coliform have been found in an area of Laguna Niguel, California. Runoff from a neighborhood is washing into Aliso Creek and then to the Pacific Ocean. In response to a cleanup order issued by state water regulators, city officials built a series of wetlands to filter fecal coliform out of runoff. The natural water treatment system will work in combination with an existing wetland, which has already been proven successful in cleaning waters to a level acceptable for swimming.

Upon completion, water will flow through a series of four stepped ponds, spread out, and remain in the wetlands for hours or days of treatment. It is estimated that it will take a year for all vegetation to grow in and nearly two years to attain maximum removal of bacteria. When the wetlands system is complete, the existing wetland will treat 35 to 40 percent of the runoff and the new wetlands will treat 35 percent of the runoff. The city hopes that the new wetlands will work as well as the existing wetlands in reducing fecal coliform from urban runoff (Vardon, 2000).

clean fill material placed on top of it for wetland plant growth (the fill material will also reduce the potential for puncture).

An island placed in the wetland can extend the length of the flow path that runoff must travel to traverse the pond. This increased flow path enhances the pollution removal function of the constructed wetland. The highest elevation of the island should be above that reachable by storage of the first inch of runoff. Islands in wetlands may attract geese, which can be undesirable in some urban settings, but there are ways to minimize habitat for geese in a constructed wetland. Because most runoff management ponds are fairly small compared with a natural marsh system, they do not provide the long glide path preferred by geese for landing and takeoff. Planting woody vegetation or allowing areas around the pond to grow without mowing also tends to discourage goose residency.

The following are typical elements of a constructed wetland:

(1) *Sediment forebays*. It is important that sediment forebays be placed at all locations where runoff enters the wetland. A forebay is designed for vehicle access to facilitate sediment removal while preventing disturbance of substrate that could disrupt wetland functions. The forebay should constitute approximately 10 percent of the total basin volume and should have a maximum depth of 4 feet. Where there are multiple inlets to the constructed wetland, the total volume of all the forebays should be 10 percent of the basin volume, with individual inlet forebays sized with respect to the percentage of contributing flow they receive. The use of stone riprap in the forebay will reduce the velocity of flow into the wetland portion of the basin and minimize resuspension of deposited sediments. An access to the forebay should be provided for cleanout equipment. An area adjacent to the constructed wetland should be set aside for disposal of the sediments that become trapped and are removed during periodic maintenance.

    The cleanout frequency of sediment forebays depends on the sediment load entering the constructed wetland. Each forebay should be inspected annually to ensure cleanout is being conducted as needed. Once the forebay has been filled to approximately 50 percent of its total volume (every 10 to 15 years), sediment should be removed, placed in an appropriate upland location, and stabilized. Costs for sediment forebay maintenance, including periodic inspection and cleaning, should be budgeted as a long-term operating expense if this practice is selected.

(2) *Diversion weir*. Diversion weirs may be needed for designs where the entire runoff volume is not directed to the constructed wetland. This diverted fraction of the runoff is often routed to collection systems or inlets. The amount of rainfall that may be diverted will vary according to local requirements and design objectives.

(3) *Outlet*. As is the case with all ponds having a normal pool of water, algae can clog outlets with small orifices that are needed for extended detention. A below-surface withdrawal structure may reduce or eliminate this problem.

(4) *Transition zone*. The maximum slope of the transition zone on wetland side slopes should be no greater than 10:1 (horizontal:vertical) and should extend at least 20 feet from the design pool of the constructed wetland. This area will be temporarily flooded whenever runoff is temporarily detained. Planting trees in the transition zone enhances nutrient uptake; the shading reduces temperature increases common in open water areas; and the trees provide habitat for wildlife. The transition zone should be mowed no more than once a year in late fall. Optimally, to promote the growth of woody vegetation, the transition area should not be mowed at all unless the pond is an embankment pond, in which case it should be mowed annually to prevent woody vegetation on the embankment.

(5) *Vegetation*. Placement of organic soils on the bottom of the pond will provide faster growth of planted or volunteer vegetation. Constructed wetlands should initially be planted with emergent plants and woody shrubs, and the wetlands should be allowed to succeed to a system dominated by woody shrubs and trees. The emergent wetland plants that are chosen should have tops that rise above the normal pool level.

It is important to consult local ecologists/plant specialists to choose suitable wetland species and to design a landscaping plan with appropriate vegetation density and spacing. Local specialists can also provide information regarding the optimal time to plant vegetation and help to design a maintenance schedule based on vegetation requirements. Native species should be used where feasible because they are well-adapted to local conditions. The USDA has a database (see http://www.plants.usda.gov/) of invasive and noxious species, which should be avoided.

The following specifications are provided as an example and apply to the Mid-Atlantic region (MDE, 2000):

- At least two aggressive species should be planted in the constructed wetland; their purpose is to rapidly spread to other unplanted areas of the wetland. In addition, at least three secondary species should be planted to increase the diversity, wildlife values, and appearance of the wetland. Ideally, plantings should include a mix of perennial and annual species.

- Plants should cover approximately 30 percent of shallow areas, with particular attention paid to areas adjacent to the shoreline. Plants should be spaced 2 to 3 feet apart, and the same species of plants should be planted in a single area to avoid interspecies competition.

- Species that are not recommended for any use in a constructed wetland are *Phragmites australis* (common reed), *Lythrum salicaria* (purple loosestrife), and *Phalaris arundinacea* (reed canary grass). Periodic inspections are important to ensure that exotic or other pest species do not dominate the plant community. In certain situations where there is an initial invasion of an aggressive, undesirable species, selective removal of the plants might be warranted, especially if the plant community that was introduced has not had time to adequately establish itself.

- Depending on site conditions, planting *Typha latifolia* (cattail) may or may not be recommended. Despite the fact that it is considered an exotic species, cattail will eventually dominate the wetland community. Additionally, cattail is an excellent plant for water treatment from a filtration and sedimentation standpoint.

- Planting will be more successful if the water level can be drawn down immediately prior to planting. This drawdown will leave the soils saturated, a condition necessary for the plants, and will improve visibility, especially when a number of people are involved in planting. The potential for damaging previously planted vegetation is reduced if the plants are clearly visible. Upon completion of planting, the outlet structure drain valve should be closed so either storm or base flow can reestablish the normal pool elevation.

- Harvesting wetland plants is only appropriate in areas such as the southern United States where plant growth is the most important mechanism for nutrient uptake. Harvesting is not needed where microbial activity is the dominant pollutant removal mechanism.

Like wet ponds, wetlands can increase adjacent property values. One study in Boulder, Colorado, found that lots located alongside a constructed wetland sold for up to a 30 percent premium over lots with no water view (USEPA, 1995). In Wichita, Kansas, a developer enhanced existing wetlands rather than filling them, and the waterfront lots sell for a premium of up to 150 percent of comparable lots (USEPA, 1995).

5.3.5 Other Practices

Other practices used to control urban runoff have not been studied as extensively as those above but have been used with varying degrees of success. They include:

- Water quality inlets;
- Hydrodynamic devices;
- “Baffle boxes;”
- Catch basin inserts;
- Vegetated filter strips;
- Street surface storage;

- On-lot storage; and
- Microbial disinfection.

In some cases, these practices are used for pretreatment or are part of an overall runoff management system, which is sometimes referred to as a “treatment train.” For example, water quality inlets, catch basin inserts, and vegetated filter strips installed upslope of a wet pond or filtration practice will help remove a portion of the pollutants present in runoff before it enters the pond or filtration practice. These other practices in the treatment train improve runoff quality and can help extend the longevity of the filtration practice and wet pond.

5.3.5.1 Water quality inlets

Water quality inlets are underground retention systems designed to remove settleable solids. There are several water quality inlet designs. In their simplest form, catch basins are single-chambered urban runoff inlets in which the bottom has been lowered to provide 2 to 4 feet of additional space between the outlet pipe and the structure bottom for collection of sediment. Some water quality inlets include a second chamber with a sand filter to provide additional removal of finer suspended solids by filtration. The first chamber provides effective removal of coarse particles and helps prevent premature clogging of the filter medium.

Other water quality inlets include an oil/grit separator. Typical oil/grit separators consist of three chambers. The first chamber removes coarse material and debris; the second chamber provides separation of oil, grease, and gasoline; and the third chamber provides safety relief if blockage occurs (NVPDC, 1980). Although water quality inlets have the potential to perform effectively, they are not recommended because they are usually designed to bypass high flows, which can resuspend captured pollutants and flush them through the water quality inlet. Frequent maintenance and disposal of trapped residuals and hydrocarbons are necessary for these devices to continuously and effectively remove pollutants.

5.3.5.2 Hydrodynamic devices

A variety of engineered hydrodynamic devices, also called swirl separators or swirl concentrators, are available for removing pollutants from runoff. Swirl separators are modifications of the traditional oil-grit separator and include an internal component that creates a swirling motion as runoff flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as runoff moves in this swirling path. Additional compartments or chambers, with or without pads, are sometimes present to trap oil and other floatables. Typically these devices are prefabricated and come in a range of sizes targeted at specific flow rates. At least two technologies are available. One is designed to remove suspended particles, oil, and grease during low flow conditions. The device removes particulate and floatable pollutants from runoff through settling of solids and floating of oils, greases, and litter. Higher runoff flows are diverted around the treatment unit so that scour and increased velocity do not carry the collected pollutants out of the treatment chamber. Maintenance requirements include the periodic removal of oil, greases, and sediments, typically by using a vacuum truck.

A second type of hydrodynamic device uses centrifugal motion to remove litter and debris and, potentially, larger sediment particles from runoff. This technology is designed to capture trash rather than pollutants, and therefore it is most applicable in coastal areas and areas that receive heavy trash loads such as leaf litter, plastics, and cans. Prefabricated units are currently available with capacities up to 300 cubic feet per second (cfs). The devices are constructed so that a vacuum truck can regularly remove the floatable and settleable debris collected in the treatment chamber.

Limited data are available on the performance of these devices, and independently conducted studies suggest marginal fine particle and soluble pollutant removal. Therefore, swirl separators should not be used as a stand-alone practice for new development. Also, these devices require regular maintenance. Communities may reduce maintenance costs by sharing a vactor truck. Swirl separators are best installed on highly impervious sites. These products have application as pretreatment to another runoff treatment practice and in a retrofit situation where space is limited.

5.3.5.3 Baffle boxes

Sediment control devices called "baffle boxes" have been used in Brevard County, Florida, as an "end of pipe" treatment method (England, 1996). They are concrete or fiberglass boxes, typically 10 to 15 feet long and 6 to 8 feet high, which are placed at the end of existing storm drain pipes. The box is divided into multiple chambers by weirs set at the same level as the pipe invert to minimize hydraulic losses. Trash screens are incorporated in the design to remove floating debris. Baffle boxes have been shown to have a removal efficiency of up to 90 percent for sand or sandy clay at entrance velocities of up to 6 feet per second, and 28 percent removal efficiency for fly ash at the same velocity. Baffle box designs can be modified to serve as a retrofit installation at curb or manhole inlets or beneath grates. Regular maintenance, especially removal of sediment and debris, is essential to maintain the effectiveness of this practice.

5.3.5.4 Catch basin inserts

Catch basin inserts consist of a frame that fits below the inlet grate of a catch basin and can be fitted with various trays that target specific pollutants. Typically the frame and trays are made of stainless steel, cast iron, or aluminum to resist corrosion. The trays may contain a variety of media. Often more than one tray is included in the design with the first tray filtering out sediment. Subsequent trays typically address a specific targeted pollutant, (e.g., wood fiber or other absorbent materials for oils and grease, or activated carbon for organics, fertilizers, and pesticides). The device is typically designed to accept the design flow rate of the inlet grate with bypasses as the trays become clogged with debris. The media require routine maintenance for replacement, cleaning, or regeneration. Catch basin inserts are typically used for smaller drainage areas. Usually the media need replacement on a quarterly basis.

The City of Santa Monica installs catch basin inserts that catch trash and debris in areas of high pedestrian traffic. Catch basin screens attach to the face of the curb and block trash from the storm drain, allowing debris to be easily removed by maintenance personnel or a street sweeper. Inserts that also filter hydrocarbons are installed on streets with automotive businesses. The city has found these practices to be effective when they are chosen carefully to suit site characteristics and are carefully installed and maintained (Shapiro, 2003).

5.3.5.5 Alum

Alum, which is an aluminum sulfate salt, can be added to storm water to cause fine particles to flocculate and settle out (USEPA, 2001a). It can help meet downstream pollutant concentration loads by reducing the concentrations of fine particles and soluble phosphorus. Alum can be added directly to or just before a pond or lake inlet, and booms can be used to ensure quiescent settling. When alum is injected into runoff it forms the harmless precipitates aluminum phosphate and aluminum hydroxide. These precipitates combine with heavy metals and phosphorus, causing them to be deposited into the sediments in a stable, inactive state. The collected mass of alum pollutants, precipitates, and sediments is commonly referred to as “floc.” Frequent maintenance and disposal of the floc is required for continuous and effective operation.

5.3.5.6 Vegetated filter strips

Vegetated filter strips (VFSs) (Figure 5.16) are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. Dense vegetative cover facilitates sediment attenuation and pollutant removal. Unlike grassed swales, vegetated filter strips are effective only for overland sheet flow and provide little treatment for concentrated flows. Grading and level spreaders can be used to create a uniformly sloping area that distributes the runoff evenly across the filter strip (Dillaha et al., 1989). Vegetated filter strips are often used as pretreatment for other structural practices, such as infiltration basins and infiltration trenches.

Typically, VFSs are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the practice treats but the length of flow leading to it. As runoff flows over the ground surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets that are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip.

VFSs should be designed on slopes between 2 and 6 percent. Steeper slopes encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff ponds on the surface on slopes flatter than 2 percent, creating potential mosquito-breeding habitat. Filter strips should not be used on soils with high clay content because they require infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor. Filter strips should be separated from the ground water by 2 to 4 feet to prevent contamination and to ensure that they do not remain wet between storms.

The design of VFSs is straightforward because they are not much more than a grassed slope. However, the following design features are critical to ensure that the filter strip provides some minimum amount of water quality treatment:

- A pea gravel diaphragm or stone drop should be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

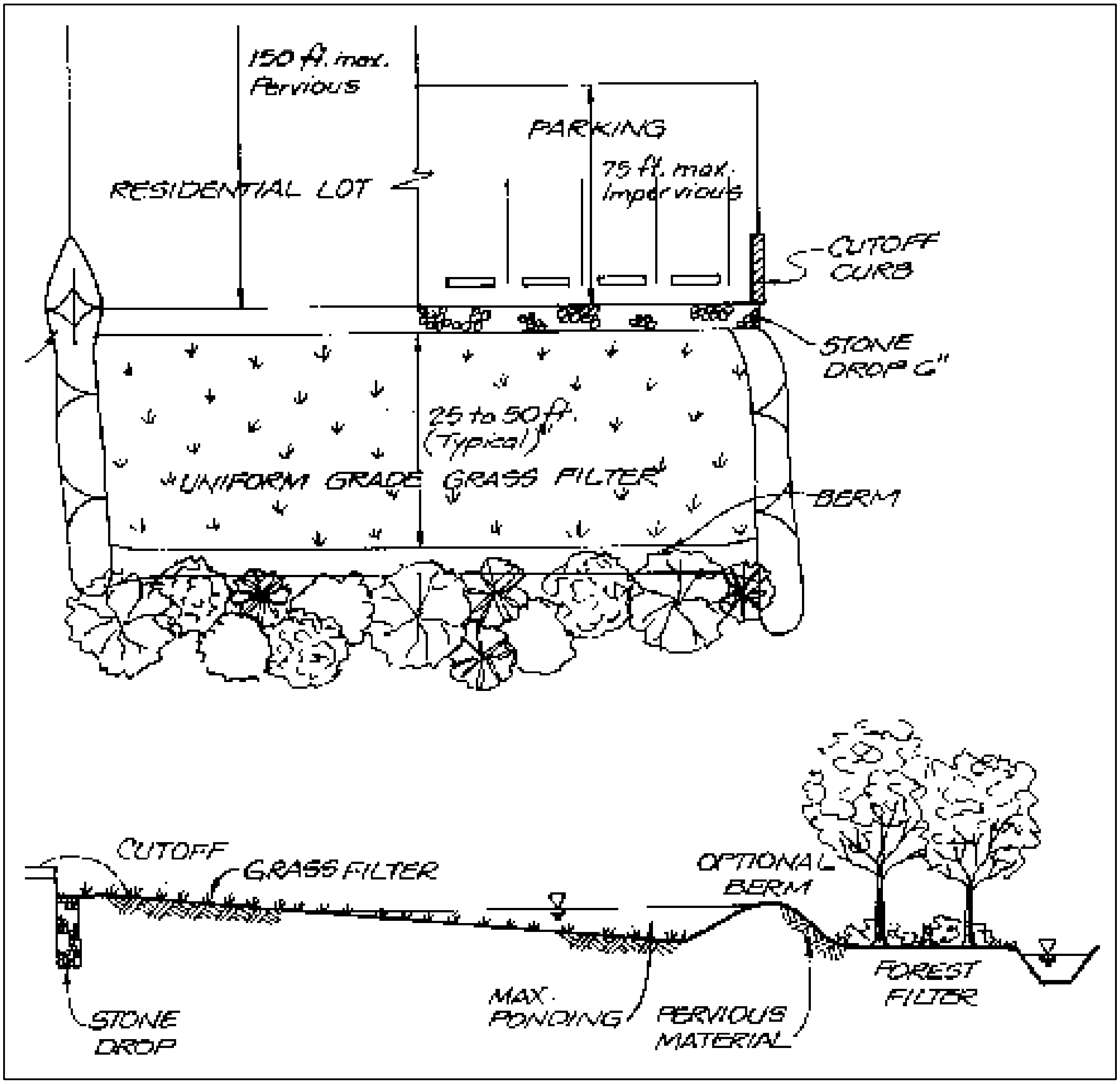


Figure 5.16: Schematic of a vegetated filter strip (Claytor and Schueler, 1996).

- The filter strip should be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½-inch of runoff over the entire drainage area to the practice.

- The filter strip should have a length of at least 25 feet to provide water quality treatment.

- Vegetation must be able to withstand relatively high velocity flows and both wet and dry periods.
- The slope should have a flat top and toe to encourage sheet flow and prevent erosion.

5.3.5.7 Street surface and subsurface storage

Figure 5.17: Runoff pooling on a street surface designed for temporary storage.

Runoff can be temporarily stored on and below the surface of streets in urban areas, as shown in Figure 5.17, to reduce peak flows to the storm sewer system (Carr et al., 1999). Runoff can be retained on and below the street using a combination of berms, flow regulators, and below-surface storage. Berms resemble speed bumps or speed humps but are broader and gentler; they retain water in a shallow pool on the street surface upstream of the berm. In some cases, this type of surface storage is inappropriate because it can result in damage to roadways. An alternative is subsurface storage in tanks or large sewer pipes. Both above- and below-ground storage systems, when combined with flow regulators that allow only a limited amount of runoff to enter the sewer system, mitigate basement flooding, combined sewer overflows, sanitary sewer overflows, and surface flooding. These systems should be designed with public safety in mind to minimize hydroplaning and icing in cold climates.

Two suburban Chicago, Illinois, towns—Skokie and Wilmette—implemented street-surface storage of runoff. The Skokie system has 2,900 flow regulators, 871 berms, 10 off-street storage facilities, 83 subsurface facilities, and several new storm and combined sewers (USEPA, 2000b). Wilmette’s runoff storage system is composed of essentially all street storage. These systems have been effective in preventing flooding and overflows and are less expensive than other alternatives such as sewer separation and relief sewers. More information about these studies can be found at http://www.epa.gov/ednnrmrl/publications/reports/epa600r00065/epa600r00065.htm.

5.3.5.8 On-lot storage practices

The term “on-lot storage” refers to a series of practices that are designed to contain runoff from individual lots. The purpose of most on-lot practices is to manage rooftop or parking area runoff. The primary advantage of managing runoff from rooftops and parking lots is to disconnect these impervious surfaces, reducing the effective impervious cover in a watershed.

Johnston et al. (2003) modeled the downstream hydrologic and economic impacts of on-site runoff storage based on flood risk reduction on property values and costs of storm drainage infrastructure. They found that use of reduced runoff practices provided property value benefits due to decreased flood risk of $21,600 to $36,300 per acre using countywide assessed values, or $17,540 to $29,240 per acre using U.S. Census Bureau census block median housing values. Benefits in avoided costs for storm drainage infrastructure (road culverts) totaled $247 to $836 per developed acre.

Although there are many on-lot treatment options, they can all be classified into one of three categories: (1) practices that infiltrate runoff; (2) practices that divert runoff to a pervious area; and (3) practices that store runoff for later use. The best option depends on the goals of a community, the feasibility at a specific site, and the preferences of the property owner.

Rooftop Runoff

Rooftop runoff, particularly in residential areas, generally has low pollutant concentrations compared with other urban sources (Schueler, 1994). Information on green rooftops can be found in Section 4.3.2.2. The practice most often used to infiltrate rooftop runoff is the dry well. In this design, the storm drain is directed to an underground rock-filled trench that is similar in design to an infiltration trench. French drains or Dutch drains can also be used for this purpose. In these designs, the relatively deep dry well is replaced with a long trench with a perforated pipe within the gravel bed to distribute flow throughout the length of the trench. Chamber systems, a widely marketed proprietary product, can be used in a similar manner.

Runoff can be diverted to a pervious area or to a treatment area using site grading or channels and berms. Treatment options can include grassed swales, bioretention cells, or filter strips. The bioretention design can be simplified for an on-lot application by limiting the pretreatment filter and in some cases eliminating the underdrain. Alternatively, rooftop runoff can simply be diverted to pervious lawn areas instead of discharging it directly to the street or a pipe drainage system.

Practices that store rooftop runoff, such as cisterns, chambers, and rain barrels (Figure 5.18), are the simplest designs for on-lot treatment systems. Some of these practices are available commercially and can be applied in a variety of site conditions. Cisterns and rain barrels are particularly valuable in the arid Southwest, where water is at a premium, rainfall is infrequent, and reuse for irrigation can save homeowners money.

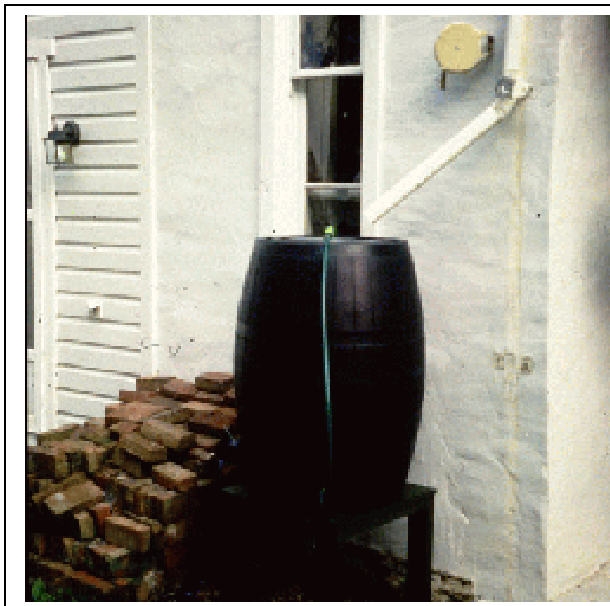


Figure 5.18: A rain barrel that collects runoff from a roof gutter downspout.

Rain barrels typically range in cost from $60 to $135. These prices do not always include the cost of additional parts needed to link the rain barrel to a downspout. These parts generally range in cost from $5 to $18, depending on the manufacturer and the design of the rain barrel (Gardener's, 2001; Jade Mountain, 2000; Midwest, 2001; Spruce Creek, 2001). If homeowners want to save money, they can build their own rain barrel, which costs approximately $15 if recycled drums are available.

Information about building a simple rain barrel is available from the Maryland Green Building Program at http://www.dnr.state.md.us/ed/rainbarrel.html (MDNR, no date). Information is also available in *How to Make a Rain Barrel*, which was published by the city of Ottawa, Ontario (no date). The manual is available by contacting the city of Ottawa toll-free at 866-261-9799, or by e-mailing info@city.ottawa.on.ca.

It is important for municipalities planning to start a rain barrel program to consider water quality issues, climate, algae and mosquito control, homeowner attitudes and willingness, and the protection of home foundations. Rain barrels can be a reliable source of water for garden and lawn watering, but if the water is intended for consumption it is crucial that the roof materials and gutter system be examined for asbestos, lead paint, and bird droppings (Sands and Chapman, 2003).

The Milwaukee Metropolitan Sewerage District (MMSD) undertook a rain barrel project in response to problems with combined sewer overflows. The project involved 40,000 single-family homes with roof areas of approximately 1,200 square feet. Two 90-gallon rain barrels were installed at each home. The MMSD found the reduction in runoff volume attributed to rain barrels to be approximately 243 million gallons. While the effort did not reduce combined sewer overflow volumes for the MMSD, it did result in savings on treatment plant costs and increased environmental awareness. The MMSD plans to continue to incorporate rain barrels into an integrated management plan that might include additional on-lot treatment practices (Sands and Chapman, 2003).

On-lot treatment practices can be applied to almost all sites with very few exceptions (e.g., very small lots or lots with no landscaping). There are currently at least two jurisdictions that offer "credits" in exchange for the application of on-site runoff management practices. In Denver, Colorado, sites designed with methods to reduce "directly connected impervious cover," including disconnection of downspout runoff from the storm drain system, are permitted to use a lower impervious area when computing the required storage of runoff management facilities (DUDFC, 1992). Similarly, new regulations for Maryland allow designers to subtract each rooftop that is disconnected from the total site impervious cover when calculating required storage in runoff management practices (MDE, 2000).

Although most residential lots can incorporate on-lot treatment, the best option for a site depends on design constraints and the preferences of the homeowner. On-lot infiltration practices have the same restrictions regarding soils as other infiltration practices. If other design practices are used, such as bioretention or grassed swales, they need to meet the siting requirements of those sites. Of all of the practices, cisterns and rain barrels have the fewest site constraints. In order for the practice to be effective, however, homeowners need to have a use for the water stored in the practice, and the design must accommodate overflow and winter freezing conditions.

Although these runoff management practices are simple compared with many others, their design needs to incorporate the same basic elements. Pretreatment is important for all of these practices to ensure that they do not become clogged with leaves or other debris. Infiltration practices may

Santa Monica Urban Runoff Program

Santa Monica's comprehensive urban runoff program combines pollution prevention and on-site practices with a runoff recycling program designed to improve water quality and harvest dry weather runoff as a resource. By protecting existing water resources, increasing infiltration on-site, and harvesting runoff for reuse, the city is maximizing the use of storm water as a resource and decreasing the demand for imported water. The city's pollution prevention program protects water quality with education, municipal housekeeping, lawn care and landscaping practices, and an ordinance that requires good housekeeping practices on construction sites. On-site practices are required by the Urban Runoff Pollution Mitigation Ordinance and include infiltration practices, porous pavement, and other low impact development techniques. The city has also installed catch basin inserts and screens to capture trash, debris, and some soluble pollutants. Finally, the Santa Monica Urban Runoff Recycling Facility (SMURRF) harvests and treats dry weather runoff and makes it available for reuse as irrigation water or for indoor toilet flushing (Shapiro, 2003).

be preceded with a settling tank or, at a minimum, a grate or filter in the downspout to trap leaves and other debris. Rain barrels and cisterns also often incorporate some sort of pretreatment, such as a mesh filter at the top of the barrel or cistern.

Both infiltration practices and storage practices should incorporate some type of bypass so runoff from larger storms flows away from the house. With rain barrels or cisterns, this bypass may be a hose set at a high level within the device that directs runoff away from both the device and the building foundation. These practices also include a hose bib set at the bottom of the device so the homeowner can use the stored water for irrigation or other uses by attaching a standard garden hose to the hose bib.

One important design requirement for on-lot infiltration practices is locating the infiltration area sufficiently far from the house (at least 10 feet) to prevent undermining of the foundation or seepage into the basement.

Infiltration practices require regular removal of sediment and debris settled in the pretreatment area, and the infiltration medium needs to be replaced when it becomes clogged. Rain barrels and cisterns require minimal maintenance, but the homeowner must ensure that the hose remains elevated during the winter to prevent freezing and cracking. In addition, the tank requires cleaning approximately once a year.

On the basis of cost per unit area treated, on-lot practices are relatively expensive compared with other runoff storage and treatment options. It is difficult to make this comparison, however, because the cost burden of on-lot practices is borne directly by homeowners. Typical costs are $100 for a rain barrel and $200 for a dry well or French drain. Often, homeowners can reduce costs by creating their own on-lot practice rather than purchasing a commercial product.

Parking Lot Runoff

Standard parking lots typically drain rapidly through curb and gutter systems to prevent flooding. This practice, however, does little to improve water quality or protect receiving waters from high flows during and after storms. Innovative designs for parking lots incorporate pervious areas for drainage, whether at the perimeter or in various islands within the lot. These pervious areas should be designed to infiltrate runoff at rates that prevent excessive ponding, which could appear unsightly or create safety issues and nuisance mosquito habitat. In cases where existing soils have poor infiltration capacity, better-drained soils should be imported or perforated under-drains installed to store infiltrated runoff underground.

The use of large-diameter underground pipes constructed of concrete, corrugated steel, or high-density polyethylene (HDPE) is becoming a more common practice for large parking areas such as shopping malls and mixed-use developments. These underground pipes and vaults as well as chamber systems can store large quantities of runoff that can be reused as needed or released at rates that will not damage natural conveyance systems.

5.3.5.9 Microbial disinfection

Other practices can be used to treat runoff for specific pollutants other than sediment. For instance, in areas where microbial pollution is an issue, runoff can be treated using ozone or ultraviolet light to prevent disease and reduce exceedances of water quality due to pathogen contamination. The City of Encinitas, California, was concerned about the number of public health warnings at its primary seaside attraction, Moonlight Beach, due to high enterococcus and coliform bacteria counts. The main source of the microbial pollution was dry weather runoff from Cottonwood Creek, which discharges at Moonlight Beach. Despite extensive evaluation of the Cottonwood Creek drainage area to identify and reduce bacterial loading, public health warnings continued to be posted. In anticipation of a total maximum daily load for bacteria under development for the region, and to reduce or eliminate the number of beach postings, the City chose to install an ultraviolet (UV) disinfection facility with partial funding from California's Clean Beach Initiative. The UV treatment facility was designed to treat 150 gallons per minute of Cottonwood Creek's dry weather flow, with 15% of the creek's flow diverted around the facility to maintain biological connectivity between upstream and downstream waters. During times of high flow (i.e., during and after storms) and high turbidity, when the system's treatment effectiveness would be reduced, the system is shut down and flow is passed through without treatment. Early monitoring results showed a significant decrease in bacterial counts downstream of the treatment facility, with a removal efficiency of more than 99.9 percent that yielded an effluent quality of 2 bacteria per 100 mL. Filters built into the system were also effective at removing suspended sediment, reducing turbidity from an average of 14.0 mg/L in the influent to 5.0 mg/L in the effluent.

5.4 Performance and Cost Information for Management Practices

Some advantages, disadvantages, and costs of specific runoff control practices described above are listed in Table 5.6. Site-specific information, regional limitations, operation and maintenance burdens, and longevity for these practices are listed in Table 5.7.

Table 5.6: Advantages and disadvantages of management practices (MDE, 2000).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Runoff control ponds			
Wet pond	– Can provide peak flow control – Can serve large developments; most cost-effective for larger, more intensively developed sites – Enhances aesthetics and provides recreational benefits – Little ground water discharge – Permanent pool in wet ponds helps to prevent scour and re-suspension of sediments – Provides moderate to high removal of both particulate and soluble urban runoff pollutants	– Not economical for drainage area less than 10 acres – Potential safety hazards if not properly maintained – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors – Requires considerable space, which limits use in densely urbanized areas with expensive land and high property values – Not suitable for hydrologic soil groups "A" and "B" (USDA-NRCS classification) unless a liner is used – With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life – Hydrologic damage to stream channels and aquatic habitat is possible due to flow volume.	Moderate to high compared to conventional runoff detention
Infiltration practices			
Infiltration basin	– Provides ground water recharge – Can serve large developments – High removal capability for particulate pollutants and moderate removal for soluble pollutants – When basin works, it can replicate predevelopment hydrology more closely than other BMP options – Basins provide more habitat value than other infiltration systems	– Possible risk of contaminating ground water – Only feasible where soil is permeable and there is sufficient depth to bedrock and water table – Fairly high failure rate – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors – Regular maintenance activities cannot prevent rapid clogging of infiltration basin	Construction cost moderate but rehabilitation cost high

Table 5.6 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Infiltration trench	– Provides ground water recharge – Can serve small drainage areas – Can fit into medians, perimeters, and other unused areas of a development site – Helps replicate predevelopment hydrology, increases dry weather baseflow, and reduces bankfull flooding frequency	– Possible risk of contaminating ground water – Only feasible where soil is permeable and there is sufficient depth to bedrock and water table – Since not as visible as other BMPs, less likely to be maintained by residents – Requires significant maintenance	– Cost-effective on smaller sites – Rehabilitation costs can be considerable
Concrete grid pavement	– Can provide peak flow control – Provides ground water recharge – Provides water quality control without additional consumption of land	– Requires regular maintenance – Not suitable for areas with high traffic volume – Possible risk of contaminating ground water – Only feasible where soil is permeable, there is sufficient depth to bedrock and water table, and there are gentle slopes	Information not available
Filtering practices			
Filtration basin	– Ability to accommodate medium-size development (3–80 acres) – Flexibility to provide or not provide ground water recharge – Can provide peak volume control	– Requires pretreatment of runoff through sedimentation to prevent filter media from premature clogging	Information not available
Bioretention	– Provides ground water recharge	–	
Open channel practices			
Grassed swale	– Requires minimal land area – Can be used as part of the runoff conveyance system to provide pretreatment – Can provide sufficient runoff control to replace curb and gutter in single-family residential subdivisions and on highway medians – Economical	– Low pollutant removal rates – Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients	Low compared to curb and gutter
Structural management practices that do not consistently remove 80% TSS			
Vegetated filter strip	– Low maintenance requirements – Can be used as part of the runoff conveyance system to provide pretreatment – Can effectively reduce particulate pollutant levels in areas where runoff velocity is low to moderate – Provides excellent urban wildlife habitat – Economical	– Often concentrates water, which significantly reduces effectiveness – Ability to remove soluble pollutants highly variable – Limited feasibility in highly urbanized areas where runoff velocities are high and flow is concentrated – Requires periodic repair, regrading, and sediment removal to prevent channelization	Low

Table 5.6 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Water quality inlet Catch basins with sand filter	– Provide high removal efficiencies of particulates – Require minimal land area – Flexibility to retrofit existing small drainage areas – Higher removal of nutrient as compared to catch basins and oil/grit separator	– Not feasible for drainage areas greater than 5 acres – Only feasible for areas that are stabilized and highly impervious – Not effective as water quality control for intense storms	Information not available
Water quality inlet Oil/grit separator	– Captures coarse-grained sediments and some hydrocarbons – Requires minimal land area – Flexibility to retrofit existing small drainage areas and applicable to most urban areas – Shows some capacity to trap trash, debris, and other floatables – Can be adapted to all regions of the country	– Not feasible for drainage area greater than 1 acre – Minimal nutrient and organic matter removal – Not effective as water quality control for intense storms – Concern exists for the pollutant toxicity of trapped residuals – Require high maintenance	High, compared to trenches and sand filters
Extended detention dry pond with micropool	– Can provide peak flow control – Possible to provide good particulate removal – Can serve large development – Requires less capital cost and land area when compared to wet pond – Does not generally release water or anoxic water downstream – Provides excellent protection for downstream channel erosion – Can create valuable wetland and meadow habitat when properly landscaped	– Removal rates for soluble pollutants are quite low – Not economical for drainage area less than 10 acres – If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors	Lowest cost alternative in size range

[a]Comparative cost information from Schueler, 1992

Table 5.7: Regional, site-specific, and maintenance considerations for management practices (USEPA, 1993; Caraco and Claytor, 1997; Schueler, in press).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
Infiltration basins *Size of drainage area*: Moderate to large *Site requirements:* Deep, permeable soils *Maintenance burdens*: High *Longevity:* Low	– Avoid areas with permafrost – Monitor ground water for chlorides – Do not infiltrate road/parking lot snowmelt if chlorides are a concern – Increase percolation requirements – Use 20 foot minimum setback between road subgrade and practice	– No recharge in hot-spot areas – Do not treat pervious areas – Use multiple pretreatment – Soil limitations exist in arid areas
Infiltration trenches *Size of drainage area*: Moderate *Site requirements:* Deep, permeable soils *Maintenance burdens*: High *Longevity:* Low	– Avoid areas with permafrost – Monitor ground water for chlorides – Do not infiltrate road/parking lot snowmelt if chlorides are a concern – Increase percolation requirements – Use 20-foot minimum setback between road subgrade and practice	– No recharge in hot-spot areas – Do not treat pervious areas – Use multiple pretreatment – Soil limitations exist in arid areas
Vegetated filter strips *Size of drainage area*: Small *Site requirements:* Low-density areas with low slopes *Maintenance burdens*: Low *Longevity:* Low if poorly maintained	– Small setback may be required between filter strips and roads when frost heave is a concern – Avoid areas with permafrost – Use cold- and salt-tolerant vegetation – Plowed snow can be stored in-practice	– Use drought-tolerant vegetation
Grassed swales *Size of drainage area*: Small *Site requirements*: Low-density areas with <15% slope *Maintenance burdens*: Low *Longevity:* High if maintained	– Avoid areas with permafrost – Use cold- and salt-tolerant vegetation – Plowed snow can be stored in the practice – Increase underdrain pipe diameter and size of gravel bed – Provide ice-free culverts – Ensure soil bed is highly permeable	– Not recommended for pollutant removal in arid areas – Of limited use in semi-arid areas – Ensure adequate erosion protection of channels
Porous pavement *Size of drainage area*: Small *Site requirements*: Deep permeable soils, low slopes, and restricted traffic *Maintenance burdens*: Moderate to high *Longevity:* Low	– Only use on non-sanded surfaces – Pavement may be damaged by snow plows – Maintenance is essential	
Filtration basins and sand filters *Size of drainage area*: Widely applicable *Site requirements*: Widely applicable *Maintenance burdens*: Moderate *Longevity:* Low to moderate	– Reduced treatment effectiveness during cold season – Underground filters only effective if placed below the frost line – Peat/compost media ineffective during winter and may become impervious if frozen	– Preferred in both arid and semi-arid areas. Arid area filters require greater pretreatment
Bioretention	– Reduced treatment effectiveness during cold season – Pretreatment should be used to prevent “choking” of vegetation	

Table 5.7 (continued).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
Water quality inlets *Size of drainage area*: Small *Site requirements:* Impervious catchments *Maintenance burdens*: Cleaned twice a year *Longevity:* High	– Few restrictions	
Extended detention dry ponds *Size of drainage area*: Moderate to large *Site requirements:* Deep soils *Maintenance burdens*: Dry ponds have relatively high burdens *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Preferred in arid climates and acceptable in semi-arid climates
Wet ponds *Size of drainage area*: Moderate to large *Site requirements*: Deep soils *Maintenance burdens*: Low *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Not recommended in arid areas and of limited use in semi-arid areas
Wetlands *Size of drainage area*: Moderate to large *Site requirements:* Poorly drained soils, space may be limiting *Maintenance burdens*: Annual harvesting of vegetation *Longevity:* High	– Protect inlet/outlet pipes – Use large-diameter (> 8 in) gravel in underdrain of outfall protection – Consider seasonal operation – Provide ice storage volume – Cold-tolerant vegetation	– Not recommended in arid areas and of limited use in semi-arid areas

Table 5.8 presents pollutant removal efficiency statistics for the management practices discussed in this section. These values originate from the *National Pollutant Removal Performance Database for Stormwater BMPs* (Caraco and Winer, 2000). The database was compiled through a comprehensive literature search focusing on runoff treatment practice monitoring sites from 1990 to present. In addition, approximately 60 previously collected monitoring studies from 1977 and 1989 were included in the database. All 139 studies meet the two following criteria: (1) the researchers used automated equipment that enabled flow or time-based composite samples; and (2) they documented the method used to compute removal efficiency. With respect to the number of storms sampled, more than three-quarters of the studies were based on five or more storm samples. The sample size was not reported in the remaining studies.

Table 5.8: Effectiveness of management practices for runoff control (adapted from Caraco and Winer, 2000).

Runoff Treatment or Control Practice Category or Type	Median Pollutant Removal (Percent)							
	No. of studies	TSS	TP	OP	TN	NOx	Cu	Zn
Quality Control Pond	3	3	19	N/A	5	9	10	5
Dry Extended Detention Pond	6	61	20	N/A	31	-2	29	29
Dry Ponds	9	47	19	N/A	25	3.5	26	26
Wet Extended Detention Pond	14	80	55	69	35	63	44	69
Multiple-Pond System	1	91	76	N/A	N/A	87	N/A	N/A
Wet Pond	28	79	49	39	32	36	58	65
Wet Ponds	43	80	51	65	33	43	57	66
Shallow Marsh	20	83	43	66	26	73	33	42
Extended Detention Wetland	4	69	39	59	56	35	N/A	-74
Pond/Wetland System	10	71	56	37	19	40	58	56
Submerged Gravel Wetland	2	83	64	14	19	81	21	55
Wetlands	36	76	49	48	30	67	40	44
Organic Filter	7	88	61	30	41	-15	66	89
Perimeter Sand Filter	3	79	41	68	47	-53	25	69
Surface Sand Filter	7	87	59	N/A	31.5	-13	49	80
Vertical Sand Filter	2	58	45	21	15	-87	32	56
Bioretention	1	N/A	65	N/A	49	16	97	95
Filtering Practices[a]	18	86	59	*57*	38	-14	49	88
Infiltration Trench	3	100	42	100	42	82	N/A	N/A
Porous Pavement	3	95	65	10	83	N/A	N/A	99
Ditches[b]	9	31	-16	N/A	-9	24	14	0
Grass Channel	3	68	29	32	N/A	-25	42	45
Dry Swale	4	93	83	70	92	90	70	86
Wet Swale	2	74	28	-31	40	31	11	33
Open Channel Practices	9	81	34	*1.0*	*84*	31	51	71
Oil-Grit Separator	1	-8	-41	40	N/A	47	-11	17

Shaded rows show data for groups of practices (i.e., dry ponds include quality control ponds and dry extended detention ponds).
Numbers in italics are based on fewer than five data points.
[a] Excludes vertical sand filters
[b] Refers to open channel practices not designed for water quality.
TSS=total suspended solids, TP=total phosphorus, OP=ortho-phosphorus, TN=total nitrogen, NOx=nitrate and nitrite nitrogen, Cu=copper, Zn=zinc.

Strecker et al. (2000) identified problems with comparing different management practice effectiveness studies. They suggested that inconsistent study methods, lack of associated design information, and multiple reporting protocols make wide-scale assessments of management practices difficult. Also, differences in monitoring strategies and data evaluation methods contribute significantly to the wide range of reported management practice effectiveness.

EPA recognizes that 80 percent TSS removal efficiency cannot be achieved for each storm event and understands that TSS removal efficiency will fluctuate above and below 80 percent for individual storms. Researchers have noted that efficiency estimation is often based on pollutant loads into and out of the management practice on a storm-by-storm basis. Therefore, a multiple-study analysis or summary is based on the assumption that all storms are equal when computing average pollutant removal. Storm-by-storm comparisons are probably not effective because many storms are not large enough to displace the permanent pool volume. They recommend that effectiveness be evaluated using statistical characterizations of the inflow and outflow concentrations because if enough samples are collected, total loads into and out of the management practice can be used reliably.

Strecker et al. (2000) also analyzed the use of effluent data to measure the influence of certain design criteria on management practice efficiency. Some studies suggest that management practices can only treat runoff to a specified pollutant concentration. However, if relatively clean water enters a practice, performance data based on removal efficiency might not fully characterize whether the practice is well designed and effective. Therefore, pollutant removal efficiency, when it is expressed as percent removal, might not be an accurate representation of

Verifying the Performance of Environmental Technologies

EPA's Environmental Technology Verification (ETV) Program, which began in October 1995, was instituted to verify the performance of innovative technical solutions to problems that threaten human health and the environment. ETV was created to significantly accelerate the entrance of new environmental technologies into the domestic and international marketplaces. The program operates through public and private testing partnerships to evaluate the performance of environmental technology in all media, including air, water, soil, ecosystems, waste, pollution prevention, and monitoring. More information about the ETV Program is available at http://www.epa.gov/etv (USEPA, 2001b).

Another method for evaluating technology is the Environmental Technology Evaluation Center (EvTEC), which was established by the Civil Engineering Research Foundation (CERF) through EPA's ETV Program. EvTEC is an independent, market-based approach to technology verification and was established to accelerate the adoption of environmental technologies into practice. More information about EvTEC is available at http://www.cerf.org/evtec (CERF, 2001).

EPA and NSF International, an independent, nonprofit testing organization, have developed a testing protocol to determine the viability of runoff treatment technologies and other wet weather flow controls, including runoff, combined sewer overflow (CSO), and sanitary sewer overflow (SSO). NSF International will also test and verify high-rate separation/clarification and high-rate disinfection technologies, flow monitoring equipment, and wet weather models.

Participants in the study include vendors who want to demonstrate the effectiveness of their technologies. Results of the pilot will be useful to a variety of stakeholders including municipalities, businesses, vendors, consulting engineers, and regulatory agencies. Once verification reports have been completed, vendors may use the results in their marketing efforts. Results will be made publicly available through EPA's and NSF's Web sites at http://www.epa.gov/etv and http://www.nsf.org/business/ETV_EPA_NSF/index.asp?program=ETVEPANSF, respectively. More information about the program is available at http://www.wateronline.com/content/news/article.asp?docid={17DDF263-29B8-11D5-A770-00D0B7694F32} (Water-Online, 2001).

International Stormwater Best Management Practices Database

The American Society of Civil Engineers, in cooperation with EPA, has compiled the *International Stormwater Best Management Practices Database*, which contains performance data from more than 200 management practice studies. Information provided for the management practices includes test site location, researcher contact data, watershed characteristics, regional climate statistics, management practice design parameters, monitoring equipment types, and monitoring data such as precipitation, flow, and water quality. More information on the database's purpose, design, and documentation can be found at http://www.bmpdatabase.org/.

how well a management practice is performing. Although more research is necessary to accurately determine the effectiveness of management practices, Strecker et al. recommend that standard methods and detailed guidance on data collection be used to improve data transferability.

Table 5.9 presents information concerning the costs associated with selected structural practices. The sources of these data are publicly available articles (some are a compilation of numerous studies).

Table 5.9: Costs of selected management practices (Claytor and Schueler, 1996; Brown and Schueler, 1997).

Management Practice	Construction Costs[a]	Useful Life (years)	Total Annual Costs
Infiltration basin[b]			
Average	$0.55/ft^3$ storage	25[c]	–
Report range	$0.22–$1.31/ft^3$	–	$0.03–$0.05/ft^3$
Probable range	$0.44–$0.76/ft^3$	–	–
Infiltration trench[b]			
Average	$4.36/ft^3$ storage	10[c]	–
Report range	$0.98–$10.04/ft^3$	–	$0.03–$0.10/ft^3$
Probable range	$2.73–$8.18/ft^3$	–	–
Infiltration practices[d]			
Average	$2.99/ft^3$ storage	–	–
Report range	$2.13-4.27/ft^3$ storage	–	–
Vegetated swales[b]			
Established from seed			
Average	$7.09/linear ft	50[e]	$1.09/linear ft
Report range	$4.91–$9.27/linear ft	–	–
Established from sod			
Average	$21.82/linear ft	50[e]	$2.18/linear ft
Report range	$8.73–$54.56/linear ft	–	–
Porous pavement[b]			
Average	$1.64/ft^2$	10[f]	$0.16/ft^2$
Report range	$1.09-$2.18/ft^2$	–	–
Concrete grid pavement[b]			
Average	$1.09/ft^2$	20	$0.05/ft^2$
Report range	$1.09–$2.18/ft^2$	–	–
Filtration basins[b]			
Average (probable)	$5.46/ft^3$ storage	25[g]	–
Report range	$1.09–12.00/ft^3$	–	$0.11–$0.87/ft^3$
Probable range	$2.18–9.82/ft^3$	–	–
Bioretention practices[d]			
Average	$6.83/ft^3$ storage	–	–
Filtration practices[d]			
Average	$2.63/ft^3$ storage	–	–
Range	$2.13-6.40/ft^3$ storage	–	–
Water quality inlet[b,h]			
Average	$2,182 each	50	$164 each
Report range	$1,200–3,273 each	–	–
Probable range	–	–	–
Water quality inlet with sand filter[b,h] Average (probable)	$10,900/drainage acre	50	$764/drainage acre

Table 5.9 (continued).

Management Practice	Construction Costs[a]	Useful Life (years)	Total Annual Costs
Oil/grit separator[b,h]			
Average	$19,640/drainage acre	50	$1,091/drainage acre
Report range	$16,370–$21,820/drainage acre	–	–
Stabilization with ground cover[b,h]			
From existing vegetation			
Average	$0	50	Natural: $109/acre
Report range	–	–	Managed: $873/acre
From seed			
Average	$436/acre	50	Natural: $131/acre
Report range	$218–$1,091/acre	–	Managed: $900/acre
From seed and mulch			
Average	$1,637/acre	50	Natural: $218/acre
Report range	$872–$3,819/acre	–	Managed: $982/acre
From sod			
Average	$12,330/acre	50	Natural: $764/acre
Report range	$4,910–$52,375/acre	–	Managed: $1,528/acre
Ext. Detention Dry Pond[b,h]			
Average	$0.55/ft^3 storage	50	–
Report range	$0.05–$3.49/ft^3	–	$0.008–$0.33/ft^3
Probable range	$0.10–$5.46/ft^3	–	–
Wet Pond and Extended Detention Wet Pond[b]	$0.55/ft^3 storage	50	$0.009–$0.08/ft^3
Storage vol. < 1 million ft^3	$0.05–$1.09/ft^3	–	–
Average	$0.55–$1.09/ft^3	–	–
Report range	$0.27/ft^3 storage	50	–
Probable range	$0.05–$0.55/ft^3	–	$0.009–$0.08/ft^3
Storage vol. > 1 million ft^3	$0.11–$0.55/ft^3	–	–
Average (probable)			
Report range (probable)			
Probable range			

[a]Costs updated using the Bureau of Labor Statistics Inflation Calculator.
[b]Claytor and Schueler, 1996.
[c]References indicate the useful life for infiltration basins and infiltration trenches at 25-50 and 10-15 years, respectively. Because of the high failure rate, infiltration basins are assumed to have a useful life span of 25 years and infiltration trenches are assumed to have a useful life span of 10 years.
[d]Brown and Schueler, 1997.
[e]Useful life is assumed to equal the life of the project, assumed to be 50 years.
[f]No information was available for porous pavement. It is assumed to be similar to infiltration trenches.
[g]No information was available for filtration basins. It was assumed to be similar to infiltration basins.
[h] These practices do not meet the 80 percent TSS removal, thus it is recommended that they be used with other management practices in a treatment train.

5.5 Managing Structural Controls to Reduce Mosquito-Breeding Habitat

In recent years, concern has been raised that storm water management facilities have been breeding grounds for mosquitoes (Conlon, 2002). This is a public health concern because mosquitoes are known vectors for disease-causing arboviruses such as malaria, yellow fever, dengue fever, St. Louis encephalitis, and West Nile virus, to name a few. The relationship between storm water management and mosquito breeding exists because the presence of standing and sometimes stagnant water facilitates the two aquatic stages of a mosquito's life cycle—the egg and larval stages.

Not all mosquito species are vectors for disease, but control is still warranted because, even if not a health risk, mosquitoes are considered a nuisance. Mosquito species have different habitat preferences, and two basic groups can breed in the urban environment: permanent water species and floodwater species (Metzger et al., 2002). Permanent water species would be likely to propagate in storm water management facilities that always contain water, such as wet detention ponds and constructed wetlands. Floodwater species would likely inhabit "dry" systems such as extended detention dry ponds that have fluctuating water levels.

This issue has caused a fair amount of controversy because mosquito-breeding habitats are prevalent in urban and suburban environments. Metzger et al. (2002) identified a few of the numerous manmade mosquito-breeding habitats in urban and suburban environments:

> Urban environments provide mosquitoes with a vast array of new habitats: humid and arid, above and below ground, small water-holding containers and large ponds, polluted and clean water. Aquatic habitats are found around people's homes (birdbaths, jars, flower pots, neglected pools and Jacuzzis and clogged rain gutters), in unregulated waste dumps (used tires, barrels, bottles, and cans), in parks (ponds, lakes, and streams), and in the city's own infrastructure (storm drains, sewer systems, catch basins, and culverts). Many of these sources are replenished frequently by stormwater and urban runoff (e.g., irrigation, washing cars). Adding to this, increasingly stringent urban stormwater runoff regulations have recently mandated the construction of structural practices for both volume reduction and pollution management, many of which have created additional sources of standing water. This abundance of habitats has favored mosquitoes and allowed many species to greatly expand their range and increase in number.

Although storm water management facilities are not the sole source of standing water, public concern has raised the question of how these facilities can be managed, redesigned, or otherwise modified to reduce the creation of disease vectors close to urban population centers.

The California Department of Health Services' Vector-Borne Disease Section (2002), in cooperation with the California Department of Transportation (Caltrans), undertook a study to evaluate retrofit opportunities for storm water management. Part of this study investigated the mosquito production of 37 structural management practices in southern California. Eight categories of practices were constructed and examined as part of the study: (1) biofiltration strips and swales; (2) filtration devices (Austin-type and Delaware-type sand media filters, multi-chambered treatment train sand media filters, and a proprietary canister filter); (3) extended detention basins; (4) infiltration devices (basins and trenches); (5) continuous deflective separators (CDSs); (6) an oil/water separator; (7) drain-inlet inserts; and (8) a constructed wetland (retention pond). The study consisted of comprehensive surveillance and monitoring of each practice for mosquito production, as well as follow-up monitoring after modifications had been made to reduce the potential to produce mosquitoes. Of the eight different technologies implemented by Caltrans, those that maintained permanent sources of standing water in sumps or basins (MCTT, CDS, and the retention pond) provided excellent habitat for immature mosquitoes and frequently supported large populations relative to other structural designs. In contrast, practices designed to drain rapidly (i.e., biofiltration swales and strips, Austin-type sand media filters, infiltration basins and trenches, and extended detention basins) provided less-suitable habitats and rarely harbored mosquitoes.

The project was expanded to a nationwide investigation using phone and mail surveys and site visits to 150 agencies in 28 states. Of the 72 agencies that completed a questionnaire, 86 percent reported mosquito production associated with storm water management facilities. The survey found that inadequate maintenance resulted in accumulation of trash and other constituents (e.g., sediment, vegetation, organic debris).

The Southwest Florida Water Management District conducted a study to determine the extent to which storm water management facilities were breeding mosquitoes and offer recommendations for minimizing mosquito production (Livingston, no date). After examining more than 200 management practices with both permanent pools and intermittent pools, they found that 76 percent of all practices were mosquito productive, and that 66 percent of the permanently flooded practices and 69 percent of the intermittently flooded practices bred mosquitoes. Larval density was smaller and more dispersed in wet detention systems than in intermittently flooded systems. The wet detention systems that did not breed mosquitoes shared a paucity of vegetation, abundant fish, and good aeration. The intermittently flooded dry detention pond systems that did not produce mosquitoes were those that drained or dried within 72 hours.

The Florida researchers also investigated several pesticides and found them to be between 91 and 100 percent effective at controlling existing larval infestations in intermittently flooded systems within 24 hours of treatment, although one treatment in a system with high organic content was found to be ineffective against dense larval populations. The researchers also found that sustained-release materials such as pellets were effective for up to five weeks after application, whereas short-term controls required regular application.

Regular monitoring for mosquito adults and larvae, retrofitting and maintenance of practices to reduce the likelihood for breeding, and pesticide application where needed are the three key actions for eliminating mosquito breeding in storm water facilities. The Centers for Disease Control and Prevention discussed the role of pesticides that kill adult mosquitoes (adulticides) in mosquito management and recommended that their use be incorporated into an integrated pest management program that includes surveillance, source reduction, chemical control (larvicide and adulticide), biological control, and public relations and education (Rose, 2001).

Surveillance programs track diseases in bird populations, vector-borne pathogens in mosquitoes, mosquito populations, larval habitats, mosquito traps, biting counts, and reports by the public (Rose, 2001). Control activities are initiated when threshold populations are exceeded, and predictions are made from seasonal records and weather data.

Source reduction entails eliminating or altering larval habitats. This can be achieved through public education campaigns, with outreach to both children and adults. Additionally, state and local mosquito control agencies can alter the hydrology of open water and marshy areas to reduce or prevent the proliferation of mosquito larvae. Rose (2001) suggests techniques in which mosquito-producing areas in marshes are connected by shallow ditches to deep-water habitats to allow drainage or fish access, and minimally flooding the marsh during the summer but flap-gating impounded areas to reintegrate them to the estuary for the rest of the year.

Biological control can be achieved using various predators such as dragonfly nymphs and predacious mosquitoes (Rose, 2001). Mosquito fish are the most commonly used agents for biological control because they are easily reared, although they also feed on non-target species. Other types of organisms that might be used for mosquito control include several fish types other than *Gambusia*, as well as fungi, protozoans, nematodes, and predacious copepods.

It is essential that storm water managers and public works crews who maintain storm water management facilities be educated in integrated pest management. They should be trained to identify design flaws or maintenance needs that might create mosquito-breeding habitat, and they should know the procedures for reporting and remedying the problem. Pesticide handlers should have the required training under the Federal Insecticide, Fungicide, and Rodenticide Act and all chemicals should be applied at rates recommended on the packaging. Treated areas should be monitored after application to determine the efficacy of the applications and identify where pesticide resistance might be occurring.

There are steps that a storm water manager can take to reduce the likelihood that mosquitoes will breed in storm water management facilities. From a design standpoint, most management practices other than wet retention ponds are intended to drain within 72 hours. This is a safe drainage time because mosquitoes need at least that long for their aquatic life stages. Additionally, Metzger et al. (2002) found that several design features of storm water management practices contributed to vector production, including the use of sumps, catch basins, or spreader troughs that did not drain completely; the use of loose riprap that could hold small amounts of water; pumps or motors designed to "automatically" drain water from structures; and effluent pipes with discharge orifices prone to clogging because of their small diameter.

Livingston (no date) recommends the following design considerations to minimize mosquitoes:

- Designs must be based on site characteristics to ensure that the most appropriate type of storm water management facility is selected. Vegetated dry retention systems should be designed as off-line systems. They should be used only where the soil and water table conditions will assure that the system drains or dries within 24 to 36 hours, and where the seasonal high water table is at least two feet below the bottom of the system. If on-line retention areas are used, they should be designed to be dry within three days of a 25-year, 24-hour storm.

- Dry retention systems need to be carefully constructed to avoid compacting the soil and reducing its infiltration rate. They also should have flat bottoms to avoid having areas of standing water.

- To minimize decaying organic matter, the grass or other vegetation in dry retention areas should be regularly mowed and the clippings removed and composted.

- The littoral zone of wet detention areas should be planted with aquatic macrophytes such as *Sagittaria latifolia* (duck potato), *Sagittaria lancifolia* (lance-leaf arrowhead), *Juncus effusus* (soft rush), *Pontedaria lancifolia* (pickerelweed), *Juncus roemerianus* (needle rush), *Scirpus californicus* (giant bulrush), and *Scirpus validus* (soft stem bulrush). Cattails (*Typha* spp.) should never be planted in or allowed to remain in storm water systems as they grow very profusely, creating a large quantity of decaying matter.

- Wet detention systems should be stocked with native *Gambusia* spp. minnows (mosquito fish) to foster biological predation of mosquito larvae. If needed because of site conditions, a "minnow sump" should be excavated in the deepest part of the pond to assure permanent habitat and survival during droughts.

- Sustained-release larvicides should be used whenever necessary with systems known to be mosquito productive treated before the onset of the mosquito life cycle.

- Regular inspection and maintenance of storm water systems is essential to ensure that the facility drains as designed. Such maintenance involves removing submerged vegetation and clearing sediments away from inlets, outlets, and the bottom of the pool or holding area.

5.6 Information Resources

The *Technology Review: Ultra-Urban Stormwater Treatment Technologies* (Brueske, 2000) was compiled to provide a review of "ultra-urban" storm water treatment technologies. These types of technologies are designed to remove pollutants from runoff in highly developed areas where land values are high and available space is limited. Ultra-urban technologies differ from traditional runoff treatment controls in that they are very compact and can be retrofitted into existing runoff collection systems. The document specifically analyzes four types of treatment technologies: gravity separation, swirl concentration, screening, and filtration. Technology review findings were then used to develop a design protocol for selecting and installing ultra-urban treatment technologies. This document can be downloaded in PDF format from http://depts.washington.edu/cuwrm/research/ultraurbn.pdf.

The California Department of Transportation (Caltrans) prepared two handbooks on storm water quality as an updated version of the *Construction Contractor's Guide and Specifications*. These new manuals are the *Construction Site Best Management Practices (BMPs) Manual* and the *Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) Preparation Manual*. The two manuals provide background information on Caltrans' program to control water pollution, offer instructions for selecting and implementing construction site best management practices, and help to standardize the process for preparing and implementing the SWPPP and the WPCP. Caltrans requires contractors to prepare and implement a program to control water pollution during the construction of all projects. The manuals are available for download at http://www.dot.ca.gov/hq/construc/stormwater/manuals.htm.

The Milwaukee Metropolitan Sewerage District developed a manual entitled "Surface Water and Storm Water Rules Guidance Manual" in 2002 that is available on their Web site at http://www.mmsd.com/stormwaterweb/Startpg.htm. The document includes an extensive discussion of the principles of storm water management, descriptions of both structural and nonstructural measures to control storm water, and sizing procedures for detention basins, among other topics.

In August 1998 the Center for Watershed Protection published *Better Site Design: A Handbook for Changing Development Rules in Your Community*. The publication covers everything from basic engineering principles to "actual versus perceived" barriers to implementing better site designs. The handbook outlines 22 guidelines for better developments and provides a detailed rationale for each principle. *Better Site Design* also examines current practices in local communities, details the economic and environmental benefits of better site designs, and presents case studies from across the country. The document is available for purchase from the Center for Watershed Protection at http://www.cwp.org/.

In 2000 the Maryland Department of the Environment published the *Maryland Stormwater Design Manual*. The manual was designed to protect Maryland waters from the adverse impacts of urban runoff, to provide design guidance on the most effective structural and nonstructural management practices for development sites, and to improve the quality of management practices that are recommended by the state of Maryland. The first volume of the manual contains information on management practice siting and design on new development sites to comply with Maryland's 14 storm water performance standards. A unique feature is the use of storm water credits for rewarding innovative storm water management designs. The second volume contains detailed technical information on runoff control practices, including step-by-step design examples. Both volumes are available for download at http://www.mde.state.md.us/environment/wma/stormwatermanual.

In 1995 the Metropolitan Washington Council of Governments (MWCOG) published *Site Planning for Urban Stream Protection*, which presents a watershed approach to site planning and examines new ways to reduce pollutant loads and protect aquatic resources through nonstructural practices and improved construction site planning. The book also provides insight into the importance of imperviousness, watershed-based zoning, concentration of development, headwater streets, stream buffers, green parking lots, and other land planning topics. The document is available for purchase from MWCOG at http://www.mwcog.org/ic/95708.html.

The *Texas Nonpoint SourceBOOK* is an interactive Web tool that was designed to provide runoff management information to public works professionals and other interested parties in Texas and elsewhere. This site, which can be accessed at http://www.txnpsbook.org/, includes a beginner's guide to urban nonpoint source management issues, a discussion of water quality issues in Texas, elements of a storm water management program, information on storm water utilities, tips for assessing and selecting management practices, a comprehensive listing of links to other sites, frequently asked questions, and nonpoint source news.

In 1999 the Denver Urban Drainage and Flood Control District published the *Urban Storm Drainage Criteria Manual*. The manual was designed to provide guidance for local jurisdictions, developers, contractors, and industrial and commercial operators in selecting, designing, implementing, and maintaining management practices to improve runoff quality. The third volume of this manual is primarily targeted at developing and redeveloping residential and commercial areas. The manual is available for purchase at http://www.udfcd.org/.

In 1995 EPA published *Economic Benefits of Runoff Controls* (EPA-841-S-95-002), which contains a description of studies that document increases in property values and rental prices when properly designed runoff controls are used as visual amenities. The document is available for download from EPA's National Environmental Publications Internet Site (NEPIS) at http://www.epa.gov/ncepihom/nepishom.

EPA published the *Preliminary Data Summary of Urban Storm Water Best Management Practices* in 1999. The document summarizes existing information and data on the effectiveness of management practices to control and reduce pollutants in storm water. The report also provides a synopsis of what is currently known about the expected costs and environmental benefits of management practices, and identifies information gaps. The document is available for download in PDF format at http://www.epa.gov/ost/stormwater/usw_a.pdf.

In 1992 the Washington State Department of Ecology published its *Stormwater Management Manual for the Puget Sound Basin*. The manual is divided into five documents: Volume I: Minimum Technical Requirements; Volume II: Construction Stormwater Pollution Prevention; Volume III: Hydrologic Analysis and Flow Control Design; Volume IV: Source Control BMPs;

and Volume V: Runoff Treatment BMPs. All five volumes are available for download at http://www.ecy.wa.gov/biblio/9911.html.

The Washington State Department of Ecology's Water Quality Program has developed a Nonpoint Source Pollution home page. This Web site, accessible at http://www.ecy.wa.gov/programs/wq/nonpoint, contains nonpoint source program information, posters, resources, and references. The Department of Ecology has also made available a copy of the draft of *Instream Flows in Washington State: Past, Present, and Future*. The document is available at http://www.olympus.net/community/dungenesswc/InstreamFlowversion12.PDF.

The Metropolitan Council of St. Paul/Minneapolis developed the *Urban Small Sites Best Management Practices (BMP) Manual* to provide assistance to communities in planning for storm water management for sites of less than 5 acres located in cold climates. The document focuses on low-impact development practices that promote the restoration and preservation of natural hydrology. The manual includes information on the selection of BMPs and model storm water ordinances and contains a regulatory analysis for watershed programs. The document is available at http://www.metrocouncil.org/environment/Watershed/bmp/manual.htm.

An excellent discussion of the design of infiltration techniques in limestone/carbonate bedrock areas can be found in a new design manual developed for the Lehigh Valley Planning Commission (LVPC) by Cahill Associates. The manual, *Technical Best Management Practice Manual and Infiltration Feasibility Report: Infiltration of Stormwater in Areas Underlain by Bedrock in the Little Lehigh Creek Watershed,* is available from the LVPC at 961 Marcon Boulevard, Suite 310, Allentown, Pennsylvania, 18109, 1-888-627-2626 (toll free), lvpc@lvpc.org.

The Virginia Municipal League published an article titled "Stafford County helps pioneer low impact design movement" describing the process by which Stafford County, Virginia, incorporated low-impact design into its development codes. The article includes links to Builders for the Bay, an organization that provides assistance to local communities wishing to update their codes, as well as several other helpful resources for communities. The article can be downloaded at http://www.vml.org/VTC/VTC3908-2.html.

The American Mosquito Control Association's Web site, located at http://www.mosquito.org/, offers information about mosquitoes and their control along with links, frequently asked questions, and West Nile virus information.

American Rivers developed a report on low impact development techniques for the Great Lakes region called *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management.* The report includes an overview of many runoff control techniques, including pros and cons of each practice. The report can be downloaded in PDF format from the American Rivers Web site at www.americanrivers.org (visit the "Resources" link and choose to view a complete list of publications).

The Villanova University Stormwater Partnership conducts research on management practices to control urban runoff. The organization has established a "Stormwater BMP Park" with a constructed wetland, a biofiltration traffic island, and a porous concrete site. Research results and outreach materials can be found at http://www3.villanova.edu/VUSP/.

The EPA "Final Action for Effluent Guidelines and Standards for the Construction and Development Category" can be found at http://www.epa.gov/fedrgstr/. The Technical Development Document (EPA-821-B-04-001), which contains information on costs and technologies, is available from US EPA/NSCEP. P.O. Box 42419, Cincinnati, Ohio 45242-2419, (800) 490-9198 or http://www.epa.gov/waterscience/guide/construction.

EPA's *The Use of Best Managment Practices (BMPs) in Urban Watersheds* evaluates design, effectiveness, and cost considerations for storm water management practices. The document canbe downloaded in PDF format from http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf (cover and table of contents) and http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184chap1.pdf (Chapters 1–6).

5.7 References

Adams, L., E. Dove, and D. Leedy. 1984. Public Attitudes Toward Urban Wetlands for Stormwater Control and Wildlife Enhancement. *Wildlife Society Bulletin* 12(3): 299–303.

ASCE. 1999. *National Stormwater Best Management Practices (BMP) Database*. American Society of Civil Engineers, Reston, VA. Last updated August 3, 1999. Accessed February 28, 2000.

ASTM International. 2002. *Standard Test Methods for Determining Sediment Concentration in Water Samples*. Standard number D3977-97 (2002). ASTM International, West Conshohocken, PA

Baladès, J-D, M. Legret, and H. Madiec. 1995. *Permeable Pavements: Pollution Management Tools.* Water Science and Technology 32(1): 49-56.

Barraud, S., A. Gautier, J. P. Bardin and V. Riou. 1999. *The Impact of Intentional Stormwater Infiltration on Soil and Groundwater.* Water Science and Technology 39(2): 185–192.

Bateman, M., E.H. Livingston, and J. Cox. No date. *Overview of Urban Retrofit Opportunities in Florida*. Florida Department of Environmental Protection, Stormwater Management Program, Tallahassee, FL.

Brattebo, B.O., and D.B. Booth. 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research* 37(18): 4,369–4376.

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

Brueske, C.C. 2000. *Technology Review: Ultra-Urban Stormwater Treatment Technologies*. University of Washington, Department of Civil and Environmental Engineering, Seattle, WA.

California Department of Health Services. 2002. *Vector-Borne Diseases in California: 2001 Annual Report.* California Department of Health Services, Vector-Borne Disease Section, Sacramento, CA.

Caraco, D., and R. Claytor. 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared by Center for Watershed Protection, Ellicott City, MD, for U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Caraco, D., and R. Winer. 2000. *Updated National Pollution Removal Performance Database for Stormwater Treatment Practices*. Center for Watershed Protection, Ellicott City, MD.

Carr, R.W., E. Carolyn, and S.G. Walesh. 1999. Street Surface Storage for Control of Combined Sewer Surcharge: Case Studies. American Society of Civil Engineers 26th Annual Water Resources Planning and Management Conference, Tempe, AZ, June 6–9, 1999.

Center for Watershed Protection (CWP). 1996. Irreducible Pollutant Concentrations Discharged from Urban BMPs. *Watershed Protection Techniques* 2(2): 369–371.

City of Ottawa, Ontario. No date. *How to Make a Rain Barrel*. Ottawa, Ontario, Canada. http://ottawa.ca/city_services/water/27_1_4_3_en.shtml. Accessed September 15, 2003.

Civil Engineering Research Foundation (CERF). 2001. *Environmental Technology Evaluation Center*. http://www.cerf.org/evtec. Accessed September 27, 2001.

Claytor, R., and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Prepared for the Chesapeake Research Consortium, Solomons, MD, and U.S. Environmental Protection Agency, Region 5, Chicago, IL, by the Center for Watershed Protection, Ellicott City, MD.

Coffman, L., and D. Winogradoff. 1999. Bioretention: An Efficient, Cost-Effective Stormwater Management Practice. In *Proceedings: National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*. EPA-625-C-99-001. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

Concretenetwork.com. 2003. Permeable/ Porous Pavers. http://www.concretenetwork.com/concrete/porous_concrete_pavers/. Accessed September 15, 2003.

Conlon, J.M. 2002. *West Nile Virus: The Clean Water Act and Mosquito Control.* Hearing before the U.S. House of Representatives, Committee on Transportation and Infrastructure, Subcommittee on Water Resources and the Environment, October 10, 2002. http://www.house.gov/transportation/water/10-10-02/10-10-02memo.html. Accessed January 20, 2003.

Curry, W.K., and S.E. Wynkoop. 1995. *How Does Your Garden Grow?: A Reference Guide to Enhancing Your Rain Garden*. Prince George's County Department of Environmental Resources, Landover, MD.

Daniels, L. 1995. Maryland Developer Grows "Rain Gardens" to Control Residential Runoff. *Nonpoint Source News-Notes* No. 42.

Delaware Department of Natural Resources and Environmental Conservation (DNREC). 2004. Green Technology Best Management Practices. *Tributary Times* 3(3). http://www.gaelwolf2.com/dnrec/trib_times_2004_3.htm. Accessed August 23, 2005. Last updated June 24, 2005.

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

Dierkes and Geiger. 1999. *Pollution Retention Capabilities of Roadside Soils.* Water Science and Technology 39(2): 201-208.

Dillaha, T.A., R.B. Renear, S. Mostaghimi, and D. Lee. 1989. Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control. *Transactions of the American Society of Agricultural Engineers* 32(2):513–519.

Emmerling-DiNovo, C. 1995. Stormwater Detention Basins and Residential Locational Decisions. Water Resources Bulletin 31(3):515-520.

England, G. 1996. *Stormwater Sediment Control Using Baffle Boxes and Inlet Devices*. Unpublished Report.

Fairfax County Environmental Coordinating Committee. 2002. *Preliminary Draft: Regional Pond as a Watershed Management Tool.* Prepared by the Regional Pond Subcommittee. http://www.co.fairfax.va.us/gov/DPWES/publications/RPC_Prelimary_Report_Draft_10_21.pdf. Accessed June 25, 2003.

Federal Highway Administration (FHWA). No date. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring.* http://www.fhwa.dot.gov/environment/ultraurb/index.htm. Accessed July 24, 2003.

Fischer, D. No date. *Stormwater Impacts on Ground Water Quality Via Detention Basins*. U.S. Environmental Protection Agency, Urban Watershed Management Branch, Edison, NJ.

Fortner, B. 2000. Desert wetlands. *Civil Engineering* September: 58–61.

Galli, F. 1990. *Peat-Sand Filters: A Proposed Stormwater Management Practice for Urban Areas*. Metropolitan Washington Council of Governments, Washington, DC.

Gardener's. 2001. *Satisfy Thirsty Plants with Pure Rainwater*. Gardener's Supply Company, Burlington, VT. http://www.gardeners.com/sell.asp?ProdGroupID=14753. Accessed August 23, 2001.

Georgia Concrete & Products Association. 2003. Pervious Concrete Pavement...Pervious Pavements for a More Livable Environment. http://www.gcpa.org/pervious_concrete_pavement.htm. Accessed September 15, 2003.

Ging, P.B., L.J. Judd, and K.H. Wynn. 1997. *Water-Quality Assessment of South-Central Texas: Occurrence and Distribution of Volatile Organic Compounds in Surface Water and Ground Water, 1993–1994, and Implications for Future Monitoring*. Water-Resources Investigation Report 97-4028, U.S. Geological Survey.

Gray, J.R., G.D. Glysson, L.M. Turcios, and G.E. Schwarz. 2000. *Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data*. Water-Resources Investigation Report 00-4191. U.S. Geological Survey. http://water.usgs.gov/osw/pubs/WRIR00-4191.pdf. Accessed September 27, 2001.

Holman-Dodds, J.K., A.A. Bradley, and K.W. Potter. 2003. *Evaluation of Hydrologic Benefits of Infiltration Based Urban Storm Water Management.* Journal of the American Water Resources Association 39(1): 205-215.

Hsieh, C. and A.P. Davis. 2003. *Evaluation of Bioretention for Treatment of Urban Storm Water Runoff*. Presented at the 2003 World Water and Environmental Resources Congress, June 23-26, Philadelphia, PA.

Hunt, B., and S. Stevens. 2001. Permeable Pavement Use and Research at Hannibal Parking Lot in Kinston, NC. *NWQEP Notes* No. 101. North Carolina State University Cooperative Extension, Raleigh, NC. http://www5.bae.ncsu.edu/programs/extension/wqg/issues/101.pdf. Accessed March 19, 2005.

J.F. Sabourin and Associates, Inc. 1999. *Research Project for the Update Investigation on the Performance Evaluation of Grass Swales and Perforated Pipe Drainage Systems*. Ottawa, Ontario, Canada.

Jade Mountain, Inc. 2000. *Rain Barrels*. http://www.jademountain.com/waterProducts/ rainbarrels.html. Accessed June 27, 2000.

Johnston, D.M., J.B. Braden, and T.H. Price. 2003. *The Downstream Economic Benefits of Storm Water Retention: A Comparative Analysis*. University of Illinois, Champaign, IL, and Conservation Design Forum, Elmhurst, IL.

Legret and Colandini. 1999. *Effects of a Porous Pavement with Reservoir Structure on Runoff Water: Water Quality and Fate of Heavy Metals.* Water Science and Technology 39(2): 111-117.

Legret, M., M. Nicollet, P. Miloda, V. Colandini and G. Raimbault. 1999. *Simulation of Heavy Metal Pollution from Stormwater Infiltration through a Porous Pavement with Reservoir Structure.* Water Science and Technology 39(2): 119-125.

Livingston, E.H. No date. *Stormwater Management Systems: A Source of Mosquitoes??* Florida Department of Environmental Protection, Stormwater/Nonpoint Source Management Section, Tallahassee, FL.

MacRae, C.R. and A.C. Rowney. No date. *The Role of Moderate Flow Events and Bank Structure in the Determination of Channel Response to Urbanization*. Kingston, Ontario, Canada.

MacRae, C.R. No date. *Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection?* Kingston, Ontario, Canada.

Maryland Department of Natural Resources (MDNR). No date. *Maryland Green Building Program*. Maryland Department of Natural Resources, Annapolis, MD. http://www.dnr.state.md.us/ed/rainbarrel.html. Accessed July 24, 2003.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual: Volumes 1 and 2.* Maryland Department of the Environment, Baltimore, MD.

http://www.mde.state.md.us/environment/wma/stormwatermanual. Accessed August 22, 2001.

Maupin, M. and T. Wagner. 2003. *Regional Facility vs. On-site Development Regulations: Increasing Flexibility and Effectiveness in Development Regulation and Implementation.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

Maxted, J.R., and Scoggins, M. 2004: *The ecological response of small streams to stormwater and stormwater controls in Austin, Texas USA*. Prepared by the Watershed Management Institute for the United States Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington DC; Cooperative Agreement 9701.

Metzger, M.E., D.F. Messer, C.L. Beitia, C.M. Myers, and V.L. Kramer. 2002. The dark side of stormwater runoff management: Disease Vectors Associated with Structural BMPs. *Stormwater* 3(2): 24–39.

Midwest Internet Sales. 2001. *Rain Barrels and Barrel Planters*. Midwest Internet Sales. http://www.midwestinternetsales.com/rainbarrels.htm. Accessed August 23, 2001.

Morrow, W.S. 1999. *Volatile Organic Compounds in Ground Water of the Lower Illinois River Basin*. Water-Resources Investigation Report 99-4229, U.S. Geological Survey, Reston, VA.

Newman A.P., C.J. Pratt, S.J. Coupe and N. Cresswell. 2002. *Oil Bio-Degradation in Permeable Pavements by Microbial Communities.* Water Science and Technology 45(7): 51-56.

Northern Virginia Planning District Commission (NVPDC). 1980. *Guidebook for Screening Urban Nonpoint Pollution Management Strategies. A Final Report*. Prepared by the Northern Virginia Planning District Commission, Annandale, VA, for the Metropolitan Washington Council of Governments, Washington, DC.

Novotny, V. 1991. *Urban Diffuse Pollution: Sources and Abatement*. Water Environment and Technology, December 1991.

Pitt, R. 1997. The control of toxicants at critical source areas. In *Effects of Watershed Development and Management on Aquatic Ecosystems*, ed. L.A. Roesner, pp. 70–92. American Society of Civil Engineers, Reston, VA.

Pitt, R., S. Clark, and K. Parmer. 1994. *Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration*. EPA-600-SR-94-051. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Pratt, C.J., A. P. Newman and P. C. Bond. 1999. *Mineral Oil Bio-Degradation within a Permeable Pavement: Long Term Observations.* Water Science and Technology 39(2): 103-109.

Prince George's County, Maryland, Department of Environmental Resources. 1993. *Design Manual for Use of Bioretention in Stormwater Management*. Prince George's County, Maryland, Department of Environmental Resources, Division of Environmental Management, Watershed Protection Branch, Landover, MD.

Prince George's County, Maryland, Department of Environmental Resources. 2000a. *Low-Impact Development Design Strategies: An Integrated Design Approach*. Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, Largo, MD.

Prince George's County, Maryland, Department of Environmental Resources. 2000b. *Low-Impact Development Design Strategies: Hydrologic Analysis*. Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, Largo, MD.

Rasmus, J., and K. Weldon. 2002. Moonlight Beach Urban Runoff Treatment Facility. *Stormwater* 3(5).

Robertson, B., R. Pitt, A. Ayyoubi, and R. Field. 1995. A Multi-Chambered Stormwater Treatment Train. In *Proceedings of the Engineering Foundation Conference: Stormwater NPDES-Related Monitoring Needs, Mt. Crested Butte, Colorado, August 7–12, 1994*, American Society of Civil Engineers, New York, NY.

Rose, R.I. 2001. Pesticides and public health: Integrated methods of mosquito management. *Emerging Infectious Diseases* 7(1): 17–23.

Sands, K. and T. Chapman. 2003. *Rainbarrels—Truth or Consequences.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

Sansalone, J.J., and S.G. Buchberger. 1997. Partitioning and First Flush of Metals in Urban Roadway Storm Water. *Journal of Environmental Engineering* 123(2): 134–143.

Sawyer, C.N., and P.L. McCarty. 1978. Chemistry for Environmental Engineering, 3rd edition. McGraw-Hill Book Company, New York, NY.

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

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

Schueler, T. 1994. Sources of Urban Stormwater Pollutants Defined in Wisconsin. *Watershed Protection Techniques* 1(1):30–32.

Schueler, T. In press. Draft of Stormwater Strategies for Arid and Semi-Arid Watersheds. *Watershed Protection Techniques*. Draft dated July 12, 1999.

Schueler, T., P.A. Kumble, and M.A. Heraty. 1992. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone*. Metropolitan Washington Council of Governments, Department of Environmental Programs, Washington, DC.

Shapiro, N. 2003. *The Stranger Among Us: Urban Runoff, the Forgotten Local Water Resource.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

Shaver, E., and J. Maxted. 1993. *Construction of Wetlands for Stormwater Treatment*. Delaware Sediment and Stormwater Program, Dover, DE.

Spruce Creek. 2001. *Spruce Creek Rainsaver*. http://www.sprucecreekrainsaver.com/order.htm. Accessed August 23, 2001.

Strecker, E., P. Mangarella, N. Brandt, T. Hesse, R. Muneepeerakul, K. Rathfelder and M. Leisenring. 2003. *Development of the San Diego Creek Natural Treatment System.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

Swisher, D. 2002. *Chemical and Hydraulic Performance of a Porous Pavement Parking Lot with Infiltration to Ground Water."* Unpublished Master's Thesis, Department of Civil and Environmental Engineering, Pennsylvania State University.

Terrene Institute. 2001. Landscaped rain gardens offer stormwater control. *Nonpoint Source News-Notes* 66:18–20.

Traver, R.G. 2003. *Best Management Practice Monitoring in Support of Industry Change*. Presented at the Pennsylvania Stormwater Management Symposium, October 2003.

U.S. Environmental Protection Agency (USEPA). 1979. *Methods for Chemical Analysis of Water and Wastes*. EPA-600-4-79-020. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1983. *Final Report of the Nationwide Urban Runoff Program*. U.S. Environmental Protection Agency, Water Planning Division, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1995. *Economic Benefits of Runoff Controls.* EPA-841-S-95-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997. *Urbanization and Streams: Studies of Hydrologic Impacts*. EPA841-R-97-009. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1999. *Florida*. U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://www.epa.gov/owow/NPS/Section319II/FL.html. Last updated October 4, 1999. Accessed August 16, 2001.

U.S. Environmental Protection Agency (USEPA). 2000a. *Bioretention Applications*. EPA-841-B00-005A. www.epa.gov/owow/nps/bioretention.pdf. Accessed March 10, 2005.

U.S. Environmental Protection Agency (USEPA). 2000b. *Street Storage for Combined Sewer Surcharge Control*. EPA-841-B-00-005C. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2001a. *National Menu of Best Management Practices: Alum Injection*. U.S. Environmental Protection Agency, Office of Water, Washington, DC. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_3.cfm. Last updated May 30, 2001. Accessed September 27, 2001.

U.S. Environmental Protection Agency (USEPA). 2001b. *The EPA's Environmental Technology Verification Program*. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC. http://www.epa.gov/etv. Last updated July 2, 2001. Accessed September 27, 2001.

U.S. Environmental Protection Agency (USEPA). 2003. *When are Storm Water Discharges Regulated as Class V Wells?* U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, Washington, DC. http://www.epa.gov/safewater/uic/pdfs/fact_class5_stormwater.pdf. Accessed August 22, 2003.

U.S. Geological Survey. 2000. *Office of Water Quality Technical Memorandum No. 2001.03: Collection and Use of Total Suspended Solids Data.* http://water.usgs.gov/admin/memo/SW/TSS.0103.htm. Last updated November 27, 2000. Accessed September 9, 2003.

URS Greiner Woodward Clyde. 1999. *Measurement of TSS in Runoff*. Issue paper prepared for U.S. Environmental Protection Agency, Washington, DC, by URS Greiner Woodward Clyde, Portland, OR.

Vardon, S.G. 2000. Wetlands designed as a purifier for urban runoff. *Orange County Register*. December 27, 2000. Available for download at the Orange County Register's Archive at http://www.ocregister.com/archive/.

Vokral, J., D. Gumb, A.D. Cavallaro, S. Mehrotra and E. Rosenberg. 2003. Wetlands at Work. *Civil Engineering* 72(2): 56-63.

Washington State Department of Ecology. 1991. *Stormwater Management Manual for the Puget Sound Basin—Public Review Draft*. Washington State Department of Ecology, Olympia, WA.

Water Environmental Federation (WEF). 1998. *Urban Runoff Quality Management*. Water Environment Federation, Alexandria, VA, and American Society of Civil Engineers, Reston, VA.

WaterOnline. 2001. Verification program to test effectiveness of wet weather flow technologies. *Stormwater Permit Manual*. http://www.wateronline.com/read/nl20010410/416710. Accessed September 27, 2001.

Watershed Management Institute (WMI). 1997a. *Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation*. Watershed Management Institute, Ingleside, MD.

Watershed Management Institute (WMI). 1997b. *Operation, Maintenance, and Management of Stormwater Management*. Watershed Management Institute, Ingleside, MD.

Woodward-Clyde Consultants. 1986. *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC.

MANAGEMENT MEASURE 6 NEW AND EXISTING ON-SITE WASTEWATER TREATMENT SYSTEMS

6.1 Management Measure

Develop or maintain on-site wastewater treatment system (OWTS) permitting and installation programs that adequately protect surface water and ground water quality. Programs should include:

- A process to identify and protect sensitive areas (e.g., wellhead protection zones, nitrogen/phosphorus limited waters, shellfish habitat) and ensure that cumulative hydraulic discharges and mass pollutant loads from on-site systems do not impair surface or ground water;
- System selection, siting, design, and installation based on performance requirements, prescriptive technologies, protective setbacks, and separation distances that protect surface water and ground water resources;
- Education, training, licensing, and/or certification programs for system designers, site evaluators, permit writers, installers, inspectors, and other service providers; and
- Inspections of new on-site systems during and immediately following construction/installation to ensure that design and siting criteria are applied appropriately in the field.

Establish and implement management programs to ensure that newly permitted and existing on-site wastewater treatment systems are operated and maintained properly to prevent the impairment or degradation of surface and/or ground waters. On-site system operation and maintenance programs should include:

- System inventories and assessments of maintenance needs that provide management information regarding the types of systems in use and their location, capacity, installation date, owner, date of last inspection/service, and other data needed to support operation and maintenance oversight activities.
- Policies to ensure that on-site systems are managed, operated, and maintained to prevent degradation and impairment of surface and ground waters. These policies should include adequate authority to conduct inspections, revoke operating permits, and require pumping, repair, replacement, upgrade, or modification technologies when conditions indicate that surface and/or ground water resources might be adversely affected (e.g., eutrophication of surface waters, microbial or nitrate contamination of ground water).
- Periodic inspection and/or monitoring requirements to ensure that on-site systems are functioning properly. Inspection and monitoring programs should consider hydraulic, hydrologic, and mass pollutant loading impacts at both the site and watershed scales.
- Requirements to ensure that residuals pumped from the tank (i.e., septage) are reused or disposed of in a manner that does not present significant risks to surface waters or ground water resources.

6.2 Management Measure Description and Selection

6.2.1 Description

When properly planned, designed, installed, operated, and maintained, OWTSs (also referred to as septic systems) can effectively remove or treat contaminants such as pathogens, biochemical oxygen demand (BOD), and nutrients in human sewage. However, many on-site systems are failing because of age, inappropriate design, hydraulic/pollutant overloading, or poor maintenance (see Table 6.1). Detrimental impacts from on-site systems can occur when they are sited in sensitive ecological areas (such as wellhead protection zones, near nitrogen/phosphorus limited waters, or near beaches or shellfish habitat) or when they are installed at densities that exceed the hydraulic and hydrologic assimilative capacities of regional soils and aquifers. Pollutants of concern from on-site systems include pathogens, nitrogen compounds (e.g., nitrates), phosphorus, BOD, and other chemicals described in Table 6.2.

Table 6.1: Common causes of OWTS failure.

Type of failure	Contributing causes
Hydraulic	Excessive hydraulic loadings to undersized systems, low soil permeability, excessive ponding at the infiltrative surface, poor maintenance. Increases in water usage over a period of years can exceed the design capacity of the wastewater treatment system.
Organic	Excessive organic loading from unpumped or sludge-filled tanks results in biomat loss of permeability (biomats are discussed further in Section 6.3.1.5.2, which describes subsurface wastewater infiltration systems).
Soil depth to ground water table or bedrock	Insufficient soil depths (i.e., soil thickness between the subsurface wastewater infiltration system [SWIS] and ground water tables, impermeable strata, or bedrock is less than the recommended depth for soil texture and structure). High ground water is deleterious to pathogen removal and hydraulic performance.
System age	Systems more than 25 to 30 years old. Systems less than 25 to 30 years old experience considerably fewer hydraulic failures. Failure rates can more than triple for older systems. Regular tank pumping and use of alternating SWISs can prolong system life indefinitely.
Design failure	Inappropriate system design for the site; failure to adequately consider or characterize wastewater strength and flow (average daily and/or peak flows); failure to identify and consider restrictive soil/rock layers (e.g., fragipan) or regional geology (e.g., karst features, creviced bedrock); failure to assess landscape position.
System density	Cumulative effluent load from all systems in watershed or ground water recharge area exceeds the hydrologic capacity of the area to accept and/or properly treat effluent.

Table 6.2: Pollutants of concern for OWTSs (adapted from Tchobanoglous and Burton, 1991).

Pollutant	Reason for concern
Pathogens	Microorganisms such as parasites, bacteria, and viruses can cause communicable diseases through direct/indirect body contact or ingestion of contaminated water or shellfish. Pathogens pose a particular threat when partially treated sewage pools on ground surfaces or migrates to recreational waters. Transport distances for some pathogens in surface or ground waters can be significant.
Nitrogen	Nitrogen is a plant nutrient that can contribute to eutrophication and depletion of dissolved oxygen in surface waters, especially in estuaries and coastal embayments. Excessive nitrate-nitrogen in drinking water can cause methemoglobinemia in infants and complications for pregnant women. Livestock also can suffer health impacts from drinking water high in nitrate.
Phosphorus	Phosphorus is a plant nutrient that can contribute to eutrophication of inland fresh waters and some marine waters and eventually deplete dissolved oxygen.
Household chemicals	Chlorine, ammonia, and other cleaning compounds in high volumes may disrupt or disable biological activity in the septic tank. Wastes from hobby or craft activities (paints, solvents, etc.) and disposal of non-organic liquid wastes (old furniture polish, pesticides/herbicides, etc.) in onsite/cluster systems can have similar impacts.
Pharmaceuticals and endocrine disruptors	Disposal of large quantities of outdated antibiotics and other medicinal products in septic tank-based systems can impair or halt biological treatment processes. Disposal of products containing chemicals that disrupt endocrine system functions (e.g., regulation of metabolism, blood sugar, reproduction, embryonic development) in on-site systems might result in leaching of these chemicals into groundwater and surface waters and impair water quality and/or aquatic organisms, in some cases. Research on this issue, including toxicology, transport, and fate of potential endocrine disruptors, is ongoing (USEPA, 1998a; North Carolina Department Environment and Natural Resources, no date).

Estimates of on-site system failure rates range from 5 to 25 percent and higher in some states (USEPA, 2001b), resulting in contamination of drinking water, beaches, shellfish beds, and surface water resources. In 1996 septic systems were a contributing source of pollution for more than one-third (36 percent) of the impaired miles of ocean shoreline surveyed. The National Oceanic and Atmospheric Administration (NOAA) reported in 1995 that the discharge of partially treated sewage from malfunctioning septic systems was identified as a principal or contributing factor in 32 percent of all harvest-limited growing areas (NOAA, 1995).

In addition, ponds, lakes, and coastal embayments have been impaired by algal blooms caused in part by nutrient over-enrichment from failing OWTSs. For example, in Sarasota County, Florida, 45,000 septic systems contribute four times as much nitrogen to Sarasota Bay as the city of Sarasota's wastewater treatment plant. Septic systems are adding an estimated 1.5 million pounds of nitrogen per year to Florida's Indian River Lagoon, causing a decrease in freshwater wetlands and commercial shellfish harvests (USEPA, 2003).

States have identified OWTSs as the third most common contributor to ground water pollution and a significant threat to drinking water sources (Parsons Engineering Science, 2000). A 1999 outbreak of gastroenteritis at the Washington County (New York) Fair was linked to a failing septic system at a nearby dormitory. A failed septic system was blamed for 46 cases of hepatitis A in Racine, Missouri, in 1992, and other states have reported both health and water resource impacts from poorly functioning OWTSs (Fobbs and Skala, 1992).

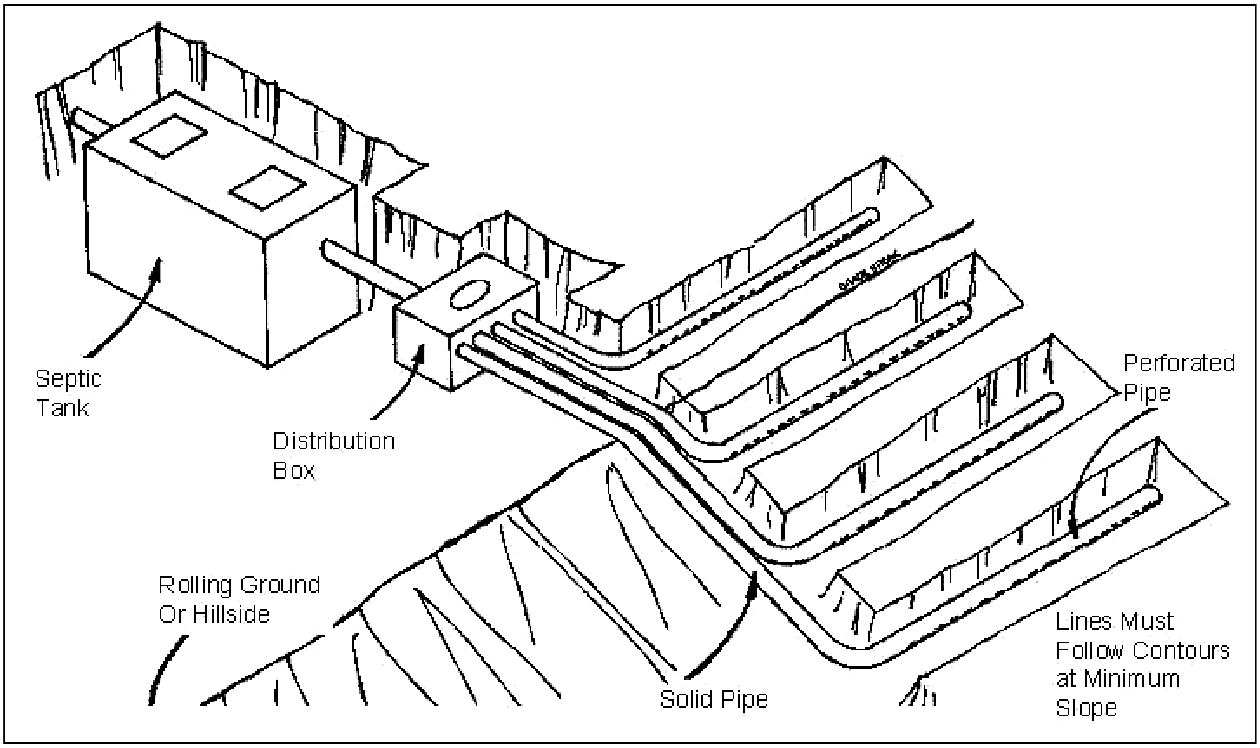


Figure 6.1: Conventional on-site wastewater treatment system.

OWTSs can generally be divided into two categories: conventional systems and alternative or innovative systems.

Conventional systems (see Figure 6.1) consist of a septic tank and a subsurface soil absorption field, commonly called a subsurface wastewater infiltration system (SWIS). Buried in the ground, septic tanks are essentially watertight, single- or multiple-chamber sedimentation and anaerobic digestion tanks. They are designed to receive and pretreat domestic wastewater, mediate peak flows, and keep settleable solids, oils, scum, and other floatable material out of the SWIS. Wastewater effluent is discharged from the tank and passes through pipes to a series of underground perforated pipes that can be wrapped in a permeable synthetic material. From there, the partially treated effluent flows onto and through the soil infiltrative surface, and finally into the SWIS infiltration medium (i.e., soil). Treatment occurs in the septic tank, on and within the biomat that forms at the soil infiltrative surface, and in the soil (or other medium); it then continues as the effluent moves through the underlying soil (biomats are discussed further in Section 6.3.1.5.2, which describes subsurface wastewater infiltration systems). Treated effluent that is not drawn into plant roots, incorporated into microbial biomass, or evaporated ultimately reaches ground waters and possibly nearby surface waters.

Alternative or innovative systems such as mound systems, fixed-film contact units, wetlands, aerobic treatment units ("package plants"), low-pressure drip applications, and cluster systems, are used in areas where conventional soil-based systems cannot provide adequate treatment of wastewater effluent. Areas that might not be suitable for conventional systems are those with nearby nutrient-sensitive waters, high densities of existing conventional systems, highly permeable or shallow soils, shallow water tables, large rocks or confining layers, and poorly drained soils. Alternative or innovative systems feature components and processes designed to promote degradation and/or treatment of wastes through biological processes, oxidation/ reduction reactions, filtration, evapotranspiration, and other processes. Cluster systems can be used to collect and treat wastewater from multiple facilities at a common site (e.g., lagoon, wetland, infiltration field). Alternative, innovative, and cluster systems often require individual septic tanks for each facility served to provide primary treatment and minimize fat, oil, grease, and solids loadings to secondary treatment units. (Note: Cluster systems that serve 20 or more people may be regulated by a federal, state, and/or local Underground Injection Control Program for Class V facilities. For more information, visit EPA's Underground Injection Control Program Web site at http://www.epa.gov/safewater/uic.html.)

Many states, tribes, and municipalities use a prescriptive approach to on-site system management. Such an approach assumes that a prescribed system design will adequately protect public health and water resources when installed at sites meeting established minimum requirements. Site evaluations are usually based on empirical approaches such as percolation tests and setback/separation distance requirements.

These evaluations do not typically consider regional hydrology or the density and cumulative discharge of existing and planned treatment systems. They do not consider the overall assimilative capacity of regional soils and hydrology and do not assess complex relationships among soil characteristics, site conditions, wastewater composition, biological mechanisms, and regional climate (Otis and Anderson, 1994). A prescriptive approach is often restrictive and arbitrary and can be underprotective or overprotective of public health and water quality.

A performance-based on-site system management approach does not require specifications for treatment methods or processes, but rather establishes treatment performance requirements for protecting human health and water resources. For example, this approach requires additional nitrogen removal in designated nutrient-sensitive areas without specifying the type of technology to be used (Code of Massachusetts Regulations, 1995). A report issued by the Maryland Department of the Environment and Maryland Office of Planning (2000) recommends installation of systems with enhanced nitrogen removal capabilities in designated "areas of special concern" to reduce nutrient loadings to the Chesapeake Bay and other sensitive waters.

Under a performance-based approach, officials are free to consider the application of alternative and innovative on-site systems in addition to conventional systems. Systems are planned, designed, sited, and installed to achieve specified performance requirements within the context of regional and individual site conditions, rather than requiring site conditions to conform to the soils, slopes, and other needs of a restricted set of prescribed technologies. Performance-based on-site programs also include rigorous and ongoing system management, such as periodic inspections and required maintenance. Such a management approach can result in fewer system failures and greater protection of public health, surface waters, and ground water.

EPA issued *EPA Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems* (USEPA, 2003), which recommends management measures for on-site systems based on the administrative and managerial capacity of management entities, the complexity of technologies used, and the value and proximity of resources to be protected. The guidance contains tools and directions to assist states and communities in developing management programs based on local needs and resources, as well as risks to human health and water resources. Activities include planning, design, site evaluation, inspections, monitoring, funding, and other functions. The guidelines note the shortcomings of on-site programs that: (1) do not have a planning element that considers regional hydrology and system densities and discharges; and (2) do not have operation and maintenance requirements that ensure monitoring, periodic septic tank pumping, system repair, and upgrades when necessary. Many existing OWTS regulatory programs fail to consider the ability of regional soils to assimilate pollutants from dozens or hundreds of treatment systems in an area and often leave operation and maintenance of these systems to uninformed and untrained homeowners.

In *EPA Voluntary National Guidelines for Management of Onsite and Clustered(Decentralized) Wastewater Treatment Systems*, EPA recognizes the benefits of both conventional and alternative systems and emphasizes the importance of proper planning, site evaluation, system design, installation, inspection, operation, monitoring, and maintenance. On-site systems, like sewage treatment plants that serve urban areas, require periodic attention and regular servicing to ensure that treatment levels meet established performance requirements. Management programs must comply with performance requirements by ensuring sludge is pumped from tanks periodically, failed or failing systems are detected promptly and repaired or replaced, and undersized or underperforming systems are upgraded.

6.2.2 Management Measure Selection

This management measure was selected to ensure that new and existing on-site wastewater treatment systems function properly. If these systems fail, wastewater can pool on ground surfaces or migrate to aquifers or surface waters and cause significant public health or environmental problems (e.g., disease outbreaks, eutrophication, loss of dissolved oxygen). This management measure supports a performance-based approach to system management and is consistent with the *EPA Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems* (USEPA, 2003) and the *Onsite Wastewater Treatment System Manual* (USEPA, 2002a).

6.3 Management Practices

6.3.1 Permitting and Installation Programs

EPA believes that on-site system permitting and installation programs that protect surface and ground waters are necessary to decrease or eliminate risks to human health and sensitive ecological resources. Approaches that match the treatment capabilities of various on-site technologies to the conditions and sensitivity of the receiving environment (ground water or surface water) are preferred. EPA recognizes that, due to a lack of staff expertise, funding, assessment data, regulatory infrastructure, public support, and other resources, not all on-site regulatory agencies or management programs will have the ability to implement performance-based approaches.

Therefore, alternative approaches, which include prescriptive standards that provide appropriate levels of protection for human health and water resources, are included among the acceptable management practices summarized in this section. These standards include prescribed treatment technologies, minimum requirements (e.g., soils, slopes) for proposed installation sites, mandatory setback and separation distances, and specific system component requirements (e.g., septic tank screens, grease traps). They will be considered acceptable management practices if they provide reasonable assurances of protecting public health and water resources when applied under the specific site conditions.

Elements supporting this Management Practice are listed below and correspond with the management measures listed in Section 6.1.

6.3.1.1 Planning activities

Comprehensive planning can provide valuable information and support for on-site system placement and management. Integrating planning with regulatory programs can provide a basis for ensuring the performance of existing systems and permitting future installations. Planning involves the examination of many variables:

- A wide range of environmental characteristics (e.g., ground water, topography, soils, climate, sensitive ecological resources);
- The locations and types of facilities that could be part of an overall wastewater management plan;
- The organizational and institutional structures that exist or may need to be created; and
- Financial support for their development and implementation.

At a minimum, planning should identify areas where:

- Installation of conventional systems can be allowed at specified densities;
- Alternative systems could be required; and
- On-site systems could be permitted only under strict design and performance requirements and assurances for long-term monitoring and maintenance.

6.3.1.1.1 *Comprehensive planning*

Comprehensive planning provides one of the best vehicles for ensuring that on-site management issues are considered under future growth and development scenarios. Comprehensive planning and zoning are closely related and are usually integrated. Comprehensive planning sets overall guidance and policies; zoning provides the detailed regulatory framework for implementation. Comprehensive planning that addresses environmental protection while providing adequate public services such as wastewater treatment can be administered through zoning regulations that:

- Specify prescriptive or performance requirements for individual or clustered systems installed in unsewered areas, preferably by watershed, subwatershed, or ground water recharge area;
- Limit, manage, or prevent development on sensitive natural resource lands or in designated critical areas (e.g., in wellhead protection zones or shellfish habitat runoff catchments, or near nutrient-sensitive waters and wetlands);
- Encourage development within urban growth areas serviced by sewer systems, if adequate capacity exists; and
- Consider factors such as system densities, hydraulic and pollutant output, proximity to water bodies, soil and hydrogeological conditions, water quality, and cumulative loadings from all systems, including future systems, in planning and zoning decisions. Large numbers of soil-based on-site systems discharging to a confined area (e.g., high-density subdivisions) can overwhelm the capacity of soils to assimilate and treat wastewater pollutants of concern, such as nutrients and pathogens.

It should be noted, however, that it is not necessary for the on-site regulatory agency or management entity to oversee or administer the planning program. In many areas, local or regional planning offices collect and store the types of information needed for on-site system management. Some of these offices have the ability to generate geographic information system (GIS) maps that can incorporate water resource, soil, topographic, and other information that provides screening-level site criteria for proposed installation of on-site systems. Coordination with planning offices to designate ecologically sensitive areas and those approved for future on-site system installations can significantly improve the management capabilities of the on-site regulatory agency or management program and improve watershed protection.

6.3.1.1.2 *Wastewater treatment continuum concept*

Decision-makers responsible for approving wastewater collection and treatment services for existing or new facilities often require information and guidance on the various options available. Protection of public health and valued water resources and cost are the primary decision-making criteria in most cases. Both centralized sewer service and decentralized/on-site systems protect public health and water resources, though treatment levels and cost may vary depending on technology, operational factors, system maintenance, and site-specific conditions (e.g., combined sewer overflows, bypasses, and nutrient removal requirements for centralized systems; and geology, soils, climate, and other factors for decentralized/on-site systems).

A number of wastewater treatment and collection options exist along the continuum between individual on-site systems and centralized sewer service. The following options are suggested for decision-makers seeking to improve collection and treatment in existing areas or to provide these services to new development (Venhuizen, 2000):

- Current practice, employing conventional septic tank/soil absorption field systems within the confines of each residential or facility lot;

- Alternative on-site systems for each lot. Examples include sand filters, aerobic treatment units, vegetated submerged wetlands, and dispersal in shallow, pressure-dosed subsurface wastewater infiltration systems;

- Small-diameter collection/treatment facilities using septic tank effluent drains (STEDs) or other shallow, low-cost collection systems to pump or route the flow from each lot to a common site for final treatment and dispersal or discharge; or

- Centralized sewage collection and treatment with the option of either conventional or alternative treatment facilities at one centralized plant.

Each of these strategies should include oversight and management programs to ensure that collection and treatment equipment and processes continually meet performance requirements. The responsible management entity (RME) should be charged with keeping collection and treatment systems working. The RME should have sufficient authority to enforce programmatic and other requirements, pay for operational and other costs, and take necessary actions in the event of performance failure or emergencies.

Developing operation, maintenance, and management strategies for decentralized/on-site systems in a manner similar to those in existence for centralized systems—or incorporating on-site treatment options into the centralized system strategy—can help to ensure that public health and water resources are protected effectively and efficiently.

6.3.1.1.3 *Centralized sewage treatment*

As development activity increases the density of OWTS-served housing, commercial establishments, and other facilities in a region, it is sometimes cost-effective to extend service lines from centralized sewage treatment facilities (i.e., publicly owned treatment works or POTW) for wastewater collection and treatment at a central plant. Small towns in the past have typically only considered connections to a regional POTW or the construction of a treatment facility. Factors to consider other than costs when deciding whether it is beneficial to use decentralized/onsite systems, construct a new treatment plant, or extend service lines of a nearby system include the following:

- Age and operational history of existing OWTSs;

- The RME's capacity and authority to properly manage OWTSs;

- Future housing and other development trends based on land use planning information;

- Proximity and capacity of existing POTW service lines and treatment facilities;

- Potential for revision to an existing NPDES discharge permit;

- Suitable financing, land area, and site conditions for construction of POTWs or collection lines; and

- Hydrological impacts and catastrophic risk assessment due to failure of collection systems and POTWs.

6.3.1.2 System selection, site evaluation, design, and installation

On-site systems often fail because of improper design and inadequate site evaluation and/or installation. Some states require higher levels of treatment near wellhead recharge zones, nutrient-sensitive waters, shellfish habitat, or other areas of special concern. On-site wastewater treatment systems discharging pathogens that can reach wells or shellfish habitat areas, and those that discharge significant inputs of nitrogen or phosphorus to nutrient-sensitive waters, should be high-priority candidates for upgrade or replacement (Commonwealth Biomonitoring, 2001). A committee advising the Maryland Department of the Environment recommended in 2000 that legislation be adopted requiring county water and sewer agencies to designate areas of special concern to address elevated nitrogen inputs from existing and new on-site systems (Maryland Department of the Environment, 2000). State income tax credits of up to $1,100 per year for three years were suggested to assist homeowners with increased system costs. Existing systems would only require nitrate removal in these areas when system replacement was required.

6.3.1.2.1 *Performance-based programs*

Performance requirements for individual or clustered on-site treatment systems are most often based on assurances that system discharges will not cause violations of surface water quality standards or drinking water standards. A performance-based program includes the following components:

- Performance goals;
- Performance criteria;
- Performance requirements; and
- Performance monitoring.

(a) *Performance goals*. Performance goals define the larger issues that are important to consider in on-site system siting, selection, design, and management. A properly functioning on-site system should be able to meet two basic performance goals: protect public health and protect water resources.

An example of a performance goal might be to protect the surface water from nutrient enrichment in environmentally sensitive areas such as lakes or estuaries. Detailed planning, design, installation, and management programs can help prevent placement of inappropriate systems in areas with unsuitable soils, on sites adjacent to valued and sensitive surface water bodies, and at densities that exceed regional hydrologic and pollutant assimilative capacities. Such an approach can help control or minimize pollutant loadings and associated impacts on surface and ground waters.

Promoting System Upgrades Through Innovative Financing

The Code of Massachusetts Regulations allows a state tax credit of up to 40 percent of the cost of a new on-site system or system repairs. The credit is capped at $1,500 per year and $6,000 total and is limited to homeowners living in the residence served by the repaired or replaced on-site system (Code of Massachusetts Regulations, 2001).

(b) *Performance criteria*. Performance criteria are measurable indicators that identify the pollutants of concern for a particular area so that benchmarks or performance requirements can be established to reduce further inputs of those pollutants. Performance criteria are used to quantify progress in achieving performance requirements for specific pollutants. Some examples of site-scale performance criteria include effluent concentration limits for nitrate, biochemical oxygen demand (BOD), fecal coliform bacteria, and overall flow. Watershed-scale criteria might include total hydraulic input to a ground water recharge zone from on-site systems, and total nitrogen load or total phosphorus load to ground water or surface waters.

(c) *Performance requirements*. Performance requirements are criteria-based limits that define acceptable environmental impacts and public health risks associated with on-site systems. Performance requirements are based on the type of water body that ultimately receives treated wastewater effluent (ground water or surface water) and the present or projected uses of that water body (e.g., drinking water source, shellfish habitat, contact recreation). Examples of a performance requirement might be that on-site systems in nitrogen-sensitive areas must not discharge more than 5 pounds of nitrogen per year, or that nitrate concentrations in OWTS effluent cannot be greater than 15–20 milligrams per liter (mg/L).

Resource protection performance requirements are based on the assumption that any given resource has a threshold (carrying or assimilative capacity) beyond which it cannot function and may deteriorate. Nitrogen requirements are more likely to be appropriate near marine waters because this nutrient is usually the limiting factor for algal growth in coastal areas. In ground waters, nitrogen can degrade drinking water resources as well. The Commonwealth of Massachusetts has designated certain areas, such as wellhead protection areas, areas in public water supply watersheds, and nitrogen-sensitive coastal embayments or other nitrogen-sensitive water bodies, as "Nitrogen-Sensitive Areas" (Code of Massachusetts Regulations, 1995) and has issued requirements to ensure their protection. Environmentally sensitive areas might include nitrogen-limited coastal waters, phosphorus-limited inland waters, shellfish habitat, and ground water used as drinking water. Typical performance criteria and examples of corresponding performance requirements are listed below:

- Fecal coliform bacteria as an indicator of the possible presence of pathogens (e.g., less than 200 colony-forming units per 100 milliliters [cfu/100 ml]) for support of primary contact recreation or 14 cfu/100 ml in shellfish waters

- Nitrogen in the form of nitrate in potable ground water (e.g., less than 10 mg/L) and as total nitrogen in nitrogen-limited coastal waters to prevent or reduce enrichment

- Phosphorus concentration in surface waters where phosphorus is the limiting element for algal growth (e.g., less than 0.025 mg/L to support warm water aquatic habitat)

- BOD for surface waters requiring high levels of dissolved oxygen for propagation of fish and shellfish (e.g., 5–10 parts per million of 5-day BOD after tertiary treatment to support warm water aquatic habitat)

- Nuisance factors (e.g., no objectionable odors emanating from the septic tank or infiltration field area, no sewage surfacing to minimize risk of human contact)

(d) *Performance monitoring*. Performance monitoring tracks progress in achieving performance requirements. Typical approaches involve measuring or assessing performance criteria at some specified point of compliance (e.g., a designated performance boundary). For example, if waters of a commercial shellfish habitat in a coastal bay are experiencing elevated bacterial contamination, a fecal coliform bacteria performance requirement for on-site systems in the area might be established at the property line or shoreline of the lot. A variety of monitoring programs have been developed to assess the performance of on-site systems. Approaches include measurement of chemical parameters (e.g., nitrogen, phosphorus, BOD, nitrate) in effluent or receiving waters; analysis of fecal coliform/fecal streptococcus ratios; and a variety of new, experimental, analytical approaches using molecular, chemical, or biochemical methods (e.g., ribotyping, antibiotic resistance analysis, randomly amplified polymorphic DNA, pulse field gel electrophoresis, caffeine tracking) (Hagedorn, 2000). Validation and cost issues prevent widespread use of the newer methodologies at the present time, but research in the field shows significant promise.

The Critical Point Monitoring (CPM) approach being developed in Washington State provides a systematic approach to choosing critical locations to monitor specific water quality parameters (Eliasson et al., 2001). The program is most suitable for responsible management entities operating comprehensive management programs. CPM provides an appropriate framework for monitoring treatment train components (i.e., septic tank, infiltration field, sand/media filters, aerobic treatment units), though it should be recognized that evaluations of overall system effectiveness—and compliance with performance requirements—should be based on monitoring at designated performance boundaries.

Tracer dye tests, analysis of *E. coli* concentrations in receiving waters, and system inspections are the most widely used methods for monitoring on-site system performance at present. The first only provides indirect hydrologic information, while the latter two offer direct utility to assess whether performance goals are being achieved. For the purpose of watershed-scale monitoring and modeling, the use of output criteria derived from typical performance ranges of on-site system types used in the area is a common practice. Models can be useful tools to predict potential ground water impacts if they are based on site- or regional-specific characteristics and are calibrated to achieve the best estimates of actual field results. They are rarely accurate under all conditions, however, and must be supplemented with actual field monitoring results when available.

6.3.1.2.2 *Modeling system performance and impacts*

There have been relatively few attempts at developing modeling tools to predict and simulate nutrient fate and transport mechanisms from on-site system effluent (Tetra Tech, 2000; Bicki and Brown, 1991; Harmesen et al., 1991). Most of the work has focused on identifying nitrate loading to ground water for the purpose of planning for drinking water protection. Computer models require a considerable amount of site-specific information regarding wastewater characteristics, discharge volumes, soils, topography, underlying geology, ground water, and climate, but they can be useful tools for assessing the long-term impacts of OWTSs in an area and developing strategies to mitigate potential problems.

The State of Florida developed a computerized model to assess ground water contamination potential in selected hydrogeologic regions as a tool to guide development of subdivision regulations (Florida HRS, 1993). The model incorporated features of the state's varied surficial hydrology and soil regimes and provided estimations of the transport and fate of nitrogen compounds. The Florida model uses a steady-state, one-dimensional flow field with three-dimensional dispersion and assumes retardation and first-order decay rates to be zero. Nitrate contaminant plumes generated by the model show a variety of dispersion and transport scenarios and confirm that increasing lot size from four homes per acre to two homes per acre (and even fewer in areas of high porosity) reduce nitrate concentration and migration in ground water by approximately 50 percent (from 10 mg/L to 5 mg/L 700 feet downgradient of the subdivision under study). The results suggest that concerns over nitrate contamination of ground waters from large, densely developed subdivisions with OWTSs are not unfounded. They support recommendations to monitor ground water nitrate concentrations below and downgradient of large subdivisions with home densities greater than four units per acre.

Another model developed for the Indian River Lagoon National Estuary Program found that nitrogen inputs linked to on-site systems constituted 12 percent of the total nitrogen load into the lagoon, an amount nearly equal to the load from cattle. The loading model provides a mechanism for calculating total nitrogen inputs into the aquatic system, and it attempts to predict the nitrogen concentrations in ground water based on hydrological parameters (University of Massachusetts, 2000). Efforts to calibrate the ground water prediction capabilities of the model are ongoing.

6.3.1.2.3 *Applying system siting criteria*

Conventional and many alternative on-site systems include a SWIS, which requires a certain minimum area of soil, sand, or other treatment media to effectively remove pathogens and other pollutants. Under a prescriptive approach, setbacks from wells, surface waters, building foundations, and property boundaries are minimum requirements necessary to eliminate or reduce threats to public health and the environment. Setbacks are used only rarely but can be established based on soil type, slope, characteristics of the water table (as defined by the implementing agency), sensitivity of aquatic resources, and type of on-site system. Under a prescriptive program, setback guidelines also should be established for both conventional and alternative on-site systems. Recommendations for horizontal separation distances are based on the degree of pre-soil application treatment achieved, as well as site-specific factors such as climate, topography, soil permeability, ground water gradient, ground water flow, and geology. The management entity should adopt measures that restrict the placement of wastewater treatment systems in inappropriate soils, in proximity to valuable surface waters, and at densities too high for soils to treat pollutants sufficiently. One example is the lack of available concentrations of certain metals that retard phosphorus movement to nearby surface waters.

Separation and setbacks can also be used under the performance-based approach. Under this approach, setback or separation distances should be based upon research or field data that demonstrate pollutant removals needed to meet performance requirements given the specific site conditions and treatment technology applied. Pretreatment systems that discharge effluent containing concentrations of bacteria, nitrogen, and phosphorus below requirements established to protect water quality can be sited closer to water resources if impact analyses determine that contamination risk is unlikely.

6.3.1.2.4 *Site evaluations that assess suitability for specific technologies*

States vary greatly in their approach to evaluating site suitability; such approaches range from no specific requirements to very detailed evaluations that require qualified soil scientists and hydrogeologists (NSFC, 1995). A performance-based approach to site evaluation may involve one or more of three evaluation approaches:

1. *Soil-based.* Sites are characterized by conducting a soil profile analysis, usually through the use of soil maps, field data, and inspection of the soil profile in a backhoe pit. Many states now require a soil profile analysis to determine site suitability for conventional systems.

   The soil-based approach focuses on site-specific observation of soil properties that significantly affect the performance of soil-based on-site systems. The soil-based approach has two major advantages: (1) direct observation of soil properties provides a considerable amount of quantitative and qualitative information that can be used to select or modify on-site system design; and (2) site evaluations for individual systems can sometimes be completed in a single visit. The major disadvantage of this approach is that it provides little quantitative information on hydrologic properties and characteristics of the region and sub-watershed. The risk of inadequate hydrogeologic characterization increases when on-site system densities increase.

   Soil assessments are best conducted by observing the soil profile on the wall of a backhoe pit that is 48 to 72 inches deep. Soil layers should be characterized to a depth of at least 3 to 5 feet below the proposed excavation of the effluent absorption field, especially in highly porous soils. Characterizing the soil profile in a backhoe pit is best accomplished using natural lighting because soil texture, structure, color, mottling, and iron or manganese concretions can be observed, assessed, and described more accurately. Hand augers tend to disturb and compress the soil and disguise soil layers, making it difficult to observe structure and other features. Pits should be excavated at the perimeter of the soil absorption field rather than in the middle of it because settling might cause problems with distribution piping and absorption trench stability, and the disturbance could modify subsequent soil system performance.

2. *Hydrogeologic-based*. Surface water and ground water hydrology and the geology of the management area are characterized to determine treatment technology selection and maximum system densities. Zones can be created to establish minimum lot sizes, maximum discharge rates per acre, or minimum treatment efficiencies (e.g., effluent nitrogen concentrations). Percolation rate tests, which have been used extensively in the past to characterize wastewater dispersion in the soil, do not predict treatment effectiveness or ensure future hydraulic performance.

   Hydrogeologic-based evaluations originated with the development of the percolation test in the 1920s. Although the percolation test is simple to conduct and can provide some information on relative infiltration rates, it does not necessarily provide design information because of its inability to discern what controls the rate of water loss from the hole. Also, the test cannot accurately predict infiltration rates at equilibrium operation or in downgradient zones through which the effluent will migrate.

Hydrogeologic characterization can also include testing for hydraulic conductivity, porosity, and permeability, usually requiring multiple extended site visits. Cluster and small community on-site systems (> 2000 gpd) require more extensive hydrogeologic characterization. Multifactor approaches for site evaluation use information regarding soils, hydrogeology, mineralogy, cation exchange, and possibly other information such as regional effluent loading models.

3. *Multifactor-based*. A variety of factors (e.g., soils, climate, ground water conditions, slopes, OWTS densities, proximity to and status of water resources) in the management area are characterized to establish zones reflecting likely treatment effectiveness and the potential for public health and environmental impacts. Conventional systems are permitted in nonsensitive zones that meet minimum soil, separation/setback, and other prescriptive requirements. Alternative systems should be required for sensitive sites that cannot support conventional SWIS-based applications. Sites within sensitive zones can be required to meet performance standards and to be closely managed for continued compliance.

Regardless of approach, the objective of the site investigation is to evaluate the wastewater treatment and dispersal capabilities of the site and surrounding area. The site evaluation systematically gathers information that is used to narrow the range of OWTS design options to the one that best accomplishes the overall performance goals of protecting human health and the environment. The evaluation should begin with a consideration of both regional hydrology and the density and discharge of existing OWTSs in the area. Regional planning programs, where they exist, can provide a significant amount of information during this stage of the process. Other reconnaissance activities prior to the actual site visit should include researching the following: soil surveys; geology, topography, and surface water and ground water resources; OWTS installations in the vicinity and their operating record; well locations and hydrogeological records in the area; and maps showing utility lines and other features that might have an impact on design and placement of the system.

Landscape position, location of treatment unit components, slopes, trees, and other features (e.g., drainages, fences, pipelines, electric lines) should be noted on a site plan that is filed with permit documents. The soil analysis should include identification of the major horizons and their structure, texture, color, mottles and concretions, as well as other notable features (e.g., rocks, organic matter, wetness). If percolation tests are used, they should be conducted in strict accordance with established procedures and should always be accompanied by a detailed investigation of the soil profile and regional conditions. Permitting of OWTSs on the basis of percolation tests alone is not recommended.

Table 6.3 presents a list of site features that might require evaluation prior to selecting the system design and installation site. The site evaluation process typically differs for individual OWTSs and larger-scale cluster or small community systems; i.e., data on every feature on the checklist does not have to be collected for every individual home site. Site assessments should be performed to determine the soil infiltration rate, expected soil pollutant removal capacity, acceptable hydraulic loading rate, and required depth to the water table, at a minimum, prior to design and application for a construction permit for on-site systems. A simple individual home site evaluation can be accomplished in a single site visit when a soil-based approach is used.

Three American Society for Testing and Materials (ASTM) practices covering surface characterization (ASTM, 1995), subsurface soil characterization (ASTM, 1996b), and preliminary sizing and delineation of subsurface soil absorption or constructed filter field areas (ASTM, 1996a) give specific guidance on how this can be accomplished (http://www.astm.org/). Surface and some subsurface characterization practices are shown in Table 6.4. The ASTM standard practice for characterizing subsurface conditions through test pit inspection is summarized in Table 6.5. These practices can be specified when hiring contractors and consultants.

Table 6.3: Site features that should be evaluated before OWTS design and installation.

Type	Site Feature
Surface Features	Location of property boundaries, location of existing and/or proposed structures, location of surface water features (landscape position and land form, including intermittent and perennial drainage ways, irrigation ditches, streams, swales, depressions, water bodies, and wetlands), topography (use local regulatory suitability criteria or Natural Resources Conservation Service [NRCS] soil survey classes), location of water supply sources (well, public water supply reservoir), location of buried anthropogenic features (water lines, utility lines, etc.), location of disturbed soil (cut and fill), other significant features (large trees, bedrock at the surface, etc.)
Soil Features	Major soil horizons, texture and structure of each horizon, color, mottles, other relevant features of each horizon (rupture resistance, penetration resistance, wetness, pore characteristics, presence of roots), depth to bedrock, depth to low permeability (i.e., restrictive) soil horizons (fragipan, caliche, duripan, etc.), depth and thickness of strong textural contrasts. Phosphorus (P) Index when P retention is needed.
Hydrogeologic Features	Depth to seasonal high water table and shallow ground water tables, potentiometric surface, ground water flow direction and gradient, percolation test results, saturated hydraulic conductivity (estimated, field, and laboratory), ground water time of travel to points of interest, unsaturated hydraulic conductivity relationships, other water budget parameters (precipitation, potential evapotranspiration, etc.)

Table 6.4: Practices to characterize surface and subsurface features of proposed OWTS sites (ASTM, 1995, 1996b).

Description of activity	Information from research
Preliminary Documentation	– Site survey map – Soil survey, U.S. Geological Survey (USGS) topographic map – Aerial photos, wetland maps – Natural resource inventories – Applicable regulations and/or setbacks – Hydraulic loading rates – Criteria for alternative OWTSs – Size of house or facility – Loading rates, discharge types – Planned location of water well
Scheduling	– Planned construction schedule – Date and time for meeting
Description of Activity	– Information from field study
Identification of Unsuitable Areas	– Water supply separation distances – Regulatory buffer zones and setbacks – Limiting physiographic features

Table 6.4 (continued).

Description of activity	Information from research
Subsurface Investigations	– Ground water depth from pit or auger – Soil profile from backhoe pit – Percolation tests
Identification of Recommended OWTS Site	– Integration of all collected data – Identification of preferred areas – Assessment of gravity-based flow – Final selection of OWTS site

Table 6.5: Practices to characterize subsurface conditions through test pit inspection (ASTM, 1996a).

Description of activity	Process steps	Information to be collected
Select backhoe pit site(s) near but not in proposed drainfield	Orient pit so that sunlight illuminates vertical face of pit	Proposed location of soil absorption field
Excavate pit to depth required by regulations	Pit excavation	Required ground water separation distance, soil profile depth
Enter test pit	– Take safety precautions – Beware of cave-ins – Select area of pit wall to examine	Safe depths for unbraced pit walls
Expose natural soil structure	Use soil knife, blade, screwdriver, or other tool to pick at area 0.5 m wide along full height of pit wall	Soil structural type (e.g., prismatic, columnar, angular blocky, subangular blocky, platy, granular)
Describe soil horizons	– Note master soil horizon layers – Describe features of each horizon	List soil horizon features: – Depth of horizon and thickness – Moisture content – Color (i.e., hue, value, chroma) – Volumetric percentage of rock – Size, shape, type of rock found – Texture of <2mm fraction of horizon – Presence or absence of mottles and other redoximorphic features – Soil structure by grade – Level of cementation – Presence or absence of carbonates – Soil penetration resistance – Abundance, size, and distribution of roots
Determine lateral changes in soil profile	Use hand auger and/or compare to profile of second pit	Determine changes, if any, in soil profile across proposed site
Interpret results	Identify limiting depths	– Check vertical separation distances – Identify mottled layers and concretions – Determine depth to saturation – Measure depth to confining layer
Issue site report	Log all data onto survey form	Develop system type, site location, and installation recommendations

Several systems have been developed to perform source water vulnerability assessments and to map locations where site conditions might preclude the use of conventional on-site systems. A system such as the DRASTIC methodology (Aller et al., 1987) can be used to map areas where aquifers might be vulnerable to pollution from on-site systems. DRASTIC considers soil permeability, depth to ground water, and aquifer characteristics. Florida adapted the DRASTIC approach to produce digital maps showing potential areas where ground water threats might increase (http://www.dep.state.fl.us/gis/datadir.asp). The U.S. Department of Agriculture (USDA) developed soil maps that contain detailed information on regional soils, including suitability for conventional on-site systems, and is updating these maps in some areas. The USDA National Soils Survey Center (http://ssldata.nrcs.usda.gov/) provides county-level soil information nationwide.

States are implementing GIS-based programs for identifying and mapping critical water supplies and aquifer protection areas. Some states have established zones that define effluent quantity and quality and system options available to meet those requirements. Computer simulation models have also been developed that assess the impact from locating on-site systems at various densities within a watershed. For example, the Buzzards Bay Project of the National Estuary Program provides an online nitrogen input modeling spreadsheet that can be adapted for local use by entering appropriate information for land use, nitrogen loading rates, watershed size, projected build-out, and other parameters (http://www.buzzardsbay.org/nitrmang/bbploadcalc.xls).

6.3.1.3 Education, training, licensing, and/or certification programs

In the past, a few states established training programs for site evaluators and adopted more-stringent codes for system design, setback distances, and general site requirements (Kreissl, 1982). If a site were declared unsuitable by these evaluators under the code prescriptions, some of these states would allow professional engineers to propose system designs that could overcome site limitations. Many jurisdictions (regulatory agencies) have begun to favor employing trained, experienced, professional staff who can make judgments and decisions on system design and siting in an efficient, effective manner. This practice must be differentiated from programs that use compliance enforcement staff to design systems. Such approaches are not recommended due to potential conflicts of interest resulting from design and compliance determinations by the same entity.

Most states have minimum requirements (e.g., college coursework, state-sponsored training) for oversight agency staff (e.g., health department permitting personnel), but some states have more stringent competency requirements.

In many states, system installers must be certified (see Table 6.6). Florida requires installers to meet certain minimum requirements, demonstrate experience, provide references, pass an examination, and complete six hours of approved classroom instruction annually to retain their certification. Minnesota has had a certification program for installers, designers, pumpers, and inspectors since the early 1970s; the program became mandatory for all service providers in 1994. Maine instituted a licensing program for site evaluators in 1974 and saw system failure rates drop to insignificant levels (Kreissl, 1982). Site evaluators in Maine must now be licensed professional geologists, soil scientists, or engineers with at least one year of relevant field experience. They must also pass a written examination and a field practices test (Maine Department of Health Services, 1996).

Requirements for site evaluators, system designers, installers, inspectors, and maintenance service providers vary widely among the states. Some states have few, if any, requirements for service personnel, whereas other states require professional certification and ongoing training for most service providers (see Table 6.6). In addition, some states issue permits or grant exemptions that allow homeowners to design and install on-site treatment systems at their primary residence.

Table 6.6: Survey of state certification and licensing programs for onsite wastewater service providers (Noah, 2000).

State	Contractors	Installers	Inspectors	Pumpers	Designers	Engineers	Geologists	Operators
AL	Y	Y	Y	Y	N	Y	Y	Y
AK	Y	Y	NA	NA	NA	Y	NA	NA
AZ	Y	Y	NA	Y	NA	Y	Y	NA
AR	N	Y	N	Y	Y	N	N	N
CA	N	N	N	N	N	N	N	N
CO	N	N	N	N	N	Y	N	Y
CT	NA	Y	Y	Y	NA	Y	NA	NA
DE	Y	Y	N	Y	Y	Y	N	Y
FL	Y	Y	Y	Y	Y	Y	Y	Y
GA	Y	Y	Y	Y	N	N	N	N
HI	N	N	N	N	N	Y	N	Y
ID	N	Y	Y	Y	N	N	N	N
IL	Y	Y	NA	Y	NA	NA	NA	NA
IN	N	N	N	N	N	N	N	N
IA	N	N	N	Y	N	N	N	N
KS	NA	NA	NA	NA	NA	Y	Y	Y
KY	Y	Y	Y	Y	N	N	N	N
LA	NA	Y	NA	NA	NA	NA	NA	NA
ME	N	Y	Y	N	Y	Y	Y	N
MD	N	Y	Y	N	N	N	N	N
MA	Y	Y	Y	Y	Y	Y	N	Y
MI	N	N	N	N	N	N	N	N
MN	NA	Y	Y	Y	Y	NA	NA	Y
MS	NA	Y	Y	Y	NA	NA	NA	NA
MO	Y	N	N	Y	N	Y	N	N
MT	N	N	N	N	N	N	N	N
NE	N	N	N	N	N	N	N	N
NV	NA	NA	NA	NA	NA	NA	NA	NA
NH	N	Y	N	N	Y	Y	N	Y
NJ	N	N	N	N	N	N	N	N
NM	Y	Y	N	N	N	N	N	N
NY	N	N	N	Y	N	N	N	N
NC	N	N	Y	N	N	N	N	Y
ND	Y	Y	Y	N	N	N	N	N
OH	N	N	N	N	N	N	N	N
OK	Y	Y	N	Y	Y	N	N	Y
OR	Y	Y	Y	Y	Y	Y	Y	Y
PA	N	N	Y	N	N	Y	Y	N
RI	Y	Y	Y	N	Y	Y	N	Y

Table 6.6 (continued).

State	Contractors	Installers	Inspectors	Pumpers	Designers	Engineers	Geologists	Operators
SC	Y	Y	NA	Y	NA	NA	NA	NA
SD	N	Y	N	N	N	N	N	N
TN	N	Y	N	Y	N	Y	Y	Y
TY	N	Y	Y	Y	N	N	N	Y
UT	N	N	N	N	N	N	N	N
VT	N	N	N	N	Y	N	N	Y
VA	N	N	N	N	N	Y	Y	Y
WA	N	N	Y	N	Y	N	N	N
WV	N	N	N	Y	N	N	N	N
WI	N	Y	Y	Y	Y	Y	Y	N
WY	N	N	N	N	Y	Y	Y	N

Y = yes; N = no; NA = not available.

NSF Onsite Wastewater Inspector Accreditation Program

NSF International has developed an accreditation program to verify the proficiency of persons performing inspections on existing on-site wastewater treatment systems (NSF International, 2000). The accreditation program includes written and field tests and provides credit for continuing education. Inspectors who pass the tests and receive accreditation are listed on the NSF International Web site and in the NSF Listing Book, which is circulated among industry, government, and other groups.

The accreditation process includes four components. A written examination, conducted at designated locations around the country, covers a broad range of topics relating to system inspections, including equipment, evaluation procedures, trouble-shooting, and the NSF International Certification Policies. The field examination includes an evaluation of an existing on-site wastewater treatment system. An ethics statement, required as part of the accreditation, includes a pledge by the applicant to maintain a high level of honesty and integrity in the performance of evaluation activities. Finally, the continuing education component requires requalification every 5 years through retesting or earning requalification credits through training or other activities.

To pass the written examination, applicants must answer correctly at least 75 of the 100 multiple choice questions and score at least 70 percent on the field evaluation. A 30-day wait is required for retesting if the applicant fails either the written or field examination.

These code provisions, which are linked to outdated farmstead or homestead exemptions, should require some demonstration of competency on the part of the prospective homeowner designer or installer. For example, Alaska allows homeowners to design and install systems at their residence if they complete an approved training course and comply with state design, construction, and siting requirements. Approval is granted after the homeowner submits an infiltration field size estimate based on a professional analysis (i.e., by an engineer or a laboratory) of soils at the proposed site (Alaska Administrative Code, 1999). Another approach could include providing technical assistance for system design and close oversight of installation to ensure that homeowner-installed systems meet performance requirements.

On-site programs should establish minimum criteria for all service providers to ensure protection of public health and water resources. The Maine program requires that site evaluators be licensed and that designers of systems treating more than 2,000 gallons per day or systems with unusual wastewater characteristics be registered professional engineers. Prerequisites for applying for a license and taking the certification examination are either a degree in engineering, soils, geology, or a similar field plus one year of experience, or a high school diploma or equivalent and four years of experience (Maine Department of Human Services, 1996).

Some jurisdictions opt to secure planning, operation, maintenance, and inspection services by partnering with other agencies or contracting with private entities to perform these functions. For example, the Massachusetts communities of Yarmouth and Dennis contract with an engineering firm to conduct system inspections (Shephard, 1996). Many management agencies in highly developed areas depend on regional planning or environmental agencies for guidance on the hydraulic and pollutant assimilation capacity of water resources in areas proposed for development. When on-site management functions are performed by outside entities, it is important to establish clear, consistent, and reasonable program requirements, administrative processes, and communication procedures.

6.3.1.4 Inspection of new on-site wastewater treatment systems

Verifying that systems are constructed and installed as designed helps to ensure that they will perform as intended. A construction management program that includes multiple field inspections will ensure that system design and specifications are followed during the construction process. If a system is not constructed and installed properly, the chances of failure increase. For example, if the natural soil structure is not preserved during the installation process (i.e., if equipment compacts or smears infiltration field soils) the infiltration field can be significantly impaired. Most failures of conventional on-site system soil absorption fields have been attributed to hydraulic overloading (USEPA, 1993a). These failures can be exacerbated by poor design and installation practices. Effective on-site system management programs ensure proper system construction and installation through construction permitting, inspections during construction, and designer/installer certification programs.

Design and plan reviews before construction begins help to acquaint the installer with site conditions as characterized by the site evaluator and the proposed system design. During this review, details of the construction schedule, inspections, and final permit issuance can be discussed and agreed upon. In general, construction should conform to the approved plan and use appropriate methods, materials, and equipment. Typical regulatory mechanisms to ensure proper installation are reviews of site evaluation procedures and findings, and inspections of systems during and after installation. The review and inspection process should include:

- Preconstruction meeting of the owner, designer, regulator, and contractor;
- Inspection after delivery of components;
- Inspections during and after construction (e.g., during excavation and installation of components, and after backfilling); and
- Issuance of a permit to operate the system as designed and built.

During the construction process, inspections should verify compliance with approved construction documents and procedures. If there are not enough management program personnel to conduct these inspections, a trained/certified inspector should be assigned to oversee installation and certify that it has been conducted and recorded properly. The construction process for soil-based systems must be flexible, as construction during wet weather may compact, smear, or otherwise alter soil structure.

6.3.1.5 Installation of conventional or alternative systems

As noted previously, selection of an on-site system should consider climate, regional hydrology, site slopes, soil, ground water characteristics, and the quality requirements of the water(s) receiving on-site system effluent. Design, operation, and maintenance information for on-site systems can be found in the *Design Manual: Onsite Wastewater Treatment and Disposal Systems* (USEPA, 1980), the *Onsite Wastewater Treatment System Manual* (USEPA, 2002a) and the *Draft Onsite Wastewater System Management Handbook* (USEPA, 2002b). Table 6.7 summarizes the different treatment technologies used to remove various pollutants of concern.

A conventional on-site system consists of a septic tank, as shown in Figure 6.2, and a SWIS. Septic tanks perform the following four important functions:

1. Removal of settleable and floatable solids, oils, and grease from raw wastewater;
2. Storage of the removed solids;

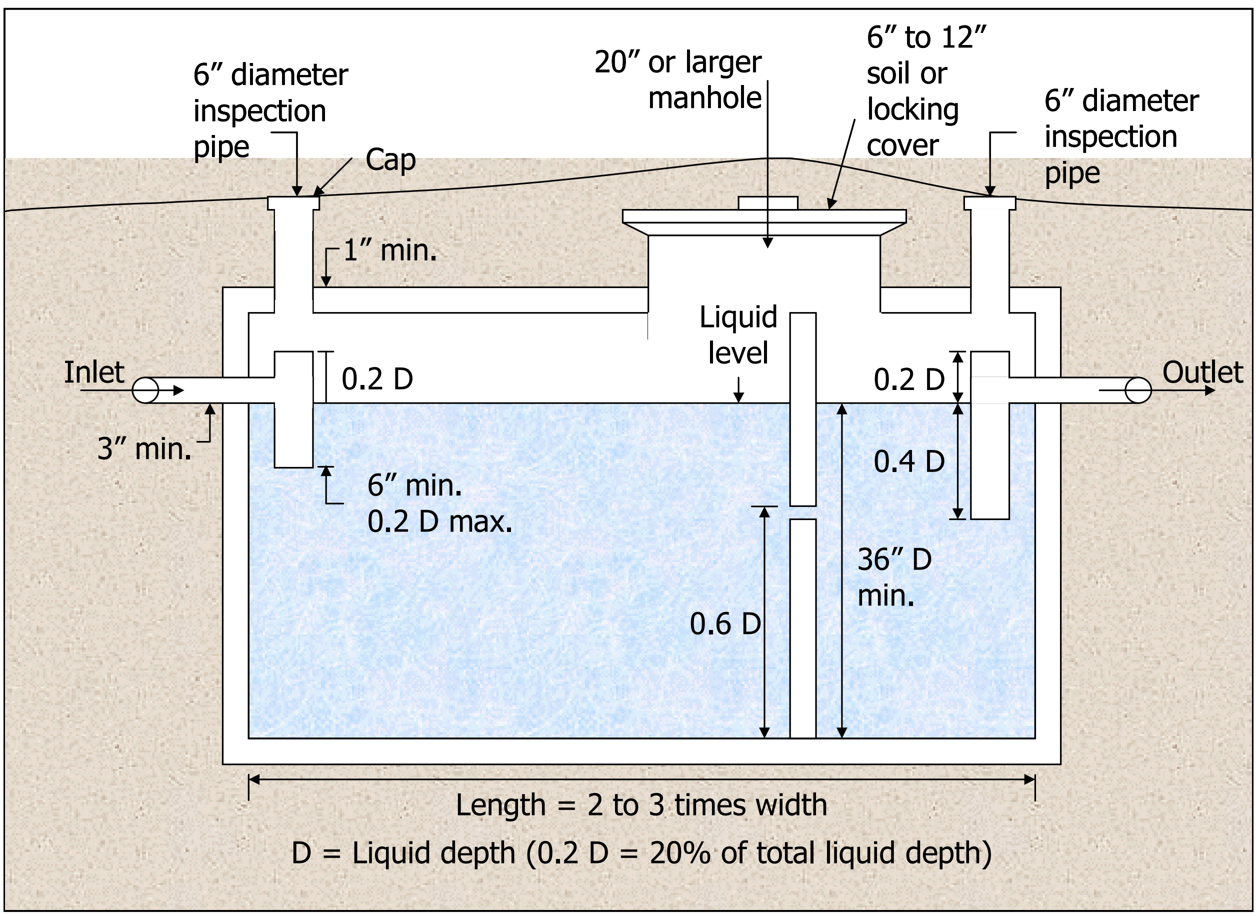


Figure 6.2: Septic tank detail (University of Missouri Extension Service, 1997).

3. Partial anaerobic digestion (liquefaction) of settled organic matter; and
4. Flow attenuation.

Table 6.7: Treatment technologies for OWTSs.

Treatment objective	Treatment process	Treatment methods
Suspended solids removal	Sedimentation	Septic tank Free water surface constructed wetland Vegetated submerged bed Lagoons Septic tank effluent screens
	Filtration	Packed bed media filters[a] Mechanical disc filters Soil infiltration
Soluble carbonaceous BOD and ammonia removal	Activated sludge	Extended aeration Fixed film activated sludge Sequencing batch reactors
	Fixed film aerobic bio-reactor	Soil infiltration Packed bed media filters[a] Trickling filter Fixed film activated sludge Rotating biological contactors
	Lagoons/wetlands	Free water surface constructed wetland
Nitrogen removal	Biological nitrification/ denitrification	Activated sludge (nitrification only) Sequencing batch reactor (only if designed with certain operating modes) Fixed film bio-reactor (nitrification only) Recirculating media filter Fixed film activated sludge (nitrification only) Anaerobic upflow filter (denitrification only) Anaerobic submerged media reactor (denitrification) Submerged vegetated bed (denitrification) Free water surface constructed wetland
	Ion exchange	Cation exchange (ammonium) Anion exchange (nitrate)
Phosphorus removal	Adsorption	Soil infiltration Iron-rich packed bed media filter Sequencing batch reactor (only if designed with certain operating modes)
Pathogen removal (bacteria, viruses, and parasites)	Filtration/predation/inactivation	Soil infiltration Packed bed media filters[a]
	Disinfection	Hypochlorite feed Ultraviolet light
Grease removal	Flotation/adsorption	Grease trap Septic tank Mechanical skimmer
	Aerobic biological treatment[b]	All types

[a] Including dosed systems; granular [sand, gravel, glass], peat, textile, foam.
[b] Incidental removal will occur, although overloading is possible.

Removal of total suspended solids (TSS) is usually 70 to 85 percent for well-designed septic tanks. Other pollutant removal rates are affected by the characteristics of the wastewater. Typically, reduction of BOD is 40 to 60 percent. Nitrogen and phosphorus removals are approximately 10 to 20 percent, while fecal coliforms are reduced by approximately 1 log (USEPA 2002a). The conventional system accepts both graywater (wastewater from showers, sinks, and laundry) and blackwater (wastewater from toilets). Depending on climate, diet, and other factors, the tank will need to be pumped every 3 to 5 years, since the pumping interval depends on the rate of accumulation of sludge, oils, and grease. Periodic visual inspection or remote sensing of the depth of those accumulations is possibly the most efficient way to determine pumping intervals.

A gravity-flow SWIS is the most commonly used treatment and discharge method for OWTS septic tank effluent. Soil absorption systems usually consist of covered excavations filled with porous media and perforated pipes or plastic leaching chambers with a distribution system for introducing and dispersing wastewater throughout. SWISs work well at sites with moderately permeable soils and sufficient vertical depth to ground water (i.e., the seasonally high water table), bedrock, or other limiting layer. The most common types of hydraulic failure of these systems are clogging of the infiltrative surface, insufficient separation distance to the water table, insufficient percolation capacity of the soil, and hydraulic overloading. Trenches and leaching chambers are the most widely used designs for both individual residences and commercial establishments. Uniform distribution and dosing via siphons or pressurized distribution are the best methods of pollutant removal because they distribute the wastewater load widely and uniformly across a large surface and sidewall area.

6.3.1.5.1 *Pollutant removal processes for conventional systems*

Nitrogen in domestic wastewater can be removed through effective linking of aerobic and anaerobic biochemical transformation processes, but in general, most conventional septic systems are not considered effective in removing nitrogen without additional treatment in the soil. Septic tanks remove approximately 30 percent of the nitrogen in raw domestic wastewater (University of Wisconsin, 1978). Percolation through 3 to 5 feet of soil can remove 0 to 20 percent of the total nitrogen in septic tank effluent (Siegrist, 2001). Additional nitrogen removal is possible under optimum soil and denitrification (e.g., anaerobic and carbon-rich) conditions. Factors that favor denitrification in soil absorption fields include fine-grained soils such as silts and clays, layered soils that feature alternating fine-grained and coarse-grained layers, and organic matter or sulfur compounds in the infiltrative medium. Placing the soil absorption field high in the soil profile where organic matter is more likely to exist, and dosing effluent to achieve alternating wet/dry (anaerobic/aerobic) cycles, can aid denitrification and reduce nitrate leaching. Maine’s Coastal Nonpoint Source Control Program and Division of Health Engineering favor shallow leach field installations to take advantage of the treatment potential in the upper soil horizon. Monitoring of shallow SWISs in Maine found total nitrogen reductions of 41 to 91 percent (Leyden, 1999).

In those areas where nitrogen is a problem pollutant, existing systems may be retrofitted to improve nitrogen removal, and new systems should include treatment components that are capable of removing nitrogen. Retrofitting upon failure of systems in these areas is recommended. Also, it is important to consider the density and overall discharge of on-site treatment systems. As the density of residences increases, lot sizes decrease and nitrogen impacts on surface and ground waters intensify. Lots of 1/2 acre to 5 acres are generally the minimal requirement of prescriptive codes for siting conventional on-site systems. The Code of Massachusetts Regulations identifies certain wellhead protection areas, public water supply recharge zones, and coastal embayments as nitrogen-sensitive areas and requires treatment systems in those areas to meet nitrogen loading limitations. For example, recirculating sand filters or equivalent technologies must be employed to limit total nitrogen (nitrogen as nitrate, nitrite, or ammonia) concentrations in effluent to no more than 25 mg/L and to remove a minimum of 40 percent of the influent nitrogen load. All systems in nitrogen-sensitive areas must discharge no more than 440 gallons of design flow per day per acre unless system effluent meets a nitrate standard of 10 mg/L or other nitrogen removal technologies or attenuation strategies are used (Code of Massachusetts Regulations, 1995). Any zone requiring such systems should have a management entity to assure sustained performance by these systems.

One of the most effective nitrogen removal methods is the recirculating sand filter (Table 6.8), which has been shown to remove approximately 50 percent of the total nitrogen from residual wastewater (USEPA, 1993b and 2002a). Other innovative and alternative systems have been developed to address site constraints and to provide improved on-site treatment and dispersal of wastewater. Many of these systems use advanced nutrient removal processes to enhance the ability of on-site systems to protect surface and ground water quality. Such systems include recirculating sand (nitrogen removal) and anaerobic upflow filters (denitrification), intermittent sand filters (nitrification), and subsurface-flow constructed wetlands (denitrification). The subsurface flow constructed wetland (i.e., vegetated submerged beds) and anaerobic upflow filters require nitrification of septic tank effluent before it enters the treatment process. Nitrification technologies include trickling filters with highly permeable plastic media, single-pass media filters, aerated sequencing batch reactors, activated sludge treatment systems, and filtration systems that use peat or other materials in place of sand. Table 6.8 presents an estimated performance summary for a variety of treatment technologies.

Another primary nutrient, phosphorus, is often the limiting factor for algal growth and eutrophication in freshwater systems. Because other nutrients necessary for the growth of algae and other aquatic plants are usually present in inland waters, low concentrations of phosphorus can lead to a direct increase in growth. Studies have shown that lakes with phosphorus concentrations as low as 20 to 30 parts per billion can become highly productive or eutrophic. Conventional OWTSs (septic tanks/SWISs) remove only 15 to 30 percent of the phosphorus in raw wastewater. Favorable phosphorus removal conditions exist for SWISs in most soils of the United States, but some phosphorus loading problems might be encountered in areas with older systems, highly permeable soils (e.g., sands), mineral-poor soils, nearby surface waters, and high system densities. Some technologies can enhance phosphorus removal (e.g., sand filters with high iron-content sand, sequencing batch reactors operated in certain modes).

Table 6.8: Wastewater constituents of concern and representative estimates of concentrations in the effluent of various treatment units (adapted from Siegrist et al., 2000).

Constituents of concern	Direct or indirect measures	Tank-based treatment unit effluent concentrations					SWIS percolate into ground water at 3- to 5-ft depth (% removal)
		Domestic STE[a]	Domestic STE with N-removal recycle[b]	Aerobic unit effluent	Recirculating sand filter effluent[c]	Recirculating foam or textile filter effluent[c]	
Oxygen demand	BOD_5 (mg/L)	140-200	80-120	5-50	2-15	5-15	>90
Particulate solids	TSS (mg/L)	50-100	50-80	5-100	5-20	5-10	>90
Nitrogen	Total N (mg N/L)	40-100	10-30	25-60	10-50	30-60	10-20
Phosphorus[d]	Total P (mg P/L)	5-15	5-15	4-10	3-9	4-10	0-100
Bacteria (e.g., *Clostridium perfringens, Salmonella, Shigella*)	Fecal coliform (organisms per 100 mL)	10^6-10^8	10^6-10^8	10^3-10^6	10^1-10^3	10^1-10^3	>99.99
Virus[e] (e.g., hepatitis, polio, echo, coxsackie, coliphage)	Specific virus (pfu/mL)	0-10^5	0-10^4	0-10^4	0-10^3	0-10^3	>99.9
Organic chemicals (e.g., solvents, petro-chemicals, pesticides)	Specific organics or totals (µg/L)	0 to trace	0 to trace	0 to trace	0 to trace	0 to trace	>99
Heavy metals (e.g., Pb, Cu, Ag, Hg)	Individual metals (µg/L)	0 to trace	0 to trace	0 to trace	0 to trace	0 to trace	>99

[a] Septic tank effluent (STE) concentrations given are for domestic wastewater. However, restaurant STE is markedly higher, particularly in BOD_5, COD, and suspended solids, while concentrations in graywater STE are noticeably lower in total nitrogen.
[b] N-removal accomplished by recycling STE through a packed bed for nitrification with discharge into the influent end of the septic tank for denitrification.
[c] Operated in recirculating mode.
[d] P-removal by adsorption or precipitation is highly dependent on media capacity, P loading, and system operation.
[e] Episodically present at high levels.

6.3.1.5.2 *Septic tanks*

Septic tanks are designed to retain a minimum 24- to 48-hour wastewater flow and are usually the first component in OWTSs. Additional treatment components (e.g., soil absorption field, sand/media filter) are necessary because the quality of septic tank effluent is not adequate for direct discharge. The septic tank should be watertight for two reasons: (1) infiltration into the tank can cause hydraulic overloading of treatment and/or dispersal components; and (2) leaks can cause discharge of scum and sludge to subsequent processes and increase potential for surface and ground water contamination. Many states and counties require tanks to be watertight. For example, Suffolk County, New York, regulations state that “all joints shall be sealed so that the tank is watertight and certified as to watertightness after installation. Tanks that are cast in place must be certified by a licensed professional engineer and, as a minimum, have the floor and walls monolithically poured.” Oregon septic tank standards stipulate that tanks are to be tested by filling them with water to a level 2 inches above the point of riser connection to the top of the tank. Leakage of no more than 1 gallon during a 24-hour period must be demonstrated. Because of leakage concerns, cast concrete and polyethylene tanks are preferred over those constructed of metal, redwood, concrete block, brick, or other materials, unless equipped with a watertight liner.

Septic tanks should be fitted with a regularly serviced effluent screen, commonly called a filter, at the outlet pipe. Several states and localities (e.g., Connecticut, Georgia, Florida, Alabama, North Carolina, Contra Costa County, California) now require septic tank screens to help protect the integrity of the SWIS for long-term performance (Schaub, 2000; Stuart, 2000). Screens not only prevent the discharge of neutrally buoyant solids and reduce TSS during tank upsets, but also provide an early warning sign that an inspection is needed, since they will clog and cause plumbing fixtures to drain poorly as they screen solids attempting to exit the tank through the outlet pipe.

Because septic tanks need to be serviced, the top of a septic tank riser should extend above the ground surface. Older installations can be difficult to locate when these features are not provided. Both septic tanks and SWISs are usually required to be at least 50 to 100 feet from any surface water body, but this setback might not be adequate in some cases (e.g., high-porosity soils, high water tables). Septic tanks should be inspected and pumped every 3-5 years.

6.3.1.5.3 *Subsurface wastewater infiltration systems*

Infiltration trenches containing perforated pipe and stone are the most widely used method for treating and dispersing septic tank effluent, though other septic tank effluent infiltration approaches (plastic open-bottomed leaching chambers, perforated pipes encased in net-wrapped foam pellets, and alternate media such as tire chips) have been used successfully. SWIS trenches are typically about 2 to 4 feet deep and about 2 to 3 feet wide. Soils, surface water drainage, and the slope of the land influence the location of the tank and field (Dickey et al., 1996). For example, septic systems are usually required to be located downslope from all wells, although ground water might not always follow this gradient. Trenches typically range in length from 45 to 100 feet.

Infiltration occurs through the bottom and sides of the trench. Gravelly soils promote rapid movement of wastewater contaminants, and poor-permeability soils (clays, etc.) require very large SWISs to accept the entire wastewater volume. Shallow trenches are generally preferred to deeper trenches because the upper soil horizons are usually more permeable and greater aeration and evapotranspiration can occur. A reserve area for future repairs or additions to the drainage field is often required by state code.

Septic tank effluent can be distributed to soil absorption system components by gravity, dosing, or uniform application. Dosing refers to periodically (e.g., 4 to 24 times per day) releasing effluent to the SWIS using a pump or siphon after a predetermined quantity has accumulated. Similarly, uniform application stores the effluent for a short time, after which it is pumped through smaller-diameter perforated pipes throughout the entire trench length to achieve uniform distribution. Distribution boxes have long been a source of poor performance in gravity-dosed systems, and they must be inspected frequently after initial installation because uneven settling causes uneven distribution of effluent. Ports with cam-type levelers can be adjusted to compensate for settling where regular inspection is required. Distribution boxes that do not have access ports or are not inspected or maintained are not recommended.

Uniform application can result in the least amount of infiltrative surface clogging and greatest treatment efficiency. Maintenance of trenches and beds is minimal, particularly if the tank is pumped regularly. Alternating SWIS systems are especially effective because they allow the use of one or more leaching systems while others rest for six months to a year to restore their effectiveness.

Most SWISs are designed to oxidize carbonaceous organics and convert the ammonium in septic tank effluent to nitrate by providing an aerobic environment. Nitrogen removal capabilities of SWISs are minimal and depend in part on temperature. Nitrate is water-soluble and travels freely to ground water. Elevated nitrate concentrations in ground water used as drinking water can cause the childhood illness methemoglobinemia (blue baby syndrome), can cause problems during pregnancy, and can present a risk to poultry livestock. In soils with no denitrifying capability, nitrate can travel with the ground water to nearby surface waters. Nitrogen loadings in coastal areas can cause eutrophication and related problems (e.g., low dissolved oxygen) that impair the life functions of desirable aquatic biota.

Some clogging of infiltrative surface pores from biomass and slimes produced by natural wastewater decomposition processes occurs under normal conditions. In coarser soils, this "biomat" improves treatment performance. Research conducted in Marion County, Florida, found that the predominant cause of hydraulic failure in systems less than five years old was hydraulic overload. After 15 years of service, root clogging was the cause of hydraulic failure in most cases. In general, SWISs located high in the soil profile provide access to both carbon (from organic matter) and oxygen (diffusion from ground surface), two elements needed for biochemical wastewater decomposition processes. Shallow placement also maximizes vertical separation between the infiltrative surface and ground water.

The vertical distance between the soil infiltration system and ground water is an important consideration. If seepage from the SWIS reaches the ground water in an area where unsaturated soil depth is inadequate, it could contaminate drinking water supplies. Furthermore, during wet seasons, ground water might rise into the SWIS, causing sewage to move upward toward the ground surface. This is especially important to consider in areas with a high water table (Lockwood, 1997) or in areas with poor permeability. Dickey et al. (1996) recommend that SWISs be placed at least 4 feet above the ground water table during the wettest season. The type of soil also influences the potential for ground water contamination. If sewage is applied to coarse soils, for example, the potential for contamination may be higher (Dickey et al., 1996). Clays that crack when dry or contain other types of macropores can also have a high contamination potential.

Installation of a conventional septic tank with a SWIS typically costs between $3,000 and $5,000 per home**,** but costs vary widely based on site-specific physical and regulatory limitations.

6.3.1.5.4 *Leaching chambers*

Molded plastic leaching chambers (see Figure 6.3) have been used in lieu of trench-based perforated pipe and aggregate infiltration systems to distribute septic tank effluent to the soil for final treatment. A typical leaching chamber infiltration system consists of interconnected arch-shaped bottomless chamber segments, installed below grade in level beds that comprise the drain field network. Aggregate is not needed, although porous media (e.g., gravel) is often used to fill in around the exterior of the vented chamber sidewalls to accommodate delivery of effluent through the sidewalls when ponding in the chambers occurs. Sizing of the network is based on wastewater characteristics, flows, and site conditions (soils, depth to groundwater/bedrock, etc.).

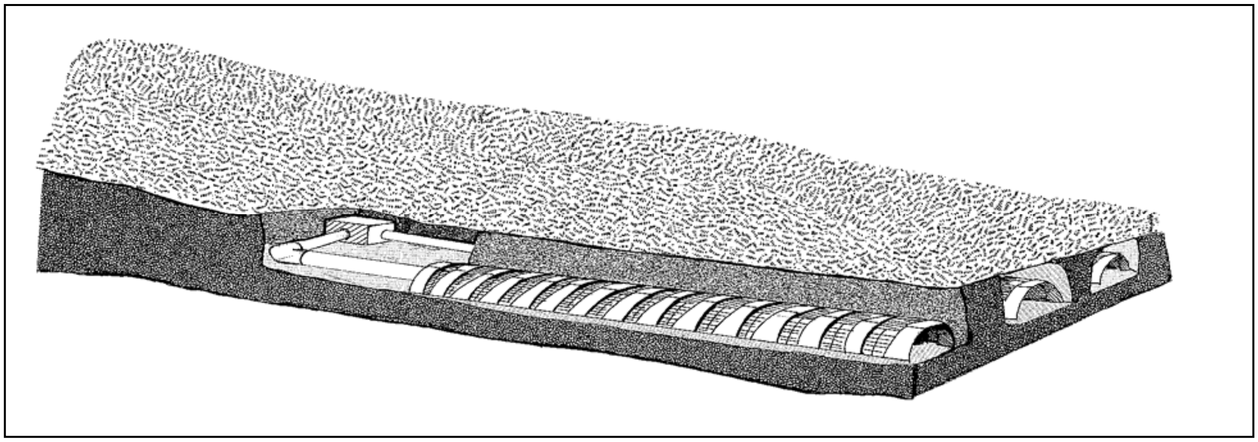


Figure 6.3: Leaching chamber subsurface wastewater infiltration system (Hoover et al., 1996).

Chamber systems have increased in use due to their performance, cost, light weight, and ease of installation.

6.3.1.5.5 *Alternative systems*

Several states have adopted provisions for the use of alternative and innovative technologies. Massachusetts has adopted a provision of its state environmental code that allows "approval of innovative (dispersal) systems if it can be demonstrated that their impact on the environment and hazard to public health is not greater than that of other approved systems" (Code of Massachusetts Regulations, 1995). Commonly referred to as Title 5, this legislation requires evaluation of pollutant loadings as well as management requirements prior to approval of alternative systems (Venhuizen, 1992).

The State of Maryland's regulations assert that the Maryland Department of the Environment (MDE) and the approving authority "shall consider all possible methods for correcting existing system failures and providing facilities for homes that lack indoor plumbing and, based on a case-by-case evaluation, provide the best technical guidance in attempting to resolve existing pollution or public health problems" (Code of Maryland Regulations, 2001). Alternative technology (with appropriate management) can be used for new construction on existing lots of record where site limitations prevent the use of conventional on-site systems. State regulations require that the local health unit and MDE monitor these systems for not less than two years.

More information on the alternative technologies described below is available from the National Small Flows Clearinghouse Environmental Technology Initiative (http://www.nesc.wvu.edu/nsfc/nsfc_ETI.htm) and EPA (http://www.epa.gov/owm/decent/treat.htm). An extensive list of links to public and private sector OWTS resources can be found at http://centreforwaterresourcesstudies.dal.ca/cwrs/onsite/info.htm. For information on loading rates, design, and performance capabilities for conventional and alternative treatment systems, refer to the *Onsite Wastewater Treatment System Manaual* (USEPA, 2002a). Table 6.9 provides a summary of capital and maintenance cost data for selected OWTS technologies.

Table 6.9: Summary of estimated capital and operation and maintenance costs for OWTSs (adapted from Hoover, 1997).

System Type	Costs (dollars)					
	Total materials & installation	Present value of total O&M[1]	Total over life of system	Amortized monthly materials & installation	Average monthly present value of O&M[1]	Average monthly over the life of the system
Septic Tank and Gravity Distribution						
Alone	2,504	6,845	9,349	20	19	39
With chambers	3,336	7,032	10,368	27	20	46
With styrene foam	2,846	6,920	9,767	23	19	42
With large diameter pipes	3,816	7,156	10,971	31	20	51
With pressure manifold	4,774	7,707	12,482	38	21	60
With pressure manifold and chambers	5,593	7,889	13,482	45	22	67
With pressure manifold and styrene foam	5,103	7,777	12,881	41	22	63
With pressure manifold large-diameter pipes	6,073	8,013	14,085	49	22	71
With sand filter pretreatment	7,296	12,069	19,364	59	34	92
With peat filter pretreatment	11,808	12,604	24,412	95	35	150
With recirculating sand filter pretreatment	6,226	12,059	18,285	50	33	84
With wetland cell	5,574	23,231	28,805	45	65	109
With 18" fill mound	4,507	6,850	11,357	36	19	55
With 18" fill mound and chambers	5,326	7,032	12,357	43	20	62
Septic Tank and LPP Distribution						
Alone	4,523	12,319	16,843	36	34	71
With sand filter pretreatment	10,223	13,338	23,561	82	37	119
With recirc. Sand filter pretreatment	8,232	13,007	21,239	66	36	102
In at-grade system	4,590	12,345	16,935	37	34	71
Septic Tank and Drip Distribution						
Alone	11,163	13,082	24,245	90	36	126
With sand filter pretreatment	15,994	14,101	30,095	129	39	168
With recirculating sand filter pretreatment	14,872	14,094	28,966	120	39	159
With sand filter pretreatment and chlorine disinfection	16,408	21,244	37,652	132	59	191
With recirculating sand filter pretreatment and chlorine disinfection	15,285	21,237	36,522	123	59	182
with sand filter pretreatment and UV disinfection	17,867	21,655	39,522	144	60	204
With recirculating sand filter pretreatment and UV disinfection	16,744	21,757	38,501	135	60	195
Septic Tank and Gravity Distribution						
Alone	2,504	6,845	9,349	20	19	39
With chambers	3,336	7,032	10,368	27	20	46
Septic Tank and Spray Irrigation						
With sand filter pretreatment and chlorine disinfection	11,890	20,670	32,580	96	57	153
With recirculating sand filter pretreatment and chlorination	10,768	20,663	31,431	87	57	144
With sand filter pretreatment and UV	13,349	21,190	34,539	107	59	166
With recirculating sand filter pretreatment and UV	12,227	21,183	33,410	98	59	157
Denitrification System Black Water and Gray Water Separation						
With gravity distribution	9,963	13,508	23,471	80	38	118
With LPP distribution	12,565	15,070	27,635	101	42	143

Table 6.9 (continued).

System Type	Costs (dollars)					
	Total materials & installation	**Present value of total O&M[1]**	**Total over life of system**	**Amortized monthly materials & installation**	**Average monthly present value of O&M[1]**	**Average monthly over the life of the system**
Other Types						
Aerobic treatment unit and gravity distribution	8,037	36,406	44,443	65	101	166
Septic tank and pressure-dosed sand mound system	4,863	12,407	17,269	39	34	74
Septic tank filter or screen (installation or retrofit into existing tank only)	200-400	938	1,250	1	<1	<1

Note: These numbers could be considered in the low to moderate range and may vary in other regions because of differences in material and labor costs.
[1] O&M = Operation and Maintenance

Regardless of the type of soil, sand, or other medium used for the absorption field, some sort of minimal maintenance is often required. It is important to restrict the operation of heavy equipment within the area proposed for soil absorption fields to prevent compaction of the soil structure and system clogging. Vehicles or other heavy equipment should not be operated over previously installed absorption fields or filters for the same reason. Concrete tanks are often capable of withstanding heavy loads, but operation of vehicles or other heavy equipment directly above them can cause settling or structural failure that can affect tank performance. Finally, because of the clogging effect of roots, vegetation above absorption fields and filter media should be restricted to types with short root structures. Trees or shrubbery should be immediately removed from absorption fields or filter medium installations.

6.3.1.5.6 *Elevated systems*

Mound systems are alternative soil absorption systems typically used at sites where insufficient ground water separation distances or slow-permeability soil conditions exist (see Figure 6.4). Mound systems are usually designed so that the effluent from the septic tank flows to a dosing tank and is then pumped to the top of the mound, which is constructed above the natural soil surface. The mound consists of a layer of suitable sand fill, an absorption bed filled with aggregate within the sand fill, and a covering layer of topsoil. The topsoil layer should be at least 6 inches deep and serves as a growth medium for vegetation. Converse and Tyler (2000) advise that mounds not be built on grades steeper than 25 percent.

At-grade systems are similar to mound systems, but the absorption bed is built directly on the ground surface, with aggregate placed on tilled soil instead of on top of raised sand. At-grade systems are typically designed for sites unsuitable for subsurface systems, but with less-restrictive conditions than sites where mounds would be needed (Converse and Tyler, 2000).

Pollutant removal effectiveness and operation and maintenance are similar to those of conventional systems with pressurized distribution. A mound system is more expensive to install than a typical soil absorption trench system. The cost of a complete mound system, including a septic tank, is typically $7,000 to $12,000 installed. Operation and maintenance include septic tank pumping every 3 to 5 years; annual or semiannual inspection of the pump, float switches, tank, and dosing chamber; and maintenance of vegetative cover (i.e., grass) to prevent erosion.

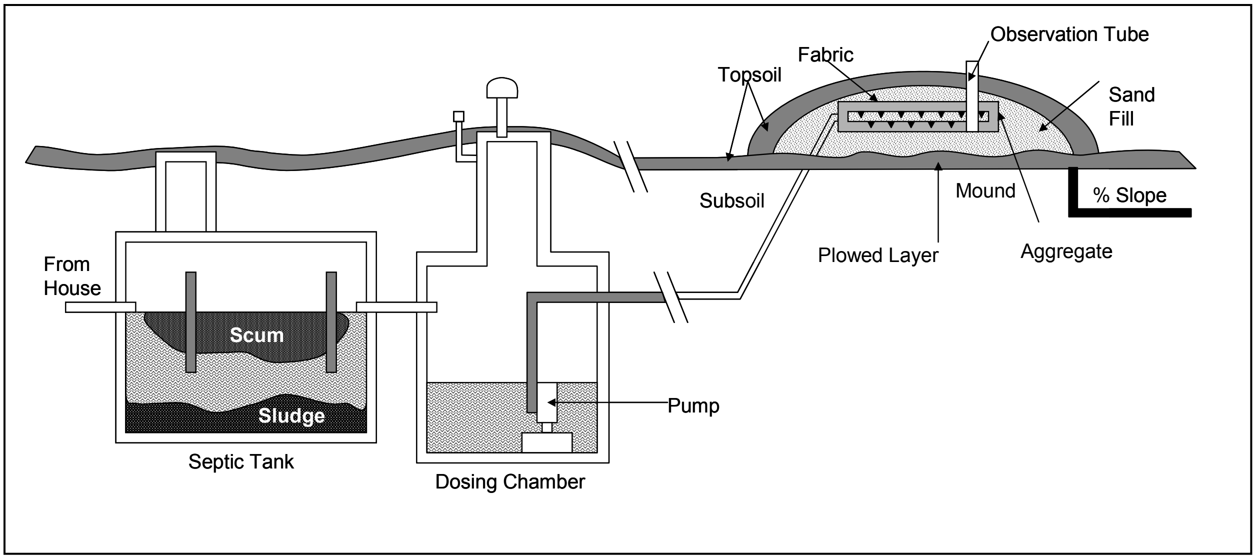


Figure 6.4: Schematic of a typical mound system (Ohio State University, no date).

6.3.1.5.7 *Intermittent sand/media filters*

An intermittent filter system receives and treats effluent from the septic tank via sand or other media (e.g., peat or composite materials) before it is discharged to the soil absorption field. Periodic, uniform dosing of septic tank effluent is distributed to the surface of the sand/media filter. The filter consists of a bed (either open or buried) of granular, synthetic, or organic material from 24 to 36 inches deep. Microorganisms living and growing on the filter medium consume nutrients and other wastes and facilitate aerobic decomposition of organic matter in the wastewater. The treatment medium is underlain by leveled rock or gravel and collector drains. Siphon or pressure distribution of septic tank effluent is used to dose wastewater to the surface of the media. Free access filters (media exposed to the atmosphere) should be covered with removable covers to prevent operation and maintenance problems (such as those caused by dust and rain), and should include insulation in cold and wet regions.

Intermittent media filters might become clogged as the pore space between the grains of the medium begins to fill with excessive amounts of inert biological materials. Resting the filter for several months in warm weather will restore hydraulic conductivity (Tyler et al., 1985). Free access filters should be checked every three to four months to prevent surface problems. Periodic raking is recommended to remove leaves and other debris where the system is not covered.

Intermittent sand filters typically produce high-quality effluents with BOD_5 and suspended solids concentrations below 10 mg/L (Tchobanoglous and Burton, 1991). Nitrogen compounds are almost completely nitrified if the filter remains aerobic, although nitrification rates might fall during cold weather. Total nitrogen removal rates average 15 to 35 percent (USEPA, 2002a). Installation cost ranges from $5,000 to $10,000. Systems that use peat or other organic media in place of the soil/sand filter media have been installed in several areas of the country to serve single- and multiple-family residences. This technology has shown excellent results in many applications but is still under study and considered a provisional application subject to monitoring in most jurisdictions.

Sand Filter System, Washington Island, Wisconsin

Washington Island, Wisconsin, covers a 36-square-mile area. Its geology consists of shallow soils and fissured, cavernous carbonate bedrock. Sinkholes are not uncommon and the threat of ground water contamination is real. Conventional systems serve older developments on the island, but the potential for ground water contamination from pathogens and nitrate spurred interest in alternative technologies. As part of a demonstration project, recirculating sand filters were installed and evaluated for 2 years. The demonstration project showed that total nitrogen could be reduced by 60 to 90 percent. Water quality was also improved by inserting an anaerobic upflow filter between the septic tank and the sand filter dosing tank.

Operation and maintenance include monitoring influent and effluent, inspecting the dosing equipment, maintaining the filtration medium surface (i.e., raking and replacing as needed), checking the discharge orifices for buildup or blockage, and flushing the distribution manifold annually. Costs for operation and maintenance of these systems include three or four visits per year ($100 to $150/year), in addition to septic tank maintenance.

6.3.1.5.8 *Recirculating sand/media filters*

A recirculating sand/media filter is a modified intermittent filter that recirculates the effluent from the filter through the septic tank and/or the recirculation tank before it is discharged to the wastewater infiltration system. The addition of the recirculation loop in the system enhances pollutant removal effectiveness by providing a denitrification step (i.e., in the septic or recirculating tank) in the treatment process. Nitrogen is both nitrified (in the media filter) and denitrified in these systems, resulting in 40 to50 percent or more (if enhanced) nitrogen removal. Recirculation rates of 3:1 or higher are generally recommended. Recirculating media filters can be used in new, on-site systems or applied to retrofits of failing conventional systems (Bruen and Piluk, 1994), particularly at sites with nitrogen concerns. Recirculating media filter effluent might also be appropriate for soil absorption systems with low-permeability soils.

BOD and suspended solid concentrations in the effluent are typically less than 10 mg/L (Roy and Dube, 1994; Bruen and Piluk, 1994; Loudon, 1996). Recirculating sand filters typically cost $8,000 to $11,000.

Operation and maintenance include monitoring effluent; inspecting the dosing equipment; maintaining the filtration surface (i.e., raking as needed); checking the discharge orifices for buildup and blockage; and flushing the distribution manifold annually in addition to septic tank maintenance.

6.3.1.5.9 *Anaerobic upflow filters*

An anaerobic upflow filter (AUF), which may resemble a septic tank filled with gravel, is designed so that the effluent flows up through the bottom of the AUF filter media (e.g., ⅜-inch gravel). Anaerobic bacteria that convert nitrate in the influent to nitrogen gas grow on the surfaces of the filter medium. Septic tank effluent is gravity-dosed or pumped (depending on site conditions) to the bottom of the AUF and up through the filter to the top, where a collection pipe transports it to a dosing chamber and/or SWIS for final discharge. A nitrogen-removal system may include a septic tank, a sand filter, an AUF, and a soil absorption field. AUFs are relatively small (e.g., 4 feet deep and 6 feet in diameter) (Boyle, 1995) and sized to allow retention times of 24 to 48 hours.

Nutrient Export from Conventional vs. Open Space Development in Maryland

Zielinski et al. (2000) undertook a study to compare nutrient export from several conventional development projects and the same projects designed using alternative open space strategies (see Management Measure 4 for a discussion of conventional and alternative development scenarios). One site was a low-density residential subdivision in Maryland. In the conventional design, each lot had an on-site private septic system and the neighborhood had a septic reserve field of approximately 10,000 square feet. When the site was redesigned to preserve open space, the individual septic systems were replaced with shared septic systems that used more advanced recirculating sand filter technology with better nutrient removal capacity and lower construction and installation costs. When the two development scenarios were modeled to determine relative rates of nutrient export, the redesigned septic system showed a substantial decrease in nutrient output. However, despite the use of more advanced technology, septic systems remained the predominant source of exported nutrients.

Total nitrogen concentrations from AUFs treating fully nitrified influent can range from less than 3 to 23 mg/L or higher, with removal efficiencies of approximately 60 to 70 percent. Boyle (1995) reported average total nitrogen concentrations below 15 mg/L in a recirculating sand filter-anaerobic upflow filter system. The cost of the filter varies by manufacturer and is approximately $1,000 to $1,500. Operation and maintenance tasks are minimal, especially if the filter medium consists of large gravel (i.e., > 1 inch). Sand-sized media will clog and should not be considered. Inspection of wastewater levels in the septic tank and AUF filter tank, as well as periodic inspection of pumps, float switches, discharge orifices, and other components, should be conducted to ensure continuous performance.

6.3.1.5.10 *Cluster systems*

For the purposes of this guidance, a cluster system is defined as a collection of individual on-site systems that provide primary treatment in septic tanks at each site. Septic tank effluent is collected and routed to another site for further treatment. Other designs in which primary treatment occurs at the treatment site instead of the septic tank are also possible. Collection and movement of effluent to the final treatment site can be accomplished by gravity flow or pumps.

Additional treatment for cluster systems may involve the use of conventional SWISs, sand filters, AUFs, constructed wetlands, aerobic lagoons, or aerobic treatment. The use of cluster systems can be advantageous in the case of inadequate soil, groundwater, or space at individual homes, or when better soil at is available at another location in the development.

6.3.1.5.11 *Constructed wetlands*

Constructed wetlands have traditionally been used for polishing effluent that has already had some degree of treatment. Vegetated submerged beds (VSBs), also known as submerged constructed wetlands, subsurface flow constructed wetlands, or plant rock filters (see Figure 6.5), are designed primarily to reduce concentrations of BOD and suspended solids in wastewater effluent from the septic tank. VSBs consist of horizontal flow gravel filters with wetland-type vegetation (e.g., cattails, canna lilies) and are usually underlain with an impermeable liner (e.g., plastic sheeting). The vegetation has a minimal role in treatment in this application. Residential vegetated submerged beds are normally followed by subsurface infiltration trenches or chambers.

The performance of constructed wetlands is not significantly degraded in colder climates during winter months because removal is by physical and chemical processes. Recent tests that

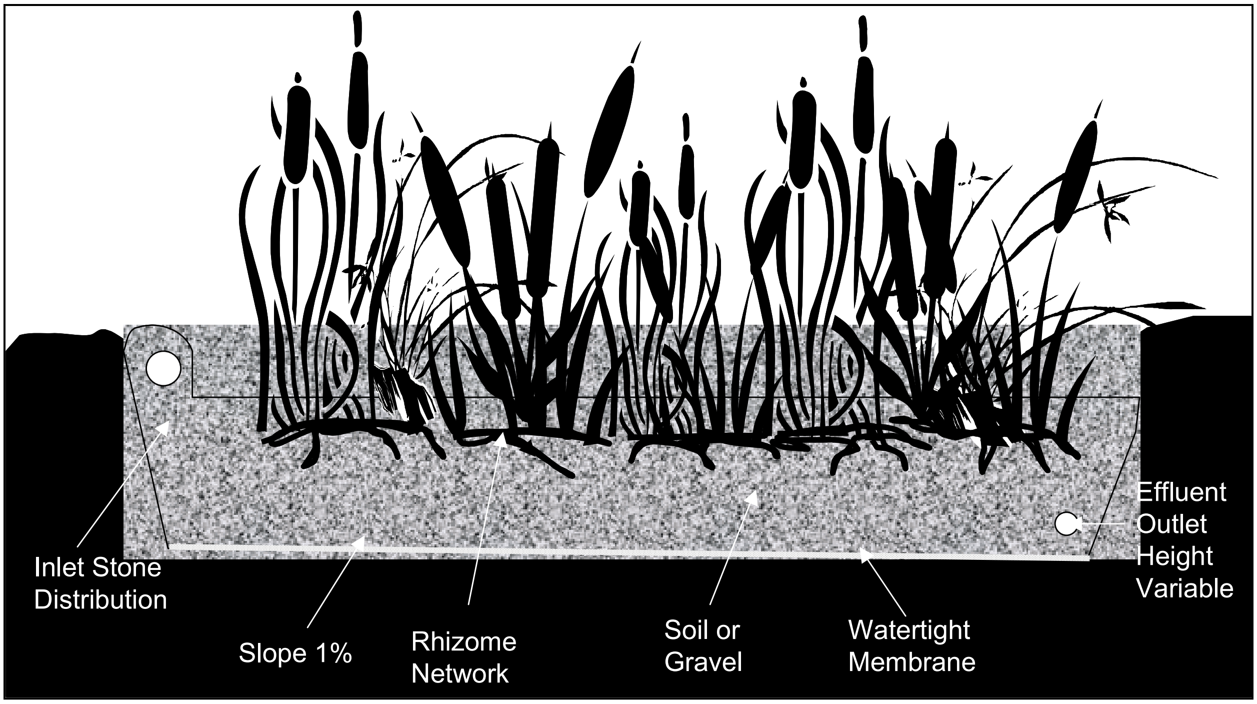


Figure 6.5: Components of a vegetated submerged bed.

incorporated a submerged aeration line in the wetland cell have shown promise in facilitating nitrification/denitrification (Wallace, 2000).

Constructed wetlands are configured as free-water surface wetlands, which can facilitate aerobic treatment processes, or subsurface flow wetlands, which are generally anaerobic. Removal rates for fecal coliform, BOD, and suspended solids can be as high as 90 percent for a gravel-based VSB (White and Shirk, 1998). However, removal of nitrogen and phosphorus compounds (e.g., ammonium, nitrate, SRP) is typically much less. Nitrogen removal can be enhanced through designs that accommodate nitrification-denitrification processes—i.e., aerobic treatment followed by anaerobic treatment zones—but significant phosphorus removal is much more difficult to achieve (USEPA, 2001a). Estimated costs for VSBs range from approximately $10,000 to $20,000 for a system serving a typical residence. Maintenance tasks include removing dead vegetation; inspecting and cleaning the inlet and outlets; inspecting wastewater levels in the tank and filter bed; and ensuring wastewater levels do not rise above the filter medium.

6.3.1.5.12 *Sequencing batch reactors*

A sequencing batch reactor (SBR) is a modified cyclically aerated and decanted activated sludge treatment system. The SBR carries out aeration, sedimentation, and clarification via timed cycles in the same tank. Continuously fed SBRs are compartmented to reduce short-circuiting. SBRs remove BOD and TSS from wastewater. Modification to the operational mode can enhance removal of phosphorus and nitrogen. Development of reliable and versatile control systems has been a major factor in the increased use of SBRs during recent years. However, repair and replacement costs and operator knowledge requirements should be considered in decisions regarding this technology.

SBRs can be used for new developments or connected to existing septic systems and can be designed to collect effluent from multiple septic tanks for treatment at a common site. SBRs can be sited in relatively small areas of only a few hundred square feet. SBR costs, operation, and maintenance requirements are greater than those of conventional on-site systems. SBRs can be suitable alternatives for sites where high-density development and/or unsuitable soils preclude adequate treatment of effluent by conventional systems.

With appropriate design and operation, SBR plants have been reported to produce high-quality effluents with very good removal rates for BOD and TSS. Typical ranges of $CBOD_5$ (carbonaceous 5-day BOD) are from 5 to 15 mg/L, while TSS levels can range from 10 to 30 mg/L in well-operated systems. Fecal coliform removal of 1 to 2 logs can be expected (USEPA, 2002b). By using an anaerobic-aerobic operating mode, significant nitrogen and phosphorus removals are also possible.

6.3.1.5.13 *Aerobic treatment units*

Packaged aerobic treatment units have been used for residential on-site use for nearly 40 years. Treatment unit storage volumes can provide a hydraulic retention time of several days based on typical household flows. These systems require regular supervision, operation, and maintenance to be effective. Since maintenance has been a particular problem with these units, requiring a perpetual maintenance contract at the time of permitting is strongly recommended. Packaged aerobic treatment units generally include pretreatment by settling (usually in a septic tank) to remove fats, oils, grease, and solids. Effluent is usually discharged to a SWIS. When additional treatment (e.g., filtration, disinfection, etc.) is provided, discharge to surface waters may be possible if a Clean Water Act Section 402 (National Pollutant Discharge Elimination System) permit is obtained. Power requirements can be significant for certain types of package plants. Mixed liquor solids must be disposed of regularly, so the system should be inspected at least every three months.

Extended aeration units can achieve BOD concentrations ranging from 30 to 50 mg/L and suspended solids concentrations ranging from 40 to 60 mg/L in well-operating systems, often reflecting 75 to 95 percent removal efficiency (Kellam et al., 1993; Ayres and Associates, 1991; Tchobanoglous and Burton, 1991). Installing a sand filter or other polishing unit to treat wastewater after an extended aeration unit can improve BOD and suspended solids removal performance, although nitrate levels might increase as a result (Kellam et al., 1993). Costs typically range from $3,000 to $6,000 for an installed unit, with maintenance costs of $200 to $300 per year.

6.3.1.5.14 *Fixed film systems*

Fixed film systems feature media (e.g. plastic disks, pellets, gravel, tire chips, fabric media, foam pellets) with large amounts of surface area where microorganisms that digest wastes become attached and grow. Colonies of bacteria and other organisms develop into a biologically active slime layer that is sustained by nutrients and other constituents in the effluent. As wastewater flows over the media, colonies of microorganisms extract soluble organic matter and nutrients as a source of carbon and energy. Oxygen, which is required by these microorganisms, can be supplied by natural ventilation or by mechanical or diffused aeration within the wastewater.

Fixed film systems include trickling filters (where the wastewater flows down through a bed of gravel, carbon-based, or composite media such as tire pellets, fabric strips, foam pellets, etc.) and rotating biological contactors (rotating plastic discs colonized by wastewater flora/fauna partially submerged in the wastewater). These systems require pretreatment of sewage in a septic tank. Final effluent can be discharged to a SWIS or reused. Disinfection is necessary if effluent may come into contact with humans or disease vectors. Both systems can achieve TSS concentrations of 60 to 80 mg/L and BOD levels of 80 to 90 mg/L. Maintenance includes periodic inspection of wastewater levels in the septic tank; inspection of pump switches and discharge orifices; and cleaning or replacement of the growth medium at regular intervals, or more frequently if clogging develops.

6.3.1.5.15 *Pressure distribution systems*

Low-pressure effluent distribution into the soil using technologies developed by the drip irrigation industry offers significant treatment performance improvements. Pumping effluent to the dispersal field typically creates a large flow surge that distributes effluent uniformly throughout the dispersal field. This minimizes localized overloading and the consequent potential for eventual failure (Venhuizen, 1995). Pressure systems are placed very high in the soil profile and use periodic dosing to distribute effluent to the soil matrix. Pressure distribution trenches are typically shallow and narrow, providing ease of installation and maximum carbon availability for treatment processes. Reaeration of the infiltrative surface and drying of the biomat between doses reduce potential clogging threats and help to ensure nitrification of ammonia in the septic tank effluent. Drip irrigation distribution lines are typically installed with a vibratory plow at shallower depths (i.e., 8-12 inches below surface grade) and should be preceded with pretreatment by a septic tank and fixed film filter to prevent clogging of emitters (USEPA, 2002a).

6.3.1.5.16 *Evapotranspiration*

Evapotranspiration (ET) systems are designed to remove wastewater through evaporation and transpiration; they are used mostly in dry climates (e.g., Arizona, New Mexico). They have been used in wetter climates where ET potential is sufficiently high in certain months. Seepage from an ET system can be reduced or eliminated by using a plastic, PVC, or clay liner, but leaving the system unlined allows both percolation and evapotranspiration to occur. Wastewater is applied below the surface to the sand medium of the ET system. Water moves to the soil surface by capillary action for use by plants or is evaporated to the atmosphere. Performance strongly depends on climate, available surface area, and physical properties of the sand. Properly operating ET systems must evaporate or transpire more water than is applied as waste or collected during precipitation. More than 5,000 ET systems are in use in the United States. The cost of installation ranges from $10,000 to $15,000, but operation and maintenance costs are generally quite low.

6.3.1.5.17 *Spray irrigation*

Spray irrigation is commonly used to discharge septic tank effluent as irrigation water to hayfields or other vegetated areas not used to produce food crops. Spray irrigation can effectively dispose of effluent from OWTSs. However, strict controls on human contact with discharges that might contain pathogens are required. Design of spray irrigation systems must consider soil permeability, slopes, climate, and the water and nutrient needs of vegetation growing on the spray field. Additional treatment and disinfection of spray irrigation water is necessary if human contact with the spray field or wet vegetation is likely. Successful applications have been installed in shallow soils in the Northeast. It is recommended that effluent be treated prior to spraying to remove most BOD for odor-prevention. Spray devices should not be activated during wet weather, freezing temperatures, or saturated soil conditions. Because large buffer areas around the spray sites are usually required, extensive land is required, limiting this option to very large lots.

6.3.1.5.18 *Disinfection devices*

In some areas (e.g., source water protection areas and sites near recreational lakes, and coastal beaches), pathogen contamination from on-site systems is a major concern. Disinfection devices can be used in conjunction with the technologies summarized above to treat effluent for pathogens before it is discharged. The three most common methods of disinfection in the United States are chlorination, ozonation, and ultraviolet (UV) disinfection (NSFC, 1998).

Installation of these devices in an on-site system increases its cost and adds to operation and maintenance requirements. Single-home chlorinators in non-dosed conventional OWTSs have a poor track record when applied without management oversight. These units can greatly overdose or not dose at all if proper operation and maintenance are not performed. Chlorine is a powerful biocide and can have significant impacts on aquatic biota at concentrations well below 1 mg/L. Some states (e.g., Maryland) have additional requirements for maximum chlorine concentrations in effluent or prohibit the use of halogen (i.e., chlorine and iodine) processes. UV units generally require controlled dosing of a high-quality influent (BOD of 30 mg/L and TSS of 30 mg/L or better) for consistent performance. Maintenance includes periodically cleaning UV tube surfaces to maintain integrity and inspecting the contact chamber to ensure that solids have not accumulated. Annual replacement of UV bulbs is suggested. UV units cost $1,000 to $2,000 (installed) or about the same as tablet chlorinator units. Operation and maintenance costs for UV are about $150 to $200, similar to the chlorinator.

6.3.1.5.19 *Water separation systems*

A water separation system separates graywater from sinks, tubs, and appliances from toilet blackwater. The graywater is treated by using a somewhat smaller conventional OWTS or a SWIS. The blackwater can be treated in another OWTS or stored in a holding tank and periodically hauled off site for treatment or disposal. For extreme situations or for seasonal residents, some form of separation of toilet wastes from bath and kitchen wastes can be helpful. Most nitrogen discharges in residential wastewater come from human wastes, and they also provide almost half of phosphorus, TSS, and BOD. Use of holding tanks can be very expensive owing to the cost of $0.10 to $0.20 per gallon for pumping and hauling.

6.3.1.5.20 *Vaults or holding tanks*

Vaults or holding tanks are used to contain wastewater in emergencies or other temporary situations and to hold wastewater from a blackwater system. These systems require frequent pumping, which can be expensive if the total wastewater flow is contained.

6.3.2 Operation and Maintenance Programs

This chapter discusses two broad functions that have an impact upon on-site wastewater treatment systems: regulatory oversight and management. In the following discussion, oversight refers to the regulatory and enforcement functions (e.g., issuing permits, compelling compliance with local or state codes) typically performed by the regulatory authority (i.e., state health departments and their agents, which are usually local health departments). The term management includes other functions and services that may or may not fall under the direction of the regulatory authority, such as long-term planning, ensuring that septic tanks are pumped regularly, conducting periodic system inspections, arranging for financial assistance for installations/repairs, and other activities.

Management services may be provided by a management entity separate from the regulatory authority, such as a sanitation district, contracted firm, or homeowners' association. It is important to recognize that while the enforcement of codes and regulations (i.e., by the regulatory authority) provides a very basic level of protection for public health and environmental resources, the execution of management tasks (e.g., planning, monitoring, operation, maintenance, inspection) by a designated management entity helps to ensure that long-term system use meets established performance requirements.

Implementation of the various management program elements will undoubtedly be subject to the authority of the regulatory agency or agencies, but may be accomplished by another management entity, such as a public or private utility, regional planning agency, or water monitoring council. Some management program elements may require special arrangements or agreements if they are to be performed by a separate management entity. For example, where state codes require the regulatory authority to oversee system design and permitting, a formal agreement would likely be required if an outside management entity assumed those duties. The exact nature of the relationship between the regulatory authority and any management entities servicing a particular jurisdiction will vary considerably and depend upon the capacity of the regulatory authority, state and local codes, and the ability of management entities to provide designated services in an acceptable manner.

According to the U.S. Census Bureau (1997b), approximately 25 percent of the estimated 112 million occupied homes in the United States are served by on-site systems, a proportion that has changed little since 1970. Distribution and density of homes with OWTSs varies widely by state, with a high of about 55 percent in Vermont and a low of around 9.8 percent in California. New England states have the highest proportion of OWTS-served homes: New Hampshire and Maine both report that about half of all homes are served by on-site systems. More than a third of homes in the southeastern states depend on OWTSs, including approximately 48.5 percent in North Carolina and about 40 percent in both Kentucky and South Carolina.

More than half of the nearly 26 million homes with on-site treatment systems are more than 30 years old (U.S. Census Bureau, 1997a, 1999) and a significant number report problems. A survey conducted by the U.S. Census Bureau (1997a) estimated that 403,000 homes experienced septic system breakdowns within a three-month period during 1997, with 31,000 reports of four or more breakdowns at the same home. Typical reported malfunction rates average between 1 and 5 percent annually, with reported failure rates in a study conducted in the State of Washington ranging between 2.6 percent and 6.1 percent (USEPA, 1993b). It has been estimated that in some areas of Connecticut, 4 percent of on-site systems fail each year. The failure rate might be high because many on-site systems are approved in areas with unsuitable soil conditions.

Reported failure rates may underestimate true failure rates because they typically consider only plumbing backup and sewage surfacing, and not ground water or surface water contamination. Parsons Engineering Science (2000) reported that dye testing conducted for the Rouge River National Wet Weather Demonstration Project found failure rates (defined as short-duration appearance of dye in receiving waters) of 39 to 72 percent. Nelson et al. (1999) reported that estimates of partial and total system failure rates in some states range as high as 50 percent and more in some cases, but definitions of failure were highly variable and included all systems that were not designed according to the states revised codes.

Besides design, installation, and maintenance problems, regional hydraulic overloading (i.e., hundreds or thousands of densely sited systems discharging into a single ground water aquifer or subwatershed) can cause OWTSs to fail to meet requirements for protection of public health and water quality. Other factors include lack of maintenance and system age. In some areas, on-site systems are installed at a density that exceeds the capacity of the local soil to assimilate hydraulic and pollutant discharge loads. In addition, the design life of many OWTSs built between 1960 and 1980 has been exceeded. System owners are not likely to repair or replace aging OWTSs unless sewage backup, septage pooling on lawns, or targeted monitoring and failure documentation occurs. Approaches for reducing operation and maintenance failures through development of management activities and systems are outlined below.

The following sections describe recommended management measures that promote the protection of public health and water resources from risks linked to on-site systems. More information on OWTS management measures and system technologies, as well as case studies from across the nation, are available from EPA at http://cfpub.epa.gov/owm/septic/home.cfm and from the National Small Flows Clearinghouse at http://www.nesc.wvu.edu/nsfc/nsfc_index.htm. A model framework for management programs and other information on OWTS issues is posted by the National On-Site Wastewater Recycling Association at http://www.nowra.org/.

6.3.2.1 Development of system inventories and assessment of maintenance needs

System inventories are critical elements of an effective on-site/decentralized system management program. An inventory is essential to both long- and short-term planning. Knowledge of factors such as system location, type, age, maintenance schedule, and potentially affected water resources is necessary to predict watershed and site-specific pollutant loadings. This knowledge is also needed to achieve a community's public health, environmental, and fiscal goals.

Inventories can also give owners information regarding the proper operation and maintenance of their systems. A typical inventory will contain information such as: owner name, contact information, system type, location, installation date, design capacity, and last date of service.

Clermont County, Ohio, developed an OWTS owner database by cross-referencing water line and sewer service customers (Caudill, 1998). Because most people in the county were public water line customers, subtracting those who were also connected to the public sewer system yielded a database of nearly all the OWTS users. Contact information from the database was used to mass-mail information on system operation and maintenance and the county's new inspection program to 70 percent of the target audience. Other approaches used in the Clermont County outreach program were advisory groups, homeowner education meetings, news releases and interview programs, meetings with real estate agents, presentations at Farm Bureau meetings, displays at public events, and targeted publications.

System inventories are essential elements for management programs, and most jurisdictions maintain databases of new systems through their permitting programs. However, older systems (e.g., those installed prior to 1970) are often not included in those data files. Some on-site management programs or other entities conduct inventories of older systems when they are included in a special study area. For example, Cass County and Crow Wing County, Minnesota, have developed projects to inventory and inspect systems at more than 2,000 properties near lakes in the north-central part of the state (J. Sumption, Deputy Director of Cass County, Minnesota, Environmental Services, 2000). The project inventoried but did not inspect systems that were less than five years old unless a complaint or other report indicated possible problems. Costs for inventorying and inspecting 234 systems in one lake watershed totaled $9,000, or nearly $40 per site (J. Sumption, Deputy Director of Cass County, Minnesota, Environmental Services, 2000).

In some cases, data necessary for on-site system management may be held and administered by other agencies. For example, land and water resource characterization data are often collected, stored, and analyzed by environmental or planning agencies. Developing data-sharing policies with other entities through cooperative agreements can help all organizations involved with health and environmental issues improve their efficiency and overall program performance. The RME should ensure that data on existing systems are available to health and water resource organizations (usually regulatory authorities) so that their activities and analyses reflect this important aspect of public health and environmental protection.

Education for system owners is an important component of the outreach for management programs that rely on homeowners for system operation and maintenance. Educational initiatives are most effective when they result in understanding of the relationship between ground water and surface water, and how septic system siting, design, installation, operation, and maintenance can affect those resources and public health. Surveys show that many people have their septic tank pumped only after the system fails. Property owners who are educated in proper system operation and maintenance practices, and who understand the consequences of system failure, are more likely to take actions to ensure that their systems function properly. Typical public outreach and education program topics for homeowners in the present system of prescriptive and conventional on-site systems include:

- How an on-site wastewater treatment system works;
- System siting and design considerations;
- How on-site systems can affect health, ground water, and surface water;
- The importance of water conservation in minimizing hydraulic failures;
- Practices to reduce mass pollutant loadings and toxic inputs to the system;
- Typical operation and maintenance practices, procedures, and timetables;
- How delaying septic tank pumpout can cause solids to clog infiltration systems; and
- Costs of repairs, upgrades, or replacement of system components.

Inventories of existing systems can be developed by consulting wastewater treatment plant service area maps, identifying areas not served by POTWs, and working with public and private utilities (drinking water, electricity, and septage pumpers and haulers) to develop a database of system owners and contact information.

A variety of commercially available software exists for managing system inventory and other information. Electronic databases can make collecting, retrieving, using, and integrating data fairly easy after the initial implementation (data entry) and learning curve have been overcome. For example, if system locations are described in terms of specific latitude and longitude coordinates, a data layer for existing on-site systems can be created and overlaid on geographic information system (GIS) topographical maps. Adding information on on-site wastewater hydraulic output, estimated mass pollutant loads, and transport times expected for specified hydrogeomorphological conditions can help managers understand how water resources become contaminated. This can also help target remediation and prioritization actions to sources primarily responsible. Models can also be constructed to predict impacts from proposed development and suggest guidance on performance requirements for on-site systems in proposed development areas.

6.3.2.2 Management, operation, and maintenance policies

There are three basic approaches for developing and implementing a management program (see below). In addition, EPA has issued the *EPA Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems* (USEPA 2003). See http://cfpub.epa.gov/owm/septic/home.cfm for management guidelines, technology fact sheets, links, and other information). The guidelines describe five progressive tiers of management in the form of model programs that can be tailored by local communities to meet their public health and water resource protection needs (Table 6.10). Appropriate adoption of these guidelines based on level of risk and value of resources affected by on-site systems is strongly recommended. Table 6.11 shows an example matrix of different on-site system management program elements and functional responsibilities.

Table 6.10: Guidelines for OWTS management programs under a tiered approach (adapted from USEPA, 2002a).

Program type	Program objectives	Basic management program elements
System inventory and awareness of operation and maintenance needs	– Owner awareness of permitting program, installation, and operation and maintenance needs – Compliance with codes and regulations	– Only conventional systems allowed – Prescriptive design and site requirements – Owner education to promote operation and maintenance – Complaint inspections and investigations – Point-of-sale inspections
Management through maintenance contracts	– Maintain prescriptive program for sites that meet siting criteria – Permit proven alternative systems on sites not meeting criteria	– Prescriptive design/site requirements – Measurable operation and maintenance requirements – Allowances for approved alternatives – Operation and maintenance contracts for alternative systems – Inspections, owner education
Operating permits	– System design based on site conditions and performance requirements – System performance verified through permit renewal inspections	– Wide variety of designs allowed – Performance governs acceptability – Compliance monitoring essential – Property sale or change of use triggers compliance assurance inspection
Management entity operation and maintenance	Public or private entity assumes operation and maintenance responsibilities for all systems in management area	– Performance governs acceptability – Operating permits ensure compliance – All systems are inspected regularly – Monthly/yearly fees support program – Owner relieved of operation and maintenance responsibility
Management entity ownership	– Public or private entity owns and operates all systems in management area – Similar to centralized sewage treatment service approach	– Performance governs acceptability – Operating permits ensure compliance – All systems are inspected regularly – Monthly/yearly fees support program – Management entity responsible for operation and maintenance – Management entity finances installation, repairs

Table 6.11: Program elements and functional responsibilities example matrix.

Program Element	Responsible Party							Comments
Planning								
Stakeholder involvement process								
Watershed assessments								
Sensitive area and critical area designations								
Performance Requirements								
Health and environmental goals								
General requirements								
Requirements for sensitive and critical areas								
Site Evaluation								
Wastewater characterization procedures								
Site suitability analysis								
Design								
Prescriptive or performance criteria								
Design review and approval process								
Construction								
Permitting requirements and process								
Construction and/or installation oversight								
Operation and Maintenance								
Owner/operator requirements								
Performance certification approaches								
Residuals Management								
Residuals removal/disposal requirements								
Tracking and reporting system								
Certification and Licensing								
Staff and service providers covered								
Certification/licensing requirements								
Education and Training								
System owner/operator education								
Requirements for staff and service providers								
Provision of training programs								
Inspections and Monitoring								
Routine (point-of-sale) and emergency inspections								
Targeted surface water and ground water monitoring								
Corrective Actions								
Compliance schedules and enforcement program								
Repair, upgrade, or replacement oversight								
Record Keeping and Reporting								
Existing and new systems inventory								
Tracking system for permits/inspection/maintenance								
Financial/administrative/program management								
Financial Assistance								
Funding source development								
Administration/management funding								
Installation and operation and maintenance assistance								

● State Health Department

■ State Water Agency

▲ District/County/Local Health Department

✪ County or Local Government Office

▼ Local/Regional Planning Office

◆ Utility District

✷ System Owner

✦ Private Contractor

6.3.2.2.1 *Voluntary Management*

An effective voluntary program develops recommended guidelines and educational materials and distributes this information to the homeowner or system operator. Voluntary management programs are highly dependent on comprehensive, easy-to-understand educational materials and an aggressive outreach program that includes distribution of the materials, training workshops, and site visits to provide individual assistance.

In 1997 the University of Minnesota Cooperative Extension Service published a guide for homeowners that incorporates important elements of an on-site training program. The guide is available online at http://www.extension.umn.edu/distribution/naturalresources/DD6583.html. Another equally useful guide can be found on the North Carolina Cooperative Extension Web site at http://ces.soil.ncsu.edu/soilscience/publications/Soilfacts/AG-439-22.

6.3.2.2.2 *Regulatory Management*

Under this approach, the regulatory authority—typically a district or local health department—oversees and enforces an on-site program of system design, permitting, installation, operation, and maintenance authorized under state and local codes. The codes may require routine inspections by the health officer either on an annual basis or at the time of property transfer, as is

On-site System Operating Permits in St. Louis County, Minnesota

St. Louis County, located in the northeastern region of Minnesota, extends from the southwestern tip of Lake Superior north to the Canadian border. The physical characteristics of the region are poorly suited for application of traditional on-site treatment systems. Many of the soils are very slowly permeable lacustrine clays, shallow to bedrock, and often near saturation. The existing state code restricts on-site systems to sites with permeable soils of sufficient unsaturated depths to maintain a 3-foot separation distance to the saturated zone. The county has adopted performance requirements that can be followed in lieu of the prescriptive requirements where less than 3 feet of unsaturated, permeable soils exist. In such cases the county requires the owner to continuously demonstrate and certify that the system is meeting performance requirements. This is achieved through the issuance of renewable operating permits for all alternative treatment systems. The operating permit is based on evaluation of system performance rather than design prescription and includes the following:

- System (technology) description.
- Description of environmental conditions.
- Site evaluation documentation.
- Performance requirements.
- System design, construction plan, specifications, and construction drawings.
- Maintenance requirements.
- Monitoring requirements (frequency, protocol, and reporting).
- Contingency plan to be implemented if the system fails to perform to requirements.
- Enforcement and penalty provisions.

The permit is issued for a limited term, typically 5 years. Renewal requires that the owner document that the permit requirements have been met. If documentation is not provided, a temporary permit is issued with a compliance schedule. If the compliance schedule is not met, the county has the option of reissuing the temporary permit and/or assessing penalties. The permit program is self-supporting through permit fees.

the case in Washtenaw County, Michigan (Washtenaw County, 1999), the Code of Massachusetts Regulations, and other state and local statutes. Financial incentives and disincentives usually aid compliance; these can vary from small fines for poor system maintenance to mandatory repairs if the wastewater treatment system is not functioning properly. Inspection fees can cover program costs. Some jurisdictions (e.g., Florida) issue renewable operating permits and/or ground water discharge permits to manage system operation and maintenance. These permits may require homeowners either to have a contract with an authorized inspection and maintenance contractor or to demonstrate that periodic inspection and maintenance procedures have been performed (Florida Statutes, 2001). Permits or inspection requirements for alternative systems, especially those with mechanical components, are recommended.

6.3.2.2.3 *Direct management*

Another option for managing and maintaining on-site systems is a management entity, typically a wastewater utility or district. From a regulatory standpoint, an OWTS management program can save both time and money by allowing a management entity to execute various management program tasks. Incorporating on-site systems into a local or regional wastewater management district, with the district responsible for system operation and maintenance, is a means to ensure that small wastewater systems in a designated area function properly and do not threaten ground water or surface water. State legislation to create wastewater management districts is sometimes required. Enabling legislation for special districts allows district personnel to enter private properties within the district for the purpose of inspecting, repairing, upgrading, or replacing on-site systems. Taxpayers in the proposed district often must vote to create the special district.

The regulatory authority also may decide to perform these tasks and assume overall responsibility for managing the on-site systems in its jurisdiction. Health departments can serve as the management entity under some of the approaches outlined above because they often have considerable permitting, installation, and inspection authority. Regardless of the approach, system users usually pay an annual fee that is applied to operation, maintenance, and management costs. Texas law authorizes local governments to petition the Texas Natural Resource Conservation Commission to assume management authority for on-site systems (Texas

On-Site Sewage Management Ordinance, Chippewa County, Michigan

Chippewa County is located on Michigan's Upper Peninsula, along the shores of Lake Superior. Over the past 10 years, the number of requests for OWTS permits has tripled. The high demand for property in the county, as well as its increased value as a tourist destination, has dramatically increased the county's population. Many of the properties to be developed are located in environmentally sensitive areas, including fractured bedrock and limestone, which puts the county's ground water at high risk of contamination from faulty septic systems.

The county's Environmental Health Department amended the existing sanitary codes to allow the installation of alternative on-site systems for lakeshore areas. County officials worked with a Michigan State University professor to educate the citizens and local officials of Chippewa County about the values of these alternative systems. Some of these alternative systems include recirculating systems, single-pass filter systems, sewage waste lagoons, and mound systems. In the end, both the public and the local government supported the new codes, and no new bacterial contamination has been found since the codes were passed.

Administrative Code, 1997). Procedures that can be used to apply the wastewater management district concept to a specific problem area include:

- Researching relevant legal and regulatory issues;
- Conducting a thorough site investigation;
- Identifying the specific geographic area to be included within the wastewater management district;
- Selecting the performance standards to be met and the means of attaining them;
- Preparing accurate cost estimates;
- Receiving approval from ratepayers within the proposed district for the creation of the management district;
- Preparing and adopting regulations, as needed, to establish the wastewater management district; and
- Adopting a management strategy (including operational, administrative, and financial processes).

Resources are available to help management entities explore the concept of an onsite wastewater management district. For example, the City of Austin, Texas, provides online resources related to its study of management district establishment (see http://www.ci.austin.tx.us/wri/altern.htm)

6.3.2.3 Inspection and monitoring programs

Inspection and monitoring programs are recommended to assess current and likely (future) on-site wastewater impacts. A means of inventorying existing and new systems, conducting inspections, providing monitoring data, or responding to treatment failures should be developed. As noted above, information on new systems (system owner, contact information, system type, location, design life and capacity, recommended service schedule) should be collected by the OWTS regulatory agency at the time of permitting and installation. Telephone, door-to-door, or mail surveys can be helpful to gather information on system type, tank capacity, installation date, last date of service (e.g., pumping, repair), problem incidents, and other relevant information. A number of private firms marketing new treatment technology packages (e.g., fixed film reactors, sand/media filters, aeration units) include remote monitoring services as part of the system package. For example, some companies install controls that continuously upload key system data (e.g., flow rates, pump cycles) to dedicated Web sites. Management staff can monitor the performance of multiple systems by accessing these Web sites, allowing detection of problems before massive failures occur. The per-unit cost of remote monitoring, which is required under the system installation contract, can range from $25 to $50 or more, depending on the type of unit and maintenance needs. The extra expense for necessary equipment is typically less than 10 percent of the cost of the packaged system.

6.3.2.3.1 *System inspections*

On-site system operation and performance inspections should check for the following (USEPA, 2002a):

- Evidence of vehicles being driven over the septic tank or reserve field;
- Installation of pavement, driveways, or structures over the septic tank or reserve field;
- Wet areas or poor drainage in or around the infiltration field;
- Slow flushing or gurgling of water in plumbing fixtures;
- Leaking toilets or addition of significant wastewater-generating fixtures such as water softeners;
- Additions to the house or building after system installation;
- Surface drainage patterns in the area of the tank and infiltration field;
- Broken or open tank access covers or doors; and
- Sludge or scum buildup in the septic tank; clogging of tank filters (if present).

More-detailed inspections of the system are recommended if there is evidence of a problem and should include the following:

- Pump and inspect the tank for structural deficiencies.
- Inspect the pumping components of the system.
- Test the system by filling the tank and observing the water level rise and fall.
- Inspect the baffles, valves, or other key appurtenances.
- Check all piping from the fixtures to the tank.
- Inspect runoff pathways of water from roofs, driveways, and other sources.
- Uncover distribution boxes (if used), and check flow distribution.
- Check for plumbing fixture leaks.

Inspections can be conducted in several ways (USEPA, 1993b). Homeowners can serve as monitors if they are educated and trained on how to inspect their own systems; however, this approach has not been effective in most cases. Brochures are often made available to instruct individuals on how to monitor their systems and the steps to take if they determine that their on-site system is not functioning properly. It should be noted, however, that homeowners rarely inspect their own systems, even with training. Trained inspectors are the best means for identifying failing systems.

Inspections can be conducted at the time of property transfer (point-of-sale inspections). Massachusetts has a rule that has required regular inspections since 1995. Colorado mandates inspections at the time of transfer, although its inspection requirements are less stringent than those of other states. Inspections are discussed further in *EPA Voluntary National Guidelines for*

Comprehensive Monitoring and Inspection Program in Nags Head

The town of Nags Head has implemented a program to identify and address on-site system impacts in that North Carolina Outer Banks community. The town's Septic Health Initiative Program secured competitive bids for tank pumping and inspection and will reimburse full inspection costs (about $65) and provide a $30 rebate on the next water bill if the system owner has the tank pumped. Monitoring consists of a series of ground water well and surface sites that are tested for fecal coliform, ammonia, dissolved oxygen, nitrate, pH, salinity, phosphorus, specific conductance, and turbidity. An education program complements the effort by circulating information on treatment processes, operation, and maintenance (Krafft, 2001).

Management of Onsite/Decentralized Wastewater Treatment Systems (http://cfpub.epa.gov/owm/septic/home.cfm).

Inspection programs operated by OWTS management agencies, special districts, and utilities can be the most effective in terms of cost and results. The State of Arizona requires routine operation and maintenance inspections for alternative on-site systems and pre-sale inspections (NSFC, 1995). Massachusetts requires inspections by a certified individual at the time of property transfer. Minnesota requires property transfers to be accompanied by certification that the on-site system is performing in a satisfactory manner. More than half of all Minnesota counties and most lending entities require inspections because of market-driven desires to ensure that on-site systems are operating properly at the time of property sale (Prager, 2000). Massachusetts also requires that systems with a design flow of 10,000 gal/day or more be inspected every three years, and shared facilities must be inspected annually (Massachusetts Department of Environmental Protection, 1996). Some counties (e.g., Washtenaw County, Michigan) with mandatory property transfer inspection programs require inspectors to be certified. New Hampshire requires an assessment and an on-site system inspection by a permitted designer prior to the sale of any developed waterfront property (New Hampshire Code of Administrative Rules, 2001).

States and localities can also indirectly assess whether on-site systems are failing through surface water and ground water monitoring. If indicator pollutants (e.g., fecal coliform as an indicator of potential pathogen contamination) are found, nearby on-site systems should be inspected to determine if they are a contributing or primary source of the contaminants. For example, residents living along the shore of Ten Mile Lake in Minnesota support a lake association that conducts regular fecal coliform monitoring below lakefront homes. High coliform concentrations prompt system inspections and involvement of property owners in remediation discussions. Owners who repair their system or install a new one are added to the OWTS "honor roll," which is published in the association's monthly newsletter.

Health department personnel and/or system inspectors often use tracer dye to observe effluent movement (USEPA, 1991). Many local agencies use non-toxic tracer dye to determine wastewater migration into nearby wells or surface waters. Tracer dye, which is typically flushed down the toilet, is often used to demonstrate to system owners that effluent is migrating rapidly into nearby surface waters or ground water. Rapid movement of effluent, that is, 20 to 30 feet in less than 30 minutes, may indicate that subsurface infiltration and treatment of wastewater have been short-circuited. Other confirmatory tests should be employed to verify this fact.

Galveston Bay Project Targets "Hot Spots"

In support of the Galveston Bay Estuary Program, the Galveston county health department conducted an intensive survey of on-site systems in the Dickinson Bayou watershed to identify failed systems and improve homeowner operation of existing systems. During the first part of the project, 36 of 90 (40 percent) systems inspected exhibited some degree of failure and were likely contributing to significant fecal coliform water quality violations in the bayou (Galveston County Health District, 1998).

A variety of online resources are available for agencies seeking information on the operation, maintenance, or inspection of on-site systems. The Rhode Island Department of Environmental Management published the *Septic System Checkup* inspection guide in 2000 and posted an online version at http://www.dem.ri.gov/pubs/regs/regs/water/isdsbook.pdf. A general operation and maintenance manual entitled *The Septic System Owner's Guide* is available online from the University of Minnesota Extension Service at http://www.extension.umn.edu/distribution/naturalresources/DD6583.html. For links to other online resources, visit the links page maintained by the Consortium of Institutes for Decentralized Wastewater Treatment at http://www.onsiteconsortium.org/links.cfm. The Wayne County, Ohio, Health District also has an extensive list of links on its Web site (http://wchd.neobright.net/wc_wastewater_tx2.html).

6.3.2.3.2 *Improving system effectiveness through water conservation and pollutant reduction*

In addition to structural methods to remove nitrogen and other pollutants from wastewater, management practices that reduce wastewater flow and/or pollutants are effective. Reducing the overall hydraulic load by installing water-saving devices and adopting water conservation practices can increase the residence times for wastewater pretreatment and, most importantly, reduce the amount of wastewater that must be infiltrated into the soil. Jarrett et al. (1985) stated that 75 percent of soil absorption field failures could be attributed to hydraulic overloading. Several practices are available to retrofit these failing systems so that they operate properly. Eliminating the use of garbage disposals (pollutant reduction), installing low-volume plumbing fixtures (flow reduction), and adopting water conservation practices (flow reduction) are usually the most cost-effective approaches for reducing pollutant and hydraulic loads to the field.

Reduced loading of organics and chemicals can extend the useful life of the on-site system and improve treatment effectiveness. Mass pollutant loads in the OWTS can be significantly decreased by avoiding detergents that contain phosphates, cleaning food debris and grease from dishes before washing, removing or not using in-sink garbage disposal units, and eliminating the disposal of sanitary napkins and disposable diapers in toilets. Inputs of discarded antibiotics, dialysis unit discharges, and toxic cleaners and other chemicals can cause treatment process upsets and may impact public health if they reach the ground water. These problems can be addressed through homeowner education and better disposal practices. See Management Measure 9 (Pollution Prevention) for more information about proper disposal practices.

Reducing hydraulic loads can achieve significant reductions in OWTS failure rates. In 1992 Congress adopted the Energy Policy Act, which established national standards governing water use and energy conservation for showers, kitchen sinks, basins, and toilets (see Table 6.12). Several states have implemented specific water conservation practices (USEPA, 1998b). If low-flow plumbing fixtures are used, it is important that on-site system design not be modified to decrease the required septic tank size. The use of smaller septic tanks could negate the advantages of using low-flow plumbing fixtures by increasing organic loading rates to the soil infiltrative surface.

Table 6.12: Comparison of current and federally mandated flow rates and flush volumes (USEPA, 1998b).

Fixture	Current Practice	Energy Policy Act of October 1992	Potential reduction in water used (%)
Kitchen Sink	3.0 gpm	2.5 gpm	17
Lavatory	3.0 gpm	2.5 gpm	17
Shower	3.5 gpm	2.5 gpm	29
Tub	6.0 gpm	4.0 gpm	33
Water closet (tank)	3.5 gal	1.6 gal	54
Water closet (valve)	3.5 gal	1.6 gal	54
Urinal	3.0 gal	1.5 gal	50

Eliminating the use of garbage disposals can significantly reduce the loading of suspended solids and BOD to OWTSs (Table 6.13) unless OWTSs are designed for their use. Eliminating garbage disposals can decrease the buildup of solids in the septic tank and reduce the frequency of pumping required. A number of states have regulations prohibiting the installation of garbage disposals where on-site systems are used. New OWTSs can be designed to accommodate garbage disposals and the associated increase in organic and solids loadings to wastewater by increasing tank volume or pumping frequency (USEPA, 2001c).

Table 6.13: Residential wastewater pollutant contributions by source (adapted from USEPA, 1992b).

Parameter		Garbage disposal (gpcd)	Toilet (gpcd)	Bathing, sinks, appliances (gpcd)	Approximate total (gpcd)
BOD_5	Mean	18.0	16.7	28.5	63.2
	Range	10.9–30.9	6.9–23.6	24.5–38.8	–
	% of total	(28%)	(26%)	(45%)	(100%)
TSS	Mean	26.5	27.0	17.2	70.7
	Range	15.8–43.6	12.5–36.5	10.8–22.6	–
	% of total	(37%)	(38%)	(24%)	(100%)
Nitrogen	Mean	0.6	8.7	1.9	11.2
	Range	0.2–0.9	4.1–16.8	1.1–2.0	–
	% of total	(5%)	(78%)	(17%)	(100%)
Phosphorus	Mean	0.1	1.6	1.0	2.7
	Range	–	–	–	–
	% of total	(4%)	(59%)	(37%)	(100%)

6.3.2.4 Management of residuals to ensure that they do not present significant risks to human health or water resources

On-site systems are not maintenance-free systems. Huang (1983) stated that half of on-site system failures are due to poor operation and maintenance. Most residential septic tanks are designed for approximately 72- to 96-hour retention of wastewater to allow for the removal of solids, greases, and fats. Some of the solids retained in the tank decompose naturally by bacterial and chemical action. As sludge accumulates on the bottom of the tank, however, the decrease in tank volume available for storing settleable solids and raw wastewater results in less contact time. When sludge or scum levels get too near the outlet entrance level, solids can move directly to the soil absorption system and cause clogging (Mancl and Magette, 1991). Septic tank effluent screens can provide some protection from neutrally buoyant solids and during tank upsets, but periodic removal of solids from the tank is necessary to protect the soil absorption system. Most tanks should be pumped out every three to five years in lieu of a regular inspection program. If a septic system is not pumped out regularly, failure will not occur immediately; however, continued neglect will cause the SWIS to fail because it is no longer protected from greases, oils, and solids. Failure may require replacement, often at considerable expense.

Responsibility for ensuring proper operation and maintenance is most often left to homeowners. Homeowners generally are not properly trained or informed on how to take care of their systems, and many do not care to do so. On-site system regulatory authorities and management entities have recognized the need for more comprehensive management programs and have developed educational and other programs to help owners understand their responsibility for system management. Some regulatory authorities have opted for a more proactive approach and have developed inspection programs, renewable permits, and financial incentives (e.g., low-interest loans, grants) for installing, upgrading, or repairing underperforming systems. More than 100 OWTS management programs that provide operational oversight beyond initial permitting are now operating across the country (Knowles, G., Coordinator, National Onsite Demonstration Program (NODP) Phase IV, personal communication, 2000; see also http://www.nodp.wvu.edu/).

The primary objective of a residuals management program is to establish procedures and rules for handling and disposing of accumulated sludge and wastewater removed from tanks (i.e., septage, also called biosolids) in an affordable manner that protects public health and ecological resources. When planning a program, it is important to have a thorough knowledge of legal and regulatory requirements regarding handling and disposal. In general, state and local septage management programs that incorporate land application or disposal to landfills must comply with Subpart C of 40 CFR (U.S. Code of Federal Regulations) Part 503. Detailed guidance for identifying, selecting, developing, and operating reuse or disposal sites for septage can be found in the two process design manuals: *Land Application of Sewage Sludge and Domestic Septage* and *Surface Disposal of Sewage Sludge and Domestic Septage* (USEPA, 1995 a and b), which are posted on the Internet at http://www.epa.gov/ORD/WebPubs/sludge.pdf. Additional information can be found in *Domestic Septage Regulatory Guidance* (USEPA, 1993a).

States and municipalities typically establish additional public health and environmental protection regulations for residuals handling, transport, treatment, and reuse or disposal. In addition to regulations, practical limitations such as land availability, site conditions, buffer zone requirements, hauling distances, fuel costs, and labor costs play a major role in evaluating septage reuse or disposal options. These options generally fall into three basic categories: land application; treatment at a wastewater treatment plant; or treatment at a special septage treatment facility. Initial steps in the residuals reuse or disposal decision-making process include characterizing the quality and quantity of the septage to be produced annually and determining potential adverse impacts associated with various reuse or disposal scenarios. In general, program officials strive to minimize the exposure of humans, animals, ground water, and surface water to potentially toxic or hazardous chemicals and pathogenic organisms found in septage.

Other key aspects of residuals management programs are tracking or manifest systems that identify septage sources, pumpers, transport equipment, final destination, and treatment, along with procedures such as vector control, wet weather runoff, and access to disposal sites for controlling human exposure to residuals.

6.4 Information Resources

The *Onsite Wastewater Treatment System Manual* (EPA, 2002a) is an update to EPA's 1980 manual entitled *Design Manual: Onsite Wastewater Treatment and Disposal Systems*. This comprehensive reference manual is designed to provide state and local governments with guidance on the planning, design, and oversight of onsite systems. This manual will also be useful for onsite wastewater professionals, developers, land planners, and academics. It is available in PDF format from http://www.epa.gov/ORD/NRMRL/Pubs/625R00008/625R00008.htm.

EPA Voluntary National Guidelines for Management of Onsite/Decentralized Wastewater Treatment Systems is a set of recommended practices needed to raise the level of performance of on-site/decentralized wastewater systems through improved management programs. Five model programs are presented as a progressive series: (1) system inventory and awareness of maintenance needs; (2) management through maintenance contracts; (3) management through operating permits; (4) operation and maintenance by a public or private management entity; and (5) ownership and management by a public or private management entity. Each of these model programs includes a set of recommended approaches for planning, siting, design, performance, installation, operation, maintenance, and monitoring of wastewater systems. The guidelines can be obtained at EPA's Office of Wastewater Management Web site at http://cfpub.epa.gov/owm/septic/home.cfm.

Funded by the U.S. Environmental Protection Agency, the National Small Flows Clearinghouse (NSFC) helps small communities and individuals find affordable wastewater treatment options to protect public health and the environment. The NSFC Web site, which can be accessed at http://www.nesc.wvu.edu/nsfc/nsfc_index.htm, offers news, publications, databases, discussion groups, information about innovative and alternative wastewater technology projects (through EPA's Environmental Technology Initiative project), and links related to small wastewater systems.

The ASTM International Web site (http://www.astm.com/) offers guides to standard practices and technical publications on environmental assessment and waste management practices that can be useful for siting, designing, and installing OWTSs.

The American Society of Agricultural Engineers (ASAE) offers several proceedings from conferences focusing on on-site wastewater treatment at its publications page (http://www.asabe.org/pubs/PubCat02/waste.html). ASAE also has a searchable library of technical articles (http://asae.frymulti.com/), many of which pertain to OWTSs.

The National Onsite Wastewater Recycling Association (NOWRA) Web site, which can be accessed at http://www.nowra.org/, offers a calendar of events related to OWTSs, contact information for state and local OWTS organizations, links to OWTS-related businesses and organizations, the *Onsite Insight* newsletter, technical guidance for owners and operators of OWTSs, a bookstore with conference proceedings available for purchase, and the *Model Framework for Unsewered Wastewater Infrastructure*, which is a guide for establishing future national policy for onsite systems.

6.5 References

Alaska Administrative Code. 1999. *Title 18 (Environmental Conservation), Chapter 72, Article 1.* Alaska Department of Environmental Conservation. April 1999 version.

Aller, L., T. Bennett, J. Lehr, R. Petty, and G. Hackett. 1987. *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*. U.S. Environmental Protection Agency, Ada, OK.

American Society for Testing and Materials (ASTM). 1995. *Standard Practice for Surface Site Characterization for On-Site Septic Systems*. Practice D5879-95e1. American Society for Testing and Materials, Conshohocken, PA.

American Society for Testing and Materials (ASTM). 1996a. *Standard Practice for Preliminary Sizing and Delineation of Soil Absorption Field Areas for On-Site Septic Systems*. Practice D5925-96e1. American Society for Testing and Materials, Conshohocken, PA.

American Society for Testing and Materials (ASTM). 1996b. *Standard Practice for Subsurface Site Characterization of Test Pits for On-Site Septic Systems*. Practice D5921-96e1. American Society for Testing and Materials, Conshohocken, PA.

Bicki, J.T., and R.B. Brown. 1991. On-site sewage disposal: the influence of system density on water quality. *Journal of Environmental Health* 53:39–42.

Boyle, W. 1995. *Nitrogen Removal from Domestic Wastewater in Unsewered Areas.* University of Washington, Seattle, WA.

Bruen, M.G., and R.J. Piluk. 1994. Performance and costs of on-site recirculating sand filters. In *On-Site Wastewater Treatment: Proceedings of the Seventh International Symposium on Individual and Small Community Sewage Systems*. American Society of Agricultural Engineers, Atlanta, GA, December 11–13, 1994.

Caudill, J.R. 1998. Homeowner Education about Onsite Sewage Systems. In *Proceedings of the 7th National Onsite Wastewater Recycling Association and Annual Conference*, Northern Kentucky, October 1998. Laurel, MD.

Center for Infrastructure Research. No date. *Drinking Water and Wastewater Treatment: Research Advancements*. University of Nebraska, Center for Infrastructure Research, Omaha, NE. http://www.unomaha.edu/~wwwcir/publications/advancements/treatment2.htm.

Code of Maryland Regulations. 2001. *Non-Conventional On-Site Sewage Disposal Systems*. COMAR 26.04.02.06. http://www.dsd.state.md.us/comar/26/26.04.02.06.htm. Accessed January 14, 2001.

Code of Massachusetts Regulations. 2001. *Part I, Title IX, Chapter 62, Taxation of Income; Section 6: Credits*. http://www.state.ma.us/legis/laws/mgl/62%2D6.htm. Accessed January 15, 2002.

Commonwealth Biomonitoring. 2001. *Indian Lakes Improvement Project: A Lake and River Enhancement Project funded by the Indiana Department of Natural Resources Division of Soil Conservation*. http://www.state.in.us/dnr/soilcons/dreamweaver/images/fivelake.pdf. Indianapolis, IN.

Converse, J.C., and E.J. Tyler. 2000. *Wisconsin Mound Soil Absorption System: Siting, Design, and Construction Manual. Small Scale Waste Management Project*. University of Wisconsin-Madison, Madison, WI.

Dickey, E.C., and P.W. Harlan. 1996. *Soils, Absorption Fields and Percolation Tests for Home Sewage Treatment*. NebGuide. University of Nebraska Cooperative Extension, Lincoln, NE. http://www.ianr.unl.edu/pubs/wastemgt/g514.htm. Last updated November 1996. Accessed July 17, 2000.

Dickey, E.C., P.W. Harlan, and G. Hosek. 1996. *A Septic Tank System for Sewage Treatment*. NebGuide. University of Nebraska Cooperative Extension, Lincoln, NE. http://www.ianr.unl.edu/pubs/wastemgt/g448.htm. Last updated November 1996. Accessed July 17, 2000.

Eliasson, J.M., D.A. Lenning, and S.C. Wecker. 2001. Critical Point Monitoring: A New Framework for Monitoring On-Site Wastewater Systems. In *Onsite Wastewater Treatment: Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems*. American Society of Agricultural Engineers, St. Joseph, MI.

Florida Department of Health and Rehabilitative Services. 1993. *Onsite Sewage Disposal System Research in Florida: An Evaluation of Current OSDS Practices in Florida*. Prepared for Florida Department of Health and Rehabilitative Services, Tallahassee, FL, by Ayres Associates, Eau Claire, WI.

Florida Statutes. 2001. *Title XXIX, Public Health; Chapter 381, General Provisions; Section 0065, Onsite Sewage Treatment and Disposal Systems; Regulations; Subjection 4(j) Permits, Installation, and Conditions.*

Fobbs, M., and M. Skala. 1992. Waterborne hepatitis A associated with a church and school. *Missouri Epidemiologist* 14(5).

Galveston County Health District. 1998. *Voluntary Inspection and Information Assistance Program to Reduce Bacterial Pollution Caused by Malfunctioning Septic Systems in Dickinson Bayou*. www.gchd.org/pages/ech/tocfr.html. Accessed January 15, 2002.

Hagedorn, C. 2000. *Bacterial Source Tracking (BST)*. www.bsi.vt.edu/biol_4684/BST/BST.html. Accessed January 15, 2002.

Harmeson, R.H., R.W. Solio, and T.E. Larson. 1971. The nitrate situation in Illinois. *Journal of the American Water Works Association* 63:303–310.

Hoover, M.T. 1997. *A Framework for Site Evaluation, Design, and Engineering of On-Site Technologies Within a Management Context*. Marine Studies Consortium and ad hoc Task Force for Decentralized Wastewater Management, Chestnut Hill, MA, and Waquoit Bay National Estuarine Research Reserve, Waquoit, MA.

Hoover, M.T., T.M. Disy, M.A. Pfeiffer, N. Dudley, R.B. Meyer, and B. Buffington. 1996. *North Carolina Subsurface Operators Training School Manual*. Soil Science Department, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, NC, and North Carolina Department of Environment, Health, and Natural Resources, Raleigh, NC.

Huang, J.Y.C. 1983. Management of on-site disposal systems: Case study. *Journal of Environmental Engineering* 109(4):845-858.

Krafft, T. 2001, February 8. E-mail to Decentralized Wastewater Management Listserver, U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC.

Kreissl, J. 1982. Evolution of State Codes and Their Implications. In *Proceedings of 4th Northwest On-Site Wastewater Disposal Short Course*, University of Washington, Seattle, WA, September 1982.

Leyden, K. 1999, November 5. Letter to Joelle Gore, Office of Ocean and Coastal Resource Management, regarding Maine's 6217 Program (On-Site Disposal Systems).

Lockwood, K. 1997. *Septic Systems—An Engineer's View*. Lockwood, Dietershagen Associates, Clifton Park, NY. www.inspect-ny.com/septic/lockwood.htm. Last updated August 7, 1997. Accessed July 17, 2000.

Loudon, T.L. 1996. *Performance of Trenches Receiving Sand Filter Effluent in Slowly Permeable Soils*. Sand Filter Information Package # WWPCGN29. National Small Flows Clearinghouse, West Virginia University, Morgantown, WV.

Maine Department of Human Services. 1996. *Rules for Site Evaluators of Subsurface Wastewater Disposal Systems*. Statutory Authority: 22 MRSA Section 42 Sub-section 3A. 10-144 Chapter 245.

Mancl, K., and W. Magette. 1991. *Maintaining Your Septic Tank.* Publication WR28. University of Maryland Cooperative Extension Service, College Park, MD.

Martin, D. 1999. *Chippewa County On-Site Sewage Management*. Chippewa County Environmental Health Department, Chippewa, MI. www.gem.msu.edu/casestd/chippewa.html. Last updated April 15, 1999. Accessed July 17, 2000.

Maryland Department of the Environment. 2000. *Septic System Advisory Committee Final Report*. www.mde.state.md.us/environment/septic/septic-report2.pdf. Last updated February 25, 2000. Accessed July 17, 2000.

Massachusetts Department of Environmental Protection. 1996. *310 CMR 15.000: The State Environmental Code, Title 5: Standard Requirements for the Siting, Construction, Inspection, Upgrade and Expansion of On-Site Sewage Treatment and Disposal Systems and For the Transport and Disposal of Septage.* www.state.ma.us/dep/brp/files/310cmr15.pdf. Last updated December 27, 1996. Accessed January 15, 2002.

National Oceanic and Atmospheric Administration (NOAA). 1995. *National Shellfish Register*. National Oceanic and Atmospheric Administration, Washington, DC.

National Small Flows Clearinghouse (NSFC). 1995. *Summary of Onsite Systems in the United States: 1993.* National Small Flows Clearinghouse, Morgantown, WV.

National Small Flows Clearinghouse (NSFC). 1997. *Management Districts Technology Package*. Document WWBKGN70. National Small Flows Clearinghouse, Morgantown, WV.

National Small Flows Clearinghouse (NSFC). 1998. *Environmental Technology Initiative Fact Sheets*. OWTS Technical Overviews. National Small Flows Clearinghouse, Morgantown WV.

Nelson, Dix, and Shephard. 1999. Unpublished draft. Survey reference and paper from RF/Parsons Engineering Science/National Small Flows Clearinghouse.

New Hampshire Code of Administrative Rules. 2001. *Part Env-WS: Waterfront Property Site Assessment Study*. Env-Ws 1025.01. Concord, NH.

Noah, M. 2000. Mandated certification of onsite professionals. *Small Flows Quarterly* 1(1).

North Carolina Department of Environment, Health, and Natural Resources (NC DEHNR). 1996. *Onsite Wastewater Management Guidance Manual*. North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Health, Onsite Wastewater Section, Raleigh, NC.

NSF International. 2000. *NSF International Onsite Wastewater Inspector Accreditation Program.* NSF International, Ann Arbor, MI.

Ohio State University. No date. *Septic Tank—Mound System*. Fact Sheet AEX-744. Ohio State University, Department of Food, Agricultural, and Biological Engineering, Columbus, OH.

Otis, R.J. and D.L. Anderson. 1994. Coming of Age: Onsite Wastewater Treatment System Management. In *Proceedings of the Wastewater Nutrient Removal Technology and Onsite Management Districts Conferences*. Waterloo, ON: Waterloo Center for Groundwater Research, University of Waterloo, pp. 97–109.

Parsons Engineering Science. 2000. *Septic System Failure Summary*. Prepared for U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, by Parsons Engineering Science, Fairfax, VA.

Prager, J. 2000. E-mail to State Regulators Listserver, National Small Flows Clearinghouse, Morgantown, WV. Responses summarized by Mark Soltman on August 8, 2000.

Purdue University, 2000. *Constructed Wetlands Diagrams*. http://abe.www.ecn.purdue.edu/~epados/septics/images/fig5.gif. Accessed July 17, 2000.

Roy, C., and J.P. Dube. 1994. A recirculating gravel filter for cold climates. In *On-Site Wastewater Treatment: Proceedings of the Seventh International Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, Atlanta, GA, December 11–13, 1994.

Schaub, F. 2000. E-mail to State Regulators Listserver on November 2, 2000. Frank Schaub, Connecticut Department of Public Health, Supervising Sanitary Engineer, Environmental Engineering Section.

Shephard, F.C. 1996. *Managing Wastewater: Prospects in Massachusetts for a Decentralized Approach. A Discussion of Options and Requirements*. Prepared for the Ad Hoc Task Force for Decentralized Wastewater Management by the Waquoit Bay National Estuarine Research Reserve, Waquoit, MA.

Siegrist, R.L. 2001. Advancing the science and engineering of onsite wastewater systems. In *On-Site Wastewater: Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, Fort Worth, TX, March 11–14, 2001.

Siegrist, R.L., E.J. Tyler, and P.D. Jenssen. 2000. Design and performance of onsite wastewater soil absorption systems. In *Proceedings of the Decentralized Wastewater Management Research Needs Conference*, Washington University, St. Louis, MO, May 19–20, 2000.

South Carolina Department of Health and Environmental Control. 1999. *A Technical Evaluation of Onsite Wastewater Disposal in South Carolina*. Prepared by the Onsite Wastewater Technical Committee in January 1999.

Stein, O.B., J.A. Biederman, P.B. Hook, and W.C. Allen. 1998. Performance data from model constructed wetlands for wastewater treatment. In *Engineering Approaches to Ecosystem Restoration: Proceedings of the 1998 Wetlands Engineering and River Restoration Conference*, American Society of Civil Engineers, Denver, CO, March 22–27, 1998.

Stuart, K. 2000. E-mail to the State Regulators Listserver on October 31, 2000. Ken Stuart, Director, Contra Costa Environmental Health Department, Concord, CA.

Tchobanoglous, G., and F.L. Burton. 1991. *Wastewater Engineering, Treatment, Disposal and Reuse*. McGraw-Hill Publishing Company, New York, NY.

Tetra Tech, Inc. 2000. *Application of the Patuxent River Septic System Nitrogen Loading Tool*. Prepared for Prince George's County, MD, by Tetra Tech, Inc., Laurel, MD.

Texas Administrative Code. 1997. *Onsite Sewage Facilities*. Title 30, Chapter 285. Adopted February 5, 1997.

Tyler, E.J., W.C. Boyle, J.C. Converse, R.L. Siegrist, D.L. Hargett, and M.R. Schoenemann. 1985. *Design and Management of Subsurface Soil Absorption Systems*. EPA-600-2-85-070. U.S. Environmental Protection Agency, Water Engineering Research Laboratory, Cincinnati, OH.

U.S. Census Bureau. 1997a. *American Housing Survey for the United States: 1997—Table 2-6. Detailed Tables for Total Occupied Housing Units—What Went Wrong?* http://www.census.gov/hhes/www/housing/ahs/97dtchrt/tab2-6.html. Last updated September 14, 2000. Accessed January 16, 2002.

U.S. Census Bureau. 1997b. *American Housing Survey for the United States: 1997—Table 2-4. Selected Equipment and Plumbing: Occupied Units.* http://www.census.gov/hhes/www/housing/ahs/ahs97/tab24.html. Last updated December 13, 2000. Accessed October 30, 2001.

U.S. Census Bureau. 1999. *Historical Census of Housing Tables: Sewage Disposal*. http://www.census.gov/hhes/www/housing/census/historic/sewage.html. Last updated December 15, 2000. Accessed January 16, 2002.

U.S. Environmental Protection Agency (USEPA). 1980. *Design Manual: Onsite Wastewater Treatment and Disposal Systems.* EPA 625-1-80-012. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1991. A method for tracing on-site effluent from failing septic systems. *Nonpoint Source News-Notes* 12 (April/May).

U.S. Environmental Protection Agency (USEPA). 1992. *Wastewater Treatment/Disposal for Small Communities.* EPA-625-R-92-005. U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Research Information, Cincinnati, OH.

U.S. Environmental Protection Agency (USEPA). 1993a. *Domestic Septage Regulatory Guidance*. EPA-832-B-92-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1993b. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-625-1-88-022. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1998a. Endocrine Disruptor Screening Program: Statement of Policy; Notice. U.S. Environmental Protection Agency. *Federal Register*, December 28, 1998, 63:71542.

U.S. Environmental Protection Agency (USEPA). 1998b. *Water Conservation Plan Guidelines—Part 1: Information for States.* http://www.epa.gov/owm/water-efficiency/wave0319/inform1.htm. Accessed January 15, 2002.

U.S. Environmental Protection Agency (USEPA). 2001a. *Constructed Wetlands Treatment of Municipal Wastewaters*. EPA-625-R-99-010. http://www.epa.gov/ORD/NRMRL/pubs/625r99010/625r99010.pdf. Last updated April 2001. Accessed January 15, 2002.

U.S. Environmental Protection Agency (USEPA). 2001b. *Estimate of National Gap for On-Site Wastewater Treatment Systems*. Draft. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2001c. *Onsite Wastewater Treatment Systems Special Issues Fact Sheet 2: High-Organic-Strength Wastewaters (Including Garbage Grinders)*. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2002a. *Onsite Wastewater Treatment System Manual.* EPA/625/R-00/008. U.S. Environmental Protection Agency, Office of Water, Washington, DC, and Office of Research and Development, Cincinnati, OH.

U.S. Environmental Protection Agency (USEPA). 2002b. *Onsite Wastewater Treatment System Management Handbook*. Draft. U.S. Environmental Protection Agency, Office of Water, Washington, DC, and Office of Research and Development, Cincinnati, OH.

U.S. Environmental Protection Agency (USEPA). 2003. *EPA Voluntary National Guidelines for Management of Onsite and Clustered(Decentralized) Wastewater Treatment Systems*. EPA-832-B-03-001. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC.

U.S. Environmental Protection Agency. (USEPA). 1995. *Process Design Manual: Land Application of Sewage Sludge and Domestic Septage*. EPA-625-R-95-001. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

University of Massachusetts. 2000. *Indian River Lagoon study calibrates nitrogen loading model*. http://www.epa.gov/owow/estuaries/coastlines/jun00. Last updated September 6, 2001. Accessed January 16, 2002.

University of Missouri Extension Service. 1997. *Residential Sewage Lagoon Systems: A Homeowner's Guide to Installation and Maintenance*. http://muextension.missouri.edu/explorepdf/envqual/wq0402.pdf. Last updated March 15, 1997. Accessed July 17, 2000.

University of Wisconsin. 1978. *Management of Small Waste Flows*. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, OH.

Venhuizen, D. 1993. *Colonia de Quemado Wastewater Facility Plan*. http://www.venhuizen-ww.com/html/papers/pd_quemado.html. Accessed October 30, 2001.

Venhuizen, D. 1995. *An Analysis of the Potential Impacts on Groundwater Quality of On-Site Wastewater Management Using Alternative Management Practices*. http://www.geocities.com/RainForest/Vines/6840/SoilTreat.html.

Venhuizen, D. 1997. *A Minnesota Regulator's Guide to the Venhuizen Standard Denitrifying Sand Filter Wastewater Reclamation System*. http://septictankinfo.info/VenhMGuide.html. Accessed July 17, 2000.

Venhuizen, D. 2000a. From wastewater to usable water. *Water Tech Online*. http://waternet.com/article.asp?indexid=5200205. Accessed July 17, 2000.

Wallace, S.D. 2000. Design and performance of cold climate wetland treatment systems. In *Proceedings of the National Onsite Wastewater Recycling Association 2000 Conference*, Grand Rapids, MI, November 1–4, 2000.

Washtenaw County, MI. 1999. *Regulation for the Inspection of Residential Onsite Water and Sewage Disposal Systems at Time of Property Transfer*. Washtenaw County, Michigan, Department of Environment and Infrastructure Services, Environmental Health Division, Ann Arbor, MI.

White, K.D., and C.M. Shirk. 1998. Performance and design recommendations for on-site wastewater treatment using constructed wetlands. In *Proceedings of the Eighth National Symposium on Individual and Small Community Sewage Systems*. American Society of Agricultural Engineers, Orlando, FL, March 8–10, 1998.

MANAGEMENT MEASURE 7
BRIDGES AND HIGHWAYS

7.1 Management Measure

Plan, design, operate, and maintain highways and bridges to:

- Protect sensitive ecosystems, including wetlands and estuaries, by minimizing road- and bridge-related impacts and water crossings, and by establishing protective measures including setbacks during construction;
- Reduce the runoff of pollutants through the use and proper maintenance of structural controls;
- Reduce the generation of pollutants from maintenance operations by minimizing the use of pesticides, herbicides, fertilizers, and deicing salts and chemicals; and
- Reduce the generation and runoff of pollutants during highway and bridge repair operations by decreasing the use of hazardous materials and incorporating practices to prevent spillage into sensitive areas.

7.2 Management Measure Description and Selection

7.2.1 Description

Motor vehicles generate runoff pollutants through emission and deposition of automobile exhaust and through discharges of both fluids and solid particles while traveling and braking. In a study of traffic-generated particulates in Cincinnati (where the average daily traffic load is 150,000 vehicles), Sansalone and Buchberger (1997) found that of the 13,500 mg of particulates per square meter of road surface generated per day, 44 to 49 percent originated from pavement wear, 28 to 31 percent from tire wear, and 15 percent from engine and brake pad wear. The study also found that 6 percent of particulates were deposited from settleable exhaust and 3 percent from atmospheric deposition.

A study by Shepp (1996) examined generation of petroleum hydrocarbons in urban runoff from four land uses: all-day parking lots, streets, gas stations, and convenience stores. Shepp found that convenience stores had the highest hydrocarbon concentration (see Figure 7.1). Evaluation of the land uses and their respective catchment areas suggested that the degree of automotive exposure (a combination of duration of exposure to vehicles with engines running and volume of traffic) is the primary factor in the generation of petroleum hydrocarbons in runoff from automotive-intensive land uses.

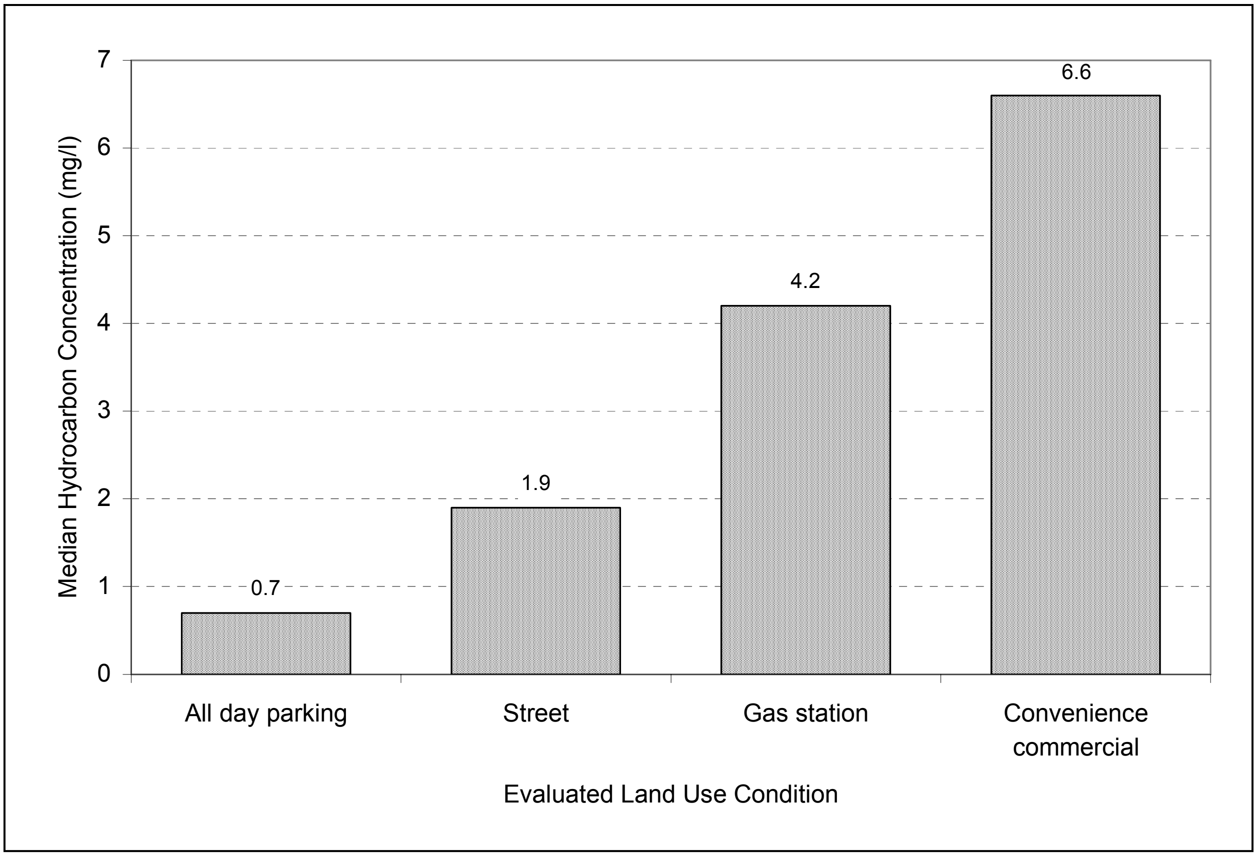


Figure 7.1: Median hydrocarbon concentrations by land use (Shepp, 1996).

The National Water Quality Assessment Program (NAWQA) of the U.S. Geological Survey (USGS) recently conducted studies on water pollution related to sprawl-induced traffic. These studies show a consistently positive correlation between increases in vehicular traffic associated with urban sprawl and the buildup of polycyclic aromatic hydrocarbons (PAHs) in 10 lakes and reservoirs in six metropolitan areas across the country. PAH sources related to motor vehicle use include tire wear, roadway wear, exhaust and soot, and crankcase oil releases (Van Metre et al., 2000). A study in Austin, Texas, demonstrated that elevated levels of PAHs found in Barton Springs sediments, although not toxic on their own, yielded 100 percent mortality in test invertebrates (amphipods, *Hyalella azteca*), when the organisms were exposed to UV radiation (Hayward et al., 2002). Mahler and Van Metre (2004) identified abrasion of coal tar emulsion sealants on parking lots as contributing significant amounts of PAHs to local water bodies and speculated that they could be the dominant source of PAHs in some urban watersheds. The U.S. Fish and Wildlife Service (USFWS) found that 50 to 68 percent of brown bullhead catfish collected from the Anacostia River in Washington, DC, had liver tumors and 13 to 23 percent had skin tumors (Reel, 2004). The USFWS attributed these tumors to DNA changes linked to PAHs from vehicle emissions and runoff.

Roads tend to accumulate particulate matter from roadsides, salting and sanding, dirty cars, brake pad dust, aerial deposition, and surface deterioration. Sansalone and Tribouillard (1999) and Sansalone et al. (1998) measured the deposition and size distribution of particles deposited on highways. They found that accumulation of particulate matter was significantly greater along the downslope of the highway than along the upslope and that particle size distributions (PSDs) along the downslope were consistently coarser across the entire size gradation than the upslope and pavement PSDs (Sansalone and Tribouillard, 1999). Solids in the 2 to 8 µm range generated the largest counts and were rapidly washed from the pavement in a "first flush" effect (Sansalone et al., 1998). Lateral pavement sheet flow rate and duration controlled the yield and size of transported solids; particle transport was mass-limited during extended, high-intensity events, but was flow-limited during intermittent, low-intensity events with high traffic (Sansalone et al., 1998).

These particles, when transported in runoff to receiving waters, contribute to high levels of total suspended solids and turbidity and act as carriers for pollutants that adhere to their surfaces. Because of this adsorption phenomenon, surface area can be an important determinant in pollutant loading from highways. A relationship exists between particle size and surface area. Sansalone et al. (1998) found that particles 425 µm to 850 µm in size contributed the greatest total surface area. Sansalone and Tribouillard (1999) found that total surface area decreased with decreasing particle size. Particle-specific surface area, however, increased with decreasing particle size (Sansalone and Tribouillard, 1999; Sansalone et al., 1998), but measured values deviated from the monotonic pattern expected for spherical particles (Sansalone et al., 1998).

Because total surface area is predominantly associated with the coarser fraction, heavy metal mass (adhered to particle surfaces) is also strongly associated with this fraction (Cristina et al., 2000). Cumulative analyses for lead, copper, cadmium, and zinc in snow residuals indicated that more than 50 percent of these heavy metals (by mass) was associated with particles greater than 250 µm, and more than 80 percent was associated with particles greater than 50 µm (Sansalone and Glenn, unpublished).

Heavy metals such as lead, iron, and aluminum are typically particulate-bound in urban runoff (Sansalone and Buchberger, 1997). Sansalone and Glenn (2000), however, found that lead was predominantly dissolved in highway runoff, a phenomenon they attributed to low urban rainfall pH and alkalinity and relatively short pavement residence times. Other metals predominantly found in the dissolved phase in highway runoff were zinc, cadmium, and copper (Sansalone and Buchberger, 1997; Sansalone and Glenn, 2000).

The California Department of Transportation (Caltrans) conducted a study of highway runoff quality from 1999 to 2000 at 100 locations throughout the state. Caltrans found a positive correlation between the concentration of most pollutants and traffic volume. In addition, more than 30 percent of the total arsenic, cadmium, chromium, copper, nickel, silver, and zinc were found in the dissolved state (Kayhanian et al., 2001).

The partitioning of heavy metals between the particulate-bound and dissolved fractions raises important questions for watershed managers regarding storm water treatment. It was previously thought that metals were associated with particulates and that removing sediment and reducing turbidity would address these pollutants. However, new research indicates that event mean concentrations of dissolved zinc, cadmium, and copper can exceed surface water quality discharge standards and can exhibit a "first flush" effect that cannot be mitigated by settling. In addition, the dissolved nature of these metals makes them highly mobile and bioavailable.

Other pollutants found in highway runoff, along with their likely sources, are shown in Table 7.1. Although runoff characteristics tend to be site-specific, a number of studies have been performed to compile typical concentrations of highway pollutants from a range of different locations from Northhampton, England, to Durham, North Carolina. Table 7.2 shows the range of values for highway contaminants presented by Newberry and Yonge (1996). These concentration levels vary significantly among the different locations. Suspended solids, for example, had concentration levels ranging from 45 mg/L to 798 mg/L; ranges for other parameters were even greater. For some pollutants, such as solids, heavy metals, and organics, concentration levels have been found to correlate with traffic volume.

Table 7.1: Primary sources of highway runoff pollutants (Adapted from NCHRP, 1999).

Pollutants	Primary Source
Particulates	Pavement wear and vehicle maintenance
Lead, cadmium, copper	Tire wear, lubricating oil and grease, bearing wear
Nitrogen, phosphorus	Roadside fertilizer application
Chromium, copper, nickel, cadmium	Metal plating, moving engine parts, brake lining wear
Chloride, sulfates	Deicing salts
PCBs, pesticides	PCB catalyst in synthetic tires, spraying highway rights-of-way
Cyanide	Anti-cake compound used to keep deicing salt granular
Petroleum, ethylene glycol	Spills and leaks of motor lubricants, antifreeze, hydraulic fluids

Table 7.2: Range of average values for runoff contaminant concentration for selected highway contaminants (Newberry and Yonge, 1996).

Contaminant	Concentration (mg/L)	Load (kg/ha/yr)	Load (kg/ha/event)
Suspended solids	45–798	314–11,862	84–107.6
Lead	0.073–1.78	0.08–21.2	0.008–0.22
Phosphorus	0.073–1.78	0.6–8.23	—
Biological oxygen demand	0.113–0.998	30.6–164	0.98
Polycyclic aromatic hydrocarbons	12.7–37	0.005–0.018	—

Runoff from the construction, operation, and maintenance of highways and bridges can adversely affect vegetation, surface waters, and wetlands with a variety of pollutants, including sediments, heavy metals, hydrocarbons, and toxic substances. Runoff issues associated with construction of highways and bridges are addressed in Management Measure 8—Construction Site Erosion, Sediment, and Chemical Control. Although the runoff constituents and concentration levels vary with highway type and location, the sources of highway runoff pollutants fall into three basic categories: vehicle traffic, snowmelt and ice-melt containing deicing chemicals, and chemicals used to manage roadside vegetation.

The specific impacts of highway and bridge runoff on aquatic ecosystems are both site-specific and runoff event-specific. In general, highway pollutants can affect water quality through either acute toxicity or gradual accumulation. Potential adverse environmental effects associated with specific constituents include the following:

- *Suspended solids* increase turbidity, transport other pollutants adhered to particle surfaces, and reduce runoff storage capacity in ponds and lakes.

- *Heavy metals* are toxic to many aquatic organisms and can bioaccumulate in fish tissues, thus posing potential health risks to humans.

- *Nutrients* degrade water quality by stimulating the growth of algae and aquatic weeds. Rapid increases in these populations can then deplete oxygen levels to the extent that fish and other aerobic organisms die off.

- *Biochemical oxygen demand (BOD)* reduces dissolved oxygen levels as a result of the biological processes that break down organic constituents in runoff.

- *PAHs* include compounds such as benzo(a)pyrene that are found in petroleum products and are carcinogenic. These compounds can pose risks to human health if drinking water or fish become contaminated with them. PAHs in streams and lakes usually do not pose a health risk for people because they tend to adhere to sediment particles rather than dissolve in water. As a result, the risk of drinking water degradation is low (Van Metre et al., 2000). Aquatic invertebrates were impacted in the previously identified study from Austin, Texas (Hayward et al., 2002).

Paved roadways often generate higher loads of metals and toxicants than other nonpoint source pollutants[1]. Nutrient loadings from highways tend to be of concern when they are located upstream of a reservoir or estuary.

Winter maintenance activities to prevent ice and snow buildup on highways can also be significant contributors to loadings of particulates, salts, and various other chemicals. Salts in particular can harm both vegetation and aquatic ecosystems. Other highway maintenance activities, including roadside vegetation management, can also contribute herbicides, pesticides, and nutrients to runoff pollutant loads.

In several studies, Sansalone and Glenn (2002a, 2002b, and unpublished) examined the characteristics of snowbanks and snowmelt. Table 7.3 summarizes their findings for several pollutants and physical characteristics. From their research, they concluded the following:

- Traffic and winter maintenance practices generate significant levels of inorganic and organic constituents, many of which become predominantly particulate-bound in the snowbank with increasing residence time.

- The accretion of traffic-generated constituents in urban highway snow is relatively rapid within the first 12 hours of the snowbank's exposure to traffic.

A research team at Oregon State University, under the National Cooperative Highway Research Program (NCHRP, 2000) identified potentially mobile constituents from highway construction and repair materials and measured their potential impact on surface and ground waters. The

[1] Several recent studies cited by the Federal Highway Administration (FHWA) indicate that few significant environmental impacts have been associated with roads with an average daily traffic volume of less than 30,000 vehicles (USDOT, 1996).

materials tested were conventional, recycled, and waste materials; and excluded constituents originating from construction processes, vehicle operation, maintenance operations, and atmospheric deposition. The research team established laboratory methods to realistically simulate the leaching of constituents from construction and repair materials in typical highway environments. They also established methods to evaluate the removal, reduction, and retardation of leached constituents by environmental processes in the highway right-of-way. The team produced extensive data sets of laboratory test results for highway construction and repair materials, and they expressed the results as aquatic toxicity and chemical concentrations. They then developed a software program called IMPACT, which estimates the fate and transport of leachates surrounding the highway right-of-way. IMPACT contains an extensive, readily accessible database of laboratory test results for materials ranging from common construction and repair products to waste and recycled materials proposed for use in highway construction.

Table 7.3: Results of three studies that analyzed chemical and physical parameters of snowmelt (Sansalone and Glenn, 2002a, 2002b, and unpublished).

Parameter	Result
Bulk density	Bulk densities increased as TSS accumulation continued and the snow matrix began to melt or evaporate.
Particle size distribution and bulk density	For all sites, particle sizes ranged from 10,000 µm to less than 25 µm, with a mean bulk density of 1,225 µm.
Specific gravity	Specific gravity of residual solids ranged from 2.5 to 3.2 g/cm^3 across the gradations; the lower specific gravity was associated with particles less than 100 µm.
Chloride and conductivity	Conductivity and chloride concentrations increased rapidly at first because of initial deicing salt applications at each site. Strong correlations indicated that conductivity trends were mainly a function of chloride trends.
Hardness	Hardness increased rapidly to nearly 100 mg/L during initial snow accumulation and remained relatively constant (100–300 mg/L) for most of the study. This increase is likely a result of liquid $CaCl_2$ mixed with rock salt and $CaCO_3$ as part of the TSS captured by the snow matrix.
COD	Temporal trends toward increasing total chemical oxygen demand (COD) exerted by roadway snow are similar to trends in TSS, with COD values of 100,000 mg/L.
TDS and TSS	Although accretion of total dissolved solids (TDS) was initially rapid with a decrease late in the event, total suspended solids (TSS) accretion demonstrated a more gradual increasing trend for the duration of roadway snow, approaching 100,000 mg/L.
Cyanide	Applications of 216,000 kg of rock salt containing cyanide as an anti-caking agent resulted in a discharge of approximately 6 kg of cyanide along the interstate.
Metals	Concentrations for lead, copper, cadmium, zinc, and cyanide were orders of magnitude higher than those of the control site and exceeded storm water runoff concentrations by 1 to 2 orders of magnitude.

Note: TSS = total suspended solids, TDS = total dissolved solids, COD = chemical oxygen demand, $CaCl_2$ = calcium chloride, $CaCO_3$ = calcium carbonate.

7.2.2 Management Measure Selection

This management measure was selected to provide general guidance on practices that can be integrated into highway and bridge maintenance and repair operations. The management measure also includes guidance for siting and constructing highways and bridges. The management measures for watershed protection; site development; new development runoff treatment; and construction site erosion, sediment, and chemical control (Management Measures 3, 4, 5, and 8) are also applicable to the planning and constructing of highways and bridges.

7.3 Management Practices

The use of structural and nonstructural runoff control practices during the planning, design, operation, and maintenance of highways and bridges can significantly mitigate the adverse effects of runoff. Specifically, by using environmentally sensitive highway and bridge designs and implementing proper operation and maintenance practices, highway authorities can reduce both the volume and concentration of contaminants generated by motor vehicle traffic and maintenance and repair operations. In addition, controls can be used to store and treat contaminants so that pollutant loadings can be further reduced or prevented from entering sensitive ecosystems.

7.3.1 Site Planning and Design Practices

A wide range of environmental planning and design management practices, especially those presented in Management Measures 3 and 4, can be used to reduce the environmental impacts of highways and bridges and can be initiated long before a road is completed. In general, highways and bridges should be planned so that mileage through sensitive environments, such as wetlands and estuaries, is minimized. River crossings should be avoided if possible, and sufficient setbacks should be established during construction to minimize disturbance of the surrounding environment. During the siting process, consideration should also be given to maintaining sufficient setbacks for the protection of drinking water sources. Efforts should be taken to avoid channelization and floodplain alteration to allow natural processes to continue after roads are in place.

Highway development is most disruptive adjacent to water bodies, riparian areas, and wetland areas because it increases sediment loss, alters surface drainage patterns, changes the subsurface water table, and results in loss of wetland and riparian habitat. Highway structures should not restrict tidal flows into salt marshes and other coastal wetland areas because such restrictions might facilitate the intrusion of freshwater plants and reduce the growth of salt-tolerant species. To safeguard these fragile areas, highways should be sited with sufficient setback distances between the highway right-of-way and any wetlands or riparian areas.

Bridge construction can also adversely affect water circulation and quality in wetland areas, necessitating special techniques to accommodate construction. By locating highways and bridges away from sensitive areas and establishing buffer zones where possible, environmental degradation from erosion and runoff can be mitigated during construction, operation, and maintenance of roadways.

As discussed previously, roads and highways have been shown to accumulate pollutants that are carried in runoff. Decreasing impervious cover by reducing the area of pavement or number of road miles could lower this pollution potential. However, each individual community should weigh the benefits of alternative road designs against the use of low-impact development techniques or treatment controls (see Management Measures 4 and 5, respectively). Where road surfaces are constructed, disconnecting and infiltrating runoff using structural runoff controls can mitigate impacts of roads and provide sufficient water quality protection.

7.3.2 Soil Bioengineering and Other Runoff Controls for Highways

Soil bioengineering techniques can be used to augment or replace structural slope stabilization practices such as retaining walls. They are appropriate for relatively moderate slopes where vegetation can be established easily. Soil bioengineering techniques can create wildlife habitats and promote infiltration of rainfall and runoff in addition to stabilizing slopes. Installation of bioengineering practices can be labor-intensive, and periodic inspection and maintenance, especially after large storms, is necessary to repair slumps and replace dead vegetation. Soil engineers or scientists should confirm that the stability and structural integrity of the site are appropriate for soil bioengineering practices. Several kinds of soil bioengineering practices are described by the U.S. Department of Agriculture (USDA, 1992):

7.3.2.1 Live stakes

The use of live stakes involves inserting and tamping live, rootable vegetative cuttings into the ground to create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and extracting excess soil moisture. Live stakes are appropriate for repairing small earth slips and slumps caused by excessively wet soil and should be used only at sites with relatively uncomplicated conditions. They are especially useful when construction time is limited and an inexpensive method is desired. They can be used to secure erosion control measures and can be used in combination with other bioengineering techniques. Finally, they facilitate plant colonization by providing a favorable microclimate for plant growth. Native species that are appropriate for the soil conditions onsite should be used wherever possible.

7.3.2.2 Fascines

Fascines are long bundles of branch cuttings bound together into sausage-like structures. They are installed in contoured or angled trenches and are secured to the slope with both live and dead stakes. They reduce surface erosion and rilling, protect slopes from shallow slides, and reduce long slopes into a series of shorter slopes that trap and hold soil. They also enhance vegetative growth by creating a microclimate conducive to plant growth.

7.3.2.3 Brushlayers

Brushlayering is much like the fascine technique except branches are placed perpendicular to the slope contour. This method is more effective than fascines with respect to earth reinforcement and mass stability. Brushlayers break up the slope length, preventing surface erosion, and reinforce the soil with branch stems and roots, providing resistance to sliding or shear displacement. Brushlayers also trap debris, aid infiltration on dry slopes, dry excessively wet sites, and mitigate slope seepage by acting as horizontal drains. Brushlayers facilitate vegetation establishment by providing a stable slope and a favorable microclimate for growth.

7.3.2.4 Branchpacking

Branchpacking involves reinforcing a slope with alternating layers of live branch cuttings and compacted backfill. This technique is useful to repair small, localized slumps and holes in earthen embankments other than dams. Branchpacking produces a filter barrier that reduces erosion and scouring and provides immediate soil reinforcement. Branchpacking is not effective in slump areas more than 4 feet deep or 5 feet wide.

7.3.2.5 Live gully repair

Live gully repair is a technique that is similar to branchpacking but is used to repair rills and gullies. Live gully repairs offer immediate reinforcement and reduce the velocity of concentrated flows. They also provide a filter barrier that reduces further rill and gully erosion. This technique is appropriate only to repair rills or gullies less than 2 feet wide, 1 foot deep, and 15 feet long.

7.3.2.6 Live cribwalls

A live cribwall is a hollow, boxlike structure of interlocking untreated logs or timber members installed with backfill material and layers of live branch cuttings. The live cuttings eventually take over the structural functions of the wall once the roots have become established. Live cribwalls are appropriate for stabilizing the toe of a slope and reducing its steepness. They should not be used in areas that are subject to large lateral stresses. Cribwalls provide both immediate and long-term stabilization and are useful where space is limited. They should be tilted if the system is built on a smoothly sloped surface, or they can be constructed in a stair-step fashion.

7.3.2.7 Vegetated rock gabions

Vegetated rock gabions consist of wire mesh or chain-link baskets layered with live branch cuttings that take root inside the gabions and bind the structure to the slope. These structures are appropriate for stabilizing the toe of a slope and reducing its steepness, especially in areas where space is limited. They should not be used in areas that are subject to large lateral stresses and should not be more than 5 feet tall.

7.3.2.8 Vegetated rock walls

Vegetated rock walls consist of a combination of rocks and live branch cuttings used to stabilize the toe of steep slopes. These structures are appropriate for stabilizing areas where space is limited and natural rock is available. The wall should not exceed 5 feet in height.

7.3.2.9 Joint planting

Joint planting stabilizes slope faces by planting live cuttings in spaces between the stones of riprap. The plantings improve drainage, bind rock materials to the slope, and help prevent washout of fine materials. Joint planting can be used where riprap has already been installed, or it can be part of a new riprap installation.

7.3.2.10 Other runoff and sediment controls for highways

Other runoff controls, such as grassed swales and filter strips, wet ponds, extended detention dry ponds, and storm water wetlands, can be used to control highway runoff. These measures are described in detail in Management Measure 5. Additionally, sediment traps and basins and inlet protection (described in Management Measure 8) can be used to collect runoff from highways, especially during construction and repair operations when pollutant loadings are great.

Highway Management Plans for Storm Water Control

In Delaware County, New York, the Department of Public Works (DPW) is extending its highway runoff management program to include town roads. This involves inventorying and assessing town roads, identifying priority storm water management needs, training highway superintendents, and evaluating and monitoring management practices. The DPW plans to dedicate a storm water/highway engineer to assist towns in prioritizing their highway storm water projects. Funding will be provided through the Catskill Watershed Corporation's Stormwater Retrofit Program and matched with capital planning funds in town highway budgets. The intent of the program is to maximize efficiency by targeting the areas critically in need of redesign, repair, and rebuilding (Delaware County Departments of Planning and Public Works, 2003). For more information, contact the Delaware County Department of Watershed Affairs, (607) 746-8914.

7.3.3 Structural Runoff Controls for Bridges

Highway runoff controls have been extensively documented and implemented. A mitigation strategy specific to bridges is crucial, however, because of the unique limitations associated with bridge building and repair. These limitations include (Transportation Research Board, 2002a):

- A lack of lateral right-of-way on which to build mitigation measures, causing runoff to be drained back onto land;
- Topographic and slope constraints at some bridges that prohibit gravity drainage back to land;
- The need to factor additional weight of storm water piping into the design of a new or retrofitted bridge; and
- The need to address maintenance constraints and safety concerns.

The Transportation Research Board (TRB) (2002b) developed a report that addresses these and other issues specific to bridge runoff. The TRB described a process for assessing sites for the potential for bridge deck runoff to cause water quality problems and for developing mitigation procedures. The process is particularly applicable in the case of large bridge construction or reconstruction projects over sensitive or highly valued receiving waters. It is also applicable in cases where regulations and policies are ambiguous or require reconsideration. This report, *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters,* is available from the TRB at http://www.trb.org/.

7.3.3.1 Scupper drains with runoff conveyance systems

Bridges have traditionally been designed to direct runoff away from the roadway as efficiently as possible without regard to impacts on the environment below the deck. While there is a significant body of research on the environmental impacts of highway runoff, there are few studies that directly address the chemical characteristics of runoff from bridge decks, and even fewer that also address the effects of that runoff on biota or other receiving water uses. Several studies have shown that direct scupper drainage into some types of water bodies, such as small lakes, can result in localized increases of metal concentrations in sediments and in aquatic biota. (TRB, 2002a).

More recently, bridge designs have been enhanced to address the potential effects of runoff pollutant loadings, especially on water bodies. The most prevalent mitigation practice is to direct the drainage from the bridge to an on-shore treatment system. For example, the runoff can be conveyed from scupper drains through a pipe onto the shore, from which it is sent to a retention pond or other runoff treatment practice. A scupper drain is an opening in the floor of a bridge that provides a means for rain or other water accumulated on the roadway surface to drain into the space beneath the structure (ODOT, 2001). Rather than draining directly to the water below, the runoff can be routed to the shore for treatment. The FHWA and EPA have developed recommendations on the design and use of scupper drains to address bridge deck runoff. Among the practices they recommend are:

- The spacing between scuppers should be maximized in accordance with established maximum hydrologic and hydraulic design. As scupper spacing increases, the volume of water that passes through each scupper increases, thus creating velocities high enough to flush outlets clogged by deposits from low-volume rainfalls.

- Careful detailing is critical when connecting scuppers to drain pipes. Because of poorly designed routing, drain pipes often create more problems than they prevent. For example, piping that is routed with too many elbows can easily clog, resulting in a buildup of contaminated runoff.

- Gravity flow collection systems should be used wherever possible.

Collection systems for scupper drains may be used to minimize the impacts of bridge runoff, although they may be expensive. Depending on the length of the bridge and traffic volume, as well as river size and climate, bridge runoff might constitute only a small fraction of the overall pollutant load to a receiving water body. Furthermore, the topography and approach slope at some bridge locations might preclude design or retrofit for gravity drainage back to land, therefore requiring the use of a pump to discharge the runoff into a suitable water quality treatment practice (TRB, 2002a). The addition of pumps could significantly increase the cost of the collection system and operation and maintenance requirements. In some cases, controlling runoff from other pollutant sources may be more cost-effective when a watershed approach is used.

7.3.3.2 Other runoff treatment practices

Runoff treatment practices like ponds, wetlands, infiltration basins and trenches, media filters, bioretention areas, vegetated swales, filter strips, and hydrodynamic devices (see Management Measure 5) can be installed on the shore to treat runoff collected and routed by scupper drains and pipes. If a bridge does not have scupper drains, runoff can be routed to the shore via gutters. Depending on site conditions, such as the space available for the practice, the suitability of the soils for filtration or infiltration, and the quantity and quality of the bridge runoff, some practices may be more cost-effective than others.

7.3.4 Bridge Operation and Maintenance Controls

Bridge repairs are those activities necessary to maintain the structural integrity and designated use of the bridge. Bridge repairs encompass a wide array of activities, ranging from minor operation practices, such as line painting, to major structural repairs. Bridge scraping and painting, which are required to prevent corrosion, can be significant sources of pollutant loads if proper management practices are not used.

Of the most common bridge maintenance activities, bridge painting has the greatest potential for environmental impact. A 1996 study found that up to 80 percent of steel bridges repainted each year had been painted with lead paint, and this material along with cleaners and abrasives, can directly enter the surrounding environment (Young et al., 1996). Paint overspray and solvents can be toxic to aquatic life (Dalton et al., 1985), and metal bridge cleaning has been found to pose a serious water quality problem (TRB, 2002b). The cost of implementing measures to mitigate the impacts of bridge painting are estimated to be an additional 10 to 20 percent for containment and 10 to 15 percent for waste disposal (Young et al, 1996).

Although most construction activities take place away from water bodies, bridge operation and maintenance activities occur within close proximity to a water body. Therefore, management practices to minimize potential adverse effects on the surrounding environment are recommended. It should be noted that, in some cases, federal regulations, including Section 404 of the Clean Water Act and Section 9 of the Rivers and Harbors Act (33 USC 401) might apply to these construction activities. Section 404 regulates the discharge of dredged or fill material to the aquatic environment or the nation's waters. Section 9 of the Rivers and Harbors Act prohibits the construction of any bridge, dam, dike, or causeway over or in navigable waterways without Congressional approval.

7.3.4.1 Enclosures

The following types of enclosures can be used to collect pollutants during bridge maintenance:

(1) *Free-hanging enclosures*. Free-hanging enclosures include tarps, drapes, plastic sheeting, screens, and rigid panels of which only two corners (or one side) are supported. Free-hanging tarps generally provide relatively low containment efficiency (estimated at no more than 50 percent). Considerations for material selection include visibility inside the enclosure, material strength, and air permeability. Free-hanging enclosures are not practical for large, high bridges where high winds can rip the materials or create a “sail effect.”

(2) *Total structural enclosures*. Total structural enclosures are drapes, tarps, screens, plastic sheeting, or rigid panels attached to a rigid steel or wood framework, scaffolding, or existing walls. Design considerations include interior air quality, visibility, structural adequacy of the enclosure, portability, and reusability. Enclosures can be used to encapsulate only part of a large structure at a time. Therefore, portability and reusability should be considered.

(3) *Negative pressure systems*. Negative pressure containment systems are used to prevent dust from escaping from an enclosure when pressurized air blasting is used for paint removal. Such systems draw outside air into the enclosure to the surface being treated; the air then exits through a filter system. The resulting continuous air exchange eliminates leaks of paint dust and abrasives to the outside, improves worker visibility, and reduces health hazards and dust accumulation on structural surfaces and equipment. These systems can be cumbersome

and expensive, however, and it is sometimes difficult to maintain a constant negative pressure in the enclosure.

7.3.4.2 Containment and collection

Fully enclosed containment structures have been found to recover 80 to 95 percent of abrasives, paint particles, and dust (Appleman, 1992). The following practices can be used to contain and/or collect pollutants during bridge maintenance activities:

(1) *Cofferdams*. Cofferdams are temporary structures used to displace water and provide dry access to submerged support structures for bridges. Cofferdams can be used during bridge construction and maintenance operations involving painting or repairing of steel structures that are in contact with the water body.

(2) *Barges*. Barges situated below the bridge with tarps or shields attached from the barge to the bridge or work platform can be used for debris capture, although winds often make this practice infeasible.

(3) *Containment booms*. Containment booms can be placed in underlying waters to capture floating debris (e.g., paint chips, fines). Lead particles and abrasives usually sink, but use of booms keeps these materials from spreading downstream while they are suspended in the water column.

(4) *Vacuum sanders*. Vacuum sanders can be used to remove paint from bridges and collect dust and chips. Sanders have been shown to immediately capture 98 percent of the dust generated, which reduces cleanup of containment areas and offers increased safety to maintenance workers (USEPA, 2001).

7.3.5 Nonstructural Runoff Control Practices

The structural management practices for highways and bridge decks described previously are designed to reduce pollutant loadings to the environment by holding and treating the highway runoff generated by precipitation. Nonstructural management practices are designed to achieve source control and can be used to augment on-site structural or other runoff management facilities. Most of the nonstructural practices for managing highway runoff pollution are applicable to virtually all highway situations, even if a specific runoff problem has not been identified.

The following management practices for highway runoff are intended to reduce the volume of particulates available for transport by runoff or to filter and settle out suspended solids. Although the practices described do not represent the complete universe of highway management practices, they are among those commonly implemented across the United States.

7.3.5.1 Implement street sweeping

Curb systems act as traps for particulates and other pollutants. The advantage of well-maintained, traditional curbs is that they trap pollutants on the paved surface, and when combined with regular vacuum street sweeping, they can be effective at removing pollutants prior to mobilization in runoff. However, if they are not properly maintained, pollutants build up and are washed out by storm water.

Street sweeping is a common practice in many communities. Street sweeping programs can be optimized to significantly reduce trash and other pollutants on urban streets. Study results suggest that reductions of up to 80 percent in annual TSS and associated pollutants could be achieved by using bimonthly to weekly sweepings. Sweeping frequency would vary with patterns of precipitation, sediment accumulation, and resuspension. The effectiveness of any street sweeping operation will vary with land use, precipitation, and the accumulation dynamics of contaminated sediments (Sutherland and Jelen, 1997). Table 7.4 shows concentrations of constituents often found in street dirt.

Table 7.4: Street dirt chemical quality (Bannerman et al., 1983; Pitt, 1979; Pitt, 1985; Pitt, 2001).

Constituent	Mass of Constituent in Street Dirt (mg constituent / kg total solids)
Phosphorus	400–1,500
Total Kjeldahl Nitrogen	290–4,300
Chemical Oxygen Demand	65,000–340,000
Copper	110–420
Lead	530–7,500
Zinc	260–1,200
Cadmium	<3–5
Chromium	31–180

Sweeping technology can have a profound effect on sweeping results. Previously, sweepers were unable to pickup very fine sediments that can be highly contaminated. One study found that the effectiveness of conventional street sweeping equipment ranged from a 35 percent removal of large particles to an increase in the loading of small particles by 10 percent. The equipment performed more efficiently on a smooth asphalt street, showing a 12 percent reduction in small particles (Pitt, 2001). Today, new street sweeping technology has proven to be an effective management practice for reducing pollutant loads to waterways. High-efficiency pavement sweepers are thought to be very effective at picking up a large portion of the very fine particulate material that accumulates on street surfaces. A high-efficiency sweeper uses strong vacuums and the mechanical action of brooms, combined with an air filtration system that returns only clean air to the atmosphere. Minton et al. (1998) found that simulated results for high-efficiency sweepers in residential areas reduced annual TSS wash-off by 51 to 87 percent. Other sweepers reduced annual TSS in these same areas by up to 71 percent. When sweeping in major arterials with high pollutant loads, simulated results indicated that annual TSS wash-off was reduced by 49 to 85 percent. Other tested sweepers reduced annual TSS wash-off in major arterials by up to 24 percent (Minton et al., 1998). When a high-efficiency sweeper was tested in a tandem sweep behind a mechanical broom sweeper, it was able to pick up 141 percent more material than the mechanical broom sweeper (Schwarze Industries, 2004). When the high-efficiency sweeper swept directly after a regenerative air sweeper, it was able to pick up 44 percent additional material.

High-efficiency sweepers were also compared to wet detention vaults (see Section 5.3.1.1; Sutherland et al., 1998). Simulated results indicate that high-efficiency sweepers removed 40 to 75 percent of annual TSS, while wet detention vaults removed 75 to 91 percent. All removal efficiency ranges depended on sweeping frequency. These projected water quality benefits of high-efficiency street sweeping are based on modeling.

7.3.5.2 Consider alternatives to curbs

As a design alternative, eliminating curbs from roads and highways allows runoff to be filtered through vegetated shoulders or medians and infiltrate to the ground water. Where curbs are necessary for traffic control or other reasons, curb breaks can be incorporated to disconnect the impervious surface and direct runoff to pervious areas. This may not be feasible for streets with high traffic volume and/or on-street parking demand. The structural integrity of the pavement can be maintained by "hardening" the interface between the swale and the pavement with grass pavers, geo-synthetics, or a low-rising concrete strip along the pavement edge. Maintenance requirements for grass channels are generally comparable to those of curb and gutter systems and involve turf mowing, debris removal, and periodic inspections.

7.3.5.3 Install catch basin inserts

Catch basin inserts can be used to treat pollutants in runoff from curbs and road surfaces before entering the storm drain system. These devices are discussed in detail in Management Measure 5 (section 5.3.5.4).

7.3.5.4 Control litter and debris on roadsides

Roadside litter control practices that have traditionally been implemented to address health and aesthetic concerns can also improve runoff quality by limiting trash in runoff conveyance and treatment systems and receiving water bodies. An effective litter and debris control program should include the following source controls:

- Conducting regular trash and debris removal and disposal;
- Educating the public with signs along roads and at rest areas;
- Enforcing littering and illegal dumping laws;
- Sealing cracks and applying pothole surface treatments that minimize the loosening of aggregate and road base debris by tires; and
- Sponsoring Adopt-A-Highway or Adopt-A-Road programs. Many state highway administrations or departments of transportation sponsor Adopt-A-Highway programs that allow businesses and community groups to conduct litter removal and beautification activities on state-owned roads. The city and county equivalent is called Adopt-A-Road.

7.3.5.5 Manage pesticide and herbicide use

Over-application of pesticides and herbicides may cause excess chemicals to leach to ground waters or flow into surface waters. Herbicides and pesticides have the same toxic effect on aquatic plants and organisms as they do on the terrestrial plants and organisms to which they were applied. Practices such as applying according to label instructions, applying at the proper time, applying only the types and amounts necessary, and considering the environmental conditions and hazards at the site are important ways to prevent pesticides and herbicides from entering water bodies. Pesticides, herbicides, and integrated pest management are discussed at length in Management Measure 9 (section 9.3.2).

7.3.5.6 Reduce fertilizer use

Improper application of fertilizers along roadsides can result in excess nutrients being transported to surface waters or leaching to ground water. Methods to reduce fertilizer use are presented in detail in Management Measure 9 (section 9.3.2).

7.3.5.7 Reduce direct discharges

Direct discharges of highway runoff to receiving waters should be avoided wherever possible. This involves the use of collection/conveyance through closed conduits. Highway runoff should be routed through one or a combination of runoff treatment practices, as described in Management Measure 5, before it is discharged to receiving waters.

7.3.5.8 Practice dewatering

Dewatering is a temporary method used to filter sediment-laden water from excavated areas on construction sites prior to discharge to a storm drain or surface waters. Dewatering pumps are applicable wherever sediment-laden water must be removed from a construction site. Dewatering practices should be considered a last-resort control measure. Adequate erosion and sediment control measures must be considered first.

7.3.5.9 Practice spill prevention and control

Prevention and control of spills eliminates or minimizes the discharge of pollutants to water bodies. Water bodies adjacent to construction sites are at highest risk of contamination from an uncontained spill. Several steps can be taken to reduce the risks: handle hazardous and nonhazardous materials, such as concrete, solvents, asphalt, sealants, and fuels, as infrequently as possible and observe all federal, state, and local regulations when using, handling, or disposing of these materials. Spill control devices such as absorbent snakes and mats should be placed around chemical storage areas, and they can be used in an emergency to contain a spill.

7.3.5.10 Properly handle and dispose of concrete and cement

Concrete and cement-related mortars can be toxic to aquatic life. Proper handling and disposal should minimize or eliminate discharges into watercourses. Fresh concrete and cement mortar should not be mixed on-site, and both dry and wet materials should be stored away from water bodies and storm drains. These materials should be covered and contained to prevent contact with rainfall or runoff. Washout should not be discharged into streets, storm drains, drainage ditches, or watercourses. A washout area should be designated, and wash water should be treated on-site or discharged to the sanitary sewer.

7.3.5.11 Manage contaminated soil and water

Soil, ponded runoff, and ground water can become contaminated if exposed to hazardous materials and should be properly managed to prevent health hazards and minimize or eliminate discharge of pollutants to storm drains and watercourses. Excavation, transport, and disposal of contaminated soil and water, as well as hazardous waste, must be in accordance with the rules and regulations of EPA, the U.S. Department of Transportation, the Department of Toxic Substances Control, and state and local regulatory agencies.

7.3.5.12 Practice environmentally friendly winter road maintenance

Some of the most damaging runoff can be generated from the melting of snow or ice that has been treated with salts or other chemicals. For example, the buildup of salts along roadsides over the course of a winter can damage and reduce the effectiveness of structural controls such as vegetative filter strips and grass-lined channels. Salts in surface or ground waters can adversely affect water quality and damage wetlands. The corrosive effects of salts also damage road infrastructure, especially bridge decks. According to TRB (1991), road salt has caused more premature bridge deck deterioration than any other factor.

Deicing chemicals deposited on road surfaces can contaminate runoff, as can chemicals that are stored in a manner that puts them in contact with precipitation or runoff. Plowed snow piled in parking lots and along roadsides often contains pollutants such as chlorides, sand, and grit, as well as hydrocarbons and heavy metals. These piles should not be deposited into water bodies or stored near water bodies. Treated snow should never be stored on a frozen pond surface because it can cause density stratification, which can prevent reoxygenation in addition to chloride problems.

Three general types of management practices can be employed to reduce the impact of salt damage on the environment. The first is to implement anti-icing operations that help reduce the amount of chemicals required to maintain safe road conditions; the second is to use alternative deicing materials, which are less corrosive and are presumably less damaging to the environment. The third is to properly store salts or other deicing chemicals to prevent runoff contamination.

(1) *Anti-icing operations*. Anti-icing operations are performed before a storm starts. The purpose of these operations is to prevent snow or ice from accumulating on road surfaces. One of the main advantages of successful anti-icing strategies is reducing the amount of chemicals and abrasives used to keep roads clear. Since 1994, 15 states have participated in the FHWA's project to test and evaluate the effectiveness of anti-icing operations. Anti-icing operations typically use the same chemicals used for deicing, but in different forms. For example, test results found that pre-wetting deicing salt and using brine solutions are effective approaches and result in fewer handling problems.

The ultimate success of anti-icing operations depends on the timing of application. Central to this approach is the use of Roadway Weather Information Systems (RWIS), which report road conditions through pavement sensors that monitor pavement temperatures and the amount of anti-icing materials present on the pavement. When this information is combined with meteorological data and fed into a central database, various modeling techniques can be applied to accurately predict the start of ice formation on pavements and the appropriate times to start anti-icing operations. The cost of implementing and maintaining an RWIS must be compared to the cost of labor and materials for deicing and snow removal. For example, the West Virginia Parkway Authority installed four RWIS units along a 95-mile stretch of highway and calculated that the agency was able to save sufficient outlays for materials and labor to pay for the system within a year. In a state with fewer snowstorms, however, the economics of installing an RWIS may be less advantageous.

Another technology option is the installation of infrared sensors on the bottoms of snowplows. These sensors measure the actual temperature of the roadway as the truck passes over it, allowing a more accurate calculation of the amount of salt needed. As part of its “smart salting” program, the Vermont Department of Transportation installed trial sensors on the bottoms of four snowplows. The agency estimates that it was using 20 to 30 percent more salt than needed because of inaccurate temperature readings. The program has currently been expanded statewide, where the average reduction in salt usage is 28 percent, resulting in an approximate savings of $2.2 million (Lehner et al., 1999).

(2) *Alternative deicers*. Over the years, the FHWA and numerous states have experimented with alternative deicing chemicals, including liquid calcium magnesium acetate (CMA), liquid calcium chloride, liquid magnesium chloride, and liquid potassium acetate. Research has found that these chemicals have both advantages and disadvantages compared to salt (see Table 7.5). Calcium chloride works better at lower temperatures but is also corrosive. CMA appears to be much less harmful to the environment. Its disadvantage is that it is significantly more expensive than salt; the NRC estimated that CMA can cost 20 times more than salt and would increase the total cost of chemical application five-fold (Chollar, 1996). CMA is also less successful than other salts at lower temperatures and is slower to act than salt.

Table 7.5: Advantages and disadvantages of road salt and alternative deicing chemicals.

Type	Advantages	Disadvantages
Road salt	– Low cost ($30-40/ton) – Readily available	– Impact on the environment – Corrosiveness
Alternative deicing chemicals	– Reduced corrosivity – Reduced impact on the environment – $CaCl_2$ can be used in very low temperatures (-20ºF)	– Higher cost (from several hundred dollars per ton to several thousand per ton) – CMA starts to act at a slower rate than salt

In general, alternatives to road salt are still being researched and tested throughout the Midwest and Northeast, but overall costs tend to be higher for these products. Less environmentally damaging products such as CMA, however, can be used selectively to protect sensitive areas like wetlands without dramatically increasing overall cost to the highway authority.

(3) *Proper storage of deicing chemicals.* Placing deicing chemicals in storage buildings minimizes the likelihood of polluting surface and ground waters with contaminated runoff and eliminates the economic loss from chemicals that are dissolved and washed away by precipitation. A permanent under-roof storage facility is the best way to protect chemicals from precipitation and runoff, but where this is not possible, salt piles and chemical containers should be stored on impermeable bituminous pads and covered with a tarp or other waterproof cover.

7.4 Information Resources

The U.S. Geological Survey (USGS) and the Federal Highway Administration (FHWA) developed an online searchable bibliography of more than 2,600 pertinent references to be published in the catalog of available information that is being collected to characterize pollutant loadings and impacts attributable to highway storm water runoff. The catalog includes reports on highway-runoff water quality, urban/storm water issues, atmospheric deposition, and highway/urban runoff management practices from the USGS, FHWA, EPA, and state transportation agencies. The database can be accessed at http://ma.water.usgs.gov/fhwa/biblio/default.htm.

The Local Technical Assistance Program Web site hosts a "Rural Roads Resources" page that includes a compendium of Web sites, manuals, videos, and other media pertaining to road design and maintenance. The site also hosts an email listserver pertaining to rural roads issues. The Local Technical Assistance Program Resources can be accessed at http://www.ltapt2.org/ by clicking "Resources."

The California Regional Water Quality Control Board produced *the Erosion and Sediment Control Field Manual* for the San Francisco Region in 1998. The document is available for a fee using an order form found at http://www.swrcb.ca.gov/stormwtr/orderform.html.

The FHWA published a study by Dorman et al. (1996) called *Detention and Overland Flow for Pollutant Removal from Highway Stormwater Runoff*, which provides guidelines for the design of management measures for the removal of pollutants from highway storm water runoff. The guidelines are based on the results of field and laboratory studies to verify design procedures and assumptions and the review of other studies. For a copy of this document, contact FHWA's Office of the Natural Environment by sending an email to environment@fhwa.dot.gov.

Fisheries and Oceans Canada published *Protecting Fish and Fish Habitat: Bridge Construction and Demolition*, a fact sheet that details the hazards to aquatic life of bridge construction and demolition and recommends practices to reduce environmental damage. This document is available at http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/guidelines-conseils/factsheets-feuillets/nfld/fact18_e.asp.

In 1992, Northern Virginia Planning District Commission and Engineers Surveyors Institute produced the *Northern Virginia BMP Handbook: A Guide to Planning and Designing Best Management Practices in Northern Virginia*. This handbook is available for download at http://www.novaregion.org/pdf/NVBMP-Handbook.pdf.

The Staff Transportation Board of the National Research Council produced a primer for a study entitled *Environmental Impact of Construction and Repair Materials on Surface and Ground Waters*. It is written in nontechnical language and explains how the test methods and supporting computer software can provide answers to questions about the environmental impact of new construction or the repair or rehabilitation of existing highways (NCHRP, 2000). Published reports from NCHRP are available from http://www.trb.org.

The Transportation Research Board (TRB) published several studies that investigate the environmental impacts of activities related to transportation infrastructure. These publications are available at http://www4.trb.org/trb/onlinepubs.nsf. For example, the National Cooperative Highway Research Program developed a synthesis of information on environmental management practices for highway and street maintenance. This report, entitled *Best Management Practices for Environmental Issues Related to Highway and Street Maintenance*, is available in hard copy from the Transportation Research Board's bookstore (http://trb.org/bookstore/) for $30. Other titles include *Highway Deicing: Comparing Salt and Calcium Magnesium Acetate* (available electronically at http://trb.org/publications/sr/sr235.html or for $22 from the online bookstore); *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 1:Final Report*, available electronically at http://gulliver.trb.org/publications/nchrp/nchrp_rpt_474v1.pdf, and *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 2: Practitioner's Handbook*, available at http://gulliver.trb.org/publications/nchrp/nchrp_rpt_474v2.pdf. Publications pending as of spring 2005 include *Guidelines for the Selection of Snow and Ice Control Materials To Mitigate Environmental Impacts* (NCHRP Project 6-16) and *Winter Highway Operations* (NCHRP topic 34-10), which reports on advances and new practices since TRB's last guide for snow and ice control. Both publications will be available at http://www.trb.org.

The TRB's *Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* (NCHRP 25-25(04)) includes numerous management practices in highway construction and maintenance. The guidance was developed from the literature, state transportation agency manuals and procedures, and the contributions of state departments of transportation and practitioners. The document serves as a guide to the development of environmental management systems and environmental strategic plans, both at the organizational level and in specific functional areas such as road construction, vegetation management, materials recycling, winter road maintenance, and many other topics. The document can be downloaded in PDF format from http://www4.trb.org/trb/crp.nsf/reference/boilerplate/Attachments/$file/25-25(4)_FR.pdf.

TRB's *Evaluation of Best Management Practices and Low Impact Development for Highway Runoff Control*, expected to be published in late 2004, includes a users' guide for management practice selection, a design manual, and monitoring guidelines to evaluate and optimize the control of runoff from highways. Visit http://www.trb.org, and enter "NCHRP 25-20" into the search field to access the report.

The Natural Resources Conservation Service (1992) published *Soil Bioengineering for Upland Slope Protection and Erosion Reduction,* which provides specifications for installing bioengineering practices to reinforce slopes and prevent erosion. This document is available for download at http://www.info.usda.gov/CED/ftp/CED/EFH-Ch18.pdf.

The U.S. Department of Transportation's (1995) *Best Management Practices for Erosion and Sediment Control* can be downloaded from the DOT's online publications site at http://isddc.dot.gov/.

The FHWA (1996) published the *Manual of Practice for an Effective Anti-Icing Program: A Guide For Highway Winter Maintenance Personnel*, which can guide maintenance personnel in developing a systematic and efficient practice for maintaining roads in the best condition possible during a winter storm. It describes the factors that should be understood and addressed in an anti-icing program, with the recognition that development of a program must be based on the specific needs of the site or region. It focuses on weather information and materials and methods that will best address site conditions such as level of service, highway agency resources, climatological conditions, and traffic. The manual can be downloaded in HTML format from http://www.fhwa.dot.gov/reports/mopeap/mop0296a.htm.

The Michigan Department of Transportation (1993) conducted a detailed study on the environmental effects and costs of using several deicing products, including salt, calcium magnesium acetate, an agricultural byproduct, a magnesium chloride product, calcium chloride, a type of concrete pavement, and sand. The study can be accessed at http://www.michigan.gov/documents/toc-deice_51451_7.pdf. More information on alternative deicers can be found at http://www.betterroads.com/articles/prod801.htm, http://www.forester.net/sw_0106_deicing.html, and http://www.wsdot.wa.gov/partners/pns/htm/resources.htm.

The Pacific Northwest Snowfighters Association Web site (http://www.wsdot.wa.gov/partners/pns/) provides resources pertaining to deicing and anti-icing products and practices, such as a list of approved products, deicing specifications, a fact sheet on magnesium chloride, and testing methods and protocols for deicing products (Washington State Department of Transportation, 2002).

Funded by EPA, the Composting Council Research and Education Foundation (CCREF), in conjunction with the United States Composting Council (USCC), developed *Compost Use on State Highway Applications* to promote compost use on state and local roadside applications. Its goal is to provide individuals and organizations—namely, roads and highways staff, policy makers, product specifiers, project designers and engineers, environmental officers, landscapers, and other interested parties—involved in the maintenance and management of roadsides and highways, with the tools necessary to use composted products to meet their specific project requirements. The document is available for download in PDF format at http://www.epa.gov/epaoswer/non-hw/compost/highway/.

7.5 References

Appleman, B.R. 1992. *NCHRP Synthesis of Highway Practice 176: Bridge Paint: Removal, Containment and Disposal.* Transportation Research Board, National Research Council, Washington, DC.

Bannerman, R., K. Baun, M. Bohn, P.E. Hughes, and D.A. Graczyk. 1983. *Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin,* Volume I. PB 84-114164. U.S. Environmental Protection Agency, Water Planning Division.

Chollar, B. 1996. *A Revolution in Winter Maintenance*. U.S. Department of Transportation, Federal Highway Administration, McLean, VA.

Crisitina, C. J. Tramonte, and J.J. Sansalone. 2000. *A Granulometry-Based Selection Methodology for Separation of Traffic-Generated Particles in Highway Snowmelt Runoff*. Louisiana State University, Department of Civil and Environmental Engineering, Baton Rouge, LA.

Dalton, Dalton and Newport/URS. 1985. *Investigations of Impacts of Selected Highway Maintenance Practices on Water Quality.* Report No. FHWA/RD-85/058.

Delaware County Departments of Planning and Public Works. 2003. *Stormwater Management: Delaware County Action Plan.* Version 1.

Dorman, M.E., J. Hartigan, R.F. Steg, and T. Quasebarth. 1996. *Retention, Detention and Overland Flow for Pollutant Removal From Highway Stormwater Runoff*. Vol. 1 Research Report. FHWA/RD 89/202. Federal Highway Administration, Washington, DC.

Federal Highway Administration. 1996. *Manual of Practice for an Effective Anti-Icing Program: A Guide For Highway Winter Maintenance Personnel.* Publication No. FHWA-RD-95-202.

Hayward, J.M.R., C.G. Ingersoll, D.W. Whites, and E.E. Little. 2002. *Toxicity Assessment of Sediments from the Barton Springs Watershed, Austin, Texas, USA*. Draft. U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO.

Kayhanian. M., J. Johnston, H. Yamaguchi and S. Borroum. 2001. CALTRANS Storm Water Management Program. *Stormwater* 2(2): 52-67.

Lehner, P., G. P. Aponte Clark, D.M.Cameron and A.G. Frank. 1999. *Stormwater Strategies: Community Responses to Runoff Pollution*. Natural Resources Defense Council. http://www.nrdc.org/water/pollution/storm/stoinx.asp. Accessed August 12, 2003.

Mahler, B.J., and P.C. Van Metre. 2004. *Parking Lot Sealants: An Unrecognized Source of Particulate PAH in Urban Runoff*. Paper No. 65-8 from the Geological Society of America Annual Meeting, November 7–10, 2004, Denver, CO.

Michigan Department of Transportation. 1993. *The Use of Selected Deicing Materials on Michigan Roads: Environmental and Economic Impacts.* Prepared by Public Sector Consultants, Inc. Lansing, MI, for the Michigan Department of Transportation, Lansing, MI.

Minton, G.R., B. Lief, and R Sutherland. 1998. High efficiency sweeping or "clean a street, save a salmon!" http://www.schwarze.com/sweepers/ev/mintonvol4No4.html. Accessed August 8, 2001.

National Cooperative Highway Research Program (NCHRP). 1999. Assessment of Impacts of Bridge Deck Runoff Contaminants on Receiving Waters. *Research Results Digest.* Number 235. National Research Council, Transportation Research Board, National Cooperative Highway Research Program, Washington, DC.

National Cooperative Highway Research Program (NCHRP). 2000. *NCHRP Report 443: Primer: Environmental Impact of Construction and Repair Materials on Surface and Ground Waters*. National Cooperative Highway Research Program, National Research Council, Washington, DC.

Newberry, G.P., and D.R.Yonge. 1996. *The Retardation of Heavy Metals in Stormwater Runoff by Highway Grass Strips*. Report no. WA-RD-404.1. Prepared for Washington State Department of Transportation, Olympia, WA.

Ohio Department of Transportation (ODOT). No date. *Ohio Department of Transportation On-Line Bridge Maintenance Manual: Preventative Maintenance/Repair Guidelines for Bridges and Culverts.* http://www.dot.state.oh.us/preventivemaintenance/. Accessed July 21, 2004.

Pitt, R. 1979. *Demonstration of Nonpoint Pollution Abatement through Improved Street Cleaning Practices.* EPA-600-2-79-161. U.S. Environmental Protection Agency, Cincinnati, OH.

Pitt, R. 1985. *Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning.* EPA-600-S2-85-038. U.S. Environmental Protection Agency, Storm and Combined Sewer Program, Risk Reduction Engineering Laboratory. Cincinnati, OH.

Pitt, R. 2001. Stormwater Management for Highway Projects. *Symposium on the Pollution of Water Sources from Road Run-off.* March 19, Tel Aviv University, Israel.

Reel, M. 2004, February 11. Tumors prevalent in Anacostia's fish. *The Washington Post*, p. B1.

Sansalone, J.J., and D.W. Glenn III. 2000. Temporal Variations in Heavy Metal Partitioning and Loading in Urban Highway Pavement Sheet Flow: Implications for In Situ Treatment Design. *Transportation Research Record* 1720 (00-0354):100–111.

Sansalone, J.J., and D.W. Glenn III. 2002a. Accretion of Pollutants in Roadway Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities—Part I. *Journal of Environmental Engineering* 128(2).

Sansalone, J.J., and D.W. Glenn III. 2002b. Accretion and Partitioning of Heavy Metals Associated with Urban Snow—Part II. *Journal of Environmental Engineering* 128(2).

Sansalone, J.J., and D.W. Glenn III. Unpublished. Physical and Chemical Characteristics of Urban Roadway Snow Residuals Generated from Traffic Activities—Part III.

Sansalone, J.J., and S.G. Buchberger. 1997. Partitioning and First Flush of Metals in Urban Roadway Storm Water. *Journal of Environmental Engineering* 123(2):134–143.

Sansalone, J.J., and T. Tribouillard. 1999. Variation in Characteristics of Abraded Roadway Particles as a Function of Particle Size: Implications for Water Quality and Drainage. *Transportation Research Record* 1690(99-0552):153–163.

Sansalone, J.J., J.M. Koran, J.A. Smithson, and S.G. Buchberger. 1998. Physical Characteristics of Urban Roadway Solids Transported During Rain Events. *Journal of Environmental Engineering* May:427–440.

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

Schwarze Industries. 2004. Virginia test further documents pickup of high efficiency sweepers. *American Sweeper* 8(1).

Shepp, D.L. 1996. Petroleum Hydrocarbon Concentrations Observed in Runoff From Discrete, Urbanized Automotive-Intensive Land Uses. In *Proceedings of Watershed 96: Moving Ahead Together*, Baltimore, MD, June 8–12, 1996.

Sutherland, R.C., and S.L. Jelen. 1997. Contrary to conventional wisdom, street sweeping can be an effective BMP. In *Advances in Modeling the Management of Stormwater Impacts*, ed. W. James, pp. 179–190. Computational Hydraulics International, Guelph, ON.

Sutherland, R.C., S.L. Jelen, and G. Minton. 1998. High efficiency sweeping as an alternative to the use of wet vaults for stormwater treatment. In *Advances in Modeling the Management of Stormwater Impacts*, ed. W. James, pp. 351–372. Computational Hydraulics International, Guelph, ON.

Transportation Research Board. 1991. *Highway Deicing: Comparing Salt and Calcium Magnesium Acetate*. Special Report 235. National Research Council, Transportation Research Board, Washington, DC.

Transportation Research Board. 2002a. *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 1:Final Report*. http://gulliver.trb.org/publications/nchrp/nchrp_rpt_474v1.pdf. Accessed June 30, 2003.

Transportation Research Board. 2002b. *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 2: Practitioner's Handbook*. http://gulliver.trb.org/publications/nchrp/nchrp_rpt_474v2.pdf. Accessed June 30, 2003.

U.S. Department of Agriculture (USDA). 1992. Soil Bioengineering for Upland Slope Protection and Erosion Reduction. Part 650, Chapter 18 in *National Engineering Field Handbook*. Natural Resources Conservation Service, U.S. Department of Agriculture, Washington, DC.

U.S. Department of Transportation (USDOT). 1996. *Evaluation and Management of Highway Runoff Water Quality*. Publication No. FHWA-PD-96-032. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating*. EPA 841-B-01-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Van Metre, P.C., B.J. Mahler, and E.T. Furlong. 2000. Urban Sprawl Leaves Its PAH Signature. *Environmental Science and Technology* 34:4064–4070.

Washington State Department of Transportation. 2002. Pacific Northwest Snowfighters. http://www.wsdot.wa.gov/partners/pns/. Last updated June 18, 2002. Accessed June 28, 2002.

Young, G.K., Stein, S., Cole, P., Kammer, T., Graziano, F., and Bank, F. 1996. *Evaluation and Management of Highway Runoff Water Quality*. Publication No. FHWA-PD-96-032.

MANAGEMENT MEASURE 8 CONSTRUCTION SITE EROSION, SEDIMENT, AND CHEMICAL CONTROL

8.1 Management Measure

Plan, design, and operate construction site land disturbance activities such that:

- An approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions is prepared and implemented prior to land disturbance.
- Erosion is reduced and, to the extent practicable, sediment is retained on-site during and after construction.
- Good housekeeping practices are used to prevent off-site transport of waste material and chemicals.
- The application and generation of pollutants, including chemicals are minimized.

8.2 Management Measure Description and Selection

8.2.1 Description

This management measure is intended to reduce the amount of sediment generated from construction sites (erosion control) and reduce the off-site transport of sediment and construction-related chemicals (sediment and chemical control). This measure is intended to work in concert with the Watershed Protection, New Development Runoff Treatment, and Site Development Management Measures in a comprehensive watershed management program framework.

Several pollutants of concern are associated with construction activities, including the following: sediment; pesticides; fertilizers used for vegetative stabilization; petrochemicals (oils, gasoline, and asphalt degreasers); construction chemicals such as concrete products, sealers, and paints; wash water associated with these products; paper; wood; garbage; and sanitary waste (Washington State Department of Ecology, 1991).

The variety of pollutants present at a site and the severity of their effects are dependent on a number of factors:

- *The nature of the construction activity*. During the clearing and grading stage, sediment is likely to be the primary pollutant of concern since few other materials are present, whereas during the building phase, concrete wash, paints, varnishes, stucco, and other materials are being used on a daily basis, increasing the likelihood of spills.

- *The physical characteristics of the construction site*. Most pollutants generated at construction sites are carried to surface waters by runoff. Therefore, the factors that affect runoff volume, such as the amount, intensity, and frequency of rainfall; soil infiltration rates; surface roughness; slope length and steepness; and size of the denuded area, also affect pollutant loadings.

- *The proximity of surface waters to the nonpoint pollutant source*. As the distance separating pollutant-generating activities from surface waters decreases, the likelihood of water quality impacts increases.

The following section is an expanded discussion of the pollutants of concern that can be generated by and released from construction activities.

8.2.1.1 Sediment

Runoff from construction sites is by far the largest source of sediment in urban areas under development. Soil erosion removes more than 90 percent of sediment by weight in urbanizing areas where most construction activities occur (Canning, 1988). Table 8.1 illustrates some of the sediment loading rates associated with construction activities across the United States. As shown in Table 8.1, erosion rates from natural areas such as undisturbed forested lands are typically less than 1 ton/acre/year, whereas erosion from construction sites ranges from 7.2 to 500 tons/acre/year.

Loss of sediment can cause impacts both on and off the construction site. On-site loss of soil reduces or eliminates the remaining soil's ability to provide nutrients, regulate water flow, and protect plants. Losses of nutrients and nutrient-holding capacity result in a less-fertile environment for lawns and plants. Lost organic matter also results in increased soil density and compaction, which can reduce the available water-holding capacity on-site. These reductions result in poorer plant growth and reduced infiltration of fertilizers and pesticides, which can contribute to the transport of these chemicals by runoff into nearby lakes and streams. Finally, organic matter is a food source and habitat for beneficial microorganisms and invertebrates. If organic matter is lost due to erosion, the soil's natural ability to combat outbreaks of pests and diseases is reduced (SQI, 2000).

Eroded sediment from construction sites causes many problems in coastal areas, including adverse impacts on water quality, critical habitats, submerged aquatic vegetation beds, recreational activities, and navigation (APWA, 1991). Water quality impacts include unwanted biological growth caused by excess nitrogen and phosphorus, and increased turbidity. Eroded sediment can also build up in stream channels and lower flow capacity, resulting in more frequent flooding in areas that never flooded or rarely flooded in the past. Reducing the incidence of flooding can also be beneficial in alleviating the financial burden of cleaning up sediment-damaged areas (SQI, 2000). Excessive erosion and sedimentation also can reduce the capacity of reservoirs.

Table 8.1: Erosion and sediment associated with construction (USEPA, 1993).

Location	Problem	Reference
Franklin County, Florida	Sediment yield (ton/ac/yr): Forest < 0.5 Rangeland < 0.5 Tilled 1.4 Construction site 30 Established urban < 0.5	Franklin County, Florida, 1987
Wisconsin	Erosion rates range from 30 to 200 ton/ac/yr (10 to 20 times those of cropland).	Wisconsin Legislative Council, 1991
Washington, DC	Erosion rates range from 35 to 45 ton/ac/yr (10 to 100 times greater than agriculture and stabilized urban land uses).	MWCOG, 1987
Anacostia River Basin, Maryland and Washington, DC	Sediment yields from portions of the Anacostia Basin have been estimated at 75,000 to 132,000 ton/yr. Total basin acreage = 112,640 acres.	U.S. Army Corps of Engineers, 1990
Anacostia River Basin, Maryland and Washington, DC	Erosion rates range from 7.2 to 100.8 ton/ac/yr. Total basin acreage = 112,640 acres.	USGS, 1978
Washington	Erosion rates range from 50 to 500 ton/ac/yr. Natural erosion rates from forests or well-sodded prairies are 0.01 to 1.0 ton/ac/yr.	Washington State Department of Ecology, 1989
Alabama North Carolina Louisiana Oklahoma Georgia Texas Tennessee Pennsylvania Ohio Kentucky	1.4 million tons eroded per year. 6.7 million tons eroded per year. 5.1 million tons eroded per year. 4.2 million tons eroded per year. 3.8 million tons eroded per year. 3.5 million tons eroded per year. 3.3 million tons eroded per year. 3.1 million tons eroded per year. 3.0 million tons eroded per year. 3.0 million tons eroded per year.	Woodward Clyde, 1991

8.2.1.2 Pesticides

Insecticides, rodenticides, and herbicides are used on construction sites to improve human health conditions, reduce maintenance and fire hazards, and curb the growth of weeds and woody plants. Common pesticides employed include synthetic, relatively water-insoluble chlorinated hydrocarbons, organophosphates, carbamates, and pyrethrins. Over-application of pesticides on

Soil Erosion from Two Small Construction Sites in Dane County, Wisconsin

Most construction regulations require sites with more than 5 acres disturbed to have some type of erosion control plan. Sites that are less than 5 acres typically require minimal erosion control measures. To evaluate the significance of erosion on sites less than 5 acres as a source of sediment to surface waters, two small construction sites (less than 5 acres each) in Dane County, Wisconsin, were studied (USGS, 2000).

Results indicate that small construction sites are potential sources of high amounts of erosion and that sediment loads from the active construction phase are significantly higher than those during the preconstruction and postconstruction periods. These sediment loads were dramatically reduced when mulching and seeding were used to control erosion. The results of this study support the need for erosion control plans for small construction sites.

revegetated areas can lead to contamination of soils and subsequent contamination of surface water and ground water. The use of pesticides is controlled by federal or state regulations, such as the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1996.

8.2.1.3 Petroleum products

Petroleum products used during construction include fuels and lubricants for vehicles, power tools, and general equipment maintenance. Specific petroleum pollutants include gasoline, diesel oil, kerosene, lubricating oils, and grease. Asphalt paving can be particularly harmful because it releases various oils after application until fully cured (NCHRP, 2000).

8.2.1.4 Fertilizers

Fertilizers are used on construction sites when revegetating graded or disturbed areas. Fertilizers contain nitrogen and phosphorus, which in large doses can adversely affect surface water quality, causing eutrophication.

8.2.1.5 Solid wastes

Trees and shrubs removed during land clearing contribute to the load of solid wastes generated during construction activities. Other common wastes are wood and paper from packaging and building materials, scrap metals, sanitary wastes, rubber, plastic and glass, and masonry and asphalt products. Improper disposal of food containers, paint canisters, cigarette packages, leftover food, and aluminum foil also contributes solid wastes to the construction site.

8.2.1.6 Construction chemicals

There are many sources of chemicals at construction sites. For example, chemicals such as paints, acids for cleaning masonry surfaces, cleaning solvents, asphalt products, soil additives used for stabilization, and concrete-curing compounds are used on construction sites and can be carried off in runoff. Other pollutants, such as wash water from concrete mixers, acid and alkaline solutions from exposed soil or rock, and alkaline-forming natural elements, can also be present and contribute to nonpoint source pollution. Improperly stored construction materials, such as creosote- or pressure-treated lumber or solvents, can lead to leaching of pollutants to surface water and ground water. People disposing of construction chemicals should follow all applicable state and local laws. Some chemicals may need to be disposed of by a licensed waste management firm.

Improper fueling and servicing of vehicles can lead to dumping of significant quantities of petroleum products onto the ground. These pollutants can then be washed off the site in urban runoff, even when proper erosion and sediment controls are in place. Pollutants carried in solution in runoff or attached to sediments may not be adequately controlled by erosion and sediment control practices (Washington Department of Ecology, 1991). Oils, waxes, and water-insoluble pesticides can form surface films on water and solid particles. Oil films can also concentrate water-soluble insecticides. Once present in runoff, these pollutants can be nearly impossible to control other than by the use of very costly water treatment facilities (Washington Department of Ecology, 1991).

In addition to spill prevention, one of the best methods to control petroleum pollutants is to retain the sediments that have come into contact with these chemicals through use of erosion and sediment control practices. Improved maintenance and storage facilities reduce the chance of contaminating a construction site. One of the greatest concerns related to the use of petroleum products is the method for waste disposal. Dumping petroleum product wastes into sewers and other drainage channels is illegal and could result in fines or site closure.

8.2.1.7 Contaminated soils

Contaminated soils can be encountered during excavation activities that uncover previously known or unknown site contamination. New contamination also can result from a spill or leak of a hazardous material used at the construction site (e.g., a release from a material or waste storage area). If previously unknown contamination is encountered, its nature should be determined. Sampling and analysis will be required to determine what types of contaminants are present and, therefore, how the contaminated soil needs to be handled.

8.2.2 Management Measure Selection

This management measure was selected to reduce sediment mobilization and transport off of the construction site area. This management measure was selected because construction activities have the potential to increased loadings of toxic substances and nutrients in water bodies. Various states and local governments regulate the control of sediment and chemicals on construction sites through spill prevention plans, erosion and sediment control plans, or other administrative devices. The practices provided herein are commonly used and well-described in handbooks and guidance manuals, and they have been shown to be both economical and effective.

The measures were selected for the following reasons:

- Setting numeric load reduction goals for construction site pollutant loadings is generally not practical; sediment and other pollutant loadings from exposed areas vary greatly, and some sediment loss is usually inevitable.
- Erosion and sediment control plans (ESCs) and specifications are required by many state and local governments to accomplish the performance goals for this measure. These ESC plans contain specifications and designs for the proper selection and placement of ESC practices. These practices have been proven to be effective when implemented at construction sites.
- Current procedure typically relies on a set of practices selected based on site-specific conditions.
- The combined effectiveness of erosion and sediment controls in systems is not easily quantified.
- An ESC plan is necessary to provide details regarding the selection, use, inspection, and maintenance of management practices to ensure they are effective in controlling erosion and preventing off-site discharges of sediment.

Eugene, Oregon's goals for erosion and sediment control on construction sites

The City of Eugene, Oregon, requires that, to the maximum extent feasible, management practices that meet a specified set of outcomes be employed at construction sites, including the following (NRDC, 1999):

- No deposit or discharge of sediment onto adjacent properties or into waterbodies.
- No degradation of waterbodies due to the removal of vegetation.
- No discharge or runoff containing construction-related contaminants into the city's runoff conveyance system or related natural resources.
- No deposit of construction-related material exceeding 0.5 cubic foot for every 1,000 square feet of lot size onto public rights-of-way and private streets and into the city's runoff conveyance system and related natural resources.

8.3 Management Practices

8.3.1 Erosion and Sediment Control Programs

8.3.1.1 Prepare erosion and sediment control plans

In many municipalities, erosion and sediment control plans are required under ordinances enacted to protect water resources (Table 8.2). These plans describe how a contractor or developer will reduce soil erosion and contain and treat runoff that is carrying eroded sediments. Plans typically include descriptions and locations of soil stabilization practices, perimeter controls, and runoff treatment facilities that will be installed and maintained before and during construction activities. In addition to special area considerations, the full ESC plan review inventory should include:

- Topographic and vicinity maps
- Site development plan
- Construction schedule
- Erosion and sedimentation control plan drawings
- Detailed drawings and specifications for practices
- Design calculations
- Vegetation plan

Table 8.2: ESC plan requirement for selected states (Adapted from USEPA, 1993; Environmental Law Institute, 1998).

State	General Requirements for ESC Plan
Delaware	ESC plans required for sites over 5,000 ft^2. Temporary or permanent stabilization must occur with 14 days of disturbance.
Florida	ESC plans required on all sites that need a runoff management permit.
Georgia	ESC plan required for all land-disturbing activities.
Indiana	ESC plan required for sites over 5 acres.
Maine	ESC plans required for sites adjacent to a wetland or water body. Stabilization must occur at completion or if no construction activity is to occur for seven days. If temporary stabilization is used, permanent stabilization must be implemented within 30 days.
Maryland	ESC plans required for sites over 5,000 ft^2 or 100 yd^3.
Michigan	ESC plans required for sites over 1 acre or within 500 ft of a water body. Permanent stabilization must occur within 15 days of final grading. Temporary stabilization is required within 30 days if construction ceases.
Minnesota	ESC plans required for land development over 1 acre.
New Jersey	ESC plans required for sites over 5,000 ft^2.
North Carolina	ESC plans required for sites over 1 acre. Controls must retain sediment on-site. Stabilization must occur within 30 days of completion of any phase of development.
Ohio	ESC plans required for sites over 5 acres. Permanent stabilization must occur within seven days of final grading or when there is no construction activity for 45 days.
Oklahoma	ESC plans required for sites over 5 acres.
Pennsylvania	All earth disturbance activities require implementation and maintenance of ESC practices to minimize the potential for accelerated erosion and sedimentation. Written ESC plans are required for all earth disturbance activities 5,000 square feet or greater. Upon completion of an earth disturbance activity or any stage or phase of an activity, the site shall be immediately seeded, mulched, or otherwise protected from accelerated erosion and sedimentation.
South Carolina	ESC plans required for all sites unless specifically exempted. Perimeter controls must be installed. Temporary or permanent stabilization is required for topsoil stockpiles and all other areas within seven days of disturbance.
Virginia	For areas within the jurisdiction of the Chesapeake Bay Preservation Act, no more land is to be disturbed than necessary for the project. Indigenous vegetation must be preserved to the greatest extent possible.
Washington	ESC provisions are incorporated into the state runoff management plan.
Wisconsin	ESC plans required for all sites over 4,000 ft^3. Temporary or permanent stabilization is required within seven days.

Brown and Caraco (1997) identified several general objectives that should be addressed in an effective ESC plan:

- *Minimize clearing and grading*. Clearing and grading should occur only where absolutely necessary to build and provide access to structures and infrastructure. This approach reduces earth-working and ESC control costs by as much as $5,000 per acre (Schueler, 1995). Clearing should be done immediately before construction, rather than leaving soils exposed for months or years (SQI, 2000).

- *Protect waterways and stabilize drainageways*. All natural waterways within a development site should be clearly identified before construction activities begin. Clearing should generally be prohibited in or adjacent to waterways. Sediment control practices such as check dams may be needed to stabilize drainageways and retain sediment on-site.

- *Phase construction to limit soil exposure*. Construction phasing is a process by which only a portion of the site is disturbed at any one time to complete the needed building in that phase. Other portions of the site are not cleared and graded until exposed soils from the earlier phase have been stabilized and the construction is nearly completed.

- *Stabilize exposed soils immediately*. Seeding or other stabilization practices should occur as soon as possible after grading. In colder climates, a mulch cover is needed to stabilize the soil during the winter months when grass does not grow or grows poorly.

- *Protect steep slopes and cuts*. Wherever possible, clearing and grading of existing steep slopes should be completely avoided. If clearing cannot be avoided, practices should be implemented to prevent runoff from flowing down slopes.

- *Install perimeter controls to filter sediments*. Perimeter controls are used to retain sediment-laden runoff or filter it before it exits the site. The two most common perimeter control options are silt fences and earthen dikes or diversions.

- *Employ advanced sediment-settling controls*. Traditional sediment basins are limited in their ability to trap sediments because fine-grained particles tend to remain suspended and the design of the basins themselves is often simplistic. Sediment basins can be designed to improve trapping efficiency through the use of perforated risers; better internal geometry; the installation of baffles, skimmers, and other outlet devices; gentler side slopes; and multiple-cell construction (see section 3.3: Sediment Control Practices).

ESC plans ensure that provisions for control measures are incorporated into the site planning stage of development. They also help to reduce the incidence of erosion and sediment problems, and improve accountability if a problem occurs. An effective plan for runoff management on construction sites controls erosion, retains sediments on-site to the extent practicable, and reduces the adverse effects of runoff. Climate, topography, soils, drainage patterns, and vegetation affect how erosion and sediment should be controlled on a site (Washington State Department of Ecology, 1989).

An effective ESC plan includes both structural and nonstructural controls. Nonstructural controls address erosion control by decreasing erosion potential, whereas structural controls are both preventive and mitigative because they control erosion and sediment movement. Typical nonstructural erosion controls include:

- Plans and designs to minimize disruption of the natural features (drainage, topography, vegetative cover);
- Phased grading to minimize the area of bare soil exposed at any given time;
- Scheduling of activities during the time of year with the least erosion potential; and
- Stabilization, e.g., mulching and seeding of exposed areas.

Structural controls include:

- Perimeter controls;
- Sediment basins and traps;
- Silt fences or filter fabrics;

- Stream crossing areas for natural and man-made areas; and
- Stabilization of cut-and-fill slopes caused by construction activities.

Some erosion and soil loss is unavoidable during land-disturbing activities. Although proper siting and design help prevent development of areas prone to erosion, construction activities invariably result in conditions where erosion can occur. To reduce the adverse impacts associated with construction, the construction management measure was written to promote the use of a system of nonstructural and structural erosion and sediment controls for incorporation into an ESC plan. Erosion controls reduce the amount of sediment transported off-site, thereby reducing the need for sediment controls and lowering overall costs. When erosion controls are used in conjunction with sediment controls, the size of the sediment control structures and associated maintenance may be reduced, decreasing overall treatment costs (SWRPC, 1991).

8.3.1.2 Provide education and training opportunities for construction personnel

One of the most important factors determining whether erosion and sediment controls will be properly installed and maintained on a construction site is the knowledge and experience of the contractor. Many communities require certification for key on-site employees who are responsible for implementing the ESC plan. Certification can be accomplished through municipally sponsored training courses. Municipalities also can hold mandatory preconstruction or pre-wintering meetings and conduct regular and final inspection visits to transfer information to contractors (Brown and Caraco, 1997). Information that should be covered in training courses and meetings includes the importance of ESC practices for water quality protection; developing

Contractor/Developer Certification Programs in Delaware and Maine

Delaware requires that at least one person on any construction project be formally certified. The Delaware program requires certification for any foreman or superintendent who is in charge of on-site clearing and land-disturbing activities for sediment and runoff control associated with a construction project. Responsible personnel are required to obtain certification by completing a Department of Natural Resources and Environmental Control-sponsored or approved training program. All applicants seeking approval of a sediment and runoff plan must certify that all personnel involved in the construction project will have a certificate of attendance at a Department-sponsored or approved training course before initiation of any land-disturbing activity (Delaware DNREC, no date). A description of this certification requirement is provided at the DNREC Web site at *www.dnrec.state.de.us/newpages/ssregs14.htm*.

The Maine Department of Environmental Protection offers the Voluntary Contractor Certification Program (VCCP), which is a nonregulatory, incentive-driven program to broaden the use of effective erosion control techniques. The VCCP is open to any contractor who is involved with soil disturbance activities, including filling, excavating, landscaping, and other types of earthworks. For initial certification, the program requires attendance at two 6-hour training courses and the successful completion of a construction site evaluation. To maintain certification, a minimum of one 4-hour continuing education course within every 2-year period thereafter is required. Local soil and water conservation district personnel will complete construction site evaluations during the construction season. Certifications are valid until December 31 of the second year after issuance. Certification entitles the holder to advertise services as a "DEP Certified Contractor" (MDEP, 1999). More information about this program is provided on the MDEP Web site at *janus.state.me.us/dep/blwq/training/is-vccp.htm.*

The California Department of Transportation's Storm Water Management Plan

The California Department of Transportation (Caltrans) operates one of the most comprehensive storm water drainage systems in the United States. It has recently undertaken a multifaceted program to investigate and address pollutant load reduction in California's storm water runoff. To improve storm water management, Caltrans created the Storm Water Task Force (SWTF) to monitor, train, and educate its employees and hired contractors about pollution prevention measures. The SWTF's goals are to raise awareness and to change work habits so that Caltrans employees can more effectively address storm water issues. The SWTF uses the following techniques to accomplish their goals (Borroum et al., 2000):

- Inspecting projects and facilities for compliance with erosion, sediment control, and waste management requirements.
- Providing classroom and on-the job training and consulting.
- Publishing a monthly storm water bulletin for employees and state and local regulatory agencies.
- Reviewing storm water pollution prevention plans for construction sites.
- Providing feedback on how well methods work and what improvements could be made to improve performance.
- Preparing specialized training materials, such as videos and model pollution prevention plans.
- Providing input for storm water guidance manuals and water pollution control specifications for highway design and construction.

and implementing ESC plans; the importance of proper installation, regular inspection, and diligent maintenance of ESC practices; and recordkeeping for inspections and maintenance activities. Training and education should logically extend to all on-site personnel responsible for implementing a construction runoff control plan.

8.3.1.3 Establish plan review and modification procedures

ESC plans should be flexible to account for unexpected events that occur after the plans have been approved, including:

- Discrepancies between planned and as-built grades;
- Weather conditions;
- Altered drainage; and
- Unforeseen construction requirements.

Changes to an ESC plan should be made based on regular inspections that identify whether the ESC practices were appropriate or properly installed or maintained.

8.3.1.4 Assess ESC practices after storm events

Inspecting an ESC practice after storm events shows whether the practice was installed or maintained properly. Such inspections also help determine whether a practice requires cleanout, repair, reinforcement, or replacement with a more appropriate practice. Inspecting after storms is the best way to ensure that ESC practices remain in place and effective at all times during construction activities.

8.3.1.5 Ensure ESC plan implementation

Because funding for ESC programs is not always dedicated, budgetary and staffing constraints may thwart effective program implementation. Brown and Caraco (1997) recommend several management techniques to ensure that ESC programs are properly administered:

- Local leadership committed to the ESC program;
- Redeployment of existing staff from the office to the field or training room;
- Cross-training of local review and inspection staff;
- Submission of erosion prevention elements for early planning review;
- Prioritization of inspections based on erosion risk;
- Requirement of designers to certify the initial installation of ESC practices;
- Investment in contractor certification and private inspector programs;
- Use of public-sector construction projects to demonstrate effective ESC controls;
- Enlistment of the talents of developers and engineering consultants in the ESC program; and
- Revision and update of the local ESC manual.

To facilitate public participation, a hotline can be established to allow for citizen “monitoring” and reporting of any illicit discharges. Materials should be distributed or public service announcements made to advertise the hotline.

An allowance item that acts as an additional "insurance policy" for complying with the erosion and sediment control plan also can be added to bid or contract documents (Deering, 2000a). This allowance covers costs to repair storm damage to erosion and sediment control measures as specified in the erosion and sediment control plan. This allowance does not cover storm damage to property that is not related to the erosion and sediment control plan, because this would be covered under traditional liability insurance. Damage caused by severe and continuous rain, windblown objects, fallen trees or limbs, or high-velocity, short-term rain on steep slopes and existing grades would be covered by the allowance, as would deterioration from exposure to the elements or excessive maintenance for silt removal. The contractor is responsible for complying with the erosion and sediment control plan by properly implementing and maintaining all specified measures and structures. The allowance does not cover damage to practices caused by improper installation or maintenance.

A study by University of North Carolina researchers measured the effects of erosion and sediment control regulations, inspections, and enforcement on stream biological condition at 17 construction sites in central North Carolina (Reice and Andrews, 2000). At each site, upstream, downstream, and at-site samples were taken before construction began, during the peak land disturbance, and after the project was completed and released by the regulatory agency. Benthic and fish communities, in addition to several water chemistry variables and leaf litter decomposition rates, were sampled. The researchers found a number of results:

- Virtually all at-site samples showed some degradation relative to upstream controls.
- Impacts at sites downstream from construction sites were highly variable.
- Degree of degradation was significantly affected by enforcement activities; stronger enforcement resulted in less environmental impact on the streams.
- The stringency of the erosion and sediment control regulations proved unimportant compared to enforcement.

They concluded that staffing, workload, attitudes, and enforcement activities strongly influenced downstream conditions.

8.3.2 Erosion Control Practices

Erosion controls are used to reduce the amount of sediment removed during construction and to prevent sediment from entering runoff. Erosion control is based on two main concepts: (1) disturb the smallest area of land possible for the shortest period of time, and (2) stabilize disturbed soils to prevent erosion from occurring. Table 8.3 shows cost and effectiveness information for several erosion control practices.

8.3.2.1 Schedule projects so clearing and grading are done during the time of minimum erosion potential

Often a project can be scheduled when the erosion potential of the site is relatively low. In many parts of the country, there is a certain period of the year when erosion potential is relatively low and construction scheduling could be very effective. For example, in the Pacific region, if construction can be completed during the six-month dry season (May 1 to October 31), temporary erosion and sediment controls may not be needed. In addition, in other areas of the country, erosion potential in northern and high-elevation areas is very high during the spring thaw. During that time, snowmelt generates a constant runoff that can erode soil. In addition, construction vehicles can easily turn the soft, wet ground into mud, which is more easily washed off the site. Therefore, in the north, limitations should be placed on clearing and grading during the spring thaw (Goldman et al., 1986).

8.3.2.2 Phase construction

Construction site phasing involves disturbing only small portions of a site at a time to prevent erosion in areas where no activity is occurring (CWP, 1997c). Grading and construction are completed and soils are effectively stabilized on one part of the site before they commence at another. This is different from the more traditional practice of construction site sequencing, in which construction occurs at only one part of the site at a time but site grading and other site-disturbing activities typically occur all at once, leaving portions of the disturbed site vulnerable to erosion. Construction site phasing must be incorporated into the overall site plan early on. Elements to consider when phasing construction activities include (CWP, 1997c):

- Managing runoff separately in each phase;
- Determining whether water and sewer connections and extensions can be included in the disturbed area and installed during the initial phases of disturbance; and
- Providing separate construction and residential accesses to prevent conflicts between residents living in completed stages of the site and construction equipment working on later stages.

Table 8.3: Cost and effectiveness of selected erosion control practices.

Practice	Percent TSS Removal	Effectiveness References	Cost (2001 Dollars[a])	Cost References
Earth dike	NA	NA	Small dikes: \$2.50–\$6.50/linear ft Large dikes: \$2.50/yd^3	NAHB, 1995; SWRPC, 1991
Pipe slope drain	NA	NA	\$5/linear ft for flexible PVC pipe; inlet and outlet structures additional	NAHB, 1995
Terraces	1%–12% slope: 70% less erosion 12%–18% slope: 60% less erosion 18%–24% slope: 55% less erosion	USEPA, 1993	Average: \$6/linear ft Range: \$1.20–\$14.50/linear ft	USEPA, 1993
Check dams	NA	NA	\$100/dam (constructed of rock)	NAHB, 1995
Seeding	Average: 90% Range: 50%–100%	USEPA, 1993	Average: \$0.10/yd^2 Range: \$0.05–\$0.25/yd^2 Maintenance costs: 15%–25% of installation costs	USEPA, 1993
Mulching	53%–99.8% reduction of soil loss 24%–78% reduction in water velocity	Harding, 1990	Average: \$0.38/yd^2 Range: \$0.21–\$0.87/yd^2	USEPA, 1993
Sodding	98–99%	USEPA, 1993	Average: \$2.20/yd^2 Range: \$1.10–\$12/yd^2 Maintenance costs: 5% of installation costs	USEPA, 1993
Erosion control blankets	70% wheat straw/30% coconut fiber: 98.7% Straw: 89.2%–98.6% Curled wood fiber: 28.8%–93.6% Jute mats: 60.6% Synthetic fiber: 71.2% Nylon monofilament: 53.0%	CWP, 1997a	Biodegradable materials: \$0.50–\$0.57/yd^2 Permanent materials: \$3.00–\$4.50/yd^2 Staples: \$0.04–\$0.05/staple	Erosion Control Systems, Inc., personal communication, March 14, 2001
Chemical stabilization	PAM: 77–93%	Rosa-Espinosa et al., No date	PAM: \$1.30–\$38.50/lb	Entry and Sojka, 1999; Sojka and Lentz, 1996

[a]Costs adjusted for inflation using the Consumer Pricing Index (BLS, 2001).

A comparison of sediment loss from a typical development and from a comparable phased project showed a 42 percent reduction in sediment export in the phased project (CWP, 1997c).

Phasing can also provide protection from complete enforcement and shutdown of the entire project. If a contractor is in noncompliance in one phase or zone of a site only, that will be the area affected by enforcement activities. This approach can help to minimize liability exposure and protect the contractor financially (Deering, 2000b).

8.3.2.3 Practice site fingerprinting

Areas of a construction site are often unnecessarily cleared. Site fingerprinting involves clearing only those areas essential for conducting construction activities, leaving other areas undisturbed. The proposed limits of land disturbance should be physically marked off to ensure that only the land area required for buildings, roads, and other infrastructure is cleared. Existing vegetation, especially vegetation on steep slopes, should be avoided and preserved through fencing, signage, and site plan notations.

8.3.2.4 Locate potential pollutant sources away from steep slopes, water bodies, and critical areas

Material stockpiles, borrow areas, access roads, and other land-disturbing activities should be located away from critical areas such as steep slopes, highly erodible soils, and areas that drain directly into sensitive water bodies to reduce the potential for pollutant loadings.

8.3.2.5 Route construction traffic to avoid existing or newly planted vegetation

Where possible, construction traffic should be directed over areas that must be disturbed for other construction activity. This practice reduces the net total area that is cleared and susceptible to erosion. It also may help to decrease the area of compacted soils.

8.3.2.6 Protect natural vegetation with fencing, tree armoring, and retaining walls or tree wells

Tree armoring protects tree trunks from being damaged by construction equipment. Fencing can also protect tree trunks, but it should be placed at the tree's drip line or critical root zone. A tree's drip line is the minimum area around the tree in which the tree's root system should be undisturbed by cut, fill, or soil compaction caused by heavy equipment. When cutting or filling must be done near a tree, a retaining wall or tree well should be used to minimize the cutting of the tree's roots, the quantity of fill placed over the tree's roots, or soil compaction.

8.3.2.7 Protect environmentally sensitive areas

When construction is taking place in an aquifer recharge area, wetland, floodplain, or other sensitive area, special consideration should be given to minimizing the environmental impacts of construction activities. Disturbance to these areas should be limited and measures taken to reduce impacts if work is conducted near or in these features. For example, the North Carolina Department of Transportation (NCDOT) used an innovative technique to reduce the impact of cleanup activities on sensitive wetlands surrounding the newly constructed Croatan Sound Bridge. NCDOT used industrial vacuums traditionally used by the shipbuilding and roofing industries to move materials off-site rather than running potentially damaging vehicles over the wetlands. Even with the purchase cost of the new equipment, NCDOT estimates a savings of more than $3 million.

8.3.2.8 Stockpile topsoil and reapply as a soil amendment to reestablish vegetation

Topsoil is essential to establish new vegetation, and it should be stockpiled and then reapplied to the site for revegetation. Reestablishment of vegetation is one of the most common and least expensive means to stabilize disturbed soils.

The Importance of Soil Amendments

Soil with adequate soil structure, pore space, organic content, and biological activity not only promotes the establishment of new vegetation, but it also provides water quality benefits. When soils are compacted during construction activities and organic matter is not replaced, the following consequences may occur (Low Impact Development Center, 2003):

- Reduced infiltration capacity, resulting in increased runoff, erosion, scouring, and sediment and other pollutant loads to receiving waters.
- Decreased ground water recharge rates.
- Reduced availability of subsurface water to plants, requiring homeowners to water more frequently.

Soil amendments minimize development impacts on native soils by restoring infiltration capacity and the chemical characteristics of healthy soils. Amended soils provide greater infiltration and subsurface storage, which helps to maintain predevelopment conditions. Soil amendments provide the following water quality benefits (Low Impact Development Center, 2003):

- Increased infiltration capacity of soil.
- Filtering and breakdown of potential pollutants.
- Decomposition of potential pollutants by soil microbes.
- Reduced need for fertilizers, pesticides, and irrigation due to increased nutrients and moisture-holding capacity in soil.
- Increasing soil stability, reducing erosion potential.
- Added protection to ground water resources, especially from heavy metal contamination.

Soil can be amended using compost, mulch, topsoil, lime and gypsum. A thorough analysis of the native soil should be conducted to maximize the benefits of soil amendments.

Soil should be amended at the completion of construction to avoid compaction from heavy equipment. Care should be taken to ensure that amendments are implemented during the right season and under the right conditions in relation to other landscaping activities.

8.3.2.9 Cover or stabilize soil stockpiles

Unprotected stockpiles are very prone to erosion and therefore must be protected. Small stockpiles can be covered with a tarp to prevent erosion. Large stockpiles should be stabilized by erosion blankets, seeding, and/or mulching.

8.3.2.10 Use wind erosion controls

Wind erosion controls limit the movement of dust from disturbed soil surfaces and encompass many different practices. Wind barriers block air currents and are effective in controlling soil movement due to wind. Many different materials can be used as wind barriers, including solid board fences, snow fences, and bales of hay. Sprinkling moistens the soil surface with water and must be repeated as needed to be effective for preventing wind erosion (Delaware DNREC, 1989); however, applications must be monitored to prevent excessive runoff and erosion.

8.3.2.11 Intercept runoff above disturbed slopes and convey it to a permanent channel or storm drain

Earth dikes, perimeter dikes/swales, or diversions can be used to intercept and convey runoff from above disturbed areas to undisturbed areas or drainage systems. An earth dike is a temporary berm or ridge of compacted soil that channels water to a desired location. A perimeter dike/swale or diversion is a swale with a supporting ridge on the lower side that is constructed from the soil excavated from the adjoining swale (Delaware DNREC, 1989). These practices should be used to intercept flow from denuded areas or newly seeded areas and to keep clean runoff away from disturbed areas. The structures should be stabilized within 14 days of installation. A pipe slope drain, also known as a pipe drop structure, is a temporary pipe placed from the top to the bottom of a slope to convey concentrated runoff down the slope without causing erosion (Delaware DNREC, 1989).

8.3.2.12 On long or steep, disturbed, or man-made slopes, construct benches, terraces, or ditches at regular intervals to intercept runoff

Benches, terraces, or ditches break up a slope by providing areas of low slope in the reverse direction. These structures keep water from proceeding down the slope at increased volume and velocity. Instead, the flow is directed to a suitable outlet or protected drainage system. The frequency of benches, terraces, or ditches will depend on the erodibility of the soils, steepness and length of the slope, and rock outcrops. This practice should be used if there is a potential for erosion along the slope.

8.3.2.13 Use retaining walls

Retaining walls can be used to decrease the steepness of a slope. If the steepness of a slope can be reduced, the runoff velocity and erosion potential can be decreased.

8.3.2.14 Provide linings for urban runoff conveyance channels

Construction activities often increase the velocity and volume of runoff. Increases in runoff velocity and volume often cause erosion in newly constructed or existing urban runoff conveyance channels. If the runoff during or after construction will cause erosion in a channel, the channel should be lined or flow control practices should be installed. The first choice of lining is grass or sod because they reduce runoff velocities and provide water quality benefits through filtration and infiltration. If the velocity in the channel would erode the grass or sod, turf reinforcement mats, riprap, concrete, or gabions can be used.

8.3.2.15 Use check dams

Check dams are small, temporary dams constructed across a swale or channel. They can be constructed using gravel, rock, gabions, or straw bales. They are used to reduce the velocity of concentrated flow and, therefore, to reduce erosion in a swale or channel. Proper design and maintenance of check dams is crucial to their ability to function as an erosion control measure. Design considerations include dams to control runoff velocity; hydraulic capacity to store and release runoff in a non-erosive manner; stability of dam construction materials; foundation preparation; construction moisture; and density control. Maintenance requirements include the periodic removal of sediment collected above the dam; immediate repair of damage; and removal of temporary dams when they are no longer needed (Loser, 2003).

8.3.2.16 Seed disturbed areas

Seeding establishes a vegetative cover on disturbed areas and is very effective in controlling soil erosion once a dense vegetative cover has been established. Seeding establishes permanent erosion control in a relatively short amount of time and has been shown to decrease solids load by 99 percent (CWP, 1997a). The three most common seeding methods are: (1) broadcast seeding, in which seeds are scattered on the soil surface; (2) hydroseeding, in which seeds are sprayed on the surface of the soil with a slurry of water; and (3) drill seeding, in which a tractor-drawn implement injects seeds into the soil surface. Broadcast seeding is most appropriate for small areas and for augmenting sparse and patchy grass covers. Hydroseeding is often used for large areas (in excess of 5,000 square feet) and is typically combined with tackifiers, fertilizers, and fiber mulch. Drill seeding is expensive and is cost-effective only on sites greater than 2 acres. Bare soils should be seeded or otherwise stabilized within 15 calendar days after final grading. Denuded areas that are inactive and will be exposed to rain for 15 days or more should also be temporarily stabilized, usually by planting seeds and establishing vegetation during favorable seasons. In very flat, non-sensitive areas with favorable soils, stabilization may involve simply seeding and fertilizing. The Soil Quality Institute (SQI, 2000) recommends that soils compacted by grading should be broken up or tilled before vegetating.

To establish a vegetative cover, it is important to use seeds from adapted plant species and varieties that have a high germination capacity. Supplying essential plant nutrients, testing the soil for toxic materials, and applying an adequate amount of lime and fertilizer can overcome many unfavorable soil conditions and establish adequate vegetative cover. Soils should be tested prior to application to determine the amount of lime or fertilizer needed. Specific information about seeds, various species, establishment techniques, and maintenance can be obtained from *Erosion Control & Conservation Plantings on Noncropland* (Landschoot, 1997) or a local Cooperative State Research, Education, and Extension Service (http://www.csrees.usda.gov/) or Natural Resources Conservation Service (http://www.nrcs.usda.gov) office.

8.3.2.17 Use mulches

Newly established vegetation does not have as extensive a root system as existing vegetation, and therefore it is more prone to erosion, especially on steep slopes. Additional stabilization should be considered during the early stages of seeding. This extra stabilization can be accomplished using mulches or mulch mats, which can protect the disturbed area while vegetation becomes established.

Mulching involves applying plant residues, compost material, or other suitable materials on disturbed soil surfaces. Mulch and mulch mat materials include tacked straw, wood chips, jute netting, coir/coconut fiber, and compost mix, and are sometimes covered by blankets or netting. Mulching alone should be used only for temporary protection of the soil surface or when permanent seeding is not feasible. The useful life of mulch varies with the material used and the amount of precipitation, but is approximately two to six months. Mulching and/or sodding may be necessary as slopes become moderate to steep, as soils become more erodible, and as areas become more sensitive.

During the times of the year when vegetation cannot be established, mulch should be applied to moderate slopes and soils that are not highly erodible. On steep slopes or highly erodible soils, multiple mulching treatments should be used.

The Texas Transportation Institute (2004) undertook a study to measure the performance of the use of compost and shredded wood mulches on highway rights-of-way. The institute found that compost applied to sand produced 92 percent vegetation cover, compost on clay produced 99 percent vegetation cover, and wood chips treated with a tackifier on clay produced 95 percent vegetation cover. Other treatments, including wood chips/tackifier on sand and wood chips with tackifier and germination stimulant on sand and clay did not produce adequate vegetation cover for erosion control (only 48 to 57 percent cover). They concluded that mulch could be advantageous as an erosion control method because it did not need to be removed after construction and it acted as a soil amendment to encourage vegetation establishment. Additionally, use of natural mulches such as compost and wood chips promotes recycling of waste materials and reduces the amount of wastes disposed of in landfills.

Hydromulches containing biosolids or other fertilizers are often useful on soils with poor nutrient organic content and in situations where there are steep slopes or other erosive forces that affect revegetation (e.g., wind).

8.3.2.18 Use sodding for permanent stabilization

Sodding permanently stabilizes an area with a thick vegetative cover. Sodding provides immediate stabilization and should be used in critical areas or where establishing permanent vegetation by seeding and mulching would be difficult. Sodding is also a preferred option when there is high erosion potential during the period of vegetative establishment from seeding. According to the Soil Quality Institute (SQI, 2000), soils that have been compacted by grading should be broken up or tilled before placing sod.

8.3.2.19 Install erosion control blankets

Turf reinforcement mats (TRMs) combine vegetative growth and synthetic materials to form a high-strength mat that helps prevent soil erosion in drainage areas and on steep slopes (USEPA, 1999). TRMs enhance the natural ability of vegetation to permanently protect soil from erosion. They are composed of interwoven layers of non-degradable geosynthetic materials, such as polypropylene, nylon, and polyvinyl chloride netting, stitched together to form a three-dimensional matrix. They are thick and porous enough to allow filling and retention of soil.

In addition to providing scour protection, the mesh netting of TRMs is designed to enhance vegetative root and stem development. By protecting the soil from scouring forces and enhancing vegetative growth, TRMs can raise the threshold of natural vegetation to withstand higher hydraulic forces on stabilization slopes, streambanks, and channels. In addition to reducing flow velocities, the use of natural vegetation provides removal of particulates through sedimentation and soil infiltration and improves the aesthetics of a site.

In general, TRMs should not be used:

- To prevent deep-seated slope failure due to causes other than surficial erosion;
- When anticipated hydraulic conditions are beyond the limits of TRMs and natural vegetation;
- Directly beneath drop outlets to dissipate impact force (although they can be used beyond the impact zone); or
- Where wave height might exceed 1 foot (although they may be used to protect areas up-slope of the wave impact zone).

The performance of a TRM-lined conveyance system depends on the duration of the runoff event to which it is subjected. For short-term events, TRMs are typically effective at flow velocities of up to 15 ft/sec and shear stresses of up to 8 lb/ft^2 (USEPA, 1999), however, specific high-performance TRMs may be effective under more severe hydraulic conditions. Practitioners should check with manufacturers for the specifications and performance limits of different products.

In general, the installed cost of TRMs ranges from \$5/yd^2 to \$15/yd^2 (USEPA, 1999). Factors influencing the cost of TRMs include: (1) the type of TRM material required; (2) site conditions, such as the underlying soils, the steepness of the slope, and other grading requirements; and (3) installation-specific factors such as local construction costs.

In most cases, TRMs cost considerably less than concrete and riprap solutions. For example, a project in Aspen, Colorado, used more than 23,000 yd^2 of TRMs to line channels for a horse ranch development project (Theisen, 1996). The TRMs were installed at a cost of \$8.25/yd^2. This cost was substantially less than the \$20/yd^2 estimate for the rock riprap alternative.

8.3.2.20 Use chemicals such as PAM to stabilize soils

Polymers can be used to reduce erosion and also to control sediment contained in runoff. Polyacrylamide (PAM) is a polymer produced mainly for agricultural use to control erosion and promote infiltration on irrigated lands (Sojka and Lentz, 1996). It is also being tested for use at construction sites to reduce erosion from disturbed areas (Aicardo, 1996; Roa-Espinosa et al., no date). When applied to soils, PAM binds to soil particles and forms a gel that decreases soil bulk density, absorbs water, and binds fine-grained soil particles.

PAM is available in powder form or as aqueous concentrate, in blocks and cubes, and as an emulsified concentrate; each type has benefits and drawbacks that alter its applicability in different settings and by different application methods. PAM costs $1.30 to $38.50 per pound (Entry and Sojka, 1999; Sojka and Lentz, 1996) and has been shown to achieve a 77 to 93 percent reduction in sediment loss from disturbed sites (Roa-Espinosa et al., no date).

Application of PAM improves surface water quality by decreasing suspended solids and the phosphorus, nitrogen, pesticides, pathogens, salts, metals, and BOD usually associated with sediment loading. However, PAM may detrimentally affect ground water quality by increasing leaching of nutrients, pesticides, and pathogens as a result of improved infiltration. Although careful application of PAM at prescribed rates can partially mitigate its negative effects on ground-water quality, its effects on water quality and wildlife are still unknown.

Questions have arisen as to PAM's environmental toxicity. Anionic PAM, the form found most often in erosion control products, has not been proven to be toxic to aquatic, soil, or plant species. The molecule is too large to cross membranes, so it is not absorbed by the gastrointestinal tract, is not metabolized, and does not bioaccumulate in living tissue. Cationic PAM, although not of major concern for erosion control applications, has been shown to be toxic to fish because of its affinity to anionic hemoglobin in the gills.

Most of the concern for PAM toxicity has arisen because of acrylamide (AMD), the monomer associated with PAM and a contaminant of the PAM manufacturing process. In laboratory experiments, AMD has been shown to be both a neurotoxin and a carcinogen. Current regulations require that AMD not exceed 0.05 percent in PAM products. Although there seems to be little risk from AMD as a result of prescribed application of PAM, it is uncertain what effects might result from spills, over-application, or other accidents.

Flocculation and filtration of colloidal solids in construction site runoff

Runoff discharged from an unstabilized sediment basin at a commercial construction site was not meeting water quality standards due to high suspended solids content, despite a filtering device installed at the basin’s outflow. The filter was designed to filter larger particles and gross solids, but did not treat silt-sized and colloidal particles. To address the smaller particle sizes, the contractor installed a sump consisting of 2 parts: a pit into which a 1,000-foot pipe discharged runoff for settling and a grid of jute baffles that would filter finer floc. A polyacrylamide blend was used to stabilize the pit and baffle grid. Solid blocks of flocculant were placed in the upstream end of the discharge pipe to introduce the material gradually into the runoff stream. Mixing occurred in the pipe, settling of floc occurred in the quiescent pit, and the baffles filtered remaining solids and floc. Samples taken at inflow and outflow points show dramatic clarification of runoff (Price and Company, Inc., 2004).

Polymers for Sediment Control

Polymers also can be used to control sediments that have been mobilized and entrained in runoff. Minton and Benedict (1999) examined the use of polymers to clarify construction site runoff that had been detained on-site.

The researchers used a multi-phase system to remove sediments and associated pollutants from construction site runoff. The first phase involved collection of storm water at interception points using the permanent drainage system installed early in the construction period and/or building excavations (see Figure 8.1). The collected runoff was then diverted, usually by pumping, to one or more storage ponds. (The permanent postdevelopment detention and treatment system, as required by local regulations, could be used for this storage during the construction phase given that it has sufficient capacity to handle site runoff, with supplemental storage provided as necessary.) The water was then pH-adjusted to optimize flocculation based on the particular polymer used. Finally, the water was pumped to one of two treatment cells, during which time the polymer was added (upstream of the transfer pump to maximize mixing and flocculation).

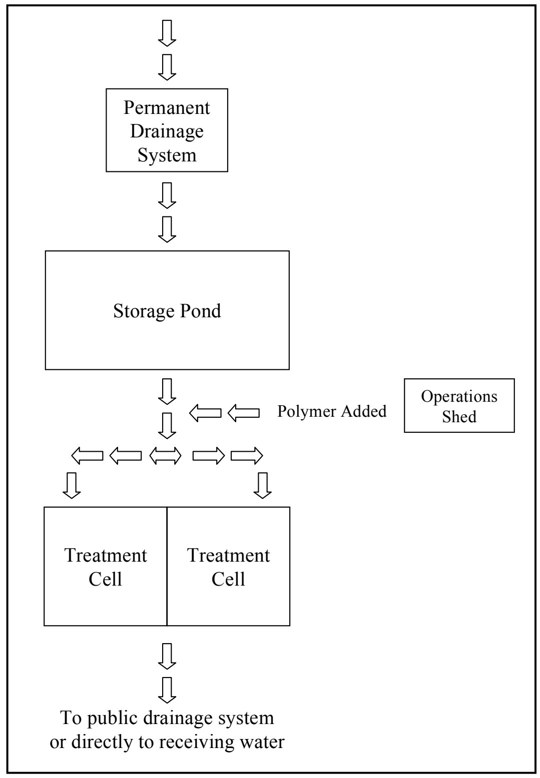


Figure 8.1: Schematic of the basic polymer treatment system (Minton and Benedict, 1999).

Two treatment cells were used so that settling could take place in one cell while runoff was pumped into the second cell. The floc was allowed to settle for a few hours to several days, with the most common practice being an overnight settling period. Water was discharged to the public discharge system using a float device with a 4-inch discharge system and a 12-inch clearance to keep the float from picking up settled sediment. Alternatively, the clarified water could be discharged to the sanitary sewer if problems arose in the treatment system.

Table 8.4 presents performance data for the six sites studied. Median turbidities of the untreated storm water varied between sites. These differences might have been caused by differences in the percentage of soil fines, the slopes, and the application of standard management practices. Developers at the test sites reported costs to be between 0.8 and 1.5 percent of the total construction cost, while another developer reported an approximate cost of $1/ft^2 for the treatment system. Temporary storage and treatment ponds, as well as piping, pumps, and other equipment, accounted for the majority of the costs associated with polymer treatment.

Table 8.4: Summary of operating performance data for six test sites (Minton and Benedict, 1999)[a].

Site	Polymer Dosage		Influent Turbidity		Effluent Turbidity		pH Control	
	Range	Median	Range	Median	Range	Median	Frequency[b]	Type[c]
1	25–250	75	12–2,960	200	1–45	6	45%	acid
2	10–200	100	31–4,700	2,000	1.9–39	11	16%	both
3	50–>100	100	12.9–900	150	0.5–45	7	18%	soda ash
4	50–200	100	8–4,000	400	<1–32.5	6	0%	–
5	300–400	350	2,780–17,000	14,000	0.8–23	8	97%	soda ash
6	85–140	110	17–6,650	117	1.7–18	4	85%	both

[a] Excludes the start-up period when effluent turbidities were not yet at desired levels (usually a week or two for most sites). [b] Approximate percentage of the number of operating days on which pH adjustment occurred. [c] Most frequent form of pH adjustment: soda ash or sulfuric acid.

8.3.2.21 Use wildflower cover

Because of the hardy drought-resistant nature of wildflowers, in some cases they may be more beneficial as an erosion control practice than turf grass. Though not as dense as turf grass, wildflower thatches and associated grasses are expected to be as effective in erosion control and contaminant absorption. An additional benefit of wildflower thatches is providing habitat for wildlife, including insects and small mammals. Because thatches of wildflowers do not need fertilizers, pesticides, or herbicides, and watering is minimal, implementation of this practice may result in cost savings. A wildflower thatch requires several years to become established, but maintenance requirements are minimal once established. Native seeds should be used because they will be better adapted to local conditions. If possible, the seed source should be within 250 miles of the proposed project for promotion of native species.

8.3.3 Sediment Control Practices

Sediment controls capture sediment that is transported in runoff. Filtration and gravitational settling during detention are the main processes used to remove sediment from urban runoff. Table 8.5 shows cost and effectiveness information for several sediment control practices.

8.3.3.1 Install sediment basins

Sediment basins, also known as silt basins, are engineered impoundment structures that allow sediment to settle out of the urban runoff. They are installed prior to full-scale grading and remain in place until the disturbed portions of the drainage area are fully stabilized. They are generally located at the low point of sites, away from construction traffic, where they can be used to trap sediment-laden runoff. Basin dewatering is achieved either through a single riser and drainage hole leading to a suitable outlet on the downstream side of the embankment or through the gravel of the rock dam. In both cases, water is released at a substantially slower rate than would be possible without the control structure.

The following are general specifications for sediment basin design criteria as presented in Schueler (1997):

- Provide 1,800 to 3,600 cubic feet of storage per contributing acre (a number of states, including Maryland, Pennsylvania, Georgia, and Delaware, recently increased the storage requirement to 3,600 ft^3 or more [CWP, 1997b]).
- Surface area equivalent to 1 percent of drainage area (optional, seldom required).
- Riser with spillway capacity of 0.2 ft^3/s/ac of drainage area (peak discharge for 2-year storm with 1-foot freeboard).
- Length-to-width ratio of 2 or greater.
- Basin side slopes no steeper than 2:1 (horizontal to vertical).
- Safety fencing, perforated riser, dewatering (optional, seldom required).

Table 8.5: Cost and effectiveness for selected sediment control practices.

Practice	Percent TSS Removal	Effectiveness References	Cost (2001 dollars[a])	Cost References
Sediment basin	Average: 70% Range: 42%-100%	CWP, 1997d; Millen et al., No date; USEPA, 1993	For 50,000 ft^3 of storage space: Average: $0.80/$ft^3$ Range: $0.25–$1.70/ft^3 storage For more than 50,000 ft^3 of storage space: Average: $0.40/$ft^3$ Range: $0.13–$0.52/ft^3 storage	USEPA, 1993
Modified risers and skimmers	Single orifice: 83% Perforated risers: 68%–94% Perforated risers w/filter fabric: 79% Skimmer: 83%–97%	Jarrett, 1999, Schueler, 1997	NA	NA
Sediment trap	50%–70%	Stahre and Urbonas, 1990	Average: $0.80/$ft^3$ storage Range: $0.25–$2.65/ft^3 storage Maintenance costs: 20% of installation costs	Brown and Schueler, 1997; USEPA, 1993
Silt fence	40%–100%	Barrett et al., 1995; Wishowski et al., 1998; CWP, 1997e	$3.80–$9.90/linear ft	SWRPC, 1991; USEPA, 1992
Inlet protection	NA	NA	$65–$131/inlet	USEPA, 1993
Stabilized construction entrance	NA	NA	Without wash rack: Average: $2,620/entrance Range: $1,310–$5,240/entrance With wash rack: Average: $3,930/entrance Range: $1,310–$6,550/entrance	USEPA, 1993
Vegetated filter strips	75-ft width: 54% 15-ft width: 84%	Yu et al., 1993	Established from existing vegetation: $0 Established from seed: Average: $530/acre Range: $270–$1,310/acre Established from sod: Average: $14,190/acre Range: $6,000–$63,300/acre Note: Values do not include land costs or costs associated with installing a level spreader	USEPA, 1993

[a]Costs adjusted for inflation using the Bureau of Labor Statistics Inflation Calculator. NA: Not available

Sediment basins can be classified as either temporary or permanent structures, depending on the length of their service. If they are designed to function for less than 36 months, they are classified as temporary; otherwise, they are considered permanent. Temporary sediment basins can also be converted into permanent urban runoff management ponds. Conversion minimizes additional disturbance and can be used where it will be difficult to restore an area previously used as a temporary sediment basin. When sediment basins are designed as permanent structures, they must meet all standards for wet ponds. It is important to note that even the best-designed sediment basin seldom exceeds 60 to 75 percent TSS removal. This number should be taken into consideration when selecting a sediment control practice. As described above, trapping efficiency in sediment basins can be improved through the use of advanced sediment-settling controls.

8.3.3.2 Use modified risers and skimmers

Because traditional riser designs provide little treatment to remove sediments, efforts have been made to improve the design of sediment basins to facilitate greater pollutant removal. Modifications to traditional designs that improve sediment removal efficiency include using perforated risers or perforated risers wrapped in a gravel jacket or filter fabric. An alternative to the riser is a skimmer device that floats on the surface of water in the basin (Faircloth, 1999). The skimmer is made of a straight section of PVC pipe equipped with a float and attached with a flexible coupling to a flow-controlled outlet at the base of the riser. Because the skimmer floats, it rises and falls with the level of water in the basin and drains only the cleanest top layer of runoff. Since the skimmer falls to the bottom of the basin as the basin drains, it is capable of more thorough dewatering than a traditional riser, thereby restoring the maximum runoff storage capacity. The sediment-removal performance of basins equipped with skimmer dewatering devices has been shown to be nearly 97 percent for a simulated 2-year, 24-hour storm (Schueler, 1997).

Jarrett (1999) tested the sediment-removal effectiveness of several types of basins (outlet placement, deeper/shallower, barrier/no barrier) and outlet designs, including perforated risers (with and without filter fabric), single-orifice risers, and several sizes of skimmers. Table 8.6 shows the sediment retention efficiency results of Jarrett's different treatments.

Jarrett drew the following conclusions from his study:

- Perforated risers and single-orifice risers had similar sediment losses.
- Deeper permanent pools resulted in greater sediment removal.
- Sediment loss was attributed partly to resuspension and partly to basin erosion.
- Perforated risers resulted in 1.8 times greater sediment loss than skimmers when the outlet devices were placed in the principal spillway.
- Barriers that trisect basin volume reduced sediment loss when perforated risers were used but did not reduce sediment loss when skimmers were used.
- Silt-sized particles were most likely to be lost from sediment basins.
- Longer dewatering time resulted in less overall sediment loss.

Table 8.6: Sediment retention efficiency[a] of sediment basins (Jarrett, 1999).

Treatment[b]	Outlet Control	Basin Size (m^3)	Hydrograph Volume Injected (m^3)	Emergency Spillway Used	Barrier Used	Dewatering Time (hr)	Permanent Pool Depth (m)	Sediment Loss (kg)	Sediment Retention Efficiency (%)
1	Perforated riser	140	100	No	No	24	0.15	32	79
2	Single orifice	140	100	No	No	24	0.15	26	83
5	Perforated Riser	140	100	No	No	24	0.46	1	92
6	Perforated riser with filter fabric	140	100	No	No	?	0.15	32	79
7	Skimmer	140	100	No	No	24	0.15	17	89
8	Perforated riser	140	100	No	Yes	24	0.15	24	84
9	Skimmer	140	100	No	No	24	0.15	20	87
10	Perforated riser	140	100	No	No	6	0.15	49	68
10	Perforated riser	140	100	No	No	168	0.15	9	94
10	Skimmer	140	100	No	No	6	0.15	22	86
10	Skimmer	140	100	No	No	168	0.15	5	97
11	Perforated riser	140	100	Yes	No	24	0.15	44	71
11	Skimmer	140	100	Yes	No	24	0.15	26	83
11a	Perforated riser	50	50	No	No	24	0.15	22	86
11a	Skimmer	50	50	No	No	24	0.15	7	95
3,4	Resuspension equaled 24% of sediment lost from basin								
3,4	Erosion from basin sides and bottom equaled 24% of sediment lost from basin								
1	Basin suspension was completely mixed during hydrograph inflow								
1	Basin suspension quickly stratified when inflow energy was reduced to zero								

[a]The 90 percent and greater TSS removal rates might be difficult to achieve in the field because (1) sizing criteria are much higher in Pennsylvania; (2) these were laboratory, not field, tests; and (3) maintenance was above average.
[b]In all treatments, effective soil injected was 154 kg.

8.3.3.3 Install sediment traps

Sediment traps are small impoundments that allow sediment to settle out of runoff water. They are typically installed in a drainageway or other point of discharge from a disturbed area. Temporary diversions can be used to direct runoff to the sediment trap. Sediment traps are ideal for sites 1 acre and smaller and should not be used for areas greater than 5 acres. They typically have a useful life of approximately 18 to 24 months. A sediment trap should be designed to maximize surface area for infiltration and sediment settling. This design increases the effectiveness of the trap and decreases the likeliness of backup during and after periods of high runoff intensity. The approximate storage capacity of each trap should be at least 1800 ft^3/acre of disturbed area draining into the trap (Smolen et al., 1988). (A number of states, including Maryland, Pennsylvania, Georgia, and Delaware, recently increased the storage requirement to 3,600 ft^3 or more [CWP, 1997b].)

8.3.3.4 Use silt fence

Silt fence, also known as filter fabric fence, is available in several mesh sizes from many manufacturers. Sediment is filtered out as runoff flows through the fabric. Such fences should be used only where there is sheet flow (no concentrated flow), and the maximum drainage area to the fence should be 0.5 acre or less per 100 feet of fence. To ensure sheet flow, a gravel collar or level spreader can be used upslope of the fence. Many types of fabrics are available commercially. The characteristics that determine a fence's effectiveness include filtration efficiency, permeability, tensile strength, tear strength, ultraviolet resistance, pH effects, and creep resistance.

The longevity of silt fences depends heavily on proper installation and maintenance. CWP (1997d) identified several conditions that limit the effectiveness of silt fences:

- The length of the slope exceeds 50 feet for slopes of 5 to 10 percent, 25 feet for slopes of 10 to 20 percent, or 15 feet for slopes greater than 20 percent.
- The silt fence is not aligned parallel to the slope contours.
- The edges of the silt fence are not curved uphill, allowing flow to bypass the fence.
- The length of disturbed area draining to the fence is greater than 100 feet.
- The fence receives concentrated flow without reinforcement.
- The fence was installed below an outlet pipe or weir.
- The silt fence is upslope of the exposed area.
- The silt fence alignment does not consider construction traffic.
- Sediment deposits behind the silt fence reduce capacity and increase breach potential.
- The alignment of the silt fence mirrors the property line or limits of disturbance but does not reflect ESC needs.

EvTEC tests a static slicing silt fence installer

A static slicing silt fence installer was recently tested by EPA's Environmental Technology Evaluation Center (EvTEC, 2001). The goal of the testing was to determine if slicing was as better method than trenching with respect to performance, cost, and ease of use. The static slicing method, an alternative to traditional trenching methods, involves inserting a narrow custom-shaped blade at least 10 inches into the ground and simultaneously pulling silt fence fabric into the opening created as the blade is pulled through the ground. The tip of the blade is designed to slightly disrupt soil upward, preventing horizontal compaction of the soil and simultaneously creating an optimum soil condition for future mechanical compaction. Compaction follows using a tire on the tractor that pulls the slicing machine. Post-setting and driving, followed with attaching the fabric to the post, finalizes the installation.

EvTEC found that the slicer performed as well as or better than the best trenching method and was superior to less stringent methods of trenching. Slicing took less time (1.75 to 4 times faster) and was therefore cost-effective because of man-hour savings. The slicing method prevented runoff seepage and blowout better than most trenching methods and performed as well as the best trenching method. Overall, the static slicing method offers several advantages over traditional trenching methods, including maneuverability, minimal soil-handling and manual labor, consistent depth and compaction, and ease of installation in windy conditions, on steep side slopes, through rocky soils, and in saturated conditions.

These conditions can be avoided with proper siting, installation, and maintenance. Silt fences typically have a useful life of approximately 6 to 12 months.

8.3.3.5 Install compost filter berms

Compost berms can be installed by spraying compost mixture along the perimeter of a denuded area to form a mound. The berms are designed to filter runoff by absorbing flows into the compost mixture's void space and gradually releasing them into the ground or offsite. They are usually installed at the bottom of a slope, but they also can be installed at the top of the denuded area to prevent clean runoff from entering exposed areas. Berms are typically installed in lieu of silt fence and are sized at 1 foot high and 2 feet wide (Tyler, 2001).

Compost berms can be used in conjunction with compost blankets (a sprayed layer of compost mix that functions as a mulch, see section 8.3.2.17); a berm at the top of the slope protects the compost blankets from erosion by preventing water from flowing underneath the protective layer, and a berm at the bottom of the slope provides filtration (Tyler, 2001).

Caine (2001) installed a triangular cross-section compost berm that was 16 to 18 inches high and 36 inches wide at its base. Installation cost was approximately $3.68 per linear foot. Runoff detention time was 17 to 26 minutes. Water was distributed throughout the berm and was released at multiple points. The berm filtered the runoff such that turbidity was reduced by 67 percent. Caine noted that the runoff mobilized humic and tannic acids from the organic material, causing the water passing through the berm to become discolored. One benefit of compost berms is that they do not require removal after construction is completed; they can be spread over the ground surface as topsoil or a soil amendment.

Mesh socks filled with composted material can be used in lieu of filter berms where the use of loose material is not practical, such as where flows might be concentrated near stream banks or shorelines (Goldstein, 2002). These filter socks function in the same manner as compost filter berms, but they are more contained.

8.3.3.6 Establish inlet protection

Inlet protection consists of a barrier placed around a storm drain inlet, which traps sediment before it enters the storm sewer system. There are five basic types of inlet protection structures: silt fence barriers, straw bale inlet barriers, block and gravel drop inlet filters, block and gravel curb inlet filters, and various excavated drop inlet protection measures (NAHB, 1995). The structures should be placed at the perimeter of the inlet structure. Inlet protection is appropriate for small drainage areas (1 acre or less) and can be used during rainy seasons (California Regional Water Quality Control Board, 1999). The structures can handle sheet flow with velocities less than 0.014 m^3/s; block and gravel barriers should be used in cases where concentrated flows exceed 0.014 m^3/s.

8.3.3.7 Designate and reinforce construction entrances

A construction entrance is a pad of gravel or rock over filter cloth located where traffic enters and leaves a construction site. As construction vehicles drive over the gravel, mud and sediment are collected from the vehicles' wheels. To maximize the effectiveness of this practice, the rock pad should be at least 50 feet long and 10 to 12 feet wide. The gravel should be 1- to 2-inch aggregate 6 inches deep laid over a layer of filter fabric. Maintenance might include pressure-washing the gravel to remove accumulated sediments and adding more rock to maintain adequate thickness. Runoff from this entrance should be treated before exiting the site. This practice can be combined with a designated truck wash-down station to ensure sediment is not transported off-site.

8.3.3.8 Install vegetated filter strips

Vegetated filter strips are low-gradient vegetated areas that are planted and used to filter overland sheet flow. Runoff must be evenly distributed across the filter strip. Channelized flows decrease the effectiveness of filter strips. Level spreading devices are often used to distribute the runoff evenly across the strip (Dillaha et al., 1989).

Vegetated filter strips should have relatively low slopes and adequate length and should be planted with erosion-resistant plant species. The main factors that influence the removal efficiency are the vegetation type, soil infiltration rate, and flow depth and travel time. These factors are dependent on the contributing drainage area, slope of strip, degree and type of vegetative cover, and strip length. Maintenance requirements for vegetated filter strips include sediment removal and inspections to ensure that dense, vigorous vegetation is established and concentrated flows do not occur.

8.3.3.9 Use vegetated buffers

Like filter strips, vegetated buffers provide a physical separation between a construction site and a water body. The difference between a filter strip and a vegetated buffer area is that a filter strip is an engineered system (soils, plants, slope, width, depth), whereas a buffer is a naturally occurring filter system. Vegetated buffers remove nutrients and other pollutants from runoff, trap sediments, and shade the water body to optimize light and temperature conditions for aquatic plants and animals (Welsch, no date). Preservation of vegetation for a buffer should be planned before any site-disturbing activities begin to minimize the impact of construction activities on existing vegetation. Trees should be clearly marked at the drip-line to preserve them and to protect them from ground disturbances around the base of the tree.

Proper maintenance of buffer vegetation is important. Maintenance requirements depend on the plant species chosen, soil types, and climatic conditions. Maintenance activities typically include fertilizing, liming, irrigating, pruning, controlling weeds and pests, and repairing protective markers (e.g., fluorescent fences and flags).

8.3.4 Develop and Implement Programs to Control Chemicals and Other Construction Materials

8.3.4.1 Develop and implement a materials management program

Areas where materials are stored at a construction site can be sources of runoff contamination due to poor housekeeping and accidental spills. Improving storage and materials management practices will help minimize exposure and risk. Erodible or potentially hazardous materials should be stored in such a manner as to prevent contact with rainfall or runoff. In general, materials should be stored in a secure, dry, covered area that is equipped with an impermeable floor and berms to prevent spills from reaching surrounding soils, ground water, and surface water. Conducting an inventory of all materials used on-site and assessing the potential they pose for contact with runoff will help in implementing effective controls.

Properly store, handle, and apply pesticides. In general, pesticides should be used only when absolutely necessary. Instructions listed on the packaging should be followed when using, handling, or disposing of these chemicals. Consideration should be given to local regulations that may govern the use or disposal of pesticide chemicals or their containers. To reduce the risk of contaminating runoff, the following practices should be implemented:

- Store pesticides in a secure, dry, covered area that has an impermeable floor.

- Provide curbs or dikes around the storage area to prevent spills and leaks from reaching unprotected areas.

- Provide site personnel with the proper pesticide spill response training and have adequate measures on-site to contain and clean up pesticide spills.

- Strictly follow recommended application rates and application methods.

- Handle pesticide wastes appropriately. Many pesticides are considered hazardous wastes when they are disposed of. Pesticide wastes should be managed as required by all applicable waste regulations.

Properly store, handle, and apply petroleum products. The following practices can help to reduce the risk of runoff contamination from petroleum products:

- Store petroleum products in designated areas that are covered, have impermeable floors, and are surrounded with dikes, berms, or absorbent pads to contain any spills.

- Provide site personnel with the proper spill response training and have adequate measures on-site to contain and clean up petroleum spills. Store spill cleanup equipment in fuel storage areas or on board maintenance and fueling vehicles.

- Conduct periodic preventive maintenance of on-site equipment and vehicles to prevent leaks.

Properly store, handle, and apply fertilizers and detergents. A number of steps can be taken to reduce the risks of nutrient pollution:

- Minimize the use of fertilizers and detergents. Determine the smallest amounts needed for the tasks at hand and avoid using unnecessary amounts. Apply fertilizers and use detergents only in the recommended manner and never in amounts greater than those recommended.

– When applying fertilizers to soil, apply them at a depth of 2 to 6 inches and not on the surface. This approach will limit the contact between runoff and nutrients.

– Apply fertilizers more frequently but at lower application rates.

– Implement appropriate erosion and sediment control practices that will control and limit the amount of nutrients leaving the site due to attachment to soil particles.

– Conduct washing/cleaning operations in designated areas that are equipped to contain wash water and prevent it from being discharged to the site runoff collection and conveyance system.

– Do not mix surplus products together unless following specific instructions from the manufacturer.

Properly store, handle, and apply hazardous products. Most problems associated with the disposal of hazardous materials are the result of carelessness, not following recommended procedures, or not using common sense. The following suggestions are meant to provide general guidance for disposal of hazardous materials:

– Determine what hazardous materials are being used on-site and which hazardous waste streams, if any, are generated as a result of construction activities. Once all of the hazardous materials used and hazardous wastes generated are identified, it is possible to implement an appropriate waste management and disposal strategy.

– Know the applicable hazardous waste regulations and the associated requirements for storing, marking, and disposing of wastes. Someone on-site should be trained to properly manage hazardous wastes. If waste disposal obligations are not clearly understood, contact the correct regulatory agency to find out what specific requirements must be followed.

– Use as much of a product as possible before disposing of containers. Containers that are not empty but have been stored for disposal can be sources of drips, leaks, or spills, and they can contaminate landfills or other disposal areas.

– Do not remove the original product label from the container. It contains important use, safety, and disposal information about the product.

8.3.4.2 Develop and implement a spill control plan

Construction sites should be equipped with suitable equipment to contain and clean up spills of hazardous materials in the areas where the materials are stored or used. Accidental spills of materials used at construction sites can be sources of runoff pollution if not addressed appropriately. All spills should be cleaned up immediately after they occur. Creation of a site-specific spill control and response plan in combination with spill response training for designated on-site personnel can be effective in dealing with accidental spills and preventing the contamination of soil, water, and runoff. Preparation of a spill containment, control, and countermeasures (SPCC) plan might be required to meet regulatory requirements (e.g., requirements regarding storage of specified chemicals above certain volume thresholds). Site managers should be aware of all applicable requirements and should contact regulatory authorities if requirements are not known.

Even if a formal plan is not required, preparing one is a good idea. In general, an SPCC plan should include guidance to site personnel on the following:

- Proper notification when a spill occurs;
- Site responsibility with respect to addressing the cleanup of a spill;
- Stopping the source of a spill;
- Cleaning up a spill;
- Proper disposal of materials contaminated by the spill;
- Location of spill response equipment programs; and
- Training for designated on-site personnel.

A periodic spill “fire drill” should be conducted to help train personnel on proper responses to spills and to keep response actions fresh in their minds.

8.3.4.3 Develop and implement a waste disposal program

Implementation of good waste disposal practices at construction sites can help to significantly reduce the potential for runoff contamination. Wastes generated at construction sites can include surplus maintenance chemicals, refuse building materials, hazardous wastes, or contaminated soil and spill cleanup materials. General practices to manage such wastes include solid waste disposal, recycling, hazardous waste management, and spill prevention and cleanup measures.

(1) *Develop procedures for disposal of construction wastes*. Construction projects can generate a significant amount of what is commonly referred to as “construction wastes.” Such wastes are unique to the activity and might include the following:

- Trees and shrubs removed during clearing and grubbing;
- Packaging materials such as wood, paper, plastic, and polystyrene;
- Scrap or surplus building materials such as scrap metal, rubber, plastic, glass, and masonry;
- Paints and paint thinners; and
- Demolition debris such as concrete rubble, asphalt, and brick.

To ensure proper disposal of construction wastes, the following steps should be followed:

- Select a designated on-site waste collection area.
- Provide an adequate number of containers with lids or covers that can be placed over the containers prior to rainfall.

- Locate containers in a covered area when possible.

- Arrange for waste collection before containers overflow.

- Explore recycling options for specific wastes generated at the site. Wastes such as used oil, used solvents, and construction debris can often be reclaimed or recycled, thereby reducing the amount of waste actually requiring permanent disposal. Numerous companies can provide recycling services, including the provision and maintenance of on-site recycling containers.

- Implement appropriate response procedures immediately when a spill does occur.

- Plan for additional containers and more frequent pickups during the demolition phase of construction activities.

- Ensure that all construction wastes are disposed of at facilities authorized to receive such wastes.

(2) *Develop procedures for disposal of hazardous products*. The correct method of disposal of hazardous products varies with the product used. Follow the manufacturer's recommended method as printed on the product label.

(3) *Develop procedures for disposal of contaminated soils*. Options for disposal of contaminated soil depend on the nature of the soil contamination. Under no circumstances should contaminated soils be disposed of in adjoining properties or in swamps or other wetlands because they will still pose a threat to surface and ground water. The appropriate solid and/or hazardous waste regulatory agency should be contacted concerning the proper procedures for characterizing, removing, and disposing of contaminated soil. Typically, contaminated soils can either be excavated and removed or cleaned on-site. In situ techniques include applying chemicals that break down or neutralize the contaminant, venting or sparging the soil to oxidize the contaminant, and using biological treatment to metabolize and destroy the contaminant.

(4) *Develop procedures for disposal of concrete truck waste*. Many construction projects include the use of concrete. Usually the concrete is mixed off-site and delivered to the project by truck. The concrete is poured and a residual amount of concrete remains in the truck, or the concrete is found to be unacceptable and is rejected by the construction inspector or foreman. The truck may be cleaned of residual concrete on-site. Excess concrete and wash water should be disposed of in a manner that prevents contact between these materials and runoff. For example, dikes could be constructed around the area to contain these materials until they harden, at which time they can be properly disposed of.

(5) *Develop procedures for disposal of sandblasting grits*. Sandblasting is frequently used to remove paint and dirt from surfaces. The grit generated contains both the spent blasting grit (commonly sand or steel granules) and the particles of paint or dirt removed from the surface. Sandblasting residue can be a hazardous waste if the material removed contains hazardous metals such as cadmium, lead, and chromium, which are sometimes found in paints. For this reason, sandblasting residue should not be allowed to be released to the ground or discharged

to a storm sewer or sanitary sewer, where it can cause soil or water contamination. Instead, it should be evaluated to determine whether it constitutes a hazardous waste. If determined to be a hazardous waste, it should be properly handled and disposed of; if not a hazardous waste, it should be properly managed and disposed of as a solid waste. Dumping wastes into sewers and other drainage channels is illegal and can result in fines or job shutdown (USEPA, 1993).

(6) *Develop procedures for disposal of sanitary wastes.* Construction sites usually are equipped with temporary sanitary facilities such as portable toilets for on-site personnel. Sanitary wastes can also be disposed of through septic systems or sanitary sewers. The type of facilities used on-site will dictate the appropriate management practices used to deal with the wastes. Domestic waste haulers should be contracted to regularly remove the sanitary and septic wastes and to maintain the facilities in good working condition. This maintenance will help to prevent overloading of the system, which could result in discharges in runoff. All septic systems should be installed, operated, and maintained in accordance with appropriate regulations. Any discharges to the sanitary sewer systems should be done in accordance with local sewer authority regulations.

8.4 Information Resources

EPA's National Menu of Best Management Practices for Stormwater Phase II developed numerous fact sheets describing management practices for construction site operators. The fact sheets cover both erosion control and sediment control topics, and they include sections for applicability, design considerations, costs, and effectiveness. They are available on EPA's Web site at http://www.epa.gov/npdes/menuofbmps (select "Construction Site Stormwater Runoff Control").

California's *Storm Water Best Management Practice Handbook: Construction* outlines waste management practices in a set of fact sheets that include erosion controls (scheduling, velocity dissipation devices, slope drains, stream bank stabilization, polyacrylamide, preservation of existing vegetation, hydraulic mulch, hydroseeding, soil binders, straw mulch, geotextiles and mats, wood mulching, earth dikes, and drainage swales), sediment controls (silt fence, storm drain inlet protection, chemical treatment, sediment basins, sediment traps, check dams, fiber rolls, gravel bag berms, street sweeping and vacuuming, sandbag barriers, straw bale barriers, stabilized construction entrances and exits, stabilized construction roadways, entrance/outlet tire washing), and wind erosion control. It can be downloaded in PDF format from http://www.cabmphandbooks.org/Construction.asp.

The *Erosion and Sediment Control Field Manual* from the San Francisco Regional Water Quality Control Board describes management practices for construction site planning and management, erosion and sediment control, pollution prevention, and sampling guidelines. Descriptions of practices are concise and include full-color graphics and installation information including guidelines, timing, and limitations. The manual also includes the new Phase II regulations, sampling and monitoring guidelines, and long-term maintenance information. Also available are several erosion and sediment control videos (in English and Spanish); guidelines for construction projects; a CD training kit for construction site planning and management for compliance with NPDES requirements; and the1999 version of the *Erosion and Sediment Control Field Manual.* It can be purchased for $30 at http://store.abag.ca.gov/construction.asp.

The *Kentucky Erosion Prevention and Sediment Control Field Guide* from the Kentucky Division of Water covers the entire erosion and sediment control process. The guide begins with sections on pre-project planning and operational activities and continues with erosion prevention and sediment control by starting at the top of the hill, above the project site, and proceeding down the slope through the bare soil area, ditches and channels, traps and basins, and to the waterways below. The guide can be downloaded in PDF format from http://www.water.ky.gov/sw/nps/Publications.htm.

The Minnesota Local Technical Assistance Program offers courses, videos, and guidebooks pertaining to erosion control and drainage. More information about these products can be found at http://www.mnltap.umn.edu/.

There are several research laboratories that conduct independent testing of erosion control products. The Texas Transportation Institute's Hydraulics, Sedimentation, and Erosion Control Laboratory conducts side-by-side, full-scale, performance comparisons of roll-type erosion control materials and flexible channel liners. Product testing information can be found at http://tti.tamu.edu/enviro_mgmt/facilities/hec/. The St. Anthony Falls Laboratory has an "applied research" Web page (http://www.safl.umn.edu/research/applied/index.html) with links to studies gauging the effectiveness of erosion control products.

Storm Water Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices (USEPA, 1992), published by EPA's Office of Wastewater Management, provides summary guidance on the development of storm water pollution prevention plans and helps users select appropriate management practices to control erosion and sediment loss resulting from construction activities. It was designed to provide technical support for construction activities that are subject to pollution prevention requirements under NPDES permits for storm water point source discharges. This document can be viewed in PDF format at http://www.epa.gov/npdes/pubs/owm0307.pdf or it can be ordered from the National Service Center for Environmental Publications (NSCEP) at http://www.epa.gov/ncepihom/index.htm or by calling 513-489-8190 (Publication # EPA 833-R-92-001).

CPESC, Inc. offers certification for erosion and sediment control professionals. This program is sponsored by the Soil and Water Conservation Society and the International Erosion Control Association to educate field professionals on the best methods for controlling erosion and sediment and to provide evidence of professional qualifications. More information about the certification program can be found at http://www.cpesc.net.

The City of Knoxville, Tennessee, developed a manual that describes storm water management practices that the city recommends. The manual includes an introduction to storm water management practices, a discussion of the theory of erosion control, steps for selecting practices, and detailed fact sheets for each practice that include design, inspection, and maintenance information. The fact sheets cover four subject areas: activities and methods, erosion and sediment, industrial and commercial, and storm water treatment. The manual can be downloaded in PDF format at http://www.ci.knoxville.tn.us/engineering/bmp_manual.

The Delaware Department of Natural Resources and Environmental Control has assembled course materials and associated standards and specifications that contain descriptions of Delaware's BMPs for erosion, sediment, and runoff control, as well as their certification requirements for contractors. These materials, entitled *Sediment and Stormwater Management Certified Construction Reviewer Course and Associated Delaware State and DOT Standards/Specifications*, can be obtained by calling 302-739-4411.

The North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR, no date) developed a suite of references pertaining to erosion and sediment control, including the *Erosion and Sediment Control Planning and Design Manual*, which provides extensive details and procedures for developing site-specific erosion and sedimentation control plans. The *North Carolina Erosion and Sediment Control Field Manual* is a conveniently sized field reference for construction and installation of erosion and sedimentation control measures and devices (does not include design charts). The *North Carolina Sediment Control Inspector's Guide* explains how to conduct inspections and evaluate projects, what to look for, and how to interact with customers. The *North Carolina Erosion and Sediment Control Practices: Video Modules* demonstrate the actual construction of 12 of the most commonly installed erosion and sediment control measures. Information for purchasing these materials can be found at the NCDEHNR Web site at http://www.dlr.enr.state.nc.us/pages/sedimentation.html.

The Texas Department of Transportation developed specifications for the use of compost for erosion control in the form of temporary erosion control devices and biodegradable erosion control logs. These specifications include a description of the practice, materials required, and construction, installation, and maintenance of the control. The specifications and other information about the use of compost for erosion control can be found at the Texas Department of Transportation Web site at http://www.dot.state.tx.us/des/landscape/compost/specifications.htm.

The Composting Council Research and Education Foundation and the U.S. Composting Council (no date) developed a manual describing ways in which compost can be used for state highway projects. The manual includes case study examples of compost use for slope stabilization, vegetation establishment, and erosion and sediment control; compost specifications and analytical testing methods; and statistics describing compost usage. *Compost Use on State Highway Applications* can be downloaded in PDF format from http://www.epa.gov/epaoswer/non-hw/compost/highway/.

8.5 References

Aicardo, R. 1996. Screening of Polymers to Determine Their Potential Use in Erosion Control on Construction Sites. In *Proceedings from Conference held at College of Southern Idaho: Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide, May 6–8, 1996, Twin Falls, Idaho*. University of Idaho Miscellaneous Publication No. 101-96.

American Public Works Association (APWA). 1991. *Water Quality: Urban Runoff Solutions*. The American Public Works Association, Chicago, IL.

Barrett, M.E., J.E. Kearney, T.G. McCoy, J.F. Malina, R.J. Charbeneau, and G.H. Ward. 1995. *An Evaluation of the Use and Effectiveness of Temporary Sediment Controls*. Technical Report CRWR 261, Center for Research in Water Resources, The University of Texas at Austin.

Borroum, S., and M. McCoy. 2000. The California Experience. *Civil Engineering* July:38–43.

Brown, W., and D. Caraco. 1997. Muddy Water In—Muddy Water Out? A Critique of Erosion and Sediment Control Plans. *Watershed Protection Techniques* 2(3):393–403.

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

Caine, E. 2001. *Quilceda-Allen Watershed Erosion Control Program Water Quality Monitoring Report.* Snohomish County Department of Planning and Development Services, Everett, WA.

California Regional Water Quality Control Board. 1999. *Erosion and Sediment Control Field Manual,* 3rd ed. California Regional Water Quality Control Board, San Francisco Bay Region, Oakland, CA.

Canning, D.J. 1988. *Construction Erosion Control: Shorelands Technical Advisory Paper No. 3.* Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, WA.

Center for Watershed Protection (CWP). 1997a. Keeping Soil in Its Place. *Watershed Protection Techniques* 2(3):418–423.

Center for Watershed Protection (CWP). 1997b. Practical Tips for Construction Site Phasing. *Watershed Protection Techniques* 2(3):413–417.

Center for Watershed Protection (CWP). 1997c. The Limits of Settling. *Watershed Protection Techniques* 2(3):429–433.

Center for Watershed Protection (CWP). 1997d. Strengthening Silt Fence. *Watershed Protection Techniques* 2(3):424–428.

Center for Watershed Protection (CWP). 1997b. Improving the Trapping Efficiency of Sediment Basins. *Watershed Protection Techniques* 2(3):434–439.

City of Knoxville, Tennessee. 2001. *Best Management Practices (BMP) Manual*. City of Knoxville, Engineering Department, Stormwater Engineering Division. http://www.ci.knoxville.tn.us/engineering/bmp_manual. Last updated March 2001. Accessed April 24, 2002.

Deering, J.W. 2000a. *Allowance Item for Soil Erosion and Sediment Control Plan/Measures*. John W. Deering, Inc., Bethel, CT.

Deering, J.W. 2000b. *Phasing, Sequence, and Methods*. John W. Deering, Inc., Bethel, CT.

Delaware Department of Natural Resources and Environmental Control (DNREC). No date. Section 13—Contractor Certification Program. Delaware Department of Natural Resources and Environmental Control, Dover, DE. http://www.dnrec.state.de.us/newpages/ssregs14.htm. Accessed March 9, 2000.

Delaware Department of Natural Resources and Environmental Control (DNREC). 1989. *Delaware Erosion and Sediment Control Handbook*. Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Dillaha, T.A., J.H. Sherrard, and D. Lee. 1989. Long Term Effectiveness of Vegetative Filter Strips. *Water Environment and Technology* 1:418–421.

Entry, J.A., and R.E. Sojka. 1999. Polyacrylamide Application to Soil Reduces the Movement of Microorganisms in Water. In *1999 Proceedings of the International Irrigation Show*. Irrigation Association, Orlando, FL, November 9, 1999, pp. 93–99.

Environmental Law Institute. 1998. *Almanac of Enforceable State Laws to Control Nonpoint Source Water Pollution*. Environmental Law Institute, Washington, DC.

Environmental Technology Evaluation Center (EvTEC). 2001. *Environmental Technology Verification Report for Installation of Silt Fence Using the Tommy Static Slicing Method*. Environmental Technology Evaluation Center, Civil Engineering Research Foundation, Washington, DC.

Faircloth, W. 1999. Searching for a Practical, Efficient, Economical Sediment Basin. In *Proceedings of Conference 30*, International Erosion Control Association, Nashville, TN, February 22–26, 1999, pp. 271–282.

Franklin County, Florida. 1987. *Land Planning Regulations for the Appalachicola Bay Area of Critical State Concern.* Franklin County Administration Commission, Appalachicola, FL.

Goldman, S.J., K. Jackson, and T.A. Borstztynksy. 1986. *Erosion and Sediment Control Handbook.* McGraw-Hill, Inc., New York, NY.

Goldstein, N. 2002. Compost and storm water management—tapping the potential. *BioCycle* (August 2002): 33–38.

Harding, M.V.. 1990. *Erosion Control Effectiveness: Comparative Studies of Alternative Mulching Techniques*. Environmental Restoration, pp. 149–156. Cited in USEPA. 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA 840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Jarrett, A.R. 1999. Designing Sedimentation Basins for Better Sediment Capture. In *Proceedings of Conference 30*, International Erosion Control Association, Nashville, TN, February 22–26, 1999, pp. 217–234.

Landschoot, P. 1997. *Erosion Control & Conservation Plantings on Noncropland*. Pennsylvania State University, College of Agricultural Sciences, University Park, PA.

Loser, J. 2003. Comments on *National Management Measures to Control Nonpoint Source Pollution from Urban Areas—Draft*. U.S. Department of Agriculture, Natural Resources Conservation Service. Beltsville, MD.

Maine Department of the Environment (MDEP). 1999. *Maine Department of Environmental Protection Issue Profile: Voluntary Contractor Certification Program*. http://www.maine.gov/dep/blwq/training/ip-vccp.htm. Last updated August 1999. Accessed March 9, 2000.

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

Millen, J.A., A.R. Jarrett, and J.W. Faircloth. No date. *Improved Sedimentation Basin Performance with Barriers and a Skimmer*. Pennsylvania State University, Agricultural and Biological Engineering Department, University Park, PA.

Minton, G.R., and A.H. Benedict. 1999. Use of Polymers to Treat Construction Site Stormwater. In *Proceedings of a Conference 30*, International Erosion Control Association, Nashville, TN, February 22–26, 1999, pp. 177–188.

National Association of Home Builders (NAHB). 1995. *Storm Water Runoff & Nonpoint Source Pollution Control Guide for Builders and Developers*. National Association of Home Builders, Washington, DC.

National Cooperative Highway Research Program (NCHRP). *Primer—Environmental Impact of Construction and Repair Materials on Surface and Ground Water*. Report 443. National Academy Press, Washington, DC.

Natural Resources Defense Council (NRDC). 1999. *Stormwater Strategies: Community Responses to Runoff Pollution*. Natural Resources Defense Council, New York, NY.

North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR). No date. *Technical Assistance: Publications List*. http://www.dlr.enr.state.nc.us/pages/sedimentation.html. Accessed April 24, 2002.

Price and Company, Inc. 2004. *Case Files: Wal-Mart*. http://www.priceandcompany.com/case%20studies/Wal-Mart.pdf. Last updated March 29, 2004. Accessed June 2, 2004.

Reice, S.R., and R.N. Andrews. 2000. *Effectiveness of Regulatory Incentives for Sediment Pollution Prevention: Evaluation Through Policy Analysis and Biomonitoring*. Prepared for the U.S. Environmental Protection Agency by the University of North Carolina, Chapel Hill, under EPA Grant No. R 825286-01-0.

Roa-Espinosa, A., G.D. Bubenzer, and E.S. Miyashita. No date. *Sediment and Runoff Control on Construction Sites Using Four Application Methods of Polyacryalmide Mix*. Dane County Land Conservation Department, Madison, WI.

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

Schueler, T. 1997. Improving the Trapping Efficiency of Sediment Basins. *Watershed Protection Techniques* 2(3):434–439.

Smolen, M.D., D.W. Miller, L.C. Wyatt, J. Lichthardt, and A.L. Lanier. 1988. *Erosion and Sediment Control Planning and Design Manual*. North Carolina Sedimentation Control Commission, Raleigh, NC.

Soil Quality Institute (SQI). 2000. *Soil Quality—Urban Technical Note No. 1: Erosion and Sedimentation on Construction Sites*. www.statlab.iastate.edu/survey/SQI/urban.shtml. Last updated September 18, 2000. Accessed March 26, 2001.

Sojka, R.E., and R.D. Lentz, eds. 1996. Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. In *Proceedings from Conference held at College of Southern Idaho, Twin Falls, Idaho.* May 6–8, 1996. University of Idaho Miscellaneous Publication No. 101-96.

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

Stahre, P., and B. Urbonas. 1990. *Stormwater Detention for Drainage, Water Quality, and CSO Management*. Prentice Hall, Englewood Cliffs, NJ.

Theisen, M. 1996. How to Make Vegetation Stand Up Under Pressure. *Civil Engineering News*.

Tyler, R. 2001. Compost filter berms and blankets take on the silt fence. *BioCycle* (January 2001).

U.S. Army Corps of Engineers (USACE). 1990. *Anacostia River Basin Reconnaissance Study*. U.S. Army Corps of Engineers, Baltimore District, Baltimore, MD.

U.S. Environmental Protection Agency (USEPA). 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices*. U.S. Environmental Protection Agency, Office of Water, Washington DC.

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

U.S. Environmental Protection Agency (USEPA). 1999. *Storm Water Technology Fact Sheet: Turf Reinforcement Mats*. EPA 832-F-99-002. U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC.

U.S. Geological Survey (USGS). 1978. *Effects of Urbanization on Streamflow and Sediment Transport in the Rock Creek and Anacostia River Basins, Montgomery County, Maryland, 1962-74*. Professional paper 1003. United States Government Printing Office, Washington, DC.

U.S. Geological Survey (USGS). 2000. *Soil Erosion from Two Small Construction Sites, Dane County, Wisconsin*. USGS FS-109-00. U.S. Geological Survey, Middleton, WI.

Washington State Department of Ecology. 1989. *Nonpoint Source Pollution Assessment and Management Program*. Document No. 88-17. Washington State Department of Ecology, Water Quality Program, Olympia, WA.

Washington State Department of Ecology. 1991. *Stormwater Management Manual for the Puget Sound Basin.* Public Review Draft. Washington State Department of Ecology, Olympia, WA.

Welsch, J.D. No date. *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources*. U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry, Randnor, PA.

Wisconsin Legislative Council. 1991. *Wisconsin Legislation on Nonpoint Source Pollution*. Wisconsin Legislative Council, Madison, WI.

Wishowski, J.M., M. Mamo, and G.D. Bubenzer. 1998. *Trap Efficiencies of Filter Fabric Fence*. Paper No. 982158. American Society of Agricultural Engineers, St. Joseph, MI.

Woodward-Clyde Consultants. 1991. *Urban BMP Cost and Effectiveness Summary Data for 6217(g) Guidance: Erosion and Sediment Control During Construction.* Draft. Woodward-Clyde Consultants, Herndon, VA.

Yu, S., S. Barnes, and V. Gerde. 1993. *Testing of Best Management Practices for Controlling Highway Runoff*. Virginia Transportation Research Council. FHWA/VA-93-R16, p. 60.

Also in Performance of Grassed Swales Along East Coast Highways. *Watershed Protection Techniques* 1(3, Fall):122–123.

MANAGEMENT MEASURE 9
POLLUTION PREVENTION

9.1 Management Measure

Implement pollution prevention and education programs to reduce nonpoint source pollutants generated from the following activities:

- The improper storage, use, and disposal of household chemicals, including automobile fluids, pesticides, paints, solvents, etc.;
- Lawn and garden activities, including the improper application and disposal of lawn and garden care products, and the disposal of leaves and yard trimmings;
- Turf management on golf courses, parks, and recreational areas;
- Commercial activities, including parking lots and gas stations;
- Improper disposal of pet wastes; and
- Activities that generate trash.

9.2 Management Measure Description and Selection

9.2.1 Description

This management measure is intended to prevent or reduce nonpoint source pollutant loadings generated from a variety of activities within urban areas. Everyday activities of citizens, municipal employees, and businesses have the potential to contribute to nonpoint source pollutant loadings. These activities include improper use and disposal of household chemicals, lawn and garden maintenance, turf grass management, operation and maintenance of diesel and gasoline vehicles, illicit discharges to urban runoff conveyances, commercial activities, and improper pet waste disposal. Reducing pollutant generation can decrease adverse water quality impacts from these sources.

The practices presented in this management measure are often referred to as source reduction practices. They are nonstructural in nature (i.e., they do not require infrastructure) and can be used to reduce pollutant generation and maintenance costs. Source control practice costs are typically associated with programmatic expenses such as signage, outreach materials, workshops, and development and enforcement of ordinances. Although agricultural sources are not specifically addressed in this chapter, agricultural sources in an urban or suburban watershed should also be considered when developing a pollution prevention plan (see Management Measure 1 – Program Framework and Objectives). Source controls for agriculture can be found

Getting in Step: A Guide to Effective Outreach in Your Watershed

Getting in Step is a guide published by EPA to provide a summary of useful tools for developing and implementing an effective watershed outreach plan. The manual uses a step-by-step approach to help watershed practitioners address public perceptions, promote management activities, and inform or motivate stakeholders. Getting in Step is divided into three parts, as follows:

- Part I presents the overall framework for developing and implementing an outreach plan. It provides specific information about defining goals and objectives; identifying the target audience; creating, packaging, and distributing the message; and evaluating the outreach plan.
- Part II provides tips and examples for developing and enhancing outreach materials, with emphasis on elements of composition and layout, using artwork and photos, establishing a watershed identity, packaging the watershed message, and estimating costs.
- Part III provides specific tips on working with the news media to gain improved media coverage of water quality issues.

Getting in Step also includes worksheets, graphics for use without permission, and information on additional outreach and education resources. The manual is available for download from http://www.epa.gov/owow/watershed/outreach/documents/getnstep.pdf or by calling Books on Demand at 1-800-521-3042.

in *National Management Measures to Control Nonpoint Source Pollution from Agriculture*, which can be accessed at http://www.epa.gov/owow/nps/agmm/index.html.

9.2.1.1 Household chemicals

Many everyday household chemicals are flammable, combustible, toxic, explosive/reactive, or corrosive. If these chemicals are released into the environment, they can pose long-term threats to human health, wildlife, vegetation, and other environmental resources. Unlike industrial hazardous wastes, not all household chemicals are regulated by federal, state, and local laws. In fact, the Federal Resource Conservation and Recovery Act, which regulates hazardous waste, has a special exemption for “household hazardous wastes” as defined in the act (Kopel, 1998). It is important to note that state and local regulations may be more stringent than federal regulations. The Federal Insecticide, Fungicide, and Rodenticide Act regulates the use and disposal of pesticides, herbicides, and fungicides through labeling. It is important that users of these chemicals follow label instructions carefully, because they provide specific information that help prevent harm to human and environmental health.

The four main avenues for household chemicals to become problem pollutants are through leaks and spills, improper use, improper storage, and improper disposal.

(1) *Leaks and spills*. Chemicals leaking from improperly maintained automobiles and lawn equipment or faulty containers can accumulate on roads, driveways, and lawns and be carried by runoff to receiving water bodies.

(2) *Improper use*. Failure to follow label instructions properly may result in over-application of fertilizers or pesticides and can lead to chemical accumulation in the soil and grass. These chemicals can leach to ground water or be carried by runoff to surface waters.

(3) *Improper storage*. Improper storage of chemicals can lead to spills that can contaminate runoff and ground water or result in dangerous chemical reactions.

(4) *Improper disposal*. It is a common practice for citizens to pour unwanted chemicals, such as detergents, cleansers, or automotive fluids, onto their lawns or driveways or directly down storm drains. Contrary to popular belief, most storm sewers do not connect to wastewater treatment plants—chemicals disposed of this way could be discharged directly to receiving water bodies. Additionally, when chemicals are poured down drains connected to a wastewater treatment plant or septic system, they could interfere with treatment systems by killing the bacteria that metabolize pollutants, causing water discharged from the plants to be contaminated. Ground water is also at risk because runoff can carry these chemicals through the soil to the water table. Product labels describe requirements for proper disposal and should be followed carefully.

(5) *Outdoor car washing*. This activity can result in high loads of nutrients, metals, and hydrocarbons being carried to receiving waters during dry weather conditions when the wash water flows into the storm drain system. According to surveys, 50 to 75 percent of households wash their own cars and 60 percent of those households wash their cars at least once a month (Schueler and Swann, 2000b).

9.2.1.2 Failing septic systems

Approximately one in four American households relies on a septic system to dispose of their wastewater. Septic systems have a failure rate of 5 to 35 percent, depending on soil conditions and other factors. When septic systems fail, the untreated or partially treated wastewater discharges to surface and ground waters. A survey conducted in the Chesapeake Bay watershed found that the average age of septic systems in the area was about 27 years, which is seven years beyond the design life of an unmaintained system. About half the owners indicated that they had not inspected or cleaned out their system in the previous three years. (Schueler and Swann, 2000b).

9.2.1.3 Lawn and garden activities

Lawn care practices are often targeted by watershed managers as contributors of pesticides and nutrients to runoff. A nationwide study by the U.S. Geological Survey (USGS) in 1999 found a high incidence of insecticides and herbicides in urban streams. Insecticides commonly used in homes, gardens, and commercial areas were found more frequently and in higher concentrations in urban streams than in agricultural streams. These concentrations often exceeded guidelines for the protection of aquatic life. Herbicides, such as those used for weed control, were found in 99 percent of sampled streams, but rarely at levels that exceeded guidelines.

A recent summary of the water quality monitoring efforts by USGS's National Water Quality Assessment Program (2004) revealed high concentrations of pesticides, most commonly diazinon, malathion, chlorpyrifos, and carbaryl, in urban waterways; these chemicals were typically found in higher concentrations in urban streams than in agricultural streams. Although several of these pesticides are used commonly in household applications, findings in Thornton Creek near Seattle suggested that many of the pesticides were from commercial or municipal activities because the chemicals are not readily available on the retail market.

Surveys showed that roughly half of the total diazinon applications in the San Francisco Bay Region were to lawns and landscaped areas. In 1995, 27 percent of urban creeks sampled in the San Francisco Bay Region demonstrated potentially toxic levels of diazinon (Katznelson and Mumley, 1997). Research on diazinon indicates that even proper use, characterized by following label instructions, can result in harmful levels of diazinon in urban streams (Schueler and Swann, 2000d).

While these results alone do not specify the relative contribution of lawn care activities to urban pollution, they do indicate that there is a need for watershed-specific management actions. Many aspects of the risks associated with commonly occurring pesticides in the environment are not yet clearly understood. Drinking water standards have only been established for 10 of the 75 pesticides detected by the USGS National Water Quality Analysis**,** and aquatic life criteria have been developed for only six (Graffy, 1998; USGS, 1999).

Maintaining a healthy lawn might require fertilizers, pesticides, and heavy watering in some areas. Overuse of fertilizers, pesticides, and water can lead to excessive growth, increased pest problems, and environmental damage. In terms of fertilizer inputs, nutrients typically are applied to lawns at about the same rates as for row crops. One study in Marquette, Michigan, indicated that nitrogen and phosphorus concentrations in runoff from lawns were five to 10 times higher than runoff from other land uses (Schueler and Swann, 2000e). Contrary to popular belief, it is possible to achieve a beautifully landscaped yard with judicious use of fertilizers, pesticides, and irrigation. A large body of literature by turf researchers shows that healthy and well-managed turf grass can actually slow runoff and trap pollutants (Beard and Green, 1994; Schueler and Swann, 2000c; USEPA, 1992). The products applied to lawns—fertilizers, pesticides, and herbicides—can pollute runoff if label instructions are not properly followed. Studies on the characteristics of urban lawns have shown that the soils are often compacted, increasing runoff to the point that it is comparable to runoff on some pavements (NCSCS, 2000). Fertilizers contain nitrogen and phosphorus, which become pollutants when runoff carries excess fertilizers into lakes and streams. Excessive nutrients stimulate algae growth that can lead to death and decay of aquatic vegetation due to light and oxygen deprivation.

Lawns also require physical maintenance in the form of mowing, raking, and removing weeds, clippings, and branches. Yard trimmings comprised 12 percent of the total tonnage of municipal solid waste generated in 2000, second only to paper products (USEPA, 2002). Alternative practices can reduce the quantity of yard wastes generated by lawns and enable reuse of yard wastes to extend the capacity of landfills.

9.2.1.4 Commercial activities

Runoff from commercial land uses, such as shopping centers, office parks, and parking lots or garages may contain high hydrocarbon loadings and metal concentrations that are twice those found in the average urban area. These loadings can be attributed to heavy traffic volumes and large areas of impervious surface on which automotive-related pollutants concentrate (refer to Management Measure 7, Bridges and Highways, for a discussion of automobile-related pollutants). Other commercial uses, such as vehicle maintenance, liquids storage, and equipment storage and maintenance, can also introduce pollutants to runoff.

In most communities, gas stations are designated as a commercial land use and are subject to the same controls as shopping centers and office parks. However, gas stations may generate high concentrations of heavy metals, hydrocarbons, and other automobile-related pollutants. Since gas stations have high potential loadings and pollutant profiles similar to those of industrial sites, good housekeeping controls, such as those used on industrial sites, are recommended.

Restaurants are sometimes considered hot spots for nonpoint source pollution because they generate oils and grease that can contaminate runoff when disposed of improperly. Grease can also clog sanitary sewer laterals if sinks are not equipped with grease traps or interceptors, resulting in sanitary sewer overflows and increased maintenance of sewer lines. Poor housekeeping practices in the outdoor areas of restaurants, such as storing food waste in uncovered or leaky garbage bins and dumpsters or hosing off floor mats in the parking lot, can cause bacteria, detergents, organic matter, and other pollutants to come into contact with runoff.

Municipalities can target pollution prevention campaigns to specific commercial activities that are suspected of contributing to nonpoint source pollution. Typically, these campaigns involve an assessment of commercial facilities to identify the types of waste produced. The campaigns also outline methods to reduce the total amount of pollutants generated on-site and to properly dispose of pollutants. A set of rules and use limitations that a commercial tenant must agree to as a condition of occupying a site can be implemented in commercial covenants, conditions, and restrictions.

9.2.1.5 Pet wastes

When pet waste is not properly disposed of, it can wash into nearby water bodies or be carried by runoff into storm drains. Since most urban storm drains do not connect to treatment facilities, but rather drain directly into lakes and streams, untreated animal waste can become a significant source of runoff pollution. As pet waste decays in a water body, the degradation process uses oxygen and sometimes releases ammonia. Low oxygen levels and the presence of ammonia, combined with warm temperatures, can be toxic to fish and aquatic life. Pet waste also contains nutrients that promote weed and algae growth. Perhaps most importantly, pet waste carries microbes, such as bacteria, viruses, and parasites, that can pose a health risk to humans and wildlife. For example, fatalities in sea otters off the coast of California have been traced to a protozoan, *Toxoplasma gondii*, found in cat feces. *T. gondii* can cause fatal brain infections in otters and muscle cysts in humans (Glausiusz, 2002). Pet waste can be controlled through enforcement of ordinances (e.g., warnings and citations, public education, signage, and disposal containers).

9.2.1.6 Trash

Trash and floating debris in waterways have become significant pollutants, especially near urban areas where a large volume of trash can be generated in a concentrated area. Trash contributes to visual pollution and detracts from the aesthetic qualities of the landscape. Boaters have complained that trash and debris clog engine intake valves and propellers, resulting in expensive repairs. Finally, municipalities must incur the cost of clean-up efforts to restore water quality.

9.2.2 Management Measure Selection

This management measure was selected to identify ways in which communities can implement practices that bring about behavioral changes to reduce nonpoint source pollutant loading from the sources listed in the management measure. Such activities include public education, proper management of maintained landscapes, source reduction, training and runoff control plans for commercial sources, pet waste management activities, and trash control. Communities can select practices that best fit local priorities and funding. It is important for the watershed manager to note that community acceptance is often the major determinant of whether education and outreach activities and administrative mechanisms such as certification and training requirements are practical and effective solutions.

9.3 Management Practices

9.3.1 Household Chemicals

A host of biodegradable cleaners and other less-toxic chemicals are commercially available. Such alternative products typically contain chemicals that rapidly break down in soil and water into fewer toxic constituents, or they are reusable or recyclable. These include low-phosphate or phosphate-free detergents and water-based products. These alternative products can be used in combination with traditional chemicals as part of an integrated pest management program or for everyday household cleaning. Although there may be instances when it is necessary to use stronger chemicals (for example, to target bacteria), often a simple, milder cleanser will do the job.

Although alternative products are generally less harmful than commercial cleaners, it is still just as important to follow their instructions for proper storage and handling. Alternative products and homemade mixtures should be stored in clean, store-bought containers and properly labeled to avoid confusion with food or drink (USEPA, no date; USEPA and Perdue University, 1997). While some alternative products may claim to be disinfectants, cleaners that are registered as disinfectants must meet EPA testing requirements. The EPA's *Source Reduction Alternatives Around the Home*, which is part of the *Consumer Handbook for Reducing Solid Waste*, provides a brief discussion of alternative cleaning methods as well as proper storage and handling procedures (USEPA, no date).

A 1994 study compared commercial cleaners with various alternative products, including lemon juice, vinegar, ammonia, baking soda, and borax. The study found that commercial cleaners were more effective than the alternatives at both soil removal and microbial reduction. Alternative cleaners were found to achieve soil removal with some additional work. Among the alternative cleaners, borax and ammonia were most effective at soil removal. Vinegar was most effective in reducing microbial contamination. The study recommended sequential use to maximize cleaning effectiveness (USEPA and Purdue University, no date).

The key to preventing household chemicals from entering receiving waters is to educate the public about the importance of taking care when storing and disposing of everyday materials.

The practices discussed below are intended to inform the public on proper procedures for handling and disposing of household chemicals to prevent pollution and to instill a sense of responsibility for their actions and choices as consumers.

9.3.1.1 Educate the public on proper storage and disposal of household chemicals

Watershed managers can produce outreach materials describing methods that citizens should follow to store household chemicals in appropriate containers and storage areas to prevent leaks, spills, accidental ingestion, and fire or explosion hazards. Tips can include covering piles of chemicals that can come into contact with rainfall or runoff; ensuring that containers for volatile, corrosive, or otherwise harmful chemicals are intact; and clearly labeling all containers with the name of the material and proper storage and disposal procedures. Pesticides, herbicides, and fungicides are addressed below in the Pest Management section.

Citizens should also be encouraged to follow the manufacturer's recommendations for disposal of household chemicals. Many communities across the country have implemented programs to collect and safely dispose of these chemicals, such as providing year-round collection facilities or sponsoring what many communities call “household hazardous waste” collection days. Effective outreach programs keep citizens informed about the location and hours of operation of disposal facilities and provide a list of waste products that are accepted.

Recycling of certain household chemicals, especially used oil and batteries, can reduce the amount of potentially harmful materials that enter a landfill. Many municipalities and automotive service stations provide used oil and antifreeze recycling facilities for “do-it-yourselfers” to encourage environmentally sound chemical management. Outreach materials, such as pamphlets and utility bill inserts, can be developed to inform the public of locations and hours of operation of local recycling facilities.

9.3.1.2 Conduct storm drain marking

Storm drain marking involves labeling storm drain inlets with painted or prefabricated messages that warn citizens of the environmental hazards of dumping materials into storm drains. Marking projects are typically conducted by volunteer groups in cooperation with local authorities. The messages can be a simple phrase to remind passersby that the storm drains connect to local water bodies and that dumping pollutes those waters. Some specify which water body the inlet drains to or name the particular river, lake, or bay. Common messages include “No Dumping—Drains to Water Source,” “Drains to River,” and “You Dump it, You Drink it. No Waste Here.” Communities with a large Spanish-speaking population might wish to develop markers in both English and Spanish or use a graphic without text (Davenport, 2003).

9.3.1.3 Encourage responsible car washing practices

Schueler and Swann (2000b) summarized results of several surveys of automobile owners and their car washing behavior. The researchers found that 55 to 70 percent of households wash their own cars, with the remainder taking their cars to commercial car washes. Sixty percent of residents washed their cars at least once a month, and between 70 and 90 percent of residents reported that their car wash water drained directly to the street and presumably into the runoff conveyance system. These results indicate that an appreciable amount of wash water laden with detergents, dirt, and automotive fluids can wash into the storm drain system or directly into receiving waters in urban areas.

It is preferable for citizens to patronize commercial car washing facilities because they are mandated under the regulatory authority of the NPDES program (see the Introduction for a description of the NPDES program) to treat and/or reuse wash water, whereas residential car washing activities are exempt from requirements under Phase I MS4 permits and Phase II general permits (USEPA, 2003b). If commercial facilities are not available or if residents prefer to wash their cars themselves, they should be encouraged to wash their cars less often, especially in areas with water bodies sensitive to nutrient enrichment. Another practice to reduce the impact of car washing on receiving waters is to wash cars on grass or another permeable surface to filter dirt and detergents (this practice should be avoided in areas that recharge drinking water supplies). Additionally, citizens should use a sponge and bucket to reduce the amount of wash water used and to allow it to be disposed of down a household drain that is connected to the sanitary sewer or septic system. Finally, low-phosphate detergents should be used to minimize the eutrophic effects of wash water in receiving waters.

Community car washes, such as those conducted for fundraisers, are not specifically addressed in Phase II MS4 requirements, but may be a particularly large source of contaminated runoff. Some communities are experimenting with fundraiser registration, practices that block storm drains during community car washes, and the designation of pervious areas for the diversion of runoff. Kitsap County, Washington, uses a patented device called a Bubble Buster to divert water away from storm drains during community car washes (USEPA, 2003b).

9.3.2 Lawn, Garden, and Landscape Activities

Lawns are a significant feature of urban landscapes. This large area of managed landscape has the potential to contribute to urban runoff pollution due to over-fertilization, overwatering, over-application of pesticides, and direct disposal of lawn clippings, leaves, and trimmings. Also, erosion from bare patches of poorly managed lawns contributes sediment to watercourses, and disposal of lawn clippings in landfills can reduce the capacity of these facilities to handle other types of waste. Public education for citizens and municipal crews with respect to pest tolerance and proper handling of fertilizers, pesticides, water, and yard waste can greatly reduce the potential for adverse impacts to waters receiving runoff from lawns. Municipalities and watershed managers should develop an outreach campaign that targets citizens, lawn care businesses, landscapers, and municipal crews. Materials should highlight the following steps to help citizens and lawn care professionals maintain healthy, attractive lawns with less maintenance and fewer chemical inputs:

- Lawn conversion
- Soil building
- Grass selection
- Mowing and thatch management
- Minimal fertilization
- Weed control and tolerance
- Pest management
- Sensible irrigation

While all of the above practices are applicable to both citizens and lawn care professionals, they will differ when implemented due to differences in scale. For example, lawn care services may have multiple employees, carry large quantities of fertilizers and pesticides, and manage vast expanses of turf. Therefore, in addition to the above practices, good housekeeping is particularly important for lawn care professionals, landscapers, and municipal crews. Housekeeping includes implementing materials management and spill prevention plans and conducting employee training (see the Commercial Activities section). In addition, site development considerations for landscaped areas and golf courses should aim to protect local water bodies by avoiding sensitive areas, providing sufficient buffers, and ensuring erosion and sediment control during construction and maintenance activities (Center for Resource Management, 1996). See Management Measure 3—Watershed Protection and Management Measure 8—Construction Site Erosion and Sediment Control for more information about buffers and erosion and sediment control, respectively. Information resources specific to citizens and landscape professionals are provided at the end of this chapter.

Local cooperative extension services can provide assistance with the practices described in this section. State-specific cooperative extension service information is available from the Cooperative State Research, Education, and Extension Service (CSREES) at http://www.csrees.usda.gov/qlinks/partners/state_partners.html. Cooperative extensions are part of a nationwide organization authorized by Congress, and each state has designated a land grant university to administer its cooperative extension. Cooperative extensions conduct applied research and educational outreach such as workshops, conferences, fact sheets, and newsletters. These organizations are an excellent resource for information and assistance with lawn care practices. For example, the Virginia Tech Cooperative Extension Web site, http://www.ext.vt.edu/, maintains the *Database of Fact Sheets on Home Gardening and Insecticides/Pesticides*. The Rutgers University Cooperative Extension publishes fact sheets such as *How to Calculate the Amount of Fertilizer Needed for your Lawn* and *Best Management Practices for Home Lawns* (http://www.rce.rutgers.edu/).

NRCS's Backyard Conservation

USDA's Natural Resources Conservation Service (2000) Web site sponsors a Backyard Conservation Web site (http://www.nrcs.usda.gov/feature/backyard/) that presents technical information and management practices to "increase food and shelter for birds and other wildlife, control soil erosion, reduce sediment in waterways, conserve water and improve water quality, inspire a stewardship ethic, and beautify the landscape." The Web site includes 10 conservation practice standards, such as composting, mulching, nutrient management, pest management, and terracing, which have been modified for use in suburban landscapes.

9.3.2.1 Lawn conversion

Grasses are very water-hungry and labor-intensive landscaping plants when compared to ground cover, flowers, shrubs, and trees. Therefore, to reduce the maintenance requirements of a lawn and address problem areas where turf is difficult to grow, property owners could identify areas where turf grass can be replaced with other types of plantings. These areas include lawn edges, frost pockets, exposed areas, dense shade, steep slopes, and wet, boggy areas. Replacement vegetation that is best suited to local conditions should be chosen to replace turf. Recommendations for drought-tolerant plants are available from a local extension office. State-specific cooperative extension service information is available from the Cooperative State Research, Education, and Extension Service (CSREES) at http://www.csrees.usda.gov.

9.3.2.2 Soil building

Lawn owners should analyze their soil every one to three years to determine its suitability for supporting a lawn and to identify whether additives are needed or adjustments should be made to optimize growing conditions. Soil characteristics that should be measured include pH, fertility, compaction, texture, and earthworm content. Soil test kits (for pH and fertility) can be purchased inexpensively at a garden center, or samples can be analyzed for free by a local cooperative extension service. Soil tests reveal whether fertilizer or lime is needed, helping to avoid over-fertilization and loss of nutrients. Surveys have indicated that only 10 to 20 percent of citizens test their soil to determine fertilization needs (Schueler and Swann, 2000c).

Prior to planting, sandy and heavy clay soils may be amended by adding organic compost to improve aeration and nutrient-holding capacity. Compacted soil under an established lawn should be aerated to improve the flow of water, fresh air, and nutrients to the system. Aeration is a non-chemical technique that relieves compaction, increases rooting, helps prevent thatch accumulation, incorporates organic matter into the soil surface, and helps prevent damage by insects and disease (Troutman, 2003). Core cultivators, which aerate by pulling small plugs of soil from the lawn, can be found at many local rental agencies (Mugaas, 1999). Soil texture can be determined with a settling test or by squeezing a handful of moistened soil through the fist. If soils prove to be very sandy or very clayey, organic matter such as compost, manure, or grass clippings should be added (USEPA, 1992). While the presence of earthworms is an indicator of healthy soil, the presence of white, healthy roots is the ultimate goal. Rooting can be checked by cutting a four-inch deep slice or plug of turf and soil. Roots should be at least four inches deep, and the tips should be white. Poor root condition may be a result of compacted soils, ineffective watering practices, or poor fertilization (Troutman, 2003). If a lawn does need soil amendments (e.g., an adjustment to pH or aeration to address compaction) a local cooperative extension service can provide the technical guidance necessary to care for the lawn properly (USEPA, 1992). State-specific cooperative extension service information is available from the Cooperative State Research, Education, and Extension Service (CSREES) at http://www.csrees.usda.gov. For more information on soil amendments, see the discussion of Erosion Control Practices in Management Measure 8—Construction Site Erosion, Sediment and Chemical Control.

9.3.2.3 Grass selection

Grass seed is available in a wide range of cultivated varieties, so citizens are able to choose the grass type that grows well in their particular climate, matches site conditions, and is consistent with the property owner's desired level of maintenance. Consideration should be given to seasonal variations in rainfall and temperature. Several grass varieties have been developed with increased resistance to disease and insect damage, which reduces pesticide use. Some turf varieties have high levels of endophytes, a fungus that does not threaten the grass but eradicates common lawn pests such as billbugs, sod webworms, and aphids. Tall fescue, zoysia grass, and Bermuda grass tend to be highly resistant to insects (Audubon Society, 2000). Other varieties have been selected to be slow growing, which requires less mowing, fertilizer, and water. Care should be taken to select the species and cultivated variety that are best adapted to the site conditions. Selecting the correct variety will result in a healthier lawn that is better able to compete with weeds and resist insects and disease (Bruneau, 2001; USEPA, 1992).

9.3.2.4 Mowing and thatch management

Each turf grass variety has an ideal mowing height range. Turf grasses use water more efficiently and out-compete weeds better when kept at the higher end of the ideal mowing height range. Mowing grass too short decreases rooting and increases the need for frequent watering. Tall turf competes more vigorously against weeds and can usually tolerate more insect and disease pressure (Troutman, 2003). Property owners might need to mow grass more frequently to maintain a minimum healthy height, depending on the type of grass planted and the local climate. Property owners should understand that grass grows at different rates throughout the seasons. As a result, some lawns may need to be mowed every four or five days when they are growing rapidly (Troutman, 2003). Therefore, grass should be mowed only as needed. If excessive thatch (which can prevent nutrients and water from reaching grass roots) has developed, the lawn should be dethatched by raking or using an automated dethatcher, or it could be sprinkled with compost and then aerated. Some grasses are more prone to developing thick layers of thatch than others. A thatch layer less than ½ inch can be beneficial by providing insulation and increasing the turf's resiliency (Mugaas, 1999; Murphy, 1994; USEPA 1992).

To prevent insects and weeds, property owners should mow high and frequently, and keep mower blades sharp to avoid tearing or injuring the grass. Longer grass is exposed to more sunlight, which allows it to develop a deep root system and increases tolerance to drought, insect damage, and disease. Lawns should not be cut shorter than 2½ to 3½ inches because weeds can grow more easily in short grasses. Grass can be cut lower in the spring and fall to stimulate root growth, but not shorter than 1½ inches (Audubon Society, 2000; USEPA, 1992). Table 9.1 lists recommended mowing heights for various types of grasses.

Table 9.1: Mowing heights for various grass types (PCLAA, No Date).

Grass Type	Mowing Height
Kentucky Bluegrass	3.0 in.
Fescues & Ryegrass	3.0 in.
Bent grass	1.0 in.
Bermuda grass	1.0 to 1.5 in.
Zoysia grass	1.0 to 1.5 in.
St. Augustine grass	3.0 in.
Bahia grass	3.0 in.
Centipede grass	1.5 in.

9.3.2.5 Yard waste management

Recent concerns about landfill capacity have prompted a number of states to ban the disposal of yard waste in landfills (Fickes, 2002). Approximately 3,800 yard waste composting programs were operating in the United States during 2000 (USEPA, 2002). Most of these were located in the Northeast, Midwest, and South where landfill capacity is of concern and many states have

Yard Waste Ban

In Syracuse, New York, a 1992 ban on yard waste disposal resulted in 45 percent of households composting yard waste and 55 percent leaving clippings on the lawn. The ban, instituted by the Onondaga County Resource Recovery Agency (OCRRA) in North Syracuse, prohibited grass, leaves, and brush from being disposed of with the trash. OCRRA has run an eight-year, $300,000 public education campaign. OCRAA's outreach program involves home composting workshops; the distribution of flyers, and TV, radio, and newspaper ads with the themes "A Recipe for Compost," "Time for a Trim," and "Keep Your Clippings on the Lawn" (Lalonde, 2000).

instituted yard waste bans. In the West, where landfill capacity is relatively high and no statewide yard waste bans exist, there are only approximately 400 composting programs.

Yard trimmings accounted for nearly half the municipal waste eliminated or diverted through source reduction programs in 2000 (USEPA, 2002). Source reduction has been a successful component of municipal waste management, and is a major reason why landfill capacity at a national level remains relatively constant. In fact, source reduction is estimated to have prevented a 25 percent increase in solid waste in 2000. As of 2000, 34 states had more than 10 years of landfill capacity remaining, 12 had five to 10 years, and two had less than five years of capacity remaining. (USEPA, 2002).

Yard clippings can be managed by reapplying them to lawns, or by composting at home or at community composting facilities. Reapplying clippings to yards, known as grass-cycling, reduces solid waste and can decrease the need for fertilizer and water by adding nutrients and limiting evaporation. Yard clippings do not contribute to thatch buildup, because thatch is comprised of the stems and roots of grass, not the blades (Mugaas, 1999; Relf, 1997). Removing a mower's collection bag is an easy way to automatically incorporate grass-cycling into regular mowing activities (PLCAA, no date (a)). Yard waste can also be composted and reapplied to improve water retention, add nutrients, and reduce erosion (Relf, 2001). Full bans on disposal are not the only option for yard waste management; partial bans and voluntary programs can also help to encourage citizens to employ yard waste management practices such as composting and leaving clippings on the lawn. Communities can integrate yard waste into their solid waste management program by offering curbside collection services or providing public drop-off sites (USEPA, 1994).

9.3.2.6 Minimal fertilization

Based on the results of the soil test described above, a lawn might require additional nutrients to promote or maintain healthy growth. Nutrients can be partly supplied by leaving a moderate amount of fine grass clippings on the lawn after mowing—these clippings can provide nearly half of the required nutrients to the lawn and they hold in moisture, speed decomposition, and relieve the burden of landfills to handle excess yard waste. Additional nutrients can be supplied with compost or commercial fertilizers that are of an organic or encapsulated nitrogen type, but they should be applied at or below the rates prescribed on the packaging. Compost or organic and encapsulated nitrogen fertilizers reduce the risk of nutrient leaching and have been shown to release nutrients more gradually. Slow-release fertilizers are also beneficial for reducing nitrogen losses from soils that are prone to leaching (Bureau, 2001). Organic products offer the additional benefits of increasing soil condition and promoting the growth of desirable soil organisms.

Timing of fertilization is very important. Cool-season grasses respond best to fall fertilization followed by light applications of fertilizer in the spring. Warm-season grasses generally benefit more from spring and summer fertilization. Fertilizers require water for activation; a light watering is usually enough (note that fertilizer should not be applied if rainfall is expected).

Excessive fertilization causes unwanted growth and the need to mow more often. Fertilizing at the wrong time of year may favor the growth of weeds rather than healthy turf. Excessive fertilization along with excessive watering can lead to the buildup of thatch that can increase insect and disease problems (Troutman, 2003).

The City of Austin recently commissioned Texas A&M University to conduct a study of the potential effects of residential lawn care practices on water quality in Stillhouse Spring, located in the environmentally sensitive recharge zone of the Northern Edwards Aquifer. Water quality tests have shown that nitrate levels in the aquifer are among the highest in the city. Nine different fertility treatments on test plots were studied. The plots were tested for appearance and the amount of nitrogen, phosphorous, and potassium that leached through the soil to ground water. The study resulted in a reevaluation of recommended fertilization practices for citizens. Recommendations still include soil testing, careful calculation of fertilizer amounts, and grass-cycling. However, researchers found that organically fertilized plots had less nitrogen leaching, were denser and more attractive, and were successful in retaining soil moisture and decreasing runoff in storm events. Because soils in Austin are particularly high in phosphorus, citizens in the area are now advised to use low-phosphorus fertilizers (Provin, 2002). Additional studies of residential lawn care practices and regionally specific runoff from urban lawns would be a beneficial addition to the large body of research on turf grass.

A local cooperative extension service should be consulted about the proper use of fertilizers. State-specific cooperative extension service information is available from the Cooperative State Research, Education, and Extension Service (CSREES) at http://www.csrees.usda.gov.

9.3.2.7 Weed control and tolerance

A property owner must decide how many weeds can be tolerated before action is taken to eradicate them. A few weeds will not substantially interrupt the continuity of the turf. The best way to keep weeds at bay is to maintain a healthy, dense lawn that shades the ground surface, preventing weed seedlings from taking root. However, if weeds do take hold, they should be dug or pulled out. Chemical herbicides should be used to spot-treat weeds, not applied universally. A local cooperative extension service should be consulted about the proper use of herbicides. State-specific information regarding cooperative extension services is available from CSREES at http://www.csrees.usda.gov.

9.3.2.8 Pest management

Integrated Pest Management (IPM) is an effective and environmentally sensitive approach that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This

Targeted Herbicide Application

Targeted herbicide application, which uses infrared and other technologies, can help locate and control roadside weeds at lower costs than conventional weed control methods (Stidger, 2001). Patchen, Inc., which is located in Ukiah, California, manufactures small sensors that can be used on trucks or other equipment to pinpoint the location of undesirable plants and then target and spray the weed with herbicide. Each sensor views a 12-inch wide area and upon finding weeds, it signals a spray nozzle to deliver a precise amount of herbicide. The unit will spray only on weeds and not on bare ground. Several California Department of Transportation districts have already mounted the sensors onto equipment. According to company reports, a side-mounted strip of sensors at the rear of the vehicle lets the unit target and spray roadside weeds at 10 miles an hour. Sensors can be also used at night when there is less traffic because the sensors have their own light source. Compared to broadcast or manual spot spraying, sensors reduce the quantity of herbicide used and cut overall costs by 50 to 80 percent. Sensors also cut costs by reducing required work hours, because only the driver is needed to apply the herbicide.

Research at North Carolina State University (Burton and Skroch, 1997) developed an herbicide applicator to attach to weed mowers to control roadside vegetation. The unit applies a film of chemical to the weed stem as the mower cuts the plant. Between 70 and 90 percent of the herbicide is absorbed into the plant to prevent future growth. With other methods, as much as 80 to 90 percent of the sprayed chemical misses its target and is wasted.

The Minnesota Department of Transportation tested four innovative herbicide sprayer designs in an effort to reduce costs. According to a research report, all four sprayers saved money when compared to traditional sprayer use. Net annual savings from each of the four sprayers ranged between $23,255 and $65,812.

information, in combination with available pest control methods, is used to manage pest damage by the most economical means and with the least possible hazard to people, property, and the environment.

IPM is not a single pest control method but a series of pest management evaluations, decisions, and controls. IPM is a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools. Biological controls involve the use of natural enemies to manage pests. Cultural practices include mowing, fertilization, irrigation, aeration, dethatching, and rolling. Physical controls include removal of insects and affected plant material by hand or removal of pests with store-bought traps. Chemical controls involve the use of pesticides. Municipalities can encourage citizens and lawn care professionals to practice IPM and train municipal maintenance crews to use these techniques for public open space.

Effective pest management begins with maintenance of a healthy, vigorous lawn that is naturally disease-resistant. Mulching can be used to prevent weeds where turf is absent; fencing can be installed to keep rodents out; and netting can be used to keep birds and insects away from leaves and fruit. Planting disease-resistant species and alternating different types of plants can help prevent infestation. In addition, simple pest prevention techniques can reduce the likelihood that pesticides will be needed. These include destroying hiding places such as diseased plants and fallen fruit, cleaning up pet waste, and removing puddles (USEPA, 1995). Citizens should monitor plants for obvious damage and should check for the presence of pest organisms. It is important to be able to distinguish beneficial insects and arachnids, such as green lacewings, ladybugs, and most spiders, from ones that will damage plants. When damage is detected or when harmful organisms are present, citizens should determine the level of damage the plant is able to tolerate. No action should be taken if the plant can maintain growth and fertility in the presence of these pest organisms. If controls are needed, there is an arsenal of low-impact pest management controls and practices to choose from that include preventative measures such as planting disease-resistant species and promoting beneficial organisms. See the USDA Regional Pest Management Centers Information System Web site at http://www.ipmcenters.org/ for more low impact strategies.

Integrated Pest Management (IPM) combines the use of these lower-impact practices with targeted chemical controls. Chemical controls are highly effective but may result in damage to or death of desirable species, such as bees. If strong chemical pesticides are applied improperly, they can contaminate receiving waters. Several less-toxic pesticide alternatives are available to prevent infestations or halt current infestations. Biopesticides, for example, are used to control pests without the use of poison. Biopesticides can be “biochemical,” such as garlic and pheromones, or “microbial,” such as bacteria, fungi and viruses (USEPA, 2003). Garlic and baking soda have been shown to be effective when applied as an aqueous solution to plants. Other pest control alternatives include insecticidal soap, which destroys pest membranes, *Bacillus thuringiensis* (a beneficial bacteria found in compost and other organic soil additives), milky spore (a natural bacteria that kills the grub phases of Japanese beetles), and dormant oil sprays applied when the plants are not growing. When used as a component of IPM programs, biopesticides can greatly decrease the need for conventional pesticides. The Biopesticides and Pollution Prevention Division in EPA’s Office of Pesticide Programs promotes the use of biopesticides as components of IPM programs. The Biopesticides Web site, http://www.epa.gov/pesticides/biopesticides, provides information on biopesticide registration, active ingredients, product lists, and contact information.

Municipalities should try to select the least-toxic, least-water-soluble, and least-volatile pesticides possible. Pesticides should be evaluated based on their toxicity and their potential to run off to surface water or leach into ground water (Peacock et al., no date). Organophosphate pesticides, such as diazinon and chlorpyrifos, were popular because they target a broad range of pests and they are less expensive than newer, less-toxic pesticides. A risk assessment by EPA has determined that chlorpyrifos posed an unacceptable risk to public health, particularly children’s health (USEPA, 2000). It was found that diazinon posed unacceptable risks to agricultural workers, birds, and other wildlife species. Chlorpyrifos was removed from retail sale and residential uses in 2001, and diazinon was phased out in 2004. Synthetic pyrethroids are more selective and typically much less toxic than organophosphates, yet they still can harm beneficial insects. When applying pesticides such as these, careful and judicious use is recommended to avoid harming non-target species.

Pesticide applicators should always read and follow instructions on the label. Pesticides should be applied to minimize drift or runoff, and they should not be sprayed near water sources. Application should be avoided during windy conditions or when rain is forecast. Granular applications should be avoided or minimized near impervious surfaces and bodies of water. Equipment should be checked for proper calibration before pesticide application. After pesticides are applied, label directions should be followed to safely dispose of containers. A local cooperative extension service can be consulted about the proper use of pesticides. State-specific information regarding cooperative extension services is available from CSREES at http://www.csrees.usda.gov.

Pest management methods can also be controlled legislatively. In response to the negative effects of many pesticides, some localities are planning to restrict or prohibit the use of certain hazardous pesticides (Johnson, 1999). For example, the city of Seattle and King County, Washington, intend to stop using pesticides that are deemed most hazardous to control bugs and weeds along roads, in parks, and on other public land. The plan will phase out the use of dozens of harmful pesticides as the city and county explore less toxic alternatives. Pesticides that will be phased out contain known cancer-causing ingredients, seep quickly into ground water or surface water, or are labeled highly toxic to birds, fish, or other animals. There will be exceptions to the ban on some chemicals, but generally only if there are major health or safety considerations.

Restrictions on the use of certain pest control products were also implemented in California. In 1994 a bill was passed that would restrict the sale and use of copper-containing root killers and copper and tri-butyl tin-containing cooling tower additives (City of Palo Alto, California, Environmental Compliance Division, 1997). These pest control products contribute to the Regional Water Quality Control Plant's exceedances of San Francisco Bay discharge standards. When used, these products are discharged to sanitary sewer systems or to storm drains that flow untreated to creeks and bays. Because cost-effective alternatives for these products are available, the Regional Water Quality Control Plant and other local wastewater treatment plants have urged restrictions on the three types of chemicals. In December 1995 the California Department of Pesticide Regulation adopted regulations that made it illegal to sell or use copper-based root control products and tri-butyl tin-containing cooling water additives within the nine San Francisco Bay area counties. These regulations became permanent in November 1996.

9.3.2.9 Point-of-sale education

Municipalities and local cooperative extensions can encourage IPM by promoting education at the point of purchase. Two studies found that most citizens who apply pesticides used home and garden centers as their source of information on pest management (Lajeunesse et al., 1997; Sclar et al., 1997). Educating store employees on less-toxic alternatives, keeping less-toxic materials in stock, and providing information on the proper use of pesticides will help facilitate the IPM process. Czapar et al. (1998) surveyed 656 retail stores in Illinois that sell pesticides. Approximately 83 percent of the survey respondents were willing to send employees to a training program on pesticides, safe handling practices, and how to recommend appropriate pesticides to customers.

The Bay Area Stormwater Management Agencies Association in the San Francisco Bay Area established the "Our Water, Our World" program to educate citizens on less-toxic alternatives to pesticides without using negative messages about conventional products. The program consists of partnerships with local retail stores that display alternative products and educational materials. The program also involves media and advertising campaigns, efforts to institute regulatory change, and monitoring of the effects of the program. Initial results from 20 participating stores indicated an increase in the sale of less-toxic products and employee satisfaction with the associated training programs (http://www.epa.gov/oppbppd1/PESP/strategies/2000/basmaa00.htm).

Bio Integral Resource Center IPM Partnership Program

The Bio Integral Resource Center (BIRC) in the San Francisco Bay Area has developed a partnership between water pollution prevention agencies, nurseries, hardware stores, and the local cooperative extension to educate the public on less-toxic pest management. The program focuses on educating consumers about pest control products at the point of purchase from nurseries and hardware stores. BIRC encourages stores to carry less-toxic products and trains employees on the use of these products.

BIRC also conducts a Healthy Garden Workshop, which is a four-hour public seminar to introduce home gardeners to various aspects of IPM such as monitoring, physical controls, horticultural controls, and biological controls. Additional topics include water conservation and the use of native plants. An illustrated Healthy Garden Handbook accompanies the workshop, and an instructor's guide is available to assist others who are interested in giving the class (http://www.pesp.org/2000/birc00-final.htm).

Alliance for Chesapeake Bay IPM Partnership Program

The Alliance for Chesapeake Bay IPM Partnership Program promotes IPM by citizens through a partnership with retailers in which less-toxic pest control options are labeled with the slogan, "From your home to our streams…Choose less toxic products." The program includes employee training workshops, IPM informational displays and fact sheets available at participating retail stores. Partnerships with garden clubs and Master Gardeners provide training on minimizing environmental impacts and less-toxic pest management techniques.

IPM information displays began appearing in retail locations in central Pennsylvania in March 2003. The IPM project is funded by the National Foundation for IPM Education and the Environmental Protection Agency. For more information contact: Susan Richards, 717-737-8622, http://www.acb-online.org/project.cfm?vid=89.

9.3.2.10 Sensible irrigation

The natural reaction of grasses to drought stress is to become dormant, halting growth, conserving resources, and turning dry and brown. In spite of this natural drought tolerance mechanism, many property owners strive to maintain lush, green lawns, even in times of dry weather. Watering practices vary from a light sprinkling to regular, sometimes excessive, automated watering. Underwatering fails to provide water below a few inches of soil, causing grasses to be fragile and shallow-rooted. Overwatering promotes excessive growth and humid, disease-prone conditions that can damage the lawn. Overwatering can also result in runoff and leaching of nutrients (PLCAA, no date (b)). One study found that overwatering increased by five to 11 times the amount of nitrogen leached (Morton et al., 1998).

It is best to water deeply, but not too often. Deep watering encourages the grass to grow deep roots, whereas shallow watering maintains shallow roots and reduces the lawn’s ability to retain moisture during dry periods (USEPA, 1992). The lawn should be watered only when needed and sprinklers should be carefully calibrated to wet the soil to a depth of 6 inches without causing runoff. Additionally, watering should be done early in the morning to prevent excessive evaporation (USEPA, 1992). Determining and controlling the rate, amount, and timing of watering will reduce soil erosion, runoff, and fertilizer and pesticide movement. An irrigation system should be designed to have an average application rate that is less than the infiltration capacity of the soil to avoid surface ponding and to maximize water percolation. Trickle and drip irrigation systems can save water by more directly irrigating the roots, resulting in less evaporation than overhead sprinklers (Relf, 1996).

Moisture in a home lawn can be retained more efficiently with organic matter, mulch, shade, and windbreaks. Organic matter increases the capacity of sandy soils to hold moisture and the availability of moisture in clay soils. Mulching helps reduce evaporation and retain moisture and humidity. Providing partial shade, particularly in the summer, and blocking wind, can also decrease moisture demand (Relf, 1996).

9.3.3 Commercial Activities

9.3.3.1 Detect and eliminate illicit connections

Illicit connections are defined as "illegal and/or improper connections to storm drainage systems and receiving waters" (Caraco et al., 1998). A discharge of industrial wastewater to a storm sewer is "illicit" because discharges of that type would ordinarily require a permit under NPDES. Many building owners and operators are unaware that improper connections exist in their facilities. In extreme cases of illicit dumping, legal action is necessary.

Illicit discharge detection and elimination programs are designed to prevent contamination of surface and ground water supplies by monitoring, inspection, and removal of these non-storm water discharges, which are illegal if an ordinance has been enacted. These ordinances grant a municipality the authority to inspect properties suspected of releasing contaminated discharges into storm drain systems. Another important factor is the establishment of enforcement actions for those properties found to be in noncompliance or that refuse to allow access to their facilities. EPA (1999), in conjunction with the Center for Watershed Protection, published a model ordinance for illicit discharges on their model ordinances Web site (http://www.epa.gov/nps/ordinance/discharges.htm). The model ordinance includes language to address illicit discharges in general as well as illicit connections specifically from industrial sites. Municipalities should modify the language to take into consideration enforcement methods that are appropriate for the local area. The Center for Watershed Protection (Brown et al., 2004) also published *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments*. This publication provides information on cost-effective methods to detect and eliminate illicit discharges from municipal storm drains. The document is available for download at http://www.cwp.org/PublicationStore/TechResearch.htm.

Identification of illicit and improper connections is necessary for all sanitary and storm sewer systems, especially in areas where pollutants with unknown sources have been detected in receiving waters. The level and type of industrial activities and the surrounding land uses will affect the methods used to identify illicit connections.

The following are some practices used to prevent, discover, and eliminate illicit connections:

- Conducting water quality monitoring and field screening at outfalls and in receiving waters to identify areas where pollutant levels are elevated. Consider bacterial source tracking analysis to determine the origins of elevated bacteria levels (see Section 2.3.5 for more information about water quality indicators and bacterial source tracking).

- Instituting building and plumbing codes to prevent connections of potentially hazardous pollutant sources to storm drains.

- Organizing structures to be inspected for illicit connections by building age, with older buildings identified as priorities. Businesses whose activities have the greatest potential to create sources that could adversely affect water quality and pose human health problems also should be given priority.

- Mapping each area to be surveyed and indicating the route of the sewer system and the locations of storm drains on the map. This enables watershed managers to estimate the likely locations of illicit connections.

- Surveying individual buildings to discover where connections to the storm drain exist.

- Inspecting sewer lines with television equipment to visually identify all physical connections.

- Comparing the results of field tests and video inspections with the known connections on the map. Areas with suspected connections should be further investigated.

- Instituting mandatory inspections for new development, redevelopment, and remodeling projects.

- Removing and testing sediment from catch basins or equivalent structures.

- Inspecting questionable connections to determine whether they should be connected to the storm drain system or to the sanitary sewer. Methods of illicit connection identification, such as dye testing, visual inspection, smoke testing, and flow monitoring, are described below.

  - *Dye testing*. Flushing fluorometric dye into suspected connections can be useful to identify illicit connections. Once the dye has been introduced into the suspected connection, the water in the collection system is monitored to determine whether a connection is present.

  - *Visual inspection*. Remotely guiding television cameras through sewer lines is another way to identify physical connections.

  - *Smoke testing*. Smoke testing is another method used to discover illicit connections. Zinc chloride smoke is injected into the sewer line and emerges via vents on connected buildings or through cracks or leaks in the sewer line. By monitoring and recording where the smoke emerges, crews can identify all connections, legal and illegal, to the sewer system. (Mechanisms on drains should prevent the smoke from entering buildings; however, in some instances, this will occur. It is important to notify the public that the smoke is nontoxic, though it should be avoided as it can cause irritation of the nose and throat in some people.)

- *Flow monitoring*. Monitoring increases in storm sewer flows during dry weather can lead investigators to sources of infiltration or flow due to illicit connections.

Rain can hamper efforts to monitor flows and conduct visual inspections. Smoke and dye testing are more accurate than visual inspection and are the preferred methods for identifying illicit connections.

The cost of smoke testing, dye testing, visual inspection, and flow monitoring can be significant and time-consuming. Site-specific factors, such as the level of impervious area, the density and ages of buildings, and land use will determine the level of investigation necessary. Case studies in Michigan have estimated the cost of two full-time field staff and other required support to be between $182,000 and $187,000 annually (Ferguson et al., 1997).

An illicit discharge detection program can be an effective method to reduce the quantity of pollutants related to industrial and commercial activities that enter the storm drain system. For example, the Montgomery County, Maryland, Department of Environmental Protection (MCDEP) has an illicit discharge detection and elimination program called "Pipe Detectives" that uses volunteer monitoring and community hotlines to identify suspicious discharges (MCDEP, 1997). When discharges are reported, DEP consults maps of surrounding areas and targets these areas for additional monitoring to narrow the search for the illicit connection. In one instance, a "milky white" discharge was reported in an area with many small businesses and large apartment buildings. Businesses were sent informational letters advising them of the discharge and requesting their assistance in identifying it by allowing MCDEP to survey the properties. Through this cooperative effort, three illicit connections were detected and removed, including a sink that was used to wash paintbrushes (the source of the milky white discharge).

The City of Portland, Oregon, addressed illicit discharges from industrial sites by developing a memorandum of agreement with the Oregon Department of Environmental Quality, the state agency charged with administering municipal storm water permits. The purpose of the agreement was to streamline the enforcement process by delegating authority to administer the permits to the city. The agreement specified the city's role in inspections, compliance, and enforcement. The first component of the city's Illicit Discharge Elimination Program involves the prioritization of storm water outfalls based on pipe size, land use, historical pollution problems, complaints, and monitoring data. These outfalls are subject to dry weather monitoring, and once pollutants are detected, upstream investigations are conducted. Second, the Connection Verification Program inventoried all connections to the MS4 from individual properties and reviewed them for questionable connections. A citizen complaint program and partnership agreements facilitate public input and participation and provide a low-cost way to improve enforcement efforts (Pronold, 2003).

The Santa Clara Valley (California) Nonpoint Source Control Program published a guide with pollution prevention practices for industrial facilities entitled *Best Management Practices for Industrial Storm Water Pollution Control* (Duke and Shannon, 1992). The guide presents 21 practices intended to reduce nonpoint source loadings from industrial and commercial activities, including employee and customer training; illicit discharge elimination; waste storage, handling, and disposal; equipment inspection and maintenance; facility design features; and storm water management. The guide presents detailed technical guidance for common pollutants generated by commercial and industrial activities. The Santa Clara Valley Nonpoint Source Control Program has other pollution prevention publications that target specific businesses, such as automotive repair, construction trades and roadwork, landscape/gardening and pool maintenance, mobile cleaners and detailers, and restaurants. Additional information can be obtained by contacting the Nonpoint Source Control Program Information Line at 800-794-2482.

9.3.3.2 Encourage good housekeeping practices at commercial facilities

One of the best and least-expensive ways to reduce or eliminate pollutants in runoff is to limit the exposure of materials that can be eroded or dissolved by rainfall and runoff. An inventory of the items on commercial sites that are exposed to rain and runoff provides useful information and a starting point for exposure-reduction activities. To help keep rain from contacting pollutants, businesses should be advised to keep dumpsters and other containers securely closed, store containers under cover, and cover stockpiled materials, such as gravel, wood chips, and building materials, with plastic sheeting. Businesses should be asked to clean up their sites, but not by washing grit and grime into the storm drain system. Instead they should pick up litter, sweep, dispose of sweepings in the garbage (unless they are hazardous and require special disposal), and use absorbent materials such as manufactured absorbent snakes, kitty litter, or sawdust to absorb oils.

9.3.3.3 Provide training and education for employees and customers

Education of employees and customers at commercial sites is key to establishing good pollution prevention practices. Training programs provide information on material handling and spill prevention and response to better prepare employees in case of an emergency. Employees should also be trained on the purpose, operation, and maintenance of pollution prevention management practices. Employees can be continually educated with periodic training courses and with signs reminding workers of good housekeeping practices. Customers should be informed of efforts to

Illicit Discharge Elimination Training

The Wayne County, Michigan, Department of Environment's Illicit Connection/Discharge Elimination Training Program provides training for county and local staff responsible for illicit discharge detection and elimination. The training program involves technical presentations, "hands on" instruction in investigative techniques, and provision of software to aid in program management. Each participant receives a notebook containing recommended standard operating procedures and field forms. State-of-the-art technology is employed, including Global Positioning System (GPS) for locating outfalls and a GIS/database software package developed by the County for site investigation. The goal of the software package is to promote coordination in reporting/tracking of illicit connections/discharges. The training program also instructs participants in the use of chemical analysis field kits for measuring water quality parameters. As of September 2002, the program had trained nearly 800 state, local and community personnel (Tuomari, 2003; Wayne County Department of Environment, 2001).

reduce waste and pollution using signage or pamphlets so they will be less likely to contribute to pollution problems that are ultimately the responsibility of the business.

9.3.3.4 Devise spill prevention, control, and clean-up plans

The best way to avoid runoff contamination from spilled materials is to prevent the spill from occurring. Careful storage of materials in sound, clearly labeled containers, and regular inspection and maintenance of equipment, are key practices to prevent spills. Materials stored outdoors should be covered and kept on a paved area to protect them from being mobilized by wind and runoff. If not roofed, the storage area should be designed to drain with a slight slope (approximately 1.5 percent) to an area that will provide treatment prior to disposal. Runoff from other areas should be excluded to reduce the volume of runoff requiring treatment by installing berms, curbs, or diversions on the perimeter of the storage area. Secondary containment should be used when liquids are stored, and runoff or spills from the containment area should be directed to the sanitary sewer where permissible or to an appropriate storage or treatment facility for reuse or disposal.

Business managers should develop and post a set of well-defined procedures for handling spills of any materials that might be exposed to rainfall or runoff. Procedures should cover small, easy-to-handle spills as well as large spills that require employees to contact emergency personnel. The procedures should emphasize that spills must be cleaned up promptly and should specify how each type of material should be handled. The use of water for clean-up should be strongly discouraged. Shop rags should be used for small spills of non-volatile chemicals, and used rags should be sent to a professional cleaning service to prevent them from causing a pollution problem in a landfill or other disposal area. Larger spills should be absorbed with vermiculite, sawdust, kitty litter, or absorbent “snakes.” Disposal methods depend on the hazard level of the spilled material. Nonvolatile liquids can be cleaned up with a wet/dry shop vacuum and disposed of with the rest of the facility's waste. Drains or inlets to storm sewers should be plugged during spill remediation to prevent off-site export of pollutants.

9.3.3.5 Conduct an environmental audit

Another approach to pollution prevention at commercial sites is to focus on source reduction, which reduces the amount of waste materials that have the potential to contaminate runoff. A reduction assessment can be performed to evaluate the type and amount of materials currently used, processes conducted, and wastes generated. Such an assessment can provide recommendations for modifying the commercial process to generate less waste, using alternative raw materials to generate non-hazardous wastes, and identifying recycling options to reduce the amount of wastes that require disposal. EPA’s Office of Pollution Prevention and Toxics Web site (http://www.epa.gov/oppt/pollutionprevention/) offers technical information and assistance about environmental audits for both businesses and state regulatory agencies (USEPA, 2001a).

9.3.3.6 Practice safe equipment washing and maintenance

It is important when washing and maintaining equipment to adhere to certain pollution prevention measures. The flow of water resulting from cleaning industrial equipment, must be discharged as process wastewater to the sanitary sewer and is not allowed in storm drains, in most cases. When cleaning greasy equipment or trucks, a special cleaning area should be designated and equipment installed to capture, pre-treat, and discharge the wash water to the sanitary sewer. In addition, instructional signs that prohibit changing vehicle oil, washing with solvents, and other activities should be posted in non-wash areas. Finally, sumps or drain lines should be installed to collect wash water for treatment and discharge to the sanitary sewer.

Waste materials from vehicle maintenance activities also deserve special attention. Proper storage of materials and proper disposal of waste products are imperative. For example, waste oil, antifreeze, spent solvents, and some other liquids can be recycled. Spent batteries, however, should not be discarded with trash, but must either be disposed of as a hazardous waste or returned to the dealer from whom they were purchased. In addition vehicle maintenance should be performed in an indoor garage, not in an outdoor parking area. If performing work outdoors, all oil and grease should be captured unless precautions are taken to prevent them from being carried in runoff, such as with the use of absorbent pads in inlets or grates.

9.3.3.7 Use care when performing construction, repairs, or remodeling

When repairing, remodeling, or constructing buildings there are several key techniques that can prevent adverse effects on natural systems. Paints should be mixed where spills can be recovered or cleaned easily, and an impermeable ground cloth should be used while painting. Paint chips and scrapings might contain lead and should be managed properly to prevent contamination of water or soil. Paint buckets and barrels of materials should be stored away from contact with runoff. During painting clean-up, if a water-based paint was used, brushes and equipment should be cleaned in a sink connected to the sanitary sewer; if oil-based paints were used, they should be stored or recycled and not be disposed of in the sink or storm drain. Spray painting requires a few extra precautions. Temporary scaffolding should be used to hang drop cloths or draperies to shield the user from the wind, to collect overspray, and to minimize the spreading of windblown materials. Users should be aware of air quality restrictions on spray paints that use volatile chemicals and should consider water-based spray paints instead to minimize adverse effects on air quality.

Sand blasting can be controlled to keep particles off of paved surfaces and out of storm drains by placing a tarp or ground cloth beneath the work to capture the blasting medium, protect the work area from wind, and capture airborne particles.

9.3.3.8 Proper disposal of pet waste

Pet owners have several options for properly managing pet waste. Collecting the waste and flushing it down the toilet, where it can be treated by a sewage treatment facility or septic tank, is the preferred method. Small quantities can also be buried in the yard (when ground water is not used in the home), where the waste can decompose slowly. When buried, the waste should be at least 5 inches below the ground surface and away from water bodies and vegetable gardens. In public areas, the waste can be sealed in a plastic bag and thrown in the trash, which is legal in most areas (Water Quality Consortium, 1999).

Many communities implement pet waste management programs by posting signs in parks or other areas frequented by pet owners, sending mailings, and making public service

Los Angeles County Pet Waste Program

The Los Angeles County Department of Public Works Environmental Programs Division developed a program to control pet waste (Lehner et al., 1999). By profiling various groups of pet owners, the division identified the best targets for reducing coastal pollution. The program included a multimedia campaign to educate new and existing pet owners about the water quality impacts of pet waste. The program also distributed clean-up kits to owners and installed plastic bag dispensers in parks. The division established partnerships with local pet stores and pet supply companies to promote the program.

announcements. Many communities have "pooper scooper" ordinances that govern pet waste clean-up. Some of these laws specifically require anyone who takes an animal off his or her property to carry a bag, shovel, or scoop. Any waste left by the animal must be cleaned up immediately (Hill and Johnson, 1994). In addition to postings, many communities have installed "pet waste stations" in popular dog parks. These stations contain waste receptacles as well as a supply of waste collection bags, scoops, and shovels.

9.3.4 Trash

When developing control strategies for trash, one should keep in mind the source of the trash and the most prevalent types of trash to target ways to control it. Second, the costs for each control strategy should be evaluated, and a budget should be developed that takes into consideration the services and facilities that are already available. Third, regular cleaning and maintenance of storm water control infrastructure is necessary to prevent the accumulation of trash at control structures from becoming a hazard. Finally, it is important to understand that control strategies should not just transport trash to another water body but should also reduce the quantity of trash entering water bodies.

There are two methods of trash control: source controls and structural controls. There are four source control types: community education, improved infrastructure, waste reduction, and clean-up campaigns. Community education, such as informing citizens about options for recycling and waste disposal and educating them about the consequences of littering, is one of the best ways to reduce the amount of trash that enters runoff control structures and receiving waters. Another topic that should be emphasized is proper trash storage and disposal. Improved infrastructure can include optimizing the location, number, and size of trash receptacles, recycling bins, and cigarette butt receptacles based on expected need. Waste reduction includes encouraging consumers to purchase products with less disposable packaging and manufacturers to reduce the amount of packaging they use. Finally, clean-up campaigns are an effective way to reduce trash. Municipal projects such as street sweeping (see section 7.3.5.1), receptacle servicing, and clean-up crews along roadsides can also be effective in preventing trash from accumulating and entering waterways. Municipalities should review their litter control program to determine if the number and placement of receptacles is adequate and if regular maintenance activities (e.g., sweeping, receptacle servicing) are preventing litter from entering receiving waters.

Structural controls include physical filtering structures and continuous deflection separation. Physical filtering structures concentrate diffuse, floating debris and trash and prevent it from traveling downstream. Some examples are trash racks, mesh nets, bar screens, and trash booms. Continuous deflection separation targets trash from storm flows during and after heavy precipitation and involves physical separation of solids and floatables from water in runoff detention structures.

The costs for trash controls vary depending on the method employed. For example, the cost of a community education program or a plan to increase the number of trash receptacles can be minimal, depending on the quality of existing programs and extent of existing infrastructure. On the other hand, a structural control strategy can be quite costly. Physical filtering structures, including trash racks, bar screens, and silt traps, can range from $250,000 to $1 million or more, not including maintenance. A large-scale, continuous deflection separation device for urban runoff can cost as much as $3 million (capital cost only).

9.3.5 Nonpoint Source Pollution Education for Citizens

Many citizens know very little about nonpoint source pollution. Schueler and Swann (2000a) reported that an estimated 41 percent of the population had an idea of what the term "watershed" means, and only 22 percent understood that runoff is the most common source of pollution to streams, rivers, and oceans. Therefore, watershed and nonpoint source education for citizens is important to increase awareness about the environmental consequences of everyday actions. A survey of the effectiveness of outreach programs showed that media campaigns and intensive training of target audiences are the most effective ways to effect change in citizen behavior (up to 10 percent change in behavior in target populations). Specifically, TV ads and programs, newspaper ads, radio ads, and direct mail campaigns were shown to be the most influential and memorable messages to the public. Table 9.2 provides a summary of cost information and target audiences for various outreach methods.

Table 9.2: Select cost and audience information for various outreach techniques (Worlton, 2003).

Element	Cost	Unit	Audience
Flyers	$0.40–$1.20	Each	Limited by requests
Fact Sheets	$0.40–$1.20	Each	Limited by requests
Radio	$2,000 or more	Per station	500,000–2,000,000
Television	$2,400 or more	Per month	250,000–500,000 per day
Billboards	$700	Per board	6,800 per day
Markers	$2.94	Each	0–5,000 per day
Trailers	$165	Per theater	5,000 or more per day

Schueler and Swann (2000a) recommend the following techniques to effectively market a watershed message:

- Present a simple, direct watershed message, repeat it frequently, use multiple types of media, and emphasize the connection between the message and a local water body.
- Develop awareness of the connection between yards, streets, storms, and streams.
- Pool resources with other local or regional organizations to expand the campaign's budget.

- Use cable network and public television channels for commercials and targeted TV programs to more effectively reach target audiences.

- Focus the campaign on one or more target audiences. Many communities are ethnically and culturally diverse, and a portion of the population speaks languages other than English, which requires a campaign specifically tailored to the local demographics. Communities can also direct messages to children or focus efforts towards reaching the disadvantaged, who otherwise might not have the opportunity to learn about or participate in programs and activities. A survey of watershed demographics and problem pollutants should be conducted to better identify target populations.

- Keep the message simple and humorous and develop durable, attractive, non-technical outreach materials.

- Educate and partner with private-sector companies such as septic tank cleaners, commercial car washes, and oil change franchises.

9.3.5.1 Use multilingual nonpoint source messages

Many communities are ethnically and culturally diverse, and a portion of the population speaks languages other than English. The messages contained in signs, brochures, advertisements, newsletters, and other outreach materials that are printed only in English are mostly lost on these groups. For example, in areas such as southern Florida and southern California, where a large proportion of the population consists of Spanish-speaking immigrants, it is important to reach out to non-English-speaking residents and inform them about storm water pollution issues and the importance of clean water, because their activities can generate a substantial amount of pollution. This type of expanded outreach program is not limited to these areas. Census 2000 figures show increasing minority populations in urban centers and suburbs such as Washington, DC (Fernandez, 2001; Cohn and Witt, 2001), and New York (Cohn, 2001), among others.

Outreach materials can be printed in multiple languages based on the demographics of a community. The North Central Texas Council of Governments (NCTCOG), as part of its pollution prevention and public awareness campaign, printed articles, press releases, brochures, flyers, and bill stuffers in both English and Spanish (NCTCOG, 2000). The University of Texas at Austin designed and installed storm drain markers in both English and Spanish (University of Texas at Austin, 1997).

9.3.5.2 Use classroom education to deliver nonpoint source messages

Providing nonpoint source education to children through schools delivers the educational message not only to students but to their parents as well, because children often take home what they learn. Watershed managers have partnered with educators and experts to develop storm water-related curricula for the classroom. Fortunately, these lessons need not be elaborate or expensive to be effective.

An example of this type of education is the Children’s Water Festival in Albuquerque, New Mexico. Several hundred fourth-grade students from schools in the area engaged in hands-on earning activities about water science, history, geography, and drama. The Albuquerque-based Ciudad Soil and Water Conservation District used its “Rolling River” educational model to show how all the components of a watershed are connected and how changes in one part affect others. Students created a mini-river, purified water from the Rio Grande, and built aquifers from edible ingredients. They also used a computer model to make projections of water use in the future and a ground water model to see how water moves underground. Students analyzed water samples and played the roles of algae, fish, and raptors to understand how toxins can travel through the food chain. They created wetlands, simulated flood and drought situations, changed the infrastructure, and then observed the effects of their manipulations.

9.4 Information Resources

9.4.1 General

The Center for Watershed Protection published *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments*. This publication provides information on cost-effective methods to detect and eliminate illicit discharges from municipal storm drains. The document is available for download at http://www.cwp.org/PublicationStore/TechResearch.htm.

EPA's GreenScapes program provides cost-efficient and environmentally friendly solutions for large-scale landscaping. GreenScapes encourages companies, government agencies, and other entities to make more holistic decisions regarding waste generation and disposal. The GreenScapes program emphasizes four elements: reduce, reuse, recycle, and re-buy**.** More information about the GreenScapes program can be found at the program's Web site at http://www.epa.gov/greenscapes.

EPA's Office of Solid Waste has released "A Collection of Solid Waste Resources" on CD-ROM. This resource contains more than 300 publications on hazardous and non-hazardous waste; documents are listed by topic and are searchable, and some documents are in both English and Spanish. More information about this CD-ROM is available at EPA's Office of Solid Waste Web site at http://www.epa.gov/epaoswer/osw/cdoswpub.htm.

EPA's Used Oil Management Program developed the "You Dump It, You Drink It" campaign aimed to educate the Hispanic automotive repair and service industry and consumers about the impacts of improper disposal of used oil. The campaign includes posers, brochures, and bumper stickers in both English and Spanish. These materials, a description of the Used Oil Management Program, and relevant publications, rules, notices, regulations, and links can be found at http://www.epa.gov/epaoswer/hazwaste/usedoil/index.htm.

Appropriate Technology Transfer in Rural Areas (ATTRA) published the guidance *Integrated Pest Management: Fundamentals of Sustainable Agriculture*, which provides a basic understanding of IPM for individuals interested in agriculture. It incorporates the steps that need to be taken prior to IPM implementation, the tools used, and some ideas about future trends for IPM. The ATTRA publication is available at http://www.attra.org/attra-pub/ipm.html (Dufour and Bachmann, 1998).

The City of Seattle's ProIPM (Seattle Public Utilities, 2000) is the Green Gardening Program's series of IPM fact sheets for landscaping professionals. The fact sheets were designed to assist landscapers in the field and when explaining the IPM approach to clients. Each provides essential facts about various northwestern United States pest or disease problems, including information regarding pest identification, life cycle information, monitoring, damage threshold, and treatments. The fact sheets are available for download at http://www.seattle.gov/util/Services/Yard/For_Landscape_Professionals/Integrated_Pest_Management/index.asp or by calling the Green Gardening Program at 206-547-7561. The ProIPM Web site also provides information about proper disposal methods for pesticide products.

The U.S. Air Force's PRO-ACT program is an environmental research service and information exchange clearinghouse (PRO-ACT, 2000). PRO-ACT's *Integrated Pest Management Fact Sheet* provides information regarding IPM policy and guidance, typical components of an IPM program, control techniques available to pest managers, and management practices that can be implemented in an IPM program. The fact sheet is available at http://www.afcee.brooks.af.mil/pro-act/fact/intpst.asp. PRO-ACT may be contacted by phone at 800-233-4356 or by e-mail at pro-act@hqafcee.brooks.af.mil.

The USDA Regional Pest Management Centers Information System Web site (http://www.ipmcenters.org/) provides information about agricultural commodities, pests, and pest management practices, as well as links to each of the four Regional Pest Management Centers. Users can access the complete Crop Profiles and Pest Management Strategic Plans databases, an IPM Expertise database, information on pesticide use, current pest management research, funding opportunities, and links to related sites. Additional region-specific information, news, and announcements can be found at the regional Web sites.

NRCS (no date) has prepared a backyard conservation tip sheet that provides the public with information on pest management. The tip sheet helps readers to identify the problem, to know what to look for, and to control various types of pests with mechanical, physical, biological, and chemical control strategies. The NRCS tip sheet is available at http://www.nrcs.usda.gov/feature/backyard/pdf/PestMgt.pdf.

The International Turf Producers Foundation (ITPF, no date) recently published *Water Right: Conserving Our Water, Preserving Our Environment*. The publication provides information about a variety of water topics, including water use and conservation, environmental and economic benefits of responsible landscape management, and landscape water conservation techniques. The document is available for download at http://www.turfgrasssod.org/waterright.html or can be obtained by contacting ITPF at 1855 Hicks Road, Suite C, Rolling Meadows, Illinois, 60008; 847-705-9898 or 800-405-8873.

Audubon Magazine published *The Audubon Guide to Home Pesticides* in 2000. This guide provides citizens with a list of popular pesticides, along with their typical uses, their toxicity to humans and wildlife, EPA's toxicity rating, and alternatives for each of the chemicals. The guide is available for download at http://www.magazine.audubon.org/pdf/pesti_chart.pdf.

The Pest Management Branch of the California Department of Pesticide Regulation published *Suppliers of Beneficial Organisms in North America*. The publication lists 143 commercial suppliers of 130 beneficial organisms that are used for biological control. Suppliers are located in Canada, Mexico, and the United States. The booklet is available for download at http://www.cdpr.ca.gov/docs/ipminov/bensuppl.htm.

The EXtension TOXicology NETwork (EXTOXNET) is a joint effort of the University of California at Davis, Oregon State University, Michigan State University, Cornell University, and the University of Idaho. EXTOXNET provides a variety of information about pesticides, including discussions of toxicological issues of concern; toxicology newsletters, fact sheets, and information briefs; pesticide information profiles; and other resources for toxicology information. The network can be accessed at http://ace.orst.edu/info/extoxnet.

The National Pesticide Telecommunication Network is a cooperative effort of Oregon State University and the U.S. Environmental Protection Agency. The network is a source of chemical, health, and environmental information about more than 600 pesticide active ingredients incorporated into at least 50,000 different products registered for use in the U.S. since 1947. The toll-free telephone service (800-858-7378) provides information about pesticide products, recognition and management of pesticide poisoning, toxicology, and environmental chemistry to any caller in the United States, Puerto Rico, or the Virgin Islands.

Nonpoint Education for Municipal Officials (NEMO) is an educational program created by the University of Connecticut for local land use decision-makers that addresses the relationship between land use and protection of natural resources, particularly water resources. NEMO is an award-winning program that uses remote sensing, geographic information systems, and Internet technologies. The NEMO model is being adapted around the country, and NEMO projects are being planned and implemented by various agencies and organizations. This nationwide group, under the leadership and coordination of the University of Connecticut NEMO Project, is called the National NEMO Network. Additional information about NEMO is available at http://www.nemo.uconn.edu/.

Organic Gardening magazine and Web site (http://www.organicgardening.com/) provide information about organic pest control and help users find soil-testing labs in their area.

Riversides is a Canadian nonprofit organization that promotes source control and nonpoint source pollution prevention strategies. An important component of the Riversides Web site is H_2infO: The Water Information Network, which provides information about current campaigns, resources, and services offered by the network. Also offered are listservers and links to agencies, associations, and non-governmental organizations. The H_2infO Web site can be accessed at http://www.h2info.org/. Also, H_2infO can be contacted at 590 Jarvis Street, Suite 200, Toronto, Ontario, Canada, M4Y 2J4; phone 416-392-1757; fax 416-960-9944; e-mail input@H2infO.org.

EPA's Biopesticide Web site provides users with specific information about biopesticides, including fact sheets, decision documents, product lists, labels, company lists, study reviews, bibliographies, regulatory information, and federal register notices. The Web site can be accessed at http://www.epa.gov/pesticides/biopesticides.

EPA (1995) published the *Citizen's Guide to Pest Control and Pesticide Safety*, which provides users with important information about pesticides, including steps to control pests in and around the home; alternatives to chemical pesticides; methods for choosing, using, storing, and disposing of pesticides; how to reduce exposure when others use pesticides; how to choose a pest control company; and what to do if someone is poisoned by a pesticide. The guide is available at http://www.epa.gov/oppfead1/Publications/Cit_Guide/citguide.pdf.

EPA (1999) published *Education Projects in the Office of Water: A How-to Guide for Developing Environmental Education Projects*. The document provides a road map for creating quality environmental education projects and outlines EPA's procedural guidelines for producing a product or supporting related projects already in existence. It also lists publications, contacts, and references, including Web sites, training opportunities, and available materials, that provide the reader with further detail and insight into the process of developing effective environmental education pieces. A list of agencies and organizations that have water-related environmental education programs and projects is provided in an appendix. The publication is available from EPA's National Service Center for Environmental Publications Web site at http://www.epa.gov/ncepihom. It can also be ordered by phone, fax, or mail from USEPA/NSCEP, P.O. Box 42419, Cincinnati, Ohio 45242-2419; toll-free 800-490-9198; fax 513-489-8695.

The Commonwealth of Kentucky published *Turfgrass: Best Management Practices for Protection of Water Resources* (USEPA, 2001b). The manual provides information and guidance on turf grass management practices that decrease adverse effects on water resources. Information about the manual, along with a list of commonly used best management practices for turf management, is available at http://www.epa.gov/Region4/water/nps/projects/ky94-2.htm.

The Council of State Governments (1999) published *Getting in Step: A Guide to Effective Outreach in Your Watershed*. The guide presents a step-by-step approach for developing and implementing an effective watershed outreach plan. *Getting in Step* is available for download in PDF format at http://www.epa.gov/owow/watershed/outreach/documents/getnstep.pdf or by calling Books on Demand (800-521-3042).

State-specific cooperative extension service information is available from the Cooperative State Research, Education, and Extension Service (CSREES) at http://www.csrees.usda.gov/.

The California Peer Review Project, funded by the California Integrated Waste Management Board, compiles and reviews scientific research on the health effects, environmental effects, and efficacy of alternative household products. The project allows interested parties to participate during the review process, and findings from these literature reviews are available for download on the Web site (http://www.peerreview.com/).

The Stormwater Quality Management Committee, sponsored by the Clark County Regional Flood Control District in Las Vegas, Nevada, has developed a Web site devoted to its campaign to prevent pollution from urban runoff. The site has a number of resources for developing education and outreach materials, including examples of a bus stop shelter ad campaign, public service announcements, brochures, and community presentations at http://www.lvstormwater.com/.

The EPA's Web site, *Yard Trimmings/Food Scraps,* provides basic information on the environmental and economic benefits of recycling yard waste and food scraps. It also includes descriptions of practices for citizens, links to case studies, and technical fact sheets. The site can be accessed at http://www.epa.gov/epaoswer/non-hw/muncpl/yard.htm.

In 1994 the EPA published *Composting Yard Trimmings and Municipal Solid Waste,* a 151-page manual on the inclusion of composting as part of an integrated solid waste management program. It provides guidance on program development, facility siting and design, and costs and benefits, and includes information on many helpful resources. This manual can be downloaded in PDF format at http://www.epa.gov/epaoswer/non-hw/compost/cytmsw.pdf.

The Region 4 DoD Pollution Prevention Partnership published *Best Management Practices Resource Guide—Household Hazardous Waste* to guide pollution prevention activities on military bases, but the information is applicable to any pollution prevention initiative. It includes guidance on proper management of household chemicals, as well as descriptions of applicable state and federal laws, regulations and reporting requirements, and state resources. It describes various types of collection programs, lists resources for disposal and recycling by material type, and includes examples of outreach and education materials. The resource guide is available in PDF format at http://www.p2pays.org/ref/13/12935.pdf.

9.4.2 Yards: General Resources

The Bay Area Water Pollution Prevention Agency's "Our Water, Our World" program published *Less-Toxic Pest Management: Problem Pesticides,* a fact sheet describing the current state of chlorpyrifos and diazinon regulation, as well as some additional pesticides of concern. It provides information on alternative pest management techniques and sources of additional information. The site can be accessed at http://www.ci.livermore.ca.us/wrd/pdf_files/pesticides.pdf.

The *National Foundation for IPM Education* (NFIPME) is a non-profit organization that promotes education, provides information, and encourages research on integrated pest management. The Web site, http://www.ipm-education.org/, contains links to sponsored programs and information on grants for pesticide environmental stewardship.

Robert Mugaas at The University of Minnesota Cooperative Extension published *Responsible Fertilizer Practices for Lawns.* The paper provides soil-specific information on fertilizer application practices to protect water quality. It can be accessed at http://www.extension.umn.edu/distribution/horticulture/DG6551.html.

9.4.3 Yard Resources for Homeowners

Water Quality and Home Lawn Care, by the North Carolina State University Cooperative Extension, takes citizens through the process of establishing a healthy lawn and maintaining it using practices that protect water quality. It provides specific instructions on watering, mowing, and fertilization. This fact sheet can be downloaded in PDF format from http://www.turffiles.ncsu.edu/PUBS/MANAGEMENT/HOMELAWN.PDF.

The U.S. EPA publication *Healthy Lawn, Healthy Environment* is a user-friendly brochure that describes lawn care practices for citizens. It covers the basic principles of soil building, mowing techniques, appropriate thatch buildup, and IPM. The brochure also discusses important considerations for citizens in selecting a professional lawn care service. The brochure can be downloaded in PDF format from http://www.epa.gov/oppfead1/Publications/lawncare.pdf.

9.4.4 Yard Resources for Lawn Care Professionals

The University of Florida Cooperative Extension maintains a database of fact sheets for lawn care professionals, *Professional Lawn and Landscape Fact Sheets*. The fact sheets cover athletic fields, golf courses, roadsides, interiorscapes and non-residential lawns. The fact sheets can be downloaded from http://edis.ifas.ufl.edu/TOPIC_Professional_Lawn_and_Landscape.

The North Carolina State University Cooperative Extension's fact sheet, *Water Quality & Commercial Lawn Care*, is a resource for lawn care professionals on fertilizer, mowing, and irrigation practices. It includes information on the leaching potential of specific chemicals, turf grass selection, and fertilizer use. The fact sheet is available in PDF format at http://www.turffiles.ncsu.edu/pubs/new/commcare.pdf.

The North Carolina State University Cooperative Extension has published *Pest Control for Professional Turfgrass Managers*. This document includes information on proper use and leaching potential for commonly used insecticides and herbicides. It provides information on tolerance and disease resistance for turf grass species. It is available for free download in PDF format from http://ipm.ncsu.edu/AG408/turfgrass.pdf.

Water Quality for Golf Course Superintendents and Professional Turf Managers, produced by the North Carolina State University Cooperative Extension, describes lawn care practices that help to protect water quality. The discussion covers turf grass selection, IPM, mowing, and fertilizer practices that are specific to commercial lawn care. The fact sheet is available as a PDF at http://www.turffiles.ncsu.edu/PUBS/MANAGEMENT/PROTURF.PDF.

North Carolina State University Cooperative Extension's fact sheet, *Water Quality and Pesticide Selection for Professional Turf Managers,* provides guidance on the chemical selection process and information on leaching potential and toxicity for herbicides, insecticides, and fungicides. The fact sheet is available as a PDF at www.turffiles.ncsu.edu/PUBS/MANAGEMENT/PESTFORMAT1.PDF.

The Cooperative Extension at Rutgers State University maintains an online *Database of Commercial Turfgrass and Landscape Maintenance Fact Sheets*, a resource for lawn care professionals. It is accessible at http://www.rce.rutgers.edu/pubs/subcategory.asp?cat=5&sub=35.

The Golf Course Superintendents Association of America (GCSAA) has developed a set of principles for the protection of water quality in golf course planning and siting, design, construction, and maintenance. These principles and practices are summarized in the online publication, *Golf and the Environment.* It can be accessed at http://www.gcsaa.org/resources/facts/principles.asp.

The Professional Lawn Care Association of America's *Grasscycling Guide* describes recommended mowing heights for various grass types, the benefits of recycling grass clippings, and simple techniques for returning grass clippings to lawns. The guide is available in PDF format at http://turf.ufl.edu/BMPmanual.pdf.

The Florida Department of Environmental Protection produced *Best Management Practices for Protection of Water Resources in Florida* to provide guidance on specific lawn care industry practices to protect water quality. The manual covers practices such as employee training, irrigation system design, the design and installation of landscapes, and irrigation system maintenance. It explains techniques for mulching, mowing and pruning, material disposal, fertilizer application, IPM, and spill prevention. It is available for download in PDF format at http://miami-dade.ifas.ufl.edu/programs/fyn/publications/PDF/GI-BMP6-20-02.pdf.

9.5 References

Audubon Society. 2000. Ten commandments for a healthy yard. *Audubon Magazine* May-June. http://www.magazine.audubon.org/pdf/pesti_tips.pdf. Accessed August 13, 2001.

Barth, C.A. 1995. Toward a low input lawn. *Watershed Protection Techniques* 2(1):254–264.

Beard, J.B. and R.L. Green. 1994. The Role of Turfgrasses in Environmental Protection and their Benefits to Humans. *Journal of Environmental Quality* 23:452-460.

Brown, E., D. Caraco, R. Pitt. 2004. *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments.* Center for Watershed Protection, Ellicott City, MD.

Bruneau, J.H. 2001. *Water Quality & Commercial Lawn Care.* North Carolina State University Cooperative Extension. http://www.turffiles.ncsu.edu/PUBS/MANAGEMENT/COMMCARE.PDF. Accessed September 5, 2003.

Burton, J., W. Skroch, and T. Lucas. 1997. *Scientists Devise New, Safer Way to Apply Roadside Herbicides*. http://www2.ncsu.edu/ncsu/univ_relations/news_services/press_releases/97_09/293.htm. Last updated September 5, 1997. Accessed October 16, 2001.

Californians for Alternatives to Toxics (CATs). 2000. *Arcata Pesticide Ordinance*. Californians for Alternatives to Toxics. http://www.alternatives2toxics.org/catsoldsite/ordinance.htm. Accessed August 2, 2001. Last updated Spring 2000.

Caraco, D., R. Claytor, P. Hinkle, H.Y. Kwon, T. Schueler, C. Swann, S. Vysotsky, and J. Zielinski. 1998. *Rapid Watershed Planning Handbook.* Center for Watershed Protection, Ellicott City, MD.

Center for Resource Management. 1996. *Environmental Principles for Golf Courses in the United States.* Salt Lake City, Utah. http://www.usga.org/turf/articles/environment/general/environmental_principles.html. Last updated March 1996. Accessed September 5, 2003.

City of Palo Alto, California, Environmental Compliance Division. 1997. *Urban Pesticide Restrictions for Water Quality Protection*. http://www.cityofpaloalto.org/public-works/documents/cb-urban.pdf. Accessed August 1, 2001.

Cohn, D. 2001, March 16. Immigration fueling big U.S. cities. *The Washington Post*, p. A1.

Cohn, D., and A. Witt. 2001, March 20. Minorities fuel growth in Md. suburbs. *The Washington Post*, p. A1.

Council of State Governments. 1999. *Getting in Step: A Guide to Effective Outreach in Your Watershed*. The Council of State Governments, Lexington, KY.

Czapar, G. F., Curry, M. P., & Lloyd, J. E. 1998. Survey of Integrated Pest Management training needs among retail store employees in Illinois. *Journal of Soil and Water Conservation*. 53(1), 31–33.

Davenport, J. 2003. Stenciling Storm Drains Raises Public Awareness. *County News Online* 35(6). March 24. http://www.naco.org/Content/ContentGroups/Publications1/County_News1/3-24-03/Stenciling_storm_drains_raises_public_awareness.htm. Accessed September 5, 2003.

Delaware Department of Natural Resources and Environmental Control (DNREC). No date. *Whole Basin Management, Inland Bays Environmental Profile: An Environmental Assessment of Southeastern Delaware*. Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Dufour, R., and J. Bachmann. 1998. *Integrated Pest Management: Fundamentals of Sustainable Agriculture*. Appropriate Technology Transfer for Rural Areas (ATTRA), Fayetteville, AR. http://www.attra.ncat.org/attra-pub/ipm.html. Accessed July 31, 2001.

Duke, L.D., and J.A. Shannon. 1992. *Best Management Practices for Industrial Storm Water Pollution Control*. Santa Clara Valley Nonpoint Source Pollution Control Program, San Jose, CA.

Ferguson, T., R. Gignac, M. Stoffan, A. Ibrahim, and H. Aldrich. 1997. *Rouge River National Wet Weather Demonstration Project*. Wayne County, Michigan, Department of the Environment, Detroit, MI.

Fernandez, M. 2001, April 5. City underwent major racial shifts in '90s, census shows. *The Washington Post*, p. D3.

Fickes, M. Nov 2002. Banned in Boston (and a few thousand other places). *Waste Age* 33(11): 48-51.

Glausiusz, J. 2002. Curb Your Cat, Save a Sea Otter. *Discover* 23(10). http://www.discover.com/oct_02/breakcat.html. Accessed July 2, 2003.

Graffy, E.A. 1998. Low-level Detection of Pesticides…So What? *Journal of Soil and Water Conservation* 53(1): 11-12.

Hill, J.A., and D. Johnson. 1994. *Pet Waste and Water Quality.* http://cecommerce.uwex.edu/pdfs/GWQ006.PDF. Accessed January 25, 2002.

International Turf Producers Foundation. No date. *Water Right: Conserving Our Water, Preserving Our Environment.* International Turf Producers Foundation, Rolling Meadows, IL.

Jenkins, V.S. 1994. *The Lawn—A History of An American Obsession*. Smithsonian Institution Press, Washington, DC.

Johnson, T. 1999. City, county to reduce their pesticide use: Most-hazardous poisons will be largely avoided. *Seattle Post-Intelligencer*. http://seattlep_i.nwsource.com/local/pest06.shtml. Last updated October 6, 1999. Accessed January 22, 2002.

Katznelson, R. and T. Mumley. 1997. *Diazinon in Surface Waters in the San Francisco Bay Area: Occurrence and Potential Impact.* Woodward Clyde Consultants and California Regional Water Quality Control Board. Oakland, CA.

Kopel, D. 1998. *Household Hazardous Waste*. i2i.org/Publications/IP/Environment/enhhw.htm. Accessed January 25, 2002.

Lajeunesse, S. E., Johnson, G. D., and Jacobsen, J. S. 1997. A homeowner survey: Outdoor pest management practices, water quality awareness, and preferred learning methods. *Journal of Natural Resources and Life Sciences Education*, 26(1) 43-48.

LaLonde, S. 2000. Yard Trimmings Ban Promotes Backyard Composting. *BioCycle* 41(12): 35-36.

Lehner, P.H., G.P. Aponte Clarke, D.M. Cameron, and A.G. Frank. 1999. *Stormwater Strategies: Community Responses to Runoff Pollution*. Natural Resources Defense Council, New York, NY.

Montgomery County Department of Environmental Protection (MCDEP). 1997. *Montgomery County NPDES Municipal Separate Storm Sewer System Annual Report*. MS-MO-95-006. Montgomery County Department of Environmental Protection, Water Quality Advisory Group, Rockville, MD.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of Overwatering and Fertilization on Nitrogen Losses from Home Lawns. *Journal of Environmental Quality*, 17(1):124-130.

Mugaas, R.J. 1999. *Lawn Care Practices to Reduce the Need for Fertilizers and Pesticides.* University of Minnesota Cooperative Extension. www.extension.umn.edu/distribution/horticulture/DG5890.html. Accessed June 12, 2003.

Murphy, J.A. 1994. *Thatch Management in Turf*. Rutgers University Cooperative Extension. http://www.rce.rutgers.edu/pubs/pdfs/fs740.pdf. Accessed June 12, 2003.

Murphy, J.A. 1995. Turfgrass Seed Selection for Home Lawns. Rutgers University Cooperative Extension. http://www.rce.rutgers.edu/pubs/publication.asp?pid=FS684. Accessed June 12, 2003.

National Integrated Pest Management Network (NIPMN). No date. *National Integrated Pest Management Network*. http://www.ipmcenters.org/. Last updated August 15, 2001. Accessed January 22, 2002.

Natural Resources Conservation Service (NRCS). No date. *Backyard Conservation Tip Sheet: Pest Management*. U.S. http://www.nrcs.usda.gov/feature/backyard/pdf/PestMgt.pdf. Accessed August 1, 2001.

North Carolina Sediment Control Commission (NCSCS). 2000. Urban Soils: A New Focus in Watershed Protection. *Newsletter of the North Carolina Sediment Control Commission* 7(3). http://www.dlr.enr.state.nc.us/vol7no3.pdf. Accessed June 12, 2003.

North Central Texas Council of Governments (NCTCOG). 2000. *Overview of the Regional Storm Water Program*. http://www.nctcog.dst.tx.us/envir/wq/inetstw.html. Last updated May 30, 2000. Accessed August 20, 2001.

Peacock, C.H., A.H. Bruneau, Emily Erickson. No date. *Water Quality and Pesticide Selection for Professional Turf Managers.* North Carolina State University Cooperative Extension. www.turffiles.ncsu.edu/PUBS/MANAGEMENT/PESTFORMAT1.PDF. Accessed June 11, 2003.

PRO-ACT. 2000. *Integrated Pest Management Fact Sheet*. http://www.afcee.brooks.af.mil/pro-act/fact/intpst.asp. Accessed July 31, 2001.

Professional Lawn Care Association of America (PLCAA). No Date(a). *Grasscycling Guide.* http://www.plcaa.org/consumer/brochures/plcaa-5.pdf.

Professional Lawn Care Association of America (PLCAA). No Date(b). *Water Quality and Your Lawn.* http://www.plcaa.org/consumer/brochures/plcaa-7.pdf.

Pronold, M.J. 2003. *Illicit and Industrial Storm Water Controls: A Municipal Perspective*. In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL. http://www.epa.gov/ORD/NRMRL/Pubs/625R03003/46Pronold.pdf. Accessed June 17, 2003.

Provin, T. 2002. *Evaluating Potential Movement of Nitrogen and Phosphorus in City of Austin Soils Following Varying Fertility Regimes: Greenhouse Simulations*. Texas A&M University. http://www.ci.austin.tx.us/growgreen/greenhouse.htm. Last updated 1995. Accessed September 5, 2003.

Relf, D. 1996. *Irrigating the Home Garden*. Virginia Cooperative Extension. http://www.ext.vt.edu/pubs/envirohort/426-322/426-322.html. Accessed June 12, 2003.

Relf, D. 1997. *Yard Waste Recycling*. Virginia Cooperative Extension. http://www.ext.vt.edu/departments/envirohort/factsheets3/landsmaint/MAY92PR5.HTML. Accessed June 12, 2003.

Relf, D. 2001. *Making Compost from Yard Waste*. Virginia Cooperative Extension. http://www.ext.vt.edu/pubs/envirohort/426-703/426-703.html - L4. Accessed June 12, 2003.

Roberts, E., and B. Roberts. 1989. *Lawn and Sports Turf Benefits*. The Lawn Institute, Pleasant Hill, TN.

Santa Clara Valley Nonpoint Source Pollution Control Program. 1992. *Best Management Practices for Automotive_Related Industries*. Santa Clara Valley Nonpoint Source Pollution Control Program, San Jose, CA.

Schueler, T. and C. Swann. 2000e. Stormwater Pollution Source Areas Isolated in Marquette, Michigan. *Watershed Protection Techniques* 3(1): 609-612.

Schueler, T., and C. Swann. 2000a. On watershed education. *Watershed Protection Techniques* 3(3):680–686.

Schueler, T., and C. Swann. 2000b. Understanding watershed behavior. *Watershed Protection Techniques* 3(3):671–679.

Schueler, T., and C. Swann. 2000c. Urban Pesticides: From the Lawn to the Stream. *Watershed Protection Techniques* 2(1):247–253.

Schueler, T., and C. Swann. 2000d. Diazinon Sources in Runoff from the San Francisco Bay Region. *Watershed Protection Techniques* 3(1): 613-616.

Sclar, D. C, Cranshaw, W. S., Jacobi, W. R., and Fleener, R. 1997. Integrated Pest Management practices in Colorado: A survey of woody plant nurseries and citizens, 1995-1996. *Tech. Bull*. TB97-2. 17 pp. Colorado State University Cooperative Extension Service.

Seattle (Washington) Public Utilities. 2000. *Integrated Pest Management*. http://www.cityofseattle.net/util/proipm/default.htm. Last updated August 3, 2000. Accessed July 31, 2001.

Stidger, R.W. 2001. Vegetation management: sprayer designs target herbicide application, cut costs. *Better Roads* May: 26–30.

Troutman, B.C. 2003. *Comments on the Draft National Management Measures to Control Nonpoint Source Pollution from Urban Areas.* ValleyCrest Companies, Sanford, FL.

Tuomari, D.C. 2003. *Sherlocks of Storm Water: Effective Investigation Techniques for Illicit Connection and Discharge Detection.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17-20, 2003, Chicago, IL.

U.S. Environmental Protection Agency (USEPA) and Purdue University. 1997. *I'd Rather Do It Myself*. USEPA Region 5 and Perdue University Department of Agricultural & Biological Engineering. http://www.purdue.edu/dp/envirosoft/housewaste/src/recipes.htm. Last updated May 7, 2001. Accessed September 5, 2003.

U.S. Environmental Protection Agency (USEPA) and Purdue University. 1996. *How Well do they Work? Report on the Research Project "Household Cleaners and the Environment*."

USEPA Region 5 and Perdue University Department of Agricultural & Biological Engineering. http://www.purdue.edu/dp/envirosoft/housewaste/src/research.htm. Last updated May 7, 2001. Accessed September 5, 2003.

U.S. Environmental Protection Agency (USEPA). 1992. *Healthy Lawn, Healthy Environment: Caring for Your Lawn in an Environmentally Friendly Way.* 700-K-92-005. Office of Prevention, Pesticides and Toxic Substances. http://www.epa.gov/oppfead1/Publications/lawncare.pdf. Accessed June 11, 2003.

U.S. Environmental Protection Agency (USEPA). 1994. *Composting Yard Trimmings and Municipal Solid Waste*. EPA 530-R-94-003. http://www.epa.gov/epaoswer/non-hw/compost/cytmsw.pdf. Accessed July 1, 2003.

U.S. Environmental Protection Agency (USEPA). 1995. *Citizen Guide to Pest Control and Pesticide Safety.* EPA 730-K-95-001. Office of Prevention, Pesticides, and Toxic Substances. http://www.epa.gov/OPPTpubs/Cit_Guide/citguide.pdf. Accessed July 22, 2003.

U.S. Environmental Protection Agency (USEPA). 1999. *Model Ordinances to Protect Local Resources: Illicit Discharges.* http://www.epa.gov/nps/ordinance/discharges.htm. Last updated October 27, 1999. Accessed June 30, 2000.

U.S. Environmental Protection Agency (USEPA). 2000. *Chlorpyrifos Revised Risk Assessment and Agreement with Registrants.* Office of Prevention, Pesticides and Toxic Substances. http://www.epa.gov/oppt/pollutionprevention/. Accessed July 22, 2003.

U.S. Environmental Protection Agency (USEPA). 2001a. *Pollution Prevention Technical Assistance*. http://www.epa.gov/p2/assist/index.htm. Last updated November 23, 2001. Accessed April 8, 2002.

U.S. Environmental Protection Agency (USEPA). 2001b. *Turfgrass: Best Management Practices for Protection of Water Resources*. http://www.epa.gov/region4/water/nps/projects/ky94-2.htm. Last updated May 21, 2001. Accessed January 22, 2002.

U.S. Environmental Protection Agency (USEPA). 2002. *Municipal Solid Waste in the United States: 2000 Facts and Figures*. EPA 503-R-02-001. http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/report-00.pdf. Accessed June 11, 2003.

U.S. Environmental Protection Agency (USEPA). 2003a. *Regulating Biopesticides.* http://www.epa.gov/pesticides/biopesticides/index.htm. Last updated April 30, 2003. Accessed June 11, 2003.

U.S. Environmental Protection Agency (USEPA). 2003b. *Managing Car Washing.* Nonpoint Source News-Notes (70). Washington, DC.

U.S. Environmental Protection Agency. No Date. *The Consumer's Handbook for Reducing Solid Waste*. http://www.epa.gov/epaoswer/non-hw/reduce/catbook/alt.htm. Last updated November 6, 2002. Accessed June 11, 2003.

U.S. Geological Survey (USGS). 1999. *The Quality of Our Nation's Waters: Nutrients and Pesticides*. USGS Circular 1225, Washington DC. http://water.usgs.gov/pubs/circ/circ1225/. Accessed June 11, 2003.

U.S. Geological Survey (USGS). 2004. *Water Quality in the Nation's Streams and Aquifers—Overview of Selected Findings, 1991–2001*. Circular 1265. U.S. Geological Survey, Reston, VA.

University of Texas at Austin. 1997. *NPDES Storm Water Management Program*. http://www.utexas.edu/safety/ehs/water/swmp_6_2000.PDF. Last updated June 12, 2000. Accessed August 20, 2001.

Water Quality Consortium. 1998. *Surface Water Quality: What's the Problem with Pet Waste?* http://www.ci.seattle.wa.us/util/surfacewater/bmp/petwaste.htm. Last updated November 18, 1998. Accessed April 5, 2001.

Wayne County Department of Environment. 2001. *Illicit Discharge Elimination Services Offered by the Watershed Management Division, Wayne County Department of Environment.* http://www.waynecounty.com/doe/watershed/idep.htm. Accessed July 30, 2003.

Worlton, M. 2003. *Overcoming Challenges in Regional Public Education & Outreach Partnerships.* Paper presented at the National Conference on Urban Storm Water: Enhancing Programs at the Local Level, February 17-20, Chicago, IL.

MANAGEMENT MEASURE 10
EXISTING DEVELOPMENT

10.1 Management Measure

Develop and implement watershed management programs to reduce runoff pollutant concentrations and volumes from existing development and redevelopment:

- Identify opportunities to reduce pollutants in priority local and/or regional watersheds (e.g., improvements to existing urban runoff control structures, including the addition of infiltration, filtration, retention, and detention practices).
- Devise a schedule for implementing appropriate runoff controls.
- Limit destruction of natural conveyance systems.
- Where appropriate, preserve, enhance, or establish buffers along surface water bodies and their tributaries.
- Promote redevelopment that reduces runoff volumes and pollutants.

10.2 Management Measure Description and Selection

10.2.1 Description

The purpose of this management measure is to protect or improve surface water quality by developing and implementing watershed management programs that pursue the following objectives:

- Reduce surface water runoff pollution loadings from areas where development has already occurred.
- Reduce the volume and peak runoff rates of surface water runoff to reduce runoff flow, increase infiltration, and minimize habitat degradation and sediment loadings from erosion of streambanks and other natural conveyance systems.
- Preserve, enhance, or establish buffers that provide water quality benefits along water bodies and their tributaries.

Maintaining water quality becomes increasingly difficult as urbanization occurs and areas of impervious surface increase. Increased peak runoff volumes from impervious surfaces result in alteration of stream channels, natural drainageways, and riparian habitat. This alteration, in turn, results in elimination or reduction of predevelopment aquatic flora and fauna and degradation of predevelopment water quality. Other effects include increased bank cutting, streambed scouring, embedded cobbles, siltation, increases in instream water temperature, decreases in dissolved oxygen, and changes to the natural structure and flow of the stream or river.

Protecting water quality in urbanized areas is difficult because of many factors, including diverse pollutant loadings, large runoff volumes, limited areas suitable for surface water runoff treatment systems, the high implementation costs associated with structural controls, and the destruction or absence of buffer zones that can filter pollutants and prevent the destabilization of streambanks and shorelines.

An important nonstructural component of many watershed management plans is the establishment and preservation of buffers and natural systems (e.g., by policy, code, or ordinance). These areas help to maintain and improve surface water quality by filtering and infiltrating urban runoff. In areas of existing development, natural buffers and conveyance systems may have been altered as urbanization occurred. Where possible and appropriate, additional impacts on these areas should be minimized, and if the areas are degraded, their functions should be restored. Establishing and protecting buffers is most appropriate along surface water bodies and their tributaries where water quality and the biological integrity of the water body are dependent on the presence of an adequate buffer or riparian area. Buffers may be necessary where the buffer or riparian area:

- Reduces significant nonpoint source pollutant loadings;
- Provides habitat necessary to maintain the biological integrity of the receiving water;
- Reduces undesirable thermal impacts on the water body; or
- Reduces erosion.

Structural practices may be a suitable option to decrease the nonpoint source pollution loads generated from developed areas in addition to nonstructural controls (see Management Measure 9: Pollution Prevention). In such situations, a watershed plan can be used to integrate the construction of new surface water runoff treatment structures and to retrofit existing surface water runoff management systems.

Retrofitting is a process that involves the modification of existing surface water runoff control structures or surface water runoff conveyance systems that were initially designed to control flooding, not to serve a water quality improvement function. By enlarging existing surface water runoff structures, changing the inflow and outflow characteristics of such devices, and increasing runoff detention and retention time, sediment and associated pollutants can be removed from the runoff. Retrofit of structural controls is often the only feasible alternative for improving water quality in developed areas. Where existing development or financial constraints limit treatment options, targeting or identifying priority pollutants and selecting the most appropriate retrofits that will result in the greatest improvement to water quality may be necessary.

Once key pollutants have been identified, an achievable water quality target for the receiving water should be set to improve current levels based on an identified objective or to prevent degradation of current water quality. Extensive site evaluations should then be performed to assess the performance of existing surface water runoff management systems and to pinpoint low-cost structural changes or maintenance programs for improving pollutant removal efficiency. Where flooding problems exist, source controls, low-impact development (LID), and infiltrative controls should be incorporated into the design of surface water runoff controls. Available land is often limited in urban areas, and the lack of suitable areas frequently restricts the use of conventional pond systems. In heavily urbanized areas, sand filters, biofilters, or water quality inlets with oil/grit separators might be appropriate for retrofits because they do not limit use of the land.

10.2.2 Management Measure Selection

The first and second components of this management measure were selected to encourage communities to develop and implement watershed management programs. Local conditions, availability of funding, and problem pollutants vary widely among communities. Watershed management programs allow communities to select and implement the practices that best address local needs. Prioritizing local and/or regional pollutant reduction opportunities and setting schedules for implementing appropriate controls were selected as logical starting points for establishing an institutional framework to address nonpoint source pollutant reduction. The first two parts of Section 10.3: Management Practices, "Identify, Prioritize and Schedule Retrofit Opportunities" and "Implement Retrofits as Scheduled" address these two components.

The third and fourth components of this management measure were selected to preserve, enhance, and establish areas within existing development, such as natural streams, ponds, and wetlands and aquatic buffers, that provide positive water quality benefits. These natural systems provide efficient runoff conveyance as well as aesthetic benefits. These components are addressed by the third, fourth, and fifth parts of Section 10.3: Management Practices: "Restore and Limit the Destruction of Natural Runoff Conveyance Systems," "Restore Natural Streams," and "Preserve, Enhance, or Establish Buffers."

The fifth component is addressed by part 5 of Section 10.3: Management Practices, "Revitalize Urban Areas." This component was selected to encourage redevelopment of urban areas that may be contributing to water quality problems via impervious surfaces, contaminated soils, or land uses that result in poor runoff quality or increased runoff volumes. Multiple goals such as surface water and ground water quality improvement, soil remediation, and quality-of-life enhancements may be simultaneously achieved using such an approach.

The Brownfields program, managed by EPA under the authority of the Small Business Liability Relief and Brownfields Revitalization Act of 2002 (USEPA, 2002b), promotes redevelopment of these areas and also can be an effective source of funding and expertise to achieve the above goals. The Act

- Provides legislative authority for the Brownfields program including grants for assessment and clean-up;
- Expands the current Brownfields program by increasing its funding authority up to $200 million per year including up to $50 million per year to assess and clean up brownfields with petroleum contamination;
- Expands eligibility for assessment and clean-up grants;
- Includes a new provision for direct clean-up grants of up to $200,000 per site;
- Streamlines current requirements for the brownfields clean-up revolving loan fund and makes funding available to nonprofit organizations;

- Applies the Davis Bacon Act, which maintains local wage and labor standards for federal construction work, on the same terms as the authority for the current program; and

- Makes funds available for technical assistance, training, and research.

More information about the Small Business Liability Relief and Brownfields Revitalization Act can be found at http://www.epa.gov/brownfields/sblrbra.htm.

Cost was a major factor in the selection of this management measure. EPA acknowledges the following constraints to implementing nonpoint source controls for existing development:

- High costs and other limitations inherent in treating existing sources to levels consistent with the standards set for developing areas;

- Frequent lack of suitable areas for structural treatment systems that can adequately protect receiving waters;

- Lack of universal cost-effective treatment options;

- Frequent lack of funding for mandatory retrofitting; and

- Extraordinarily high costs associated with implementing retention ponds and exfiltration systems in developed areas.

10.3 Management Practices

10.3.1 Identify, Prioritize, and Schedule Retrofit Opportunities

In the watershed assessment phase of the urban runoff management cycle, watershed managers should identify water bodies that have been degraded by urban runoff and prioritize them for restoration based on the costs and benefits for watershed stakeholders. One method to halt further degradation and initiate water body recovery is to retrofit existing runoff management practices or conveyance structures. It is important for watershed managers to have clear goals and realistic expectations for retrofitting existing structures. Each retrofit project should be planned in the context of a comprehensive watershed plan, and managers should have a clear set of objectives to ensure that the project results in measurable improvements in hydrologic, habitat, and/or water quality indicators.

10.3.1.1 Evaluate existing data

The first step in identifying candidate sites for storm water retrofitting is to examine existing data. These data can include results from a watershed assessment, topographic maps, land use or zoning maps, property ownership maps, aerial photos, and maps of the existing drainage network. For example, results from a watershed assessment can be used to identify areas with good habitat and water quality that should be protected, as well as areas with poor habitat and water quality that need to be improved. Topographical maps can be used to delineate drainage units within the watershed at the subwatershed and catchment levels. Land use or zoning maps can be used to estimate areas of high impervious cover to target areas that contribute a large amount of runoff to receiving waters, while property maps provide land ownership data. Finally, aerial photographs can be used to identify open spaces that can be more easily developed into runoff management facilities. According to the Center for Watershed Protection (CWP, 1995a), the best retrofit sites:

- Are located adjacent to existing channels or at the outfall of storm drainage pipes;
- Are located within an existing open area;
- Have sufficient runoff storage capacity;
- Are feasible for diverting runoff to a potential treatment area (forested or vegetated area) or structural management practice; and
- Have a sufficient drainage area to contribute meaningfully to catchment water quality.

Specific areas well-suited for new runoff controls include undeveloped parkland and open space, golf courses, wide floodplains, highway rights-of-way, and edges of parking lots.

Information for potential retrofit sites, such as location, ownership, approximate drainage area, utility locations, and other pertinent details, can be compiled in a retrofit inventory sheet (CWP, 1995a). A site visit can provide information on site constraints, topography, adjacent sensitive land uses, receiving water conditions, utility crossings, and other considerations that would affect the feasibility of implementing the management practice. At this point, a conceptual sketch for rerouting drainage and siting management practices should be drawn and preliminary cost estimates made for each site.

10.3.1.2 Choose appropriate management practices based on site conditions

The choice of one potential retrofit site over another for management practice implementation can be based on several different factors in addition to site limitations and cost. For instance, the preliminary goals of a retrofit program may be to preserve streams or reaches known to have high-quality habitat or exceptional water quality. The goal of another program may be to restore poor habitat and degraded water quality. The program may elect to target particular land uses thought to contribute the majority of pollutants to receiving waters. Retrofit facilities also can be installed to treat runoff from large parts of a watershed or subwatershed (regional controls), thereby requiring fewer overall projects. Once retrofit sites are identified and prioritized, a schedule for installing new facilities or updating old facilities should be devised.

10.3.1.3 Incorporate low-impact development practices into existing development

In many cases, sites that are already developed can be retrofitted with low-impact development practices such as biofilters, rain barrels, rooftop greening, and cisterns (see Management Measure 5 for a more detailed discussion of these practices). Soil rehabilitation and tree planting can also contribute to the reduction of runoff. All of these practices can be designed on a small scale to accommodate space constraints that may be present on developed sites. The use of these practices will aid in retaining runoff on-site and help to reduce the total volume of runoff reaching receiving waters. For example, in Washington, DC, trees have saved $4.74 billion in gray infrastructure costs per 30-year construction cycle, and reduced the need for storm water retention structures by 949,000 ft^3 (NALGEP, 2003).

The City of Chicago has incorporated low-impact development practices such as rooftop greening and downspout disconnection into its urban runoff management strategy. The City Hall Rooftop Garden is a $1.5 million retrofit project to demonstrate the benefits of green roofs. The city has published *A Guide to Rooftop Gardening* (http://www.cityofchicago.org/Environment/GreenTech/pdf/GuidetoRooftopGardening.pdf) to communicate the lessons learned from this project and provide information to the public on green roof development. The city is also targeting flood-prone areas for its downspout disconnection campaign, distributing door hangers and brochures to residents, and encouraging the use of rain barrels (Murante, 2003).

The *Low-Impact Development Design Strategies: An Integrated Design Approach* (Prince George's County, Maryland, Department of Environmental Resources, 2000) and the Low Impact Development Center Web site (http://www.lowimpactdevelopment.org/) can provide more information about these and other practices appropriate for existing developments. Additionally, a search for "urban forestry" on the USDA Forest Service's Web site (http://www.fs.fed.us/) produces many good references about how trees can be used to reduce runoff volume and improve runoff quality.

10.3.1.4 Identify undeveloped and privately owned land for acquisition

In addition to the installation of conventional storm water management practices, the acquisition and preservation of open space in developed watersheds can protect against the threat of further development, reduce runoff volume, and provide storm water treatment. This practice involves the identification of parcels in a developed watershed that are undeveloped or privately owned and can be protected or restored to provide storm water benefits by attenuating additional runoff volume and peak flow. This watershed-wide planning effort involves mapping open space, cadastral data (e.g., property boundaries, subdivision lines, buildings), drainage systems, urban forests, floodplains, and other land use data. The planning effort also involves selecting sites based on their proximity to receiving waters, the condition of the soil and vegetation, and ease of purchase. Selected parcels are purchased, restored if necessary, and modified to receive and retain more runoff using berms or diversions (O'Leary, 2003). For more information on land acquisition, see Management Measure 3: Watershed Protection.

10.3.1.5 Use routine maintenance as an opportunity for retrofitting existing infrastructure

One of the major challenges in controlling runoff from existing development is the potentially high cost of retrofitting infrastructure to reduce runoff quantity and improve quality. One way to reduce costs is to modify runoff controls during routine maintenance procedures. Retrofits can be constructed as part of the routine maintenance and repair of urban infrastructure. This approach requires less capital outlay for retrofit compared to large-scale, capital-intensive approaches. For example, pervious surfaces can be installed when resurfacing parking areas, and newly disturbed areas can be restored to the desired vegetative condition (e.g., forest or meadow). When storm water ponds are dredged every few years, sediment forebays can be redesigned to improve performance.

Retrofitting Catch Basins for On-Street Runoff Storage

An example of a retrofit to reduce downstream impacts of urbanization can be found in the towns of Skokie and Wilmette, Illinois. These towns are urban areas that are served by a combined sewer system (CSS). Both communities wanted to control CSS surcharge but did not want to build expensive relief sewers. As a result, they were willing to try alternative approaches. The towns decided to modify street cross sections and storm drain inlets to allow runoff to be stored temporarily on the street surface during storm events to reduce hydraulic loading to CSSs. The street surface storage projects combined the following elements (USEPA, 2000b):

- Street storage.
- Downspout disconnection.
- Flow regulators.
- Subsurface storage.
- New storm and combined sewer systems.
- Improvements to existing storm and combined sewer systems.

The projects involved installing a system of street berms, 7 to 9 inches high, at the curb line to detain water on the street. Flow regulation devices were installed at catch basin outlets to reduce the rate of storm water flow to the CSS. Both the street surface and the inlet structure were used for storage. Subsurface storage facilities were also installed in the street right-of-way and in other public areas at critical points in the system and in pedestrian walkways, parking areas, and high-traffic areas, where ponding was unacceptable.

The project resulted in a number of benefits. Researchers estimated a cost savings from using street storage rather than conventional sewer separation systems. Estimated costs for the Skokie system are approximately 38 percent of conventional sewer separation system costs. Berm costs are a small fraction of the overall cost of the CSS surcharge relief project. Another benefit of the storage system is traffic control. Berms can function as speed humps and help control traffic. The street storage system also reduces the volume and frequency of combined sewer overflows, resulting in less runoff-related pollution entering receiving waters. Icing of ponded areas during the winter was not a problem because retention times were relatively short (less than 30 minutes), but consideration should be given to safety hazards associated with ponded water during periods of high rainfall.

10.3.2 Implement Retrofit Projects as Scheduled

CWP (1995b) describes six common types of retrofitting projects:

- Modifying existing runoff management facilities;
- Constructing new management practices at the upstream end of road culverts;
- Constructing new management practices at storm drainage pipe outfalls;.
- Constructing small instream practices in channels;
- Constructing management practices at the edge of large parking areas and
- Constructing new management practices in highway rights-of-way.

10.3.2.1 Retrofit existing runoff management facilities

Many older dry detention basins were designed for the singular purpose of flood control. In some cases, a facility of this type can be converted into an extended detention pond/wetland or a conventional wet pond. If this retrofit is designed well, it will increase pollutant removal capabilities and aquatic habitat functions without losing any of its flood control benefits. This modification also typically results in only minimal impacts on the surrounding environment. Dry detention ponds can be modified to accommodate a greater variety of species by transforming them into constructed wetlands or installing aquatic platforms, which are shallow benches on which aquatic vegetation can be planted (see Section 5.3.1.3 for more information about constructed wetlands; Fairfax County Environmental Coordinating Committee, 2002).

The retrofit process often includes:

- Analyzing existing hydraulic characteristics and the flood control design specifications of the facility;
- Determining whether there is available storage for water quality treatment;
- Excavating the pond bottom to create permanent pool storage (for pond and wetland systems) if water quality storage is available;
- Raising the embankment or modifying the outlet structure to obtain additional storage if extended detention is needed;
- Increasing the flow path from inflow point to discharge point by using baffles or earthen berms or by regrading the pond's contours to increase particulate settlement; and
- Addressing safety considerations, such as fencing and adding underwater benches or shallow fringe areas along shorelines, to reduce the risk of drowning.

Bioengineering to enhance water quality benefits

The City of Griffin, Georgia, constructed a bioengineering system within the North Griffin Regional Detention Pond and within a forested wetland area downstream of the pond to improve water quality in the receiving waterbody, Flint River. The bioengineering system is comprised of specific species of vegetation that provide natural filtration and breakdown of pollutants in runoff. The wetland plants selected include cattail, bulrush, pickerel weed, soft rush, wool grass, southern cutgrass, and shallow sedge. Experts chose these species based on their anticipated ability to break down and filter various pollutants commonly found in runoff. The system has low maintenance requirements and relatively low construction and operating costs in comparison to conventional treatment facilities. In addition to water quality benefits, the system will enhance wildlife habitat (City of Griffin, no date). The Consulting Engineers Council of Georgia recognized the project design and performance success with an Engineering Excellence Award in February 2000. The Georgia Environmental Protection Division and USEPA Clean Water Act (CWA) Section 319(h) Program also acknowledged the project's achievement (Greuel and Feldner, 2001). A detailed summary of this project is available in EPA's Section 319 Success Stories, Vol. III at http://www.epa.gov/owow/nps/Section319III/GA.htm.

10.3.2.2 Modify the upstream end of road culverts

A good retrofit opportunity can sometimes be found at the upstream end of a road culvert. A gabion, concrete weir structure, or riser/barrel control structure can be installed to create a small, permanent micropool excavated to provide water storage, water quality, and habitat benefits. This method can be used to provide a dry extended detention basin with a maximum depth of 6 feet above the culvert invert. If the upstream area is open floodplain, it might be possible to construct a wet pond or extended detention pond/wetland retrofit.

Cost-Effectiveness Study of Retrofitting Runoff Treatment Facilities

EPA's Office of Research and Development investigated retrofitting wet-weather flow treatment facilities to determine their feasibility and cost-effectiveness (Moffa et al., 2000). The following retrofit scenarios were analyzed:

- Converting or retrofitting primary settling tanks with dissolved air flotation and lamellae (thin, flat membranes or layers) and/or microsand-enhanced plate or tube settling units.
- Retrofitting existing wet-weather flow storage tanks to provide enhanced settling/treatment and post-storm solids removal.
- Converting dry ponds to wet ponds for enhanced treatment.
- Retrofitting wet-weather flow storage tanks for dry-weather flow augmentation.
- Using storage for sanitary sewer overflow control.
- Retrofitting for industrial wastewater control in a combined sewer system.
- Bringing outdated/abandoned treatment plants back on-line as wet-weather flow treatment facilities.

The cost-benefit analysis examined site-specific, operational, cost, and design parameters. Each retrofit scenario was analyzed over a range of flow and/or volume conditions. The study revealed that in certain circumstances, retrofitting existing wet-weather flow treatment facilities is technically feasible and can be more cost-effective than construction of new conventional control and treatment facilities. The authors concluded that these results were highly site-specific and recommended that retrofitting existing control facilities be identified as one of several alternatives to reduce impacts from storm events. The full report is available at the Office of Research and Development's Web site at http://www.epa.gov/ednnrmrl/news/main.htm.

Because roadways are not constructed as runoff management embankments, special measures might be necessary to ensure that these facilities meet dam safety specifications for seepage control and passage of the 100-year storm. Consideration and evaluation of secondary impacts, such as modification of the 100-year floodplain, creation of fish migration barriers, and changes to the wetland hydrologic regime is also warranted with this type of retrofit.

10.3.2.3 Modify storm drainage pipe outfalls

A volume of runoff can be diverted at or near a storm drainage pipe outfall to a sand filter, peat-sand (or other medium) filter, bioretention system, centrifugal deflection system, off-line wetland or pond system, or other water quality treatment facility for treatment before it reenters a receiving water.

10.3.2.4 Add retention structures to channelized streams

Small weir walls or check dams can sometimes be placed in small, previously channelized streams to retain sediments and create a ponding area for wetland vegetation. This type of retrofit is usually easy to install and can provide moderate pollutant removal benefits. Because it can potentially affect channel design flows and the floodplain, however, careful analysis must be conducted before the instream practice is implemented. In addition, cleanout frequency should be considered before selecting this practice, as regular maintenance will be needed to remove trapped sediments.

10.3.2.5 Install runoff management practices in or adjacent to large parking areas

Retrofit practices can be installed near large parking lots to capture, detain, and/or treat runoff. Infiltration practices such as bioretention areas, porous pavement, sand filters, and underground vaults are good candidates. Two examples of successful use of bioretention areas can be found at http://www.epa.gov/owow/nps/bioretention.pdf (USEPA, 2000a). In addition, a case study illustrating the effectiveness of porous pavement in reducing runoff is provided at http://www.epa.gov/owow/nps/pavements.pdf (USEPA, 2000b).

10.3.2.6 Construct new practices in highway rights-of-way

Existing highway systems can have significant open spaces for the installation of various practices. For example, cloverleaf open space can be an ideal location for storm water wetlands and pond systems if drainage areas and patterns allow. Care must be taken to avoid creating a safety hazard for traffic, and maintenance access should be an integral part of the design.

10.3.2.7 Install trash-capturing devices

Trash racks are inclined metal grates that trap floatables as water passes through. The racks can be installed at storm sewer inlets or outfalls or in the stream itself. These structures effectively remove trash from the water, but they require a high level of maintenance (inspection for damage or clogging after storms and regular trash removal). If these racks are poorly maintained, their effectiveness decreases and they can clog, which can cause a flood hazard. A less-expensive alternative to metal trash racks is plastic mesh trash collectors with floating piers that stretch across the width of the stream. They are easier to maintain because they are simply removed and replaced with a new collector.

The applicability of these trash collection methods is limited to small streams with relatively low flow and low-level trash inputs. More substantial trash collection methods, such as vortex devices that use centrifugal force to separate floatables from water, can be installed to handle larger flows or high trash loads.

10.3.2.8 Install inlet and grate inserts

A wide variety of inserts that trap oil and grease from parking lots, maintenance yards, and streets are also commercially available. These can be used with or without trash capture in storm drain inlets and grates. Inspection and maintenance one to four times per year (depending on pollutant concentrations in runoff) is usually recommended. Catch basin inserts are discussed in more detail in Management Measure 5 (section 5.3.5.4).

10.3.3 Restore and Limit the Destruction of Natural Runoff Conveyance Systems

Existing development has likely resulted in a modification of natural drainage patterns as compared to predevelopment conditions. As a result, increases typically occur in imperviousness, runoff, peak flows during storm events, erosion, and pollutant transport. The use of traditional runoff management technology, such as piping, channeling, and curbing, has aggravated these impacts.

Efforts should be made to restore previously developed or redeveloping sites so they more closely mimic predevelopment hydrologic conditions. The predevelopment condition should be estimated based on historical records and existing slopes, soils, and natural drainage features. Consideration should be given to the time of concentration—the time it takes water to travel from the farthest point in a subwatershed to the outlet. (Sites might contain multiple subwatersheds and multiple outlets.) Paving and curbing substantially reduce time of concentration, resulting in high peak flows during storms. Time of concentration can be increased substantially by modifying drainage patterns and installing infiltration and detention practices. The practices presented in this section can be used to increase time of concentration on a particular site. Additional technical guidance for restoration practices can be found at EPA's River Corridor and Wetland Restoration Web site at http://www.epa.gov/owow/wetlands/restore (USEPA, 2002a). Another resource is *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG, 1998), which can be downloaded at http://www.nrcs.usda.gov/technical/stream_restoration/newgra.html or ordered by contacting the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone 703-605-6000 or 800-553-NTIS; e-mail orders@ntis.fedworld.gov.

10.3.3.1 Disconnect impervious areas

Roof downspouts can be disconnected from streets and culverts and runoff diverted over vegetated areas or infiltration systems (for treatment) or into cisterns or rain barrels (for reuse; see Management Measure 5 for more information on these practices). Also, roadway runoff can be converted to sheet flow and directed to vegetated buffers, infiltration devices, or other pervious areas.

Rooftop runoff also can be controlled with a vegetated roof cover. These systems consist of a high-quality waterproof membrane covered by drainage material, a planting medium, and vegetation. Vegetated roof covers use foliage and a lightweight soil mixture to absorb, filter, and detain rainfall. The systems are designed to control high-intensity storms by intercepting and retaining water until the rainfall peak passes (USEPA, 2000d). Additionally, vegetated roof covers improve insulation and reduce the amount of reflected solar radiation, resulting in lower temperatures in urban areas. More information about vegetated roof covers can be found at http://www.epa.gov/owow/nps/roofcover.pdf.

The City of Portland, Oregon, encourages residents to reduce the connectivity of impervious surfaces through its Downspout Disconnection Program, originally established in 1996 to address problems with combined sewer overflows. Through an interagency agreement, the local plumbing code was revised to allow downspout disconnection without a permit. The program has developed safety standards that establish criteria for the feasibility of a disconnection, as well as an inspection and maintenance program to ensure safety. Homeowners can choose to have the city disconnect a downspout free of charge, or they can disconnect it themselves and receive a cash incentive. Since the start of the program, nearly 17,000 homes have been disconnected and data have been collected on an additional 20,000 potential disconnections (Hottenroth, 2003).

More information about the Downspout Disconnection Program can be found at http://www.portlandonline.com/oni/index.cfm?c=28992.

10.3.3.2 Encourage overland sheet flow

Concentrated flow of runoff during storms results in decreased time of concentration, decreased infiltration, and increased erosion due to high runoff velocity. Careful regrading to reduce steep slopes slows runoff, promotes infiltration, and reduces erosion. (Note that regrading efforts should not result in increased compaction; if compaction has occurred, soil amendments and rehabilitation may be necessary.) A level spreader, which typically consists of a shallow, gravel-filled trench that receives concentrated flows and converts them to sheet flow, can be installed to convey runoff to vegetated areas. A flat, grassy area can also be used to promote overland flow.

10.3.3.3 Increase flow path

Increasing the path of runoff results in increased storm water detention and increased travel time. Directing concentrated flows from impervious areas to infiltration areas, swales, dry wells, cisterns, or bioretention facilities increases the time it takes for runoff to leave the site and mitigates peak runoff flows.

10.3.3.4 Use open swales in place of traditional storm drain systems

Grassed swales are an effective and natural means of conveying runoff. Because the water comes into contact with vegetation, the runoff velocity decreases, which promotes infiltration, reduces erosion, and lengthens time of concentration. Because grassed swales are wider and shallower than conventional channels, runoff is less concentrated. They are especially appropriate alongside roadways or on the border of a site. Swales can be combined with terraces and infiltration devices to enhance runoff retention. Swale installation requires a minimum amount of excavating and regrading. Vegetation should be established immediately to prevent excessive erosion; while vegetation is being established, geotextiles or turf reinforcement mats can be used to stabilize exposed soils in the swale.

One neighborhood in Seattle, Washington, underwent a transformation from conventional to natural drainage systems as part of a pilot project, called "SEA Street" (for Street Edge Alternatives), conducted by Seattle Public Utilities. Monitoring before and after the installation of swales indicated a decline from approximately 5,000 cubic feet of runoff from 8 inches of rain to only 132 cubic feet of runoff from 9 inches of rain. The project, which cost approximately $800,000, was equivalent to the cost of a conventional curb-and-gutter system and provides additional water quality benefits and an anticipated boost to property values (Taus, 2002). More information about this project can be found at http://www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Street_Edge_Alternatives/index.asp.

10.3.3.5 Establish vegetation throughout the site

Vegetation intercepts rainfall, decreases runoff velocity by increasing surface roughness, and promotes infiltration. Establishing vegetated areas in strategic locations that currently receive runoff from impervious areas requires minimal effort, especially when native plant species are used. Excess compaction of these areas by heavy equipment should be avoided. To enhance the benefits of vegetated areas, part of a site can be regraded during redevelopment activities to direct runoff to these areas. See Management Measure 3: Watershed Protection (section 3.3.3.8) for a discussion of urban forestry practices that can help in achieving these goals.

10.3.3.6 Reestablish ground water recharge

Traditional development techniques that focus on quickly conveying runoff off-site have resulted in decreased infiltration of rainfall to ground water. This ground water deficit results in a lowered water table and decreased seepage and baseflow in streams during dry periods. Infiltration practices can be installed to promote ground water recharge. Such practices include infiltration trenches, infiltration basins, sand filters, biofiltration systems, and vegetated areas underlain by permeable soils (see Management Measure 5: New Development Runoff Treatment).

A Watershed Restoration Plan for the Norwalk River Watershed

Habitat quality and water quality in the Norwalk River watershed of southeastern Connecticut have been degraded by erosion, sediment, pesticides, excessive algae growth, driftwood and other impoundments, and other types of pollution associated with increased watershed urbanization (NWRI, 1998). In 1997 federal, state, and local government agencies, environmental groups, and concerned citizens formed the Norwalk River Watershed Initiative (NRWI) to halt further degradation and promote water quality recovery. Subcommittees were tasked with developing goals for four key issues: (1) habitat restoration; (2) land use, flood protection, and open space; (3) water quality; and (4) stewardship and education.

The NWRI assessed existing water quality and riparian conditions based on data collected by the Connecticut Department of Environmental Protection, U.S. Geologic Survey, and U.S. Department of Agriculture. They also identified land uses that contribute to water quality problems, areas where stream channels had been modified by dams or flood control projects, and point sources such as municipal wastewater treatment facilities.

Based on the results of the assessment, the NWRI developed the Norwalk River Watershed Action Plan, which describes specific objectives and action items to accomplish those objectives for each of the four key areas listed above. Each objective contains a list of specific tasks with the implementing group clearly identified, the proposed time line for each task, and a measure of the tasks' success. The NWRI also developed an outreach program to foster stewardship and to educate watershed residents about the impacts of daily activities that contribute to the degradation of the Norwalk River watershed.

For more information on the Watershed Action Plan or to obtain a copy of the plan, contact the Norwalk River Watershed Coordinator, Connecticut Department of Environmental Protection, Bureau of Water Management, 79 Elm Street, Hartford, CT 06106; telephone 860-424-3096; e-mail tessa.gutowski@po.state.ct.us.

Restoration in the Anacostia River Watershed

The Anacostia River has been cited nationally as exemplifying urban watershed problems (AWRC, 1998). These problems are typified by

- Conversion of natural drainage networks into man-made channels.
- Increased runoff and urban pollutants from impervious surfaces.
- Channel erosion and associated loss of aquatic habitat from changes in land use.
- Sediments laden with toxic substances and other pollutants from motor vehicles.
- Electrical transformers, past applications of persistent pesticides, poorly timed applications of fertilizers, combined sewer overflows, atmospheric deposition, and pet waste.
- Thousands of tons of trash and debris.

As a result of this degradation, in 1987 a concerted effort to restore and protect the Anacostia watershed was initiated in the form of the Anacostia Watershed Restoration Agreement and the establishment of the Anacostia Watershed Restoration Committee (AWRC), which involved the District of Columbia, Montgomery and Prince George's counties in Maryland, the State of Maryland, the U.S. Army Corps of Engineers, the Metropolitan Washington Council of Governments, and the Interstate Commission on the Potomac River Basin. The cooperative effort was expanded in 1996 with the creation of the AWRC's Anacostia Watershed Citizens Advisory Committee (AWCAC). The AWCAC has brought formal recognition of the importance and need for citizen input and involvement in the restoration.

The AWRC established a framework to guide long-term restoration efforts and identified 580 restoration projects to correct existing environmental problems and enhance overall ecosystem quality. As of 1997 approximately $20 million had been spent on implementing roughly 29 percent of the 580 identified projects, with additional millions of dollars spent on planning, design, land acquisition, and maintenance. An additional $54 million had been spent on engineering controls designed to reduce the impacts of combined sewer overflows on the tidal river and of leaking, aging sewer lines on tributary streams. As a result of the restoration efforts, the submerged aquatic vegetation once absent from the river is beginning to reappear, signaling some improvement in water clarity, as the volume and concentrations of pollutants from urban runoff have been reduced. The successes have required the identification of problems and associated solutions, coordination of programs, and the mobilization of critical government, political, and financial resources. Key features in the success of the Anacostia program have been the development of common watershed restoration goals and the identification and establishment of partnerships.

More information about the Anacostia Watershed Restoration Project can be found at http://www.anacostia.net/awrc.htm.

10.3.3.7 Protect sensitive areas

Areas that should be considered for preservation and restoration at sites with existing development include riparian areas, 100-year floodplains, wetlands, woodlands and valuable trees, and areas with permeable soils. Steep slopes and erosive soils should be protected and stabilized to the extent possible.

10.3.4 Restore Natural Streams

Streams degraded by prior urbanization should be restored, if possible, using preexisting conditions as a goal or guideline. Eight restoration tools can be applied to help restore urban streams. These tools are intended to compensate for stream functions and processes that have been diminished or degraded by prior watershed urbanization. Best results are usually obtained when the tools are applied together; otherwise, the same sources that degraded the stream remain unchanged, causing similar effects.

A resource for information about restoring natural streams is *Stream Corridor Restoration: Principles, Processes, and Practices* (FISRWG, 2000), which is available for purchase or download at http://www.usda.gov/stream_restoration/newgra.html. Another resource is *Urban Stream Restoration: A Video Tour of Ecological Restoration Techniques* (Riley, 1998b), which is available for purchase at http://www.noltemedia.com/nm/urbanstream/index2.html. Finally, the Center for Watershed Protection developed 11 manuals, collectively called the Urban Subwatershed Restoration Manual Series, that present the information needed to restore small urban watersheds in a format that can easily be accessed by watershed groups, municipal staff, environmental consultants, and other users. The manuals are available for a fee in hard copy or as a download at http://www.cwp.org/USRM_verify.htm.

10.3.4.1 Partially restore the predevelopment hydrologic regime

The primary objective of storm water management is to reduce the frequency of bankfull flows and other erosive events in the contributing watershed. This is often done by constructing upstream storm water retrofit ponds that capture and detain increased storm water runoff for up to 24 hours before release (i.e., extended detention). Extended detention systems are often designed to control the one-year, 24-hour storm. Storm water retrofit ponds are often critical in the restoration of small and mid-sized streams, but they might be less cost-effective in larger streams and rivers unless implemented on a watershed basis.

10.3.4.2 Stabilize channel morphology

Over time, urban stream channels can become enlarged and are subject to severe bank and bed erosion. Therefore, it is important to stabilize the channel and, if possible, restore equilibrium to the channel geometry. In addition, it is useful to provide undercuts or overhead tree canopy to improve fish habitat. Depending on the stream order, the impervious cover in the watershed, and

Restoring Channel Morphology in a North Carolina Stream

Long Leaf Creek is located in an urbanized watershed along coastal North Carolina (Sotir, 2000). The stream had deepened and widened as a result of increased runoff and severe storms, including hurricanes. The changes resulted in reduced aesthetic value, damaged riparian vegetation and aquatic and terrestrial habitats, and degraded water quality. Managers selected a soil bioengineering approach over other alternatives after considering such issues as erosion control, streambank stabilization, safer and healthier environment, flood control, timely project completion, environmental and aesthetic improvement, property loss minimization, hydraulic efficiency, and cost feasibility. They installed live fascines, brush layer/live fascine combinations, joint planting, and vegetated geogrids.

The survival rates of the live vegetation ranged from 60 to 80 percent depending on the species used; maintenance proved to be a key factor in survival rates. Several important needs were identified, including studying bed conditions in areas that have had high deposits of mobile materials, employing sophisticated grade control structures, following installation procedures and maintenance schedules, and encouraging communication and cooperation between engineers and wetland scientists.

the height and angle of eroded banks, a series of different tools can be applied to stabilize the channel and prevent further erosion. Bank stabilization measures include revegetated riprap and soil bioengineering methods (see Management Measure 7) such as willow stakes, brush bundles, bio-logs, lunker structures, and rootwads.

10.3.4.3 Restore instream habitat structure

Most urban streams have poor instream habitat structure, often typified by indistinct and shallow low-flow channels within a much larger and unstable storm channel. The goal is to restore instream habitat structure that has been blown out by erosive floods. Key restoration elements include creating pools and riffles, confining and deepening the low-flow channels, and providing greater structural complexity across the streambed. Typical tools include installation of log check dams, stone wing deflectors, and boulder clusters along the stream channel.

Urban Stream Restoration in the Waukegan River, Illinois

An urban stream restoration project is underway in the Waukegan River in Illinois to repair channel instabilty caused by runoff from impervious surfaces and lack of storm water controls. The project uses biotechnical bank restoration to stabilize streambanks and low stone weirs to restore pool and riffle sequences. A habitat monitoring design was also used to document water quality changes. The project has improved biological diversity through pool and riffle restoration, yet it did not significantly improve stream fisheries. For more information about the project, refer to *Section 319 Nonpoint Source National Monitoring Program: Successes and Recommendations* (NCSU, 2000).

10.3.4.4 Reestablish riparian cover

Riparian cover is an essential component of the urban stream ecosystem. Riparian cover is necessary to stabilize banks, provide large woody debris and detritus, and provide shade to maintain water temperatures. Reestablishment of the riparian cover plant community along the stream network is often essential to achieve the goals and objectives of the program. This can entail active reforestation of native species, removal of exotic species, or changes in mowing operations to allow gradual succession. Establishment of an urban stream buffer can achieve many of these objectives (see section 3.3.3.6 of Management Measure 3 for a discussion of setbacks/stream buffer zones).

Citizen Involvement in Planting Riparian Forests

In Lexington, Kentucky, a unique program is underway to restore riparian areas to local streams. Because the city's limited budget does not allow for an expensive riparian planting effort, Reforest the Bluegrass was established as a cooperative effort by local private and nonprofit organizations, citizen groups, and government agencies. Reforest the Bluegrass provides training for citizen volunteers to participate in replanting efforts. The program provides public education for participants and for local residents through outreach, while significantly reducing program costs. Participants are taught the value of riparian systems in protecting water quality, combating the "urban heat island" effect, and providing habitat for wildlife. As of April 2002, nearly 4,000 volunteers had planted 108,000 seedlings. The program was financed with $85,000 from local government and $50,000 from private donations, compared with an estimated cost $675,000 if the project had been completed by contractors (Gabbard and Poe, 2003).

Restoring Atlanta's Watersheds

The International Life Sciences Institute's Risk Science Institute (RSI) was tasked with assessing the condition of streams in Atlanta, Georgia; developing a watershed management implementation plan; and identifying specific watershed restoration activities that would improve riparian habitat and water quality in four example subwatersheds (RSI, 1998). They identified several habitat and water quality impacts that can be attributed to urbanization, including

- Increased magnitude and frequency of bankfull and subbankfull events.
- Stream channel dimensions out of equilibrium with hydrologic regime.
- Enlarged, highly modified channels.
- Increased sediment load due to upstream channel erosion.
- Decreased baseflow.
- Decreased wetted perimeter.
- Degraded in-stream habitat structure.
- Reduced large woody debris.
- Increased number of stream crossings, which are potential barriers to fish migration.
- Fragmentation and narrowing of riparian forests.
- Degraded water quality.
- Increased summer stream temperatures.
- Reduced aquatic diversity.
- Combined sewer overflows.

To address these issues, RSI developed a watershed management program for the Atlanta region that includes the following elements:

- Creation of an institutional framework for watershed management (Management Measure 1).
- Development of a comprehensive storm and surface water control program.
- Establishment of erosion and sediment control programs.
- Establishment of detention pond requirements.
- Expansion of the tree canopy.
- Management of buffers, sensitive areas, and floodplains.
- Establishment of land development provisions.
- Daylighting of streams.
- Relocation of utilities.
- Eradication of invasive and exotic species.
- Development of a public education and outreach campaign.

RSI also developed several objectives for the watershed management program and identified environmental indicators that can be used to gauge the effectiveness of management activities (see Management Measure 2). Finally, RSI examined four subwatersheds to identify specific management practices that can be used to fulfill the objectives of the watershed management program. In each case study, they identified the activities in the subwatershed that were contributing to resource degradation and suggested methods, such as separating storm and sanitary sewers and improving storm water infiltration, that would reduce runoff to prevent further waterbody degradation. These methods would also increase the effectiveness of in-stream and riparian restoration activities. RSI then identified site-specific restoration activities such as streambank stabilization, riparian buffer management, and creation or restoration of in-stream habitat.

For more information about the Watershed Management Program for Atlanta or to receive a copy of RSI's report, contact the Risk Science Institute, International Life Sciences Institute, 1126 16th Street, NW, Washington, DC 20036-4810; e-mail rsi@ilsi.org.

10.3.4.5 Protect critical stream substrates

A stable, heterogeneous streambed is often a critical requirement for fish spawning and secondary production by aquatic insects. The bed of an urban stream, however, is often highly unstable and clogged by deposits of fine sediment. It is often necessary to mechanically restore the quality of stream substrates at points along the stream channel. Often, the energy of urban storm water can be used to create cleaner substrates through the use of flow concentrators and other manufactured devices. (See Management Measure 5 for more information about these practices.) If thick deposits of sediment have accumulated on the bed, mechanical sediment removal might be needed.

10.3.4.6 Promote recolonization of the aquatic community

It may be difficult to reestablish the fish community in an urban stream if downstream fish barriers prevent natural recolonization. In these instances it is important to seek the judgment of a fishery biologist to determine whether downstream fish barriers exist, whether they can be removed, or whether selective stocking of native fish is needed to recolonize the stream reach.

10.3.4.7 Daylight streams

Daylighting involves returning a stream that has been buried in a pipe or culvert to the surface. In many cases the stream can be restored to its original channel, but sometimes a new channel must

Daylighting Jolly Giant Creek, Arcata, California

A classic example of daylighting is Arcata, California's Jolly Giant Creek (Pinkham, 1998). The daylighting and stream restoration project was initiated in 1991 by a high school biology teacher, Lewis Armin-Hoiland, and Humboldt State University students Melissa Bukosky and Tom Hagberg. They initially started the project to provide environmental education to high school and college students on stream ecology and restoration, but Bukosky continued to gather data and designed a new channel and restoration plan for the creek.

The Redwood Community Action Agency, a nonprofit regional development organization, obtained a grant from the California Department of Water Resources Urban Streams Restoration Program. Other funding sources included U.S. Fish and Wildlife Service Challenge Cost-Share, the city of Arcata, and donations from a local heavy equipment contractor and the National Tree Trust. A substantial amount of volunteer labor was used for revegetation and to conduct assessment and monitoring. Funding for the project totaled $120,000.

The first phase of the stream restoration project included removing nearly 100 feet of culvert; installing a sedimentation basin, a ⅓-acre pond, and 75 feet of new stream channel; providing bank stabilization and flow control measures; and rerouting the stream through an older dry channel with existing riparian vegetation. The second phase involved creating a new channel within the old, wider channel at an abandoned mill site; creating berms around part of the property; restoring more than 400 feet of the Jolly Giant Creek; and providing a seasonal wetland and wet weather detention pond with substantial runoff storage capacity.

For more information contact Richard Pinkham, Senior Research Associate, Rocky Mountain Institute, 1739 Snowmass Creek Road, Snowmass, CO 81654; telephone 970-927-3807; e-mail rpinkham@rmi.org.

be engineered. Flow control structures and flood control measures can be incorporated into the design of the new or restored channel. Planting, restoring, and maintaining streambank vegetation and providing a diversity of instream habitat for submerged aquatic vegetation, fish, and aquatic insects are important aspects of the stream restoration project.

Daylighting typically requires a large capital investment for acquiring permits, engineering designs and expertise, equipment and labor for excavation, and plantings and labor to establish desirable stream morphology. Because communities are typically in favor of daylighting projects, many of these costs can be offset by recruiting sponsors such as property owners, community groups, housing associations, municipalities, environmental groups, and contractors. The benefits of a daylighting project for a particular stream reach should be carefully considered and weighed against the cost to determine whether the project is worthwhile.

A source of information is *Daylighting: New Life for Buried Streams*. In addition to summary findings, recommendations, and conclusions, the report provides information about completed and proposed daylighting projects (Pinkham, 2000).

10.3.5 Preserve, Enhance, or Establish Buffers

Stream buffers may be present as part of previous development, but it is unlikely that existing buffers were established or maintained to maximize pollutant removal. As the intensity of surrounding development increases, runoff and pollutant loads increase and can result in damage to the buffer. If the buffer is not protected from disturbance or excessive traffic, it can deteriorate over time. Buffers serve several important functions: they help improve soil and water quality, stabilize streambanks, decrease flood severity, replenish ground water supply, and provide wildlife habitat (Schultz et al., 1996). Some steps that can be taken to preserve or enhance existing buffers include:

- Delineating buffer boundaries and establishing management zones within the buffer (streamside, middle, and upland zones);
- Developing vegetative and use strategies within these zones;
- Establishing provisions for buffer crossings;
- Integrating structural runoff management practices where appropriate to protect the buffers and to augment their performance; and
- Developing buffer education and awareness programs.

A buffer can be established in the area between the stream and existing development when buildings are set back from the stream to prevent damage from flooding. These areas can be mapped and buffer boundaries established based on runoff and pollutant loadings. In some cases, impervious surfaces in the buffer need to be removed or parts of the buffer regraded to ensure maximum pollutant removal efficiency. The buffers are then divided into three zones—the streamside, middle, and upland zones—that contain different types of vegetation and accomplish pollutant removal in different ways (Herson-Jones et al., 1995). Design considerations for stream buffers are discussed in more detail in Management Measure 3.

10.3.6 Redevelop Urban Areas to Decrease Runoff-Related Impacts

10.3.6.1 Encourage infill development

Infill development is a tool planners use to encourage siting of new development on unused lands in existing urban areas. Infill development usually works in tandem with community redevelopment initiatives to foster revitalization of existing neighborhoods by replacing dilapidated buildings and underused properties with new housing or businesses. However, from a water quality perspective, if infill development is promoted on unused lands in existing developed areas, sites should be selected that result in decreased pollutant loadings and runoff volumes. Open space that provides valuable flood control and pollutant removal functions should be preserved or enhanced if possible. Trees within existing developments should be protected or replanted as necessary.

Infill and redevelopment can be employed in either large or small projects. One impediment to more widespread implementation of infill projects is the existing condition of a potential redevelopment site in terms of environmental constraints. The restrictive nature of many land use regulations and pressing social and economic issues may also impede implementation. Faced with these constraints, local governments often need to modify local zoning or building codes to make infill development and redevelopment more inviting to developers. Experience has shown that citizen involvement has often been a catalyst for leveraging funding or revising codes for this type of renewal.

10.3.6.2 Assess vacant, abandoned lots and areas of potentially contaminated soils to promote redevelopment

In many urbanized areas, changes in development patterns and economic decline have resulted in deterioration or abandonment of industrial and commercial sites. Many of these sites have contaminated and compacted soils that discharge polluted runoff during and after storms. These underused areas can be identified and assessed to determine if redevelopment or remediation can result in significant reductions in pollutant loadings or flow to improve surface water or ground water quality. Social and economic benefits may also accrue. Redevelopment plans can include the use of practices such as disconnection of impervious areas to reduce the total effective impervious area (see section 4.3.2) or infiltration practices including bioretention and onsite runoff storage.

EPA's Office of Solid Waste and Emergency Response has a brownfields initiative that encourages the redevelopment of abandoned, lightly contaminated industrial sites in economically stressed communities (USEPA, 1999). The program provides funding and guidance to help communities locate potential brownfields redevelopment sites, to perform soil and ground water assessments to determine the nature and extent of contamination, and to promote environmental clean-up and redevelopment of these sites. The program includes tax incentives for potential redevelopers and waivers of liability for past contamination. It encourages federal, state, and local coordination of enforcement activities and stakeholder and community involvement to identify and plan new uses for brownfields to promote environmental health and safety, environmental justice, and economic growth for economically depressed communities.

The brownfields initiative has several advantages for communities with underused, potentially contaminated sites. It provides a catalyst for assessment of urban areas for sites in need of clean-up and redevelopment to improve the community's surface water and ground water quality, quality of life, and property values. Redeveloping properties that have already been disturbed helps to prevent development of greenfields—undeveloped suburban areas—and slows the growth of imperviousness in the outskirts of urban areas. It also provides an incentive for communities to alleviate soil and ground water contamination and to convert abandoned, eyesore lands to viable businesses, recreational facilities, or other uses.

In 2002, the brownfields program was expanded and strengthened through ratification of the Small Business Liability Relief and Brownfields Revitalization Act (see http://www.epa.gov/brownfields/sblrbra.htm for more information). More information about EPA's Brownfields Initiative is available at http://www.epa.gov/brownfields.

Chicago Calumet Initiative

Calumet is located on the southeast side of Chicago along the Calumet River, adjacent to Lake Michigan, that has been subject to more than 120 years of heavy industrial activity. Calumet currently has thousands of acres of contaminated brownfields located amongst open space that serves as habitat for many types of wildlife, including birds listed by the state as endangered or threatened.

In 2000 Chicago mayor Richard Daley and former Governor George Ryan launched the "Calumet Initiative," a revitalization project that involves brownfields clean-up, the preservation of land and wetlands, urban forestry, renewable energy, and low impact development. The City is working in partnership with the Illinois Department of Natural Resources, the U.S. Forest Service, EPA, the Fish and Wildlife Service, the Illinois Environmental Protection Agency, and 15 other governmental partners.

The Initiative includes plans to redevelop 3,000 acres of brownfields into a region with sustainable industries such as a new Ford Motor Company supplier park that uses low impact development techniques and minimizes runoff to adjacent waterbodies. The Calumet Tax Increment Financing District was established to encourage industries to relocate to the revitalized area.

The Calumet Open Space Reserve will provide 4,800 acres of rehabilitated and preserved wetlands and crucial habitat for the 700 plant and 200 bird species that occupy the land currently. The property will be managed through a watershed-based ecological management strategy combined with land acquisition and preservation (NALGEP, 2003).

10.4 Information Resources

The *Anacostia Watershed Restoration Progress and Conditions Report 1990–1997* summarizes accomplishments and ongoing projects of the Anacostia Watershed Resoration Committee as they relate to their six restoration goals. In addition, the report provides recommendations to the committee for future actions to sustain and further promote the restoration effort.

The Federal Interagency Stream Restoration Working Group (2000), which is a collaboration among of 15 federal agencies including EPA and USDA, published *Stream Corridor Restoration: Principles, Processes, and Practices*. This document covers background information about stream corridors, including processes, characteristics, and disturbances; development of a stream corridor restoration plan; and application of restoration principles to stream corridor projects. *Stream Corridor Restoration: Principles, Processes, and Practices* can be purchased or downloaded in PDF format at http://www.nrcs.usda.gov/technical/stream_restoration/newgra.html.

Riparian Buffer Strategies for Urban Watersheds (Herson-Jones et al., 1995) provides guidance on riparian buffer programs used to mitigate the impact of urban areas on nearby streams. The document uses the results of a national survey of riparian buffer programs as well as a comprehensive review of riparian buffer literature to make recommendations on buffer design. It also analyzes buffer pollutant removal potential and pollution prevention techniques via chemical, biological, and physical processes. It is available for purchase at http://www.mwcog.org/ic/95703.html.

The Save Our Streams Program is a national watershed education and outreach program by the Izaak Walton League (no date). The league offers many stream-related resources, including information on stream projects and publications such as *A Citizen's Streambank Restoration Handbook*. The Save Our Streams Program can be reached by e-mail at sos@iwla.org, by calling 1-800-BUG-IWLA, or by visiting the Web site at http://www.iwla.org/sos.

The Natural Resources Conservation Service's National Conservation Buffer Initiative Web site (http://www.nrcs.usda.gov/feature/buffers/) contains information about buffers, links to technology information, and buffer initiative contacts (NRCS, no date).

Urban Restoration: A Video Tour of Ecological Restoration Techniques (Riley, 1998b) is a video tour of six urban stream restoration sites. It includes background information on how the projects were funded and organized with community involvement and the history and principles of restoration. Additionally, examples are presented of stream restoration in very urbanized areas, recreating stream shapes and meanders, creek daylighting, soil bioengineering, and ecological flood control projects. A companion to the video is *Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens* (Riley, 1998a). This book includes detailed information on all relevant components of stream restoration projects, from historical background to hands-on techniques. The book and video can be purchased at http://www.noltemedia.com/nm/urbanstream/index2.html.

EPA and the LID Center conducted a literature review of LID studies to assess the state of knowledge about LID practices (USEPA, 2000c). The final report contains a brief overview of LID principles and programmatic issues such as use, ownership, and cost. The heart of the document is a summary of the information available regarding the pollutant removal effectiveness of the most common LID practices. The report is available for download in PDF format at http://www.epa.gov/owow/nps/lidlit.html. This page also contains links to low-impact development fact sheets on bioretention, vegetated roof covers, permeable pavements, and street surface storage of runoff.

EPA's River Corridor and Wetland Restoration Web site contains general information about restoration and its benefits, a list of restoration guiding principles that cover the entire life of a restoration project from early planning to postimplementation monitoring, restoration project descriptions, and links to other restoration resources. The site is located at http://www.epa.gov/owow/wetlands/restore.

The Center for Watershed Protection developed 11 manuals, called the Urban Subwatershed Restoration Manual Series, that present the information needed to restore small urban watersheds in a format that can easily be accessed by watershed groups, municipal staff, environmental consultants, and other users. The manuals are available for a fee in hard copy or as a download at http://www.cwp.org/USRM_verify.htm.

10.5 References

Anacostia Watershed Restoration Committee (AWRC). 1998. *Anacostia Watershed Restoration Progress and Conditions Report 1990–1997*. Prepared for the Anacostia Watershed Restoration Committee, Washington, DC, by the Metropolitan Washington Council of Governments, Washington, DC.

Center for Watershed Protection (CWP). 1995a. Assessing the potential for urban watershed restoration. *Watershed Protection Techniques* 1(4):166–172.

Center for Watershed Protection (CWP). 1995b. Stormwater retrofits—a tool for watershed enhancement. *Watershed Protection Techniques* 1(4):188–191.

City of Griffin. No date. *City of Griffin Stormwater Department: Projects.* http://www.griffinstorm.com/SW/Projects.htm. August 1, 2003.

Dahme, Joanne. 2003. *Clean Water – Green City.* Presented at the World Water and Environmental Resources Congress, Philadelphia, PA, June 2003.

Fairfax County Environmental Coordinating Committee. 2002. *Preliminary Draft: Regional Pond as a Watershed Management Tool.* Prepared by the Regional Pond Subcommittee. http://www.co.fairfax.va.us/gov/DPWES/publications/RPC_Prelimary_Report_Draft_10_21.pdf. Accessed June 25, 2003.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. PB98-158348LUW. Federal Interagency Stream Restoration Working Group, Washington, DC.

Gabbard, H.D. and A. Poe. 2003. *Reforest the Bluegrass: Empowerment of the Citizen Watershed Manager.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17–20, 2003, Chicago, IL.

Gruel, R.A. and R.A. Feldner. North Griffin Regional Detention Pond: Wetlands Filtration and Treatment for Nonpoint-Source Pollution Control and Abatement: A well-planned system prevents flooding and removes pollutants. *Stormwater* 2(4).

Herson-Jones, L.M., M. Heraty, and B. Jordan. 1995. *Environmental Land Planning Series: Riparian Buffer Strategies for Urban Watersheds*. Metropolitan Washington Council of Governments, Washington, DC.

Hottenroth, D.C. 2003. *Using Incentives and Other Actions to Reduce Watershed Impacts from Existing Development.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17–20, 2003, Chicago, IL.

Izaak Walton League. No date. *Welcome to the Save Our Streams Program*. http://www.iwla.org/sos. Accessed April 25, 2002.

Moffa, P.E., H.M. Goebel, D.P. Davis, and J.J. La Gorga. 2000. *Retrofitting Control Facilities for Wet-Weather Flow Treatment: Research Report*. EPA-600-R-00-020. Prepared for U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC, by Moffa & Associates Consulting Engineers, Syracuse, NY.

Murante, R.U. 2003. *Storm Water Management in the City of Chicago.* In Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level, February 17–20, 2003, Chicago, IL.

National Association of Local Government Environmental Professionals (NALGEP). 2003. *Smart Growth for Clean Water: Helping Communities Address the Water Quality Impacts of Sprawl.* National Association of Local Government Environmental Professionals, Trust for Public Land, ERG. http://www.resourcesaver.com/file/toolmanager/CustomO93C337F42157.pdf. Accessed June 30, 2003.

Natural Resources Conservation Service (NRCS). No date. *Buffer Strips: Common Sense Conservation*. http://www.nrcs.usda.gov/feature/buffers/. Accessed April 25, 2002.

North Carolina State University (NCSU). 2000. *Section 319 Nonpoint Source National Monitoring Program: Successes and Recommendations*. Preprint. North Carolina State University Water Quality Group, Raleigh, NC.

Norwalk River Watershed Initiative Committee (NWRI). 1998. *The Norwalk River Watershed Action Plan*. http://www.norwalkriverwatershed.org/action.html. Accessed April 30, 2001.

O'Leary, M.J. 2003. *Conservation Plan for Three Watersheds with the Milwaukee Metro Sewerage District.* In *Proceedings, National Conference on Urban Stormwater: Enhancing Programs at the Local Level*, February 17–20, 2003, Chicago, IL.

Pinkham, R. 1998. Buried urban streams see the light. *Nonpoint Source News-Notes* 53. Terrene Institute, Alexandria, VA.

Pinkham, R. 2000. *Daylighting: New Life for Buried Streams*. Rocky Mountain Institute, Snowmass, CO.

Prince George's County, Maryland, Department of Environmental Resources. 2000. *Low-Impact Development Design Strategies: An Integrated Design Approach.* Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, Largo, MD.

Riley, A. 1998a. *Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens*. Island Press, Washington, DC.

Riley, A. 1998b. *Urban Restoration: A Video Tour of Ecological Restoration Techniques*. Noltemedia, Santa Rosa, CA.

Risk Science Institute (RSI). 1998. *Mitigation of Urban Runoff Impacts on Atlanta Streams*. Risk Science Institute Expert Working Group on Watershed Management in Atlanta, International Life Sciences Institute, Washington, DC.

Schueler, T. 1995. Env*ironmental Land Planning Series: Site Planning for Urban Stream Protection*. Metropolitan Washington Council of Governments, Washington, DC.

Schultz, R.C., A. Kuehl, J.P. Colletti, P. Wray, and T. Isenhart. 1996. *Stewards of Our Streams: Riparian Buffer Systems*. Iowa State University, University Extension, Ames, IA.

Sotir, R.B. 2000. Getting Past the Obvious. Pages 83–93 in *National Conference on Tools for Urban Water Resource Management and Protection*. U.S. Environmental Protection Agency, Office of Research and Development, Chicago, Illinois, February 7–10, 2000. EPA-625-R-00-001.

Taus, Margaret. 2002. Innovative Design Cuts Street Runoff. *Seattle Post-Intelligence*. November 20, 2002. http://seattlepi.nwsource.com/local/95881_model20.shtml. Accessed June 23, 2003.

U.S. Environmental Protection Agency (USEPA). 1999. *Brownfields*. http://www.epa.gov/brownfields. Last updated October 5, 1999. Accessed October 20, 1999.

U.S. Environmental Protection Agency (USEPA). 2000a. *Bioretention Applications*. http://www.epa.gov/owow/nps/bioretention.pdf. Last updated October 2000. Accessed April 30, 2001.

U.S. Environmental Protection Agency (USEPA). 2000b. *Field Evaluation of Permeable Pavements for Stormwater Management*. http://www.epa.gov/owow/nps/pavements.pdf. Last updated October 2000. Accessed April 30, 2001.

U.S. Environmental Protection Agency (USEPA). 2000c. *Low Impact Development Literature Review*. EPA-841-B-00-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2000d. *Vegetated Roof Cover*. EPA-841-B-00-005D. http://www.epa.gov/owow/nps/roofcover.pdf. Last updated October 2000. Accessed March 29, 2001.

U.S. Environmental Protection Agency (USEPA). 2002a. *River Corridor and Wetland Restoration*. http://www.epa.gov/owow/wetlands/restore. Last updated February 14, 2002. Accessed April 25, 2002.

U.S. Environmental Protection Agency (USEPA). 2002b. *Small Business Liability Relief and Brownfields Revitalization Act*. http://www.epa.gov/brownfields/sblrbra.htm. Last updated May 3, 2002. Accessed May 17, 2002.

Wilson, A., J.L. Uncapher, L. McManigal, L.H. Lovins, M. Cureton, and W.D. Browning. 1998. *Green Development: Integrating Ecology and Real Estate*. John Wiley & Sons, Inc., New York, NY.

MANAGEMENT MEASURE 11
OPERATION AND MAINTENANCE

11.1 Management Measure

Develop a program for regular inspection and maintenance of urban runoff management practices.

- Develop and implement an operation and maintenance plan for urban runoff management practices. The plan should include scheduled inspections, scheduled maintenance activities, and scheduled evaluations of operation and maintenance practices.
- Inspect, maintain, and repair runoff treatment controls to maintain design treatment capacity.
- Inspect, maintain, and restore riparian buffers.

11.2 Management Measure Description and Selection

11.2.1 Description

The maintenance of storm water controls is essential to ensure that overall program goals are met and that each management practice or set of practices continues to function as designed. Storm water controls need to be periodically inspected and maintained as necessary to fine-tune performance, prevent malfunction, and address any problems that may arise. Although maintenance issues should be a major consideration during the management practice selection process, they are often overlooked and inadequately planned for and budgeted. As a result, many management practices fail to perform as intended.

An operation and maintenance (O&M) plan is one way to systematically ensure that scheduled inspections, maintenance, and practice evaluations occur. Formalizing an operation and maintenance plan also can be helpful in determining and securing the funding necessary to properly operate and maintain runoff management practices.

Program managers should consider incorporating the following elements in their operation and maintenance programs:

- Scheduled inspections (based on climate, precipitation, and runoff management practice);
- Scheduled maintenance activities, such as removal of forebay sediment;
- Use of maintenance checklists to systematize and document the inspection process; and
- Initial and follow-up monitoring of management practices to establish performance baselines and trends to guide maintenance activities.

Maintenance activities may vary by management practice. For example, vegetation management is necessary for some extended detention wet ponds and constructed wetlands to maintain optimal removal efficiency, to avoid the net export of nutrients during winter, and to maintain design flow patterns. Removal of sediment build-up is essential to maintain properly functioning practices. Infiltration devices must be protected and maintained to prevent pore clogging and loss of infiltration capacity.

Preventative maintenance may also be necessary to protect the performance of management practices. Run-on sedimentation from off-site areas may need to be addressed through stabilization measures to prevent unnecessary maintenance expenditures.

The incorporation of maintenance considerations into management practice designs will often reduce subsequent maintenance costs and repairs and help to avoid failures. For example, the removal of material from sediment traps can be facilitated by designs that allow easy access to accumulated sediments without specialized equipment. Safe and convenient access to inlet and outlet structures can reduce maintenance costs and prevent nuisance flooding. Finally, the use of proper construction techniques and phasing can reduce the potential for initial clogging of infiltration devices during the construction process.

Enforcement of inspection and maintenance programs is crucial to their success. A 1992 study in Maryland evaluated 250 storm water practices to determine whether they were being maintained in compliance with the state's Stormwater Management Act. The researchers found that after a few years, approximately one-third of the practices were not functioning as designed, and most required maintenance. Approximately one-half of the facilities were undergoing sedimentation and many had problems with clogging (Lindsey et al., 1992). Implementing the practices described under this management measure can help develop an effective O&M program for continued effectiveness and longevity of runoff management practices.

11.2.2 Management Measure Selection

This management measure was selected because improper operation and maintenance of runoff control practices can result in poor performance and increased discharge of pollutants to downstream waters. Flooding may occur and downstream channel stability could be jeopardized. Poorly maintained runoff systems also may increase risks to public safety and the potential for property damage.

To prevent these potential impacts, effective maintenance programs should include standards for the inspection and maintenance of runoff controls. The entities responsible for maintaining runoff controls must be clearly identified and adequate resources must be provided to conduct the necessary maintenance activities. Because maintenance issues are critical to successful program implementation, they should be planned for at the outset of the runoff management program and conducted continuously for the lifespan of the practice(s).

The following section contains descriptions of specific O&M requirements for various types of management practices.

11.3 Management Practices

11.3.1 Establishing an Operation and Maintenance Program

The following section outlines several practices that will facilitate development of a runoff control O&M program.

11.3.1.1 Establish a runoff control operation and maintenance ordinance

One way for local governments to ensure that maintenance of runoff control facilities is performed is to establish an ordinance that mandates these activities. The O&M language in a runoff control ordinance can specify that runoff management practices must be designed to facilitate easy maintenance and require that regular maintenance activities be performed.

EPA (2000) has provided model ordinance language (at http://www.epa.gov/nps/ordinance) that includes consideration of maintaining runoff control management practices. Ordinance language examples from across the country are provided, including a sample maintenance agreement, a sample easement and right-of-way agreement, an inspection checklist, and a performance bond.

It is important for O&M ordinances to contain language that requires the identification of the specific entity or entities responsible for long-term maintenance and requires regular inspection visits. The ordinance also should provide design guidelines that can help ease the maintenance burden, such as the inclusion of maintenance easements. Note that runoff control ordinance language regarding the maintenance of erosion and sediment control practices differs from that regarding maintenance of postconstruction controls because of the short-term nature of the former.

The City of Alexandria, Virginia has incorporated inspection and maintenance requirements into the Alexandria Zoning Ordinance. The ordinance requires the submission of a long-term inspection and maintenance plan that identifies all maintenance requirements and responsible parties. A standard maintenance and monitoring agreement approved by the city council is required for urban runoff practices in Alexandria and cannot be modified without council approval (Bell, 1997).

11.3.1.2 Make provisions for maintenance in the design and construction of management practices

Because maintenance programs play such an important role in ensuring the proper operation of most structural practices and some source controls, emphasis should be given to maintenance issues when identifying management practices under any runoff management program. Making provisions for maintenance at the design and construction phase involves identifying the urban runoff practices to be used when designing a new facility. Practices should be designed so that maintenance equipment (mowers and vacuum trucks) can easily access the site. Many practices have been designed with inadequate pre-treatment (i.e., without a sediment basin at the inlet), and they have not performed as anticipated. Inlet and outlet structures also tend to clog easily without proper design and maintenance. Adequate size and storage volume based on expected sediment loads from the contributing drainage area should be factored into the design of inlets and pre-treatment structures.

11.3.1.3 Identify mechanisms for program funding

It is important to identify the entity responsible for operating and maintaining structural runoff control practices. The responsible party can be a property owner, homeowners' association, certified contractor, or local government agency. Local governments may assume the responsibility of maintaining privately owned facilities. When private entities do not fulfill their maintenance responsibilities and the facilities fail, the burden of maintaining runoff control and performing downstream restoration may ultimately fall under the local government's responsibility. Public financing for maintenance of both public and private facilities can be generated from general tax revenues, storm water utility fees, inspection or permit fees, or dedicated contributions. Sources of funding should be dedicated to runoff program budgets and or maintenance programs whenever possible. A discussion of these and other financing options for maintenance of runoff control facilities is provided in Chapter 8 of the Watershed Management Institute's *Operation, Maintenance, and Management of Stormwater Management Systems* (1997).

It is important that the funding source for maintenance of runoff control facilities be supported by the public. The Watershed Management Institute (1997) stresses the importance of public education to inform citizens about the locations and functions of runoff control facilities and the importance of regular maintenance. The institute believes that citizens and government officials will be more willing to allocate funds to projects that they know will provide tangible benefits to the community. The institute also recommends that funding programs for maintenance activities have the following attributes:

- Be based on a stable source of consistent funds that will ensure a long-term commitment of personnel, equipment, and materials;
- Be compatible with the local organizational structure to allow use of existing billing, collection, and bookkeeping operations;
- Include provisions for four essential operations: (1) program administration; (2) accounting and budgeting; (3) revenue management; and (4) information management;
- Be based on an equitable, understandable, and defensible fee or rate structure;
- Be continually reviewed and updated to meet the changing maintenance needs of the runoff control program; and
- Be consistent with applicable state laws and regulations.

11.3.1.4 Plan regular inspections

Inspections are essential to maintain the successful operation of the facility. Inspectors should have on hand equipment necessary for taking measurements and making minor repairs, be trained in identifying and remedying problems, and have a set of standard inspection procedures from which to work. An inspection schedule and checklist for each type of management practice should be developed and followed. Inspections and maintenance should be conducted both on a regular schedule and following storms to identify and repair any damage.

11.3.1.5 Schedule maintenance, cleaning, and debris removal to avoid sediment accumulation

Sediment and debris can contain hazardous contaminants and can clog filtration and infiltration practices, reducing their effectiveness over time. In addition to major structural controls, maintenance programs should include measures for cleaning catch basins and drainage channels. Establishment of an effective O&M program should include the creation of maintenance logs and identification of specific maintenance triggers for each class of control (e.g., removing sediment from forebays every year and retention ponds every five years, cleaning catch basins at least annually prior to the rainy season, removing litter from channels twice a year). If maintenance activities are scheduled infrequently, regular inspections should be made to ensure that the control is operating adequately. Additionally, maintenance should be performed following significant storms.

11.3.1.6 Make provisions for monitoring treatment criteria

Regularly monitoring the influent to and effluent from structural management practices will support program goals by facilitating development of a database to track the effectiveness of these practices, which can help guide future decisions about management practice implementation. These data will make it easier to quantify the performance of the practice and determine the behavior of the system as a result of regular maintenance.

11.3.1.7 Implement training and certification programs to provide educational opportunities for management practice operators

Training and certification programs are gaining popularity around the country at both the state and local levels. Municipalities sometimes use contractors to conduct inspections and maintenance because resources are not available to purchase equipment and hire dedicated staff. Good training programs can ensure that inspections and maintenance activities are carried out in a thorough and consistent manner. Also, training programs can be customized to address local concerns and conditions such as high flows, highly erodible soils, or invasive species.

11.3.1.8 Disposal of residuals

Runoff can carry both natural and anthropogenic pollutants and materials to receiving waters. Natural materials, such as leaves and soils, can accumulate in the system and cause localized flooding. Anthropogenic sources, which include oil and grease, heavy metals, deicing materials, and litter, can become adsorbed to leaf litter and sediments (Lenhart and Harbaugh, 2000). The mixed composition of solids that are removed from the storm drain system (termed residuals) can require special handling and treatment, which increases disposal costs (Field and O'Shea, 1994). The characteristics of residuals tend to vary with season and land use. Table 11.1 summarizes the results of a number of studies analyzing residuals in runoff (Field and O'Shea, 1992; Marquette University, 1982; Schueler and Yousef, 1994).

Table 11.1: Properties of urban storm water solids/residuals (adapted from USEPA, 1999).

Properties of Residuals	Wet Ponds[1]	Sediment Basin[2]	Swirl and Helical Bend Solids Separators[3]	In-Line Upsized Storm Conduit[4]	Urban Storm Water Runoff Residuals[5]
Solids					
Volatile Suspended Solids	6%	104–155 mg/l	107,310 mg/l	25,800 mg/l	90 mg/l
Total Suspended Solids	43%	233–793 mg/l	344–1,140 mg/l	161,000 mg/l	415 mg/l
Nutrients					
Phosphorus	583 mg/kg	< 5 mg/l	<5 mg/l	0.3–2,250 mg/l	502–1,270 mg/kg
Total Kjeldahl Nitrogen	2,931 mg/kg	<5 mg/l	<5 mg/l	0.3–2,250 mg/l	1,140–3,370 mg/kg
Heavy Metals					
Zinc	6–3,171 mg/kg				302–352 mg/kg
Lead	11–748 mg/kg				251–294 mg/kg
Chromium	4.8–120 mg/kg				168–458 mg/kg
Nickel	3–52 mg/kg				69–143 mg/kg
Copper	2–173 mg/kg				251–294 mg/kg
Cadmium	No detect–15 mg/kg				
Iron		6.1–2,970 mg/l	6.1–2,970 mg/l	6.1–2,970 mg/l	
Hydrocarbons	2,087-12,892 mg/kg				

[1] Scheuler and Yousef, 1994
[2] Marquette University, 1982 (Racine, Wisconsin)
[3] Marquette University, 1982 (Boston, Massachusetts)
[4] Marquette University, 1982 (Lansing, Michigan)
[5] Field and O'Shea, 1992

A system for managing residuals in runoff should address the proper handling and disposal of both liquid and solid residuals. Ponds, infiltration practices, vegetative controls, and catch basin inserts have different removal mechanisms, and the type of residuals generated from these practices will vary. All residuals should be tested for contamination (unless the management entity has determined that residuals from an individual practice or category of practices pose no hazard), and maintenance employees should be trained in properly identifying and handling contaminated waste according to the requirements of the Resource Conservation and Recovery Act (RCRA) and state and local regulations (USEPA, 1999). Removal mechanisms and requirements for specific practices are described below.

Non-hazardous solids in residuals can be recycled, sent to a landfill, or applied to land. Land application involves spreading the material on designated land at approved application rates. The material should not be applied to cropland, but application to a nonagricultural vegetated area may be appropriate (USEPA, 1999). Disposal of the waste in a landfill may be the most expensive option because of travel costs, testing requirements, and disposal fees (Lenhart and Harbaugh, 2000).

There are a number of low-cost options for recycling. Coarse sand and gravel can be used for road base, and road sand can be recycled for winter maintenance activities. The City of Olympia, Washington uses dried solids from treatment systems by mixing them with cement. The organic portion of residuals can be composted after removing the coarse inorganic materials. These organic residuals can then be combined with yard debris, leaves, straw, or soil. The Washington Department of Transportation mixes solids with mulch and bark for use as topsoil along roadsides (Lenhart and Harbaugh, 2000). In general, urban runoff residuals have very low nutrient content and thus require mixing with high nutrient content organic matter to provide fertilization benefits (Field and O'Shea, 1994).

Additional considerations for the disposal of residuals include air and noise pollution from machinery operation at the disposal site, unpleasant odors, possible ground water or surface water contamination, and public health. To address these issues, local and state agencies should address the following when developing guidelines for disposal of residuals: application rates, treatment requirements, site suitability, and proximity to schools, parks, and residential areas (Field and O'Shea, 1994).

The City of Everett, Washington uses a source separation system that requires operators of vacuum trucks to determine whether contamination of residuals is suspected based on sheen, odor, and color. Residuals suspected of contamination are handled in accordance with state and local regulations. Otherwise, materials are collected and recycled as aggregate material on medians and selected roadsides after being tested for contamination (Lenhart and Harbaugh, 2000).

11.3.2 Source Control Operation and Maintenance

11.3.2.1 Infrastructure

(1) *Street sweeping.* Street cleaning reduces pollutants carried in runoff from street surfaces. The frequency of cleanings should reflect the rate of pollutant buildup and should increase just before the rainy season. An effective program requires that street sweeping be conducted on a regular basis. Sweeper operators require training, and equipment needs to be maintained regularly to ensure that it is functioning as designed. Finally, parking restrictions can be implemented to guarantee adequate cleaning despite on-street parking. Table 11.2 shows O&M costs associated with street sweeping. See Management Measure 7 for more information about types of street sweepers (brush vs. vacuum sweepers and their relative effectiveness, section 7.3.5.1) and roadside trash removal (section 7.3.5.4).

Table 11.2: Street sweeper O&M costs (adapted from CWP, 1998).

Maintenance Considerations		Sweeper Type	
		Mechanical Sweeper	**Vacuum-Assisted Sweeper**
O&M costs (1998 dollars)	Cost ($/curb mile)	30	15
	Weekly sweeping ($)	1,680	946
	Biweekly sweeping ($)	840	473
	Monthly sweeping ($)	388	218
	4 times per year sweeping ($)	129	73
	Twice per year sweeping ($)	65	36
	Annual sweeping ($)	32	18
Expected life (years)		5	8

(2) *Storm drain flushing*. This practice is used to remove deposited materials from storm drain pipes to maintain their flow capacity. The flushing schedule should be designed to prevent excessive buildup based on estimated inputs from the contributing drainage areas, cleaning history, and visual inspections. Flushing is performed either at or upstream from problem areas. There are costs to consider for collecting and disposing of sediments, debris, and flush water, in addition to supplying flush water and treating sediment-laden water if the storm drains are being flushed to a receiving water body.

(3) *Catch basin cleaning*. Cleaning catch basins removes excess pollutants, thereby reducing high pollutant concentrations in a storm's first flush, preventing clogging, and restoring sediment-trapping capacity. Maintenance should target areas with the greatest pollutant loading and those near sensitive water bodies. A maintenance log should be kept to track progress. If there are many catch basins in a community, mechanical cleaners (vacuums or bucket loaders) may be required; otherwise, hand cleaning will suffice. Proper record-keeping, waste disposal, and safety procedures are essential for a successful program.

(4) *Highway, bridge, and road maintenance*. Maintenance of roads and bridges can be a significant source of pollutants. Some methods to prevent materials from contaminating runoff are limiting the use of salts; using suspended tarps, vacuums, or booms to reduce pollutant drift onto waters from scraping and painting; and training road crews in proper waste control and disposal methods. Treatment controls also can be used on-site to reduce the amount of polluted runoff that enters receiving waters. Runoff reduction, conveyance, and treatment practices (e.g., infiltration swales in median strips) can be incorporated into the design of new roadways and bridges to help contain pollutants from traffic as well as from

Sediment Removal from Catch Basins

The Delaware County, New York, Department of Public Works, with the assistance of the Catskill Watershed Corporation, purchased a vacuum truck capable of removing sediment from culverts and catch basins. The truck, which has a 30-foot pipe reach and a 12 cubic yard storage capacity, is available for use by neighboring counties based on need and availability. In the first month of operations, approximately 700 cubic feet of sediment was removed. The sediment s disposed of without posing a threat of contamination to the Cannonsville and Pepacton reservoirs. The County will be sampling sediment in an attempt to quantify the amount of contaminants removed (Delaware County Departments of Planning and Public Works, 2003).

maintenance activities. For more information about runoff management practices for roads, highways, and bridges, see Management Measure 7: Bridges and Highways.

11.3.2.2 Trash in channels and creeks

Clean-up of trash from streams and storm water conveyance infrastructure can reduce pollutant levels in downstream waters. Areas where dumping occurs frequently can be identified and inspected regularly, and "no littering" or "no dumping" signs can be posted to deter future dumping. Steep fines for dumping may also discourage potential transgressors. Associated costs for these practices are the purchase of signs and equipment, paying personnel to conduct inspections and clean-up, and providing landfill space to dispose of recovered items. Cost savings can be achieved through community or volunteer clean-up programs.

11.3.3 Treatment Control Operation and Maintenance

Runoff treatment controls require periodic inspection and maintenance to ensure that sediment, trash, and overgrown vegetation are not impeding their performance. Regular inspections should be performed along with routine maintenance. Nonroutine maintenance may be required to repair structures, control erosion, and remove unwanted vegetation. Table 11.3 and the following practices describe maintenance costs, activities, and schedules for several categories of urban runoff treatment practices.

Table 11.3: Maintenance costs, activities, and schedules for runoff control practices in 1998 dollars (Adapted from CWP, 1998).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Detention ponds or vaults	Dry ponds	~1%	$1,200	– Cleaning and removal of debris after major storms (>2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repair of embankment and side slopes – Repair of control structure	Annual or as needed
				– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle

Table 11.3 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Ponds	Extended detention ponds, wet ponds, multiple pond systems, "pocket" ponds	3%–6%	$3,000–$6,000	– Cleaning and removal of debris after major storm events (>2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repair of embankment and side slopes – Repair of control structure	Annual or as needed
				– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
Wetlands	Shallow wetlands, pond wetlands, "pocket" wetlands	~2%	$3,800	– Cleaning and removal of debris after major storm events (>2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repair of embankment and side slopes – Repair of control structure	Annual or as needed
				– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle

Table 11.3 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Infiltration practices	Infiltration trench	5%–20%	\$2,300–\$9,000	– Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				– Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
	Infiltration basin	1%–3%	\$150–\$450	– Cleaning and removal of debris after major storm events; (>2" rainfall) – Mowing and maintenance of upland vegetated areas – Sediment cleanout	Annual or as needed
		5%–10%	\$750–\$1,500	– Removal of accumulated sediment from forebays or sediment storage areas when 50% of the original volume has been reduced	3- to 5-year cycle
Open channel practices	Dry swales, grassed channels, biofilters	5%–7%	\$200–\$2,000	– Mowing and litter/debris removal – Stabilization of eroded side slopes and bottom – Nutrient and pesticide use management – Dethatching of swale bottom and removal of thatching – Discing or aeration of swale bottom	Annual or as needed
				– Scraping of swale bottom, and removal of sediment to restore original cross-section and infiltration rate – Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle

Table 11.3 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Filtration practices	Sand filters	11%–13%	$2,200	– Removal of trash and debris from control openings – Repair of leaks from the sedimentation chamber or deterioration of structural components – Removal of the top few inches of sand, and cultivation of the surface, when filter bed is clogged	Annual or as needed
				– Clean-out of accumulated sediment from filter bed chamber once depth exceeds approximately ½ inch, or when the filter layer will no longer draw down within 24 hours – Clean-out of accumulated sediment from sedimentation chamber once depth exceeds 12 inches	3- to 5-year cycle
	Bioretention	5%–7%	$3,000–$4,000	– Repair of erosion areas – Mulching of void areas – Removal and replacement of all dead and diseased vegetation – Watering of plant material	Biannual or as needed
				– Removal of mulch and application of a new layer	Annual
	Filter strips	$320/acre (maintained)	$1,000	– Mowing and litter/debris removal – Nutrient and pesticide use management – Aeration of soil on the filter strip – Repair of eroded or sparse grass areas	Annual or as needed.

11.3.3.3 Ponds and wetlands

Extended dry detention ponds are submerged only during storms and are dry between storms. Depending on the type of vegetative cover used, they may require mowing at least once a month to maintain turf grass cover, or once a year to prevent the establishment of woody vegetation. Sediments should be removed when they are dry and cracked to separate them from vegetation more easily. Pilot or low-flow channels require inspection to prevent undermining of concrete channels and overgrowth of stone channels. Inlets and outlets should be cleared of sediment and debris to prevent clogging.

Wet ponds are susceptible to algae blooms as a result of high nitrogen levels and may need to be cleaned periodically. Sediments that accumulate in the pond inlet or forebay should be removed more frequently than fine sediment, which collects near the pond outlet. Sediment removal requires draining the pond (some water to maintain fish populations should be left), collection of solids, and drying and testing of the residuals before disposal. Pond water should be disposed of in a locally approved manner; it should be tested for pollutants and released to the receiving water, if allowed, or pumped and hauled to a disposal facility. During the period in which the stockpiled materials are drying, erosion controls should be implemented to prevent sediment loss. All structures and surrounding areas should be inspected for leakage, seepage, corrosion, and wear and tear. Inspectors and crews should pay special attention to structural integrity to ensure that ponds operate safely.

Constructed wetlands should be inspected approximately four times per year to determine if they are retaining and discharging storm water at an appropriate rate and whether maintenance is needed. Constructed wetlands require periodic cropping; removal of trash, weeds, invasive species, or woody vegetation; repair of animal burrows in embankments; and clearing of inlets and outlets. Side slopes should be stabilized with vegetative cover to prevent erosion. Wetland plants should be thinned and transplanted as necessary to maintain adequate cover throughout the wetland. In general, semiannual sediment removal is recommended to ensure that treatment capacity is maintained. Mosquitoes may be a problem in some areas, and introducing natural predators such as mosquito fish (*Gambusia*) can be one method of control. Consultation with a wetland scientist is recommended to ensure that the constructed wetland functions as intended.

11.3.3.4 Infiltration practices

Infiltration practices, such as basins, trenches, vegetated swales, and porous pavement, are subject to clogging from sediment, oil, grease, and microbes. Clogging impairs their effectiveness in reducing runoff volume and pollutant loading to downstream waters. When clogging occurs, standing water tends to collect. Seasonal water table fluctuations or ground water mounding can also cause standing water. Facility inspection during dry periods will identify whether standing water is present and provide clues to the possible causes. Inspections should include a site assessment of the contributing drainage area because sediment accumulation in a facility stems from erosion in surrounding areas that can be prevented if the areas are adequately stabilized. The frequency of required maintenance depends on loads from the contributing drainage areas.

If clogging results in pooling, sediment can be removed to restore the facility to its original capacity. If the standing water results from high water table conditions, the facility owner should consider converting the site to a permanent pool facility such as a constructed wetland or detention pond. For systems designed with filter fabric to collect sediments, periodic inspections can identify when and where the mesh should be replaced. In cold climates where street sanding occurs in the winter, the filter fabric in infiltration devices adjacent to roads and parking lots should be replaced prior to spring.

Promotion of a vegetative cover will help to maintain percolation rates, slow runoff velocity, and minimize ground water pollution. To maintain aeration and permeability, nonvegetated basins require tilling or disking and leveling after sediment is removed. Vegetated filters adjacent to infiltration trenches should be cleared of sediments periodically to prevent sediment loading to the trench.

Regular monitoring of infiltration rates after storms will indicate when maintenance is required to maintain the system’s treatment design capacity.

11.3.3.5 Filtration practices

Filtration practices include media filters (typically sand) and biofilters. Sand filters contain two phases: a sedimentation chamber and a filtration chamber. The sedimentation chamber can be inspected by measuring to determine if the deposited sediments are becoming deep enough to interfere with the filtration chamber. Different types of sand filters require different levels of maintenance. The Austin sand filter system usually requires maintenance every five to 10 years, depending on the stability of soils in the contributing areas, and can be treated like a dry detention facility. The filter component can be raked of fine sediments or skimmed with a shovel to restore permeability. The Washington and Delaware sand filter sedimentation chambers, which maintain a pool of water, should be vacuumed to remove sediment when inspections identify accumulation greater than 75 percent of capacity. Filtration chambers for these systems may need to be cleaned of fine particles as frequently as twice per year to maintain their efficiency and prevent overflows. A flat-bottomed shovel can be used to remove the sediment-laden filter media and roughen surfaces to improve permeability.

Each system should be inspected for vandalism, leaks, cracks, or damage to concrete at least once per year. These problems should be remedied immediately. Forebays should be pumped or cleaned as necessary. All materials removed from the systems should be tested for contamination and to identify how the material should be disposed of (e.g., as clean fill, in a landfill, or as a hazardous waste).

Biofiltration system vegetation should be mowed periodically to maintain an optimum height (2 to 6 inches) that maximizes infiltration and minimizes runoff velocity. Special effort should be made to promote native species and exclude invasive species, which can grow too vigorously and reduce treatment capacity. Some natural vegetation replacement is desirable, such as wetland plants that colonize a low-lying biofilter. Inspection and maintenance records should reflect these changes.

Biofiltration facilities should be inspected and maintained regularly. Sediment removal is an important and sometimes expensive part of biofilter maintenance. Sediment should be removed when it fills 20 percent of the design depth in any spot or starts to cover vegetation. Efforts should be made to return the system to its original topographic and vegetative condition once the sediment has been removed. Inlets and outlets should be cleared of particles and debris to prevent backups and overflows. Biofiltration systems may also need periodic replacement or amendment of system soils if clogging has occurred.

Maintenance equipment for the tasks described previously, along with purchase and rental costs, is presented in Table 11.4.

Table 11.4: Typical O&M equipment and material costs (WMI, 1997).

Equipment	Purchase	Rent (per day)
Grass Maintenance		
Hand mower	$300–$500	$25–$50
Riding mower	$3,000–$7,000	$75–$150
Tractor mower	$20,000–$30,000	$150–$450
Trimmer/edger	$200–$500	$25–$35
Spreader	$100–$200	$20–$30
Chemical sprayer	$200–$500	$25–$40
Vegetative Cover Maintenance		
Hand saw	$15–$20	$5
Chain saw	$300–$800	$15–$35
Pruning shears	$25–$40	$5
Shrub trimmer	$200–$300	$25–$35
Brush chipper	$2,000–$10,000	$100–$300
Sediment, Debris, and Trash Removal		
Vactor truck	$100,000–$250,000	$700–$1,200
Front-end loader	$60,000–$120,000	$250–$500
Backhoe	$50,000–$100,000	$250–$500
Excavator	>$100,000	$400–$1,000
Grader	>$100,000	$400–$1,000
Transportation		
Van	$18,000–$30,000	$50–$100
Pickup truck	$15,000–$25,000	$50–$100
Dump truck	$40,000–$80,000	$100–$200
Light-duty trailer	$3,000–$6,000	$50–$100
Heavy-duty trailer	$10,000–$20,000	$100–$250
Miscellaneous		
Shovel	$15	$5
Rake	$15	$5
Pick	$20	$5
Wheelbarrow	$100–$250	$15–$25
Portable compressor	$800–$2,000	$50–$150
Portable generator	$750–$2,000	$50–$150
Concrete mixer	$750–$1,500	$50–$100
Welding equipment	$750–$2,000	$50–$100
Materials		
Topsoil	$35–$50/cubic yard	
Fill Soil	$15–$30/cubic yard	
Grass seed	$5–$10/pound	
Soil amenities	$0.10–$0.25/square foot	

Table 11.4 (continued).

Equipment	Purchase	Rent (per day)
Materials (continued)		
Chemicals	$10–$30/gallon	
Mulch	$25–$40/cubic yard	
Dry mortar mix	$5/50-pound bag	
Concrete delivered	$60–$100/cubic yard	
Machine/motor lubricants	$5–$10/gallon	
Paint	$20–$40/gallon	
Paint Remover	$10–$20/gallon	

11.4 Information Resources

The South Carolina Department of Health and Environmental Control (2000) published *A Citizen's Guide to Stormwater Pond Maintenance in South Carolina*, which is available for download in PDF format at http://www.scdhec.net/eqc/admin/html/eqcpubs.html. The booklet is intended as a guide for homeowners' associations and others responsible for the proper maintenance of storm water ponds. Photos and descriptions of nuisance aquatic plant species are presented in the guide to aid in identifying these species and removing them from ponds. Copies of the guide are available from Ward Reynolds at 843-747-4323.

The Stormwater Manager's Resource Center (CWP, no date) has sample O&M checklists available for download from its Web site (http://www.stormwatercenter.net/). When at the site's homepage, click on "Manual Builder" and choose "Construction and Maintenance Checklists" from the pull-down list. There are checklists for the following practices: ponds, infiltration trenches, infiltration basins, bioretention facilities, sand filters, and open channel practices.

11.5 References

Bell, W.B. 1997. *BMP Maintenance Agreements and Responsibilities.* Presented at the Stormwater BMP Maintenance Workshop, May 20, 1997, Linthicum, MD.

Center for Watershed Protection (CWP). No date. *Construction and Inspection Checklists.* Stormwater Manager's Resource Center. http://www.stormwatercenter.net/. Accessed March 29, 2002.

Center for Watershed Protection (CWP). 1998. *Costs and Benefits of Storm Water BMPs: Final Report 9/14/98.* Center for Watershed Protection, Ellicott City, MD.

Delaware County Departments of Planning and Public Works. 2003. *Stormwater Management: Delaware County Action Plan.* Version 1.

Field, R. and M.L. O'Shea. 1994. The handling and disposal of residuals from the treatment of urban stormwater runoff from separate storm drainage systems. *Waste Management and Research* 12: 527–539.

Lenhart, J.H. and R. Harbaugh. 2000. *Maintenance of Stormwater Quality Treatment Facilities.* http://www.stormwaterinc.com/pdfs/maintenance_facil.pdf. Accessed July 24, 2003.

Lindsey, G., L. Roberts and William Page. 1992. Maintenance of Stormwater BMPs in Four Maryland Counties: A Status Report. *Journal of Soil and Water Conservation* 47(5): 417–422.

Marquette University. 1982. *Characteristics and Treatability of Urban Runoff Residuals.* Prepared for U.S. EPA, Municipal Environmental Research Laboratory, Cincinnati, OH.

Schueler, T. and Y.L. Yousef. 1994. Pollutant Dynamics of Pond Muck. *Watershed Protection Techniques* 1(2).

South Carolina Department of Health and Environmental Control. 2000. *A Citizen's Guide to Stormwater Pond Maintenance in South Carolina.* South Carolina Department of Health and Environmental Control, Office of Ocean and Coastal Resource Management, Columbia, SC.

U.S. Environmental Protection Agency (USEPA). 1999. *Storm Water O&M Fact Sheet: Handling and Disposal of Residuals.* EPA 832-F-99-015. http://www.fxbrowne.com/html/gs-facts/handdisp.pdf. Accessed July 1, 2003.

U.S. Environmental Protection Agency (USEPA). 2000. *Model Ordinances to Protect Local Resources.* http://www.epa.gov/nps/ordinance. Last updated October 29, 1999. Accessed August 14, 2000.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems.* Watershed Management Institute, Inc., Crawfordville, FL.

MANAGEMENT MEASURE 12
EVALUATE PROGRAM EFFECTIVENESS

12.1 Management Measure

Develop and implement a program to evaluate and improve the effectiveness of the urban runoff management program.

12.2 Management Measure Description and Selection

12.2.1 Description

The purposes of this management measure are to:

- Determine whether implementation of the runoff management program framework is protecting and/or improving water quality by evaluating management practices that are being used to meet Management Measure 1. If these practices aren't effective, improvements to the runoff management program framework should be implemented.

- Periodically reassess the watershed (see Management Measure 2) to determine whether water quality has improved or declined. Based on this assessment, each management measure should be reevaluated to determine whether additional practices should be implemented, if improvements should be made to existing practices, or if specific practices should be discontinued.

12.2.2 Management Measure Selection

This management measure was selected because runoff management programs need to be dynamic (i.e., they need to be periodically adjusted to respond to changing conditions and optimize program effectiveness and expenditures). Areas where program improvement is possible should be identified. Programs that are periodically reviewed and evaluated also are perceived as being more effective, and they will be more likely to receive the public and political support necessary to achieve success. The basic elements of a successful program evaluation are described in this management measure.

12.3 Management Practices

12.3.1 Assess the Runoff Management Program Framework

It is important for watershed managers to objectively assess the runoff management program framework to determine whether the goals of the Program Framework and Objectives Management Measure (Management Measure 1) are being met. This effort should be undertaken periodically to identify aspects of the program that need to be strengthened or revised. Each aspect of the program framework will require a different type of measurement. Watershed managers can choose from both qualitative and quantitative measures as indicators of program effectiveness, using the watershed baseline conditions as a point of reference (see Management Measure 2: Watershed Assessment). Quality assurance and quality control procedures should be followed regardless of whether qualitative or quantitative measures are used.

There are several factors that should be considered when designing an evaluation program. First, some urban management practices, or aspects of their implementation that can be analyzed, vary with time of year, phase of construction, or length of time after installation. Another consideration is that variables generally will not directly relate to management measure implementation, as most urban management measures are combinations of several management practices. Evaluation of management measure implementation, therefore, usually will be based on separate assessments of two or more management practices, and the implementation of each management practice will be based on a unique set of variables. Finally, it is very important to consider the purpose of the program when selecting the variables for which the information is collected.

EPA has developed the Web-based *Measurable Goals Guidance for Phase II MS4s* to assist small municipal separate storm sewer system (MS4) owners and operators in complying with the requirement to select measurable goals to evaluate the effectiveness of individual control measures and the storm water management program as a whole. Even though this document is intended for use by NPDES-permitted MS4 operators, it contains guidance valuable to any institution developing a storm water management program that includes management practices and methods for program evaluation. It includes examples of management practices with corresponding measurable goals and environmental indicators that can be used to document the effectiveness of both management practices and storm water programs. The guidance is available online at http://cfpub.epa.gov/npdes/stormwater/measurablegoals/index.cfm.

12.3.1.1 Qualitative measures

Urban runoff management programs can be evaluated using any number of qualitative measures, such as those presented by WMI (1997a):

- Project permit review times
- Frequency of inspections
- Evaluation by targeted groups
- Appearance of control practices on sites
- Response time for complaints
- Number of permits issued
- Number of individuals trained
- Recognition by others
- Enforcement actions taken
- Maintenance activities
- Reduced number of complaints

For example, Delaware uses the number of individuals attending training courses and receiving state certification as one measure of program success. In addition to monitoring water chemistry, sediments, and the biological community, Florida measures program success by the number of local government storm water utilities implemented, as well as the number of educational and public involvement activities.

Watershed managers can use a combination of measures to assess their program framework based on goals and priorities that were identified at the outset of program implementation. In addition to the qualitative measures listed above, watershed managers can track the implementation, operation, and maintenance of management practices as indicators of the success of a program framework. See Section 12.3.2 for a discussion of management practice tracking.

12.3.1.2 Quantitative measures

Another way for watershed managers to gauge the effectiveness of their runoff management program framework is to quantitatively determine if water quality or habitat has improved. Quantitative measures include:

- Chemical monitoring of practices
- Chemical monitoring of receiving waters
- Biological monitoring of receiving waters (bioassessments)
- Habitat assessments
- Stream flow monitoring
- Stream shoreline condition assessments
- Sediment monitoring (deposition, chemistry)
- Measuring the volume of material removed by street sweeping and catch basin cleaning
- Temperature monitoring

See the section 12.3.3, “Gauge Improvements in Water Quality Resulting from Management Practice Implementation” for a more thorough discussion of the different types of monitoring that can be used to gauge changes in water quality after practice implementation.

12.3.1.3 Quality assurance/quality control

An integral part of the design phase of any monitoring project is quality assurance/quality control (QA/QC). Development of a quality assurance project plan (QAPP) is the first step for incorporating QA/QC into a monitoring project. The QAPP is a critical document for the data collection effort inasmuch as it is used to integrate the technical and quality aspects of the planning, implementation, and assessment phases of the project. The QAPP documents how QA/QC elements will be implemented throughout a project’s life. It states expectations and requirements and provides procedures for data collection and data management that are specific to the project. Development and implementation of a QA/QC program, including preparation of a QAPP, can require up to 10 to 20 percent of project resources (Cross-Smiecinski and Stetzenback, 1994). A thorough discussion of QA/QC is provided in Chapter 5 of EPA’s *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA, 1997).

12.3.2 Track Management Practice Implementation

Implementation monitoring can be used to determine the extent to which management measures and practices are implemented in accordance with relevant standards and specifications. This involves establishing a program that tracks either whether the practices have been implemented or whether management practices have been operating and maintained as designed. For example, some states and municipalities have developed programs that track and record septic tank maintenance or erosion and sediment control practices, or that inventory all runoff control structures.

It is not always possible to track the implementation of every management practice of interest. Sampling a subpopulation and extrapolating the findings to the entire population may be preferred due to time, funding, or personnel constraints. Lack of adequate legal authority may also hinder the collection of data sufficient to track management practice implementation. If an inventory of all management practices of interest is not possible, care should be taken to prepare a statistically valid sampling plan. The primary basis for selecting a design approach should be based on a careful review of study objectives and the pros and cons of each sampling method. An extensive discussion of the different sampling designs and methods for analysis can be found in *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban* (USEPA, 2000), which is available on EPA's Nonpoint Source Web site at http://www.epa.gov/owow/nps/urban2.html. Below are several tools that can be used to track management practice implementation.

12.3.2.1 Track permits

States and local agencies employ a variety of legal mechanisms, including nuisance prohibitions, general water pollution discharge prohibitions, land use planning and regulation laws, building codes, health regulations, and criminal laws to regulate urban nonpoint source water pollution (Environmental Law Institute, 1997). Although not all pollutant-generating activities are covered by these mechanisms, they present opportunities for inventorying management practice implementation. Activities that are typically regulated in some manner include erosion and sediment control, onsite sewage disposal systems, runoff from development sites, construction activities, and industrial activities. A permitting system places on the applicant the burden of obtaining and supplying all necessary data and information to obtain the permit. Issuance of these permits encourages compliance with local laws and regulations in the construction and operation of management practices.

12.3.2.2 Use operation and maintenance records

In many instances, proper operation and maintenance of a management practice are as important as proper design and installation. Regular inspection of management practices can identify the need for repairs or retrofits in addition to identifying areas in the watershed that require additional management resources. If the right types of information are collected when a management practice is installed, it becomes much easier to track operation and maintenance activities and ascertain the cost and effectiveness of the practice.

12.3.2.3 Use geographic information systems

Geographic information systems (GISs) are useful tools for inventorying management practice implementation. A GIS can detect and track trends in management practice implementation, land treatment, changes in land use, and virtually any data related to management practices and water quality. Another advantage is the ability of a GIS to update information and integrate it with existing data in a timely manner. GISs allow watershed managers to do more than just manage information in a database—they are powerful analysis tools that can be used to design sampling protocols for tracking studies and help watershed managers analyze program effectiveness by integrating land treatment and water quality information.

12.3.2.4 Develop surveys

Surveys of property managers and developers can be used to collect background information about management practice implementation, such as:

- Type, number, and size of management practices installed
- Management practice location/watershed
- Land use (i.e., residential, commercial, industrial)
- Percent impervious area
- Inspection results
- Operation and maintenance practices

Maryland's GIS-Based Restoration Project Tracking Database

The Maryland Department of Natural Resources has developed a Restoration Project Tracking Database that provides a list of riparian forest buffer and stream restoration projects by watershed and county with details such as waterway; length, width, area, and other quantifiers as appropriate; and details about the project such as owner type, planting reason, year established or completed, and project components. These data can be displayed in tabular format and are linked on the Web site to an interactive GIS for the public and interested parties to browse (MDNR, 2004). The database can be accessed at http://dnrweb.dnr.state.md.us/watersheds/surf/tracking/track_map.htm.

Maryland also has a "BMP Tracking Reports" Web site (http://dnrweb.dnr.state.md.us/watersheds/surf/bmp/) that provides tributary-specific information regarding implementation of management practices. This information is used to help measure Maryland's progress in reducing nonpoint source pollution and meeting the goals of the Chesapeake Bay 2000 agreement. Users can choose a statewide management practice summary report or they can generate a report by tributary. They list 3 categories of practices: urban practices, resource protection and improvement practices, and agricultural practices. The data for each management practice type is summarized by year in units appropriate for the practice. For example, the urban practice "Erosion and Sediment Control" was implemented on 2,213 acres in 2000, 11,133 acres in 2001, and 10,442 acres in 2002. More information is provided for each practice, including a photo, a brief description, and general pollutant removal information for different land use applications (if the practice is applicable in multiple settings). The pollutant removal information is limited to nitrogen, phosphorus, and sediment.

To complete these efforts, Maryland DNR developed estimates from the Departments of Agriculture, Environment, and Natural Resources. This information was compiled from data received from volunteer groups and county, state, and federal reports provided to each department.

- Dates of management practice installation
- Design specifications
- Type of water body or area protected
- Previous management practices used
- Erosion and sediment control plans (for construction)
- Dates of plan preparation and revisions
- Date of initial plan implementation
- Total acreage under management
- Certification requirements

Watershed managers can use the information obtained from these surveys to identify locations for new management practices and to more closely examine practices used upstream of waters known to be degraded to determine if they are operating as designed or if they require redesign or maintenance.

12.3.2.5 Consider expert evaluations

Expert evaluations may be needed to augment or verify information provided in surveys. Experts are especially useful in determining the following:

- Proper design
- Proper installation
- Adequacy of operation and maintenance plans and activities
- Verification of conclusions derived from self-evaluations (i.e., an objective third party's review of data and reports)

Each of these tools can be used to help watershed managers locate management practices and identify those that are not performing as expected (i.e., not meeting the goals of the management measures). These tools can be used separately or in combination to obtain and organize management practice data and use it to better meet the goals of the management measures.

12.3.3 Gauge Improvements in Water Quality Resulting from Management Practice Implementation

Watershed managers can determine the effectiveness of the runoff program by monitoring changes in water quality after the management measures and practices are implemented. The most fundamental step in the development of a monitoring plan is to define the goals of the monitoring program. Monitoring goals are broad statements such as "to measure improvements in Elephant Butte Reservoir" or "to verify nutrient load reductions into the Chesapeake Bay." Designing a monitoring plan also includes selecting sampling variables, a sampling strategy, station locations, data analysis techniques, the length of the monitoring program, and the overall level of effort to be invested.

Once the monitoring goals have been established, existing data and constraints should be considered. A thorough review of literature pertaining to water quality studies previously conducted in the geographic region of interest should be completed before starting a new study.

The review should help determine whether existing data provide sufficient information to address the monitoring goals and what data gaps exist.

The next step should be to identify project constraints such as finances, staffing, and time. Clear and detailed information should be obtained on the time frame for management decisions, the amounts and types of data that must be collected, the level of effort required to collect them, and the equipment and personnel needed to conduct the monitoring. This will determine whether available personnel and budget are sufficient to implement or expand the monitoring program.

As with its design, the program's level of monitoring is largely determined when goals and objectives are set, although there is some flexibility for achieving most monitoring objectives. Watershed managers should determine the appropriate timeframe and geographic scope of the monitoring program based on program goals and objectives. For example, if the objective is to determine the effectiveness of a nutrient management program for reducing nutrient inputs to a downstream lake, monitoring a subwatershed for five years or longer might be necessary.

Watershed managers also need to determine the size of the watershed, because many have an influence on stream characteristics and water quality, and therefore on the complexity of the monitoring program design. These factors include drainage patterns, stream order, stream type, climate, number of landowners in the area, homogeneity of land uses, watershed geology, and geomorphology. An analysis of these considerations in combination with budgetary and time constraints will determine the exact nature of the monitoring program.

It is important to ensure that expectations for the monitoring program are realistic. Ward et al. (1990) identify the following key steps to ensure that policymakers and other stakeholders know the types of information that a monitoring program can produce:

- Perform a thorough review of the legal basis for the management effort and define the resulting implications for monitoring.
- Review the administrative structure and procedures developed from the law in order to define the information expectations of the management staff.
- Review the ability of the monitoring program to supply information.
- Formulate an information expectations report for the monitoring system.
- Present the information expectations report to all users of the information.
- Develop consensus as to an agreeable formulation of information expectations and related monitoring system design criteria.

The next task when developing a monitoring program plan is to set monitoring objectives, which are more specific statements than goals and can be used to complete the monitoring design process. The objectives must be detailed enough to allow the designer to define precisely what data will be gathered and how the resulting information will be used.

Another important aspect of setting up a monitoring and evaluation program is variable selection. Variables should be selected based on the monitoring objectives. For example, if a dissolved oxygen problem is suspected, then dissolved oxygen should be monitored in addition to biochemical oxygen demand, sediment oxygen demand, temperature, and nutrients. Surrogate measures can also be used to satisfy monitoring objectives. For example, if the objective is to monitor the condition of salmon spawning areas, surrogate measures are necessary because the condition of salmon spawning areas is a composite of many factors. Good surrogate variables would be stream bank undercut, embeddedness, and vegetative overhang (Platts et al., 1983). The corresponding surrogate goals could be to reduce cobble embeddedness and to increase vegetative overhang to appropriate levels for salmon spawning. Subsequent monitoring goals could be to document changes in cobble embeddedness and vegetative overhang.

Because there are numerous variables to choose from and monitoring budgets are limited, some method to prioritize variable selection is often necessary. Table 12.1 shows groups of variables and examples of each. When available, existing data should be used to guide variable selection. Further discussion on variable selection, prioritization, and optimization are provided by USDA (1996), MacDonald et al. (1991), and Sherwani and Moreau (1975). In some cases, optimal variable selection is not possible, which may be due to lack of local data. In such cases, the researcher might need to rely on professional judgement and the review of monitoring programs of similar nature and scope.

Table 12.1: Examples of variables that can be measured to assess changes in management practice implementation and water quality.

Variable Type	Examples
Physical and chemical water quality data	Flow (streams), temperature, transparency, suspended sediment, sedimentation transparency, suspended sediment, sedimentation rate, dissolved oxygen, pH, conductivity, alkalinity/acid neutralizing capacity (lakes), and nutrients.
Biological data	Bacteria, algal biomass, macrophyte biomass and location, macroinvertebrate and fish populations.
Precipitation data	Total rainfall, rainfall intensity, storm interval, and storm duration.
Land use data	Treatments applied to land, current and historical use of the land, spatial and temporal information on land use activities, and changes in land use made before and during a project.
Topographic data	Slope length, slope steepness, slope shape, channel slope, channel side slope.
Soil characteristics data	Hydrologic soil group, soil organic carbon content, depth to water, net recharge, aquifer media, and vadose zone characteristics.

Designing and implementing a monitoring program often requires an interdisciplinary approach that may require interagency coordination and input. In many cases, technical staff will need to integrate “new” monitoring with what is already being done to demonstrate to program managers that duplicate work is not proposed. The most effective way to achieve this goal is to bring all the involved agencies and other stakeholders in the monitoring effort together. One or more agencies should coordinate to clarify project roles and responsibilities. Agreements to participate can be formalized as commitments and specified in the quality assurance project plan.

Such coordinated cooperation permits each involved party to offer the results of its ongoing activities to the monitoring effort, lessens the burden on each participating agency, and may decrease overall project costs. For example, USGS might already have a tracking system for management practices, while other agencies, including the U.S. Fish and Wildlife Service and EPA, might have other ongoing monitoring programs. When multiple agencies are involved in the monitoring program, each can benefit from the others' efforts.

Two types of objectives will be discussed in this section: analyzing trends in water quality and measuring the effectiveness of management practices.

12.3.3.1 Conduct trend monitoring

Trend monitoring can be useful for determining whether there has been a change in the extent to which management measures and management practices are being implemented. Trend monitoring involves long-term tracking of changes in one or more parameters. Public attitudes, land use, and the use of various urban management practices are examples of parameters that could be measured with trend monitoring.

Isolating the impacts of either individual or sets of management measures and management practices on water quality also requires trend monitoring. Because trend monitoring involves measuring a change (or lack thereof) in some parameter over time, it is necessarily of longer duration and requires establishment of a baseline. Any changes in the measured parameter are then detected in reference to the baseline. Baseline monitoring requires ascertaining the existing conditions before some management action or change in land use occurs. Factors such as weather conditions should be considered if baseline monitoring is to be used as a reference point for trend analysis and management decisions. The ability to relate water quality changes to changes in land management depends on the quality and quantity of data collected on land management practices.

Public attitudes, land use, and the use of various urban management practices are examples of parameters that could be measured with trend monitoring. Isolating the impacts of management measures and management practices on water quality also requires trend monitoring. For example, an objective of trend analysis can be to answer the question, "Is water quality changing over time?"

12.3.3.2 Conduct effectiveness monitoring

Effectiveness monitoring involves evaluating individual management practices or groups of management practices to determine the extent of pollution control they provide. Monitoring for individual management practices can typically be conducted on a plot or field scale, whereas monitoring for management practice systems is usually conduced on a watershed scale. Studies of some individual practices can be conducted in a relatively short time (less than five years), while others might take longer. Evaluation of management practice systems is typically conducted over a long term (more than five years) because management practice implementation can take years to affect water quality. In fact, there may be a lag in response time that may be 10 to 20 years or longer. This type of monitoring is difficult due to the presence of pollutant reserves in soil and sediments, the effect of many land uses within a study area, the variety of approaches that landowners use to implement similar management practice systems, and the need to track land management as well as water quality and climatic variables.

A guidance manual describing protocols for monitoring the effectiveness of storm water management practices, *Urban Stormwater BMP Performance Monitoring*, is available for download in PDF format from the International Stormwater Best Management Practices Database Web site (http://www.bmpdatabase.org/docs/Urban Stormwater BMP Performance Monitoring.pdf). Along the same lines, EPA's Environmental Technology Verification Center offers the *Protocol for the Verification of Stormwater Source Area Treatment Technologies* (http://www.epa.gov/etv/pdfs/vp/04_vp_stormwater.pdf).

12.3.4 Develop and Implement a Schedule to Improve the Management Program Framework

Data on management practice effectiveness and water quality should be carefully reviewed to determine where deficiencies in the runoff management exist. Effectiveness monitoring results should be compared with expected values published in the literature or with values provided with proprietary products. If the system is underperforming, possible causes should be considered:

- Is the practice properly designed and sized?
- Are site conditions (geology, land use, etc.) inappropriate for this practice?
- Were maintenance activities not performed as scheduled or needed?
- Were influent pollutant concentrations different than expected?

The next step is to determine whether the management practice needs to be retrofitted, replaced, or removed. Is pretreatment needed? Should a treatment train approach be used? Should additional capacity be added? Should maintenance be scheduled more frequently? A plan should be developed to implement proposed changes on a practice-by-practice basis.

A review of monitoring data on ambient water quality should be conducted to determine if water quality is improving. Consideration should be given to activities or events that might have skewed results (i.e., flooding, drought, landslides, significant changes in surrounding land use). If water quality has not improved, the following questions should be asked:

- Are management practices not performing as well as they should be?
- Were the wrong practices selected?
- Are additional practices needed?

Monitoring data should be examined to determine which pollutants and sources (if known) are a problem, and additional activities to address these sources should be proposed.

Once a list of planned changes to the program has been compiled, each project should be prioritized. Projects that should receive a higher priority are those that are most likely to improve water quality, those that the community has shown support for or is likely to support, and those that are relatively straightforward or inexpensive to implement. Implementation of proposed projects should be completed before the next program evaluation (usually within five years).

12.4 Information Resources

Restoring Life in Running Waters: Better Biological Monitoring (Karr, 1998) describes how and why biological monitoring and multi-metric indices can be used to assess environmental degradation and how this information can be integrated into regulatory and policy decisions. This book can be purchased at bookstores or ordered from Island Press at http://www.islandpress.com/.

Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls, published by EPA's Office of Water in 1997, gives an overview of nonpoint source pollution and covers the development of a monitoring plan, data analysis, quality assurance/quality control, and biological monitoring. It can be ordered through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban (USEPA, 1998) helps local officials to focus limited resources by establishing statistical sampling to assess, inspect, or evaluate a representative set of management practices, erosion and sediment controls, and onsite wastewater treatment systems. The document can be downloaded in PDF format at http://www.epa.gov/owow/nps/urban.pdf, or it can be ordered through EPA's National Service Center for Environmental Publications at http://www.epa.gov/ncepihom/index.htm.

EPA's Volunteer Monitoring Program provides technical assistance, serves as a regional contact for volunteer programs, manages grants to state agencies that organize volunteer monitoring programs, and provides information exchange services for volunteers. A listserver is available for volunteer monitoring program coordinators on the EPA Web site, http://www.epa.gov/owow/monitoring/volunteer. Also available are a national newsletter for volunteer monitors, a directory of volunteer monitoring programs, and manuals on volunteer monitoring methods and planning and implementing volunteer programs.

Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements presents monitoring protocols for studies measuring the effectiveness of storm water management practices and is available for download in PDF format from the International Stormwater Best Management Practices Database Web site (http://www.bmpdatabase.org/docs/Urban Stormwater BMP Performance Monitoring.pdf).

EPA's Environmental Technology Verification Center developed the *Protocol for the Verification of Stormwater Source Area Treatment Technologies* (http://www.epa.gov/etv/pdfs/vp/04_vp_stormwater.pdf), which establishes guidelines for measuring the effectiveness of storm water treatment technologies. The protocol was developed to ensure that technology verification studies are carried out in a consistent and objective manner that assesses the appropriate performance characteristics.

12.5 References

Cross-Smieckinski, A., and L.D. Stetzenback. 1994. *Quality Planning for the Life Science Researcher: Meeting Quality Assurance Requirements*. CRC Press, Boca Raton, FL.

Environmental Law Institute (ELI). 1997. *Enforceable State Mechanisms for the Control of Nonpoint Source Water Pollution*. Environmental Law Institute Project 970300, Washington, DC.

Karr, J.R., and E.W. Chu. 1998. *Restoring Life in Running Waters: Better Biological Monitoring.* Island Press, Washington, DC.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*. EPA-910-9-91-001. U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Maryland Department of Natural Resources (MDNR). 2004. *Watershed Projects*. http://www.dnr.state.md.us/watersheds/surf/proj/proj.html. Last updated March 26, 2004. Accessed March 31, 2004.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for Evaluating Stream, Riparian, and Biotic Conditions*. General Technical Report INT-138. U.S. Department of Agriculture, Forest Service, Ogden, UT.

Sherwani, J.K., and D.H. Moreau. 1975. *Strategies for Water Quality Monitoring*. Report 107, Water Resources Research Institute of the University of North Carolina, Raleigh, NC.

U.S. Department of Agriculture (USDA). 1996. *National Handbook on Water Quality Monitoring*. National Water Quality Handbook, Part 600. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1997. *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls*. EPA 841-B-96-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1998. *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban*. EPA 841-B-00-007. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1990. *Design of Water Quality Monitoring Systems.* Van Nostrand Reinhold Company, NY.

Watershed Management Institute (WMI). 1997a. *Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation*. Watershed Management Institute, Ingleside, MD.

Watershed Management Institute (WMI). 1997b. *Operation, Maintenance, and Management of Stormwater Management Systems.* Watershed Management Institute, Ingleside, MD.