National Management Measures to Control Nonpoint Source Pollution from Urban Areas—Draft

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Office of Wetlands, Oceans, and Watersheds
Nonpoint Source Control Branch
1200 Pennsylvania Avenue, N.W.
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http://www.epa.gov/owow/nps

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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 25 years, 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: 1998 Report to Congress* identified urban runoff as one of the leading sources of water quality impairment in surface waters (USEPA, 2000c). Of the 11 pollution source categories listed in the report, urban runoff/storm sewers was ranked as the sixth leading source of impairment in rivers, fourth in lakes, and second in estuaries (Table 1.1).

Table 1.1: Leading sources of water quality impairment related to human activities for rivers, lakes, and estuaries (USEPA, 2000c).

	Rivers and Streams	Lakes, Ponds, and Reservoirs	Estuaries
Pollutants	Siltation (38%)[a]	Nutrients (44%)[a]	Pathogens (47%)[a]
	Pathogens (36%)	Metals (27%)	Organic enrichment (42%)
	Nutrients (28%)	Siltation (15%)	Metals (27%)
Sources[b]	Agriculture (59%)	Agriculture (31%)	Municipal point sources (28%)
	Hydromodification (20%)	Hydromodification (15%)	Urban runoff/storm sewers (28%)
	Urban runoff/storm sewers (12%)	Urban runoff/storm sewers (12%)	Atmospheric deposition (23%)

[a]Values in parentheses represent the percentage of surveyed river miles, lake acres, or estuary square miles that are classified as impaired.
[b] Excluding unknown, natural, and "other" sources.

A. Purpose and Scope of the Guidance

National summaries, such as those shown in Table 1.1, are useful in providing an overview of the magnitude of 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 as a national problem.

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 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 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. 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 1.1 presents the components of a comprehensive runoff management program.

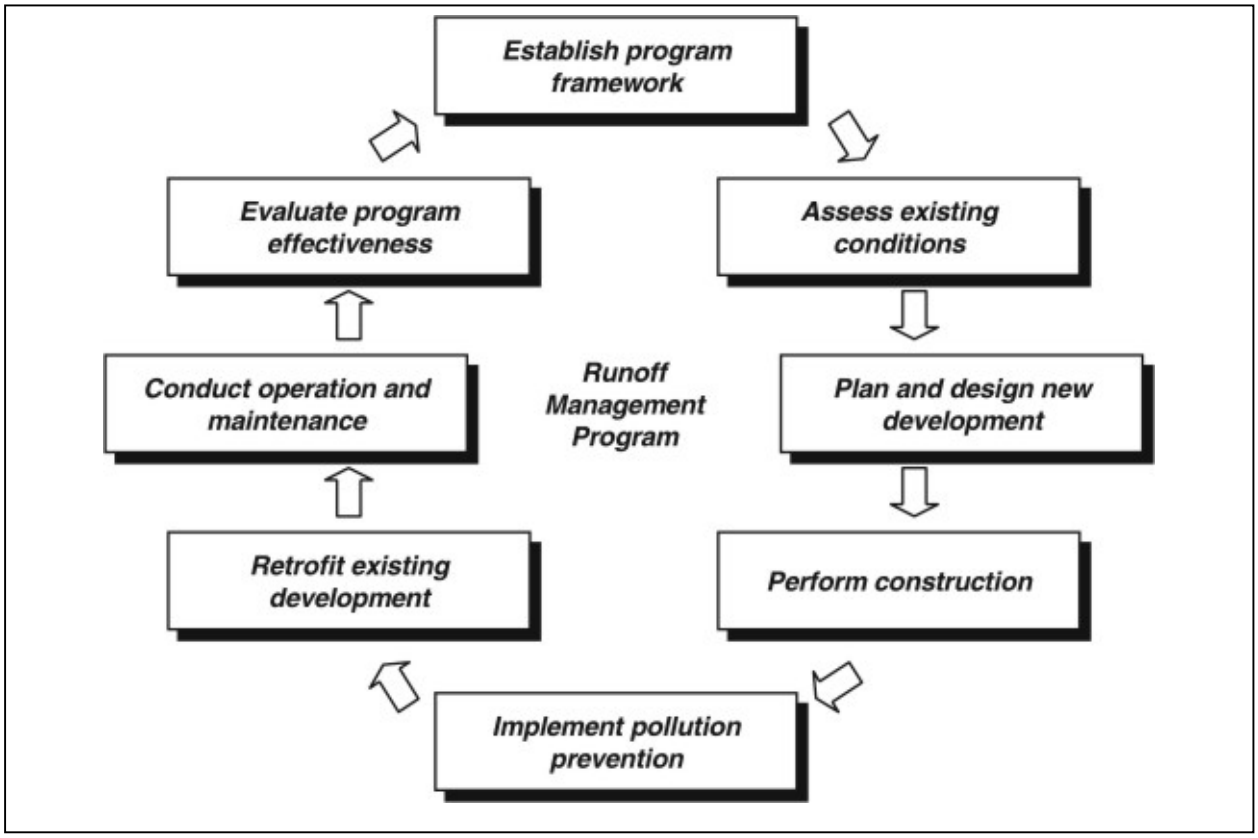

Figure 1.1: Components of a comprehensive runoff management program.

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. A total of 12 management measures have been included in this guidance. Figure 1.2 groups these measures within the context of the runoff management program cycle.

Each management measure listed in Figure 1.2 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 this issue because if exposed soils are allowed to erode and move off construction sites as sediments, they can clog storm drains, streams, and other waterbodies, 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 1.2 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).

The planning development management measures (3–7) address issues associated with new development. The watershed protection management measure (3) focuses on siting development and establishing measures 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

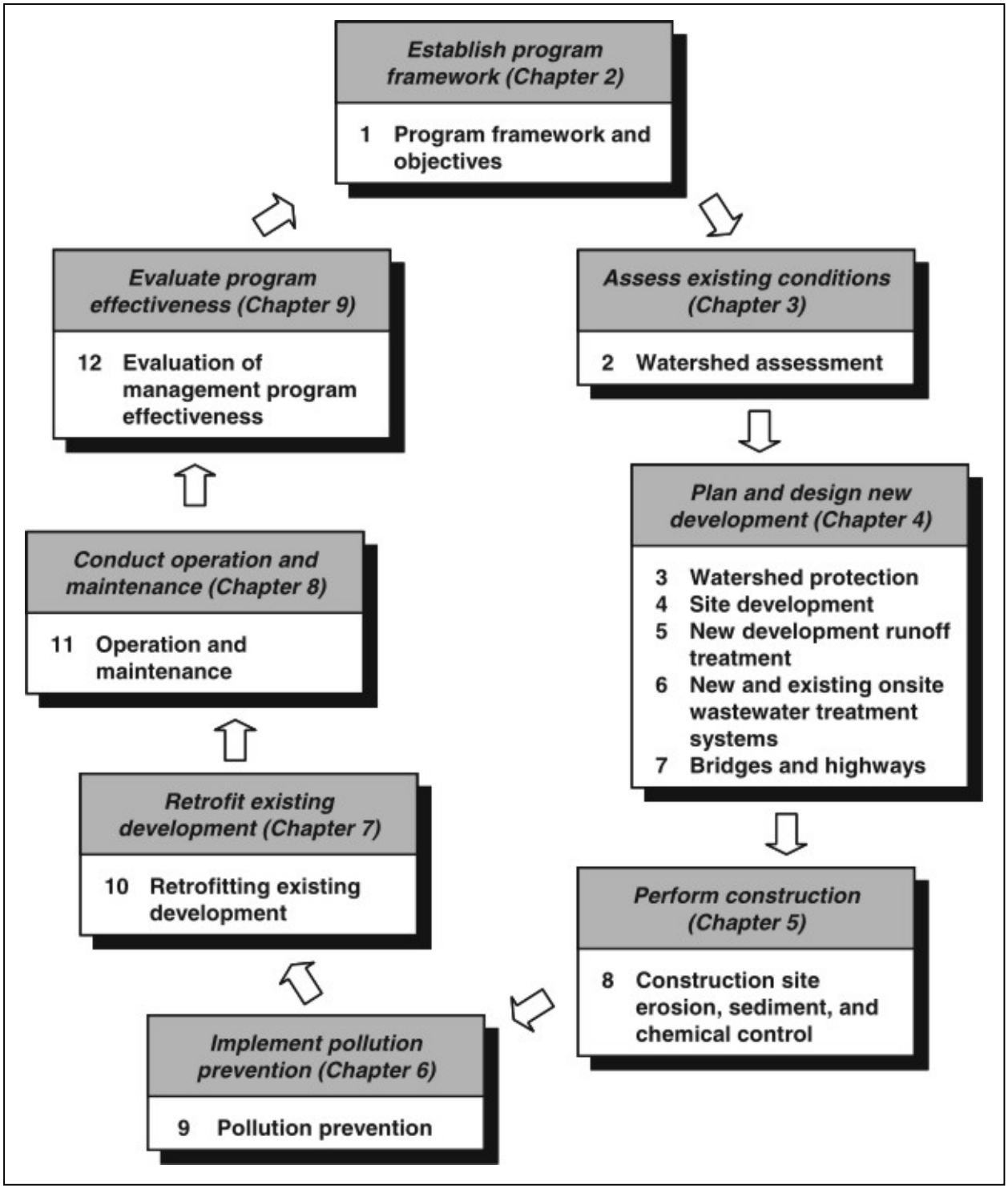

Figure 1.2: Twelve management measures associated with the runoff management program cycle.

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 the effectiveness of their programs 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 reevaluation also identifies areas where additional restoration or preservation activities are needed, which will guide future watershed initiatives and thereby restart the management cycle.

Case Study: 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 David Ramsay, Friends of the Chicago River, 407 South Dearborn, Suite 1580, Chicago, Illinois, 60605. Phone: 312-939-0409, ext. 21.

2. Document Organization

Chapters 2 through 9 of this document consecutively focus on the eight components of the runoff management program cycle (Figure 1.2). 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.

B. Origin and Regulatory Context

1. Origin of This Guidance

This document is an update of the urban management measures and practices provided in Chapter 4 of a U.S. Environmental Protection Agency (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 protecting 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 have 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 1.2.

Table 1.2: 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 published	1993	2001
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 context of a comprehensive watershed program

2. Regulatory Context

During the first 15 years of the national program to abate and control water pollution (1972–1987), EPA and the states focused most of their water pollution control activities on traditional point sources. These point sources have been regulated by EPA and the states through the National Pollutant Discharge Elimination System (NPDES) permit program established by Section 402 of the Clean Water Act. The NPDES program functions as the primary regulatory tool for assuring that water quality standards are met. 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 the 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 permitting using a two-phased approach. (Detailed information on both phases of the NPDES Storm Water Program is available at *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 places 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. Under the permit, regulated operators must develop and

implement storm water management programs/plans. 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 and develop storm water management programs or plans. 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 if deemed necessary to protect water quality. 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 wavier 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 and 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 guide 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.

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 nonpoint source 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 2 years, and states are required to develop a Total Maximum Daily Load (TMDL) for each pollutant causing impairment for waterbodies on the list. More information on the TMDL program and 303(d) lists is provided at *www.epa.gov/owow/tmdl*.

- *Section 305(b) and the National Water Quality Inventory: Report to Congress*. Every 2 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 *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 *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 apply to certain categories of activities having minimal adverse environmental effects. Implementation of Section 404 is shared between the U.S. Army Corps of Engineers 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, and 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 *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 *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 *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 SRF Program. More information about the Safe Drinking Water Act and Source Water Protection Programs can be found at *www.epa.gov/ safewater/protect.html*.

C. Key Concepts

1. Watershed Approach

Since 1991, USEPA has promoted the watershed approach as the key framework for dealing with problems caused by urban runoff and other sources that impair surface 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 100 square miles in size. Local agencies and urban communities, however, can apply the approach to watersheds as small as 1 square mile in size.

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 scale and small scale practices. Often, a combination of nonstructural and structural practices is the most cost-effective approach.

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 1.3). 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 1.3: 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

a. 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) system, 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 *nhd.usgs.gov*.

b. 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 they 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

c. Local-level scales

The hierarchy established by the HUC system identifies scales useful for watershed planning and management by national, regional, state, and multistate 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 in area, 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 1.3):

- *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 or there might be multiple catchments on a large development site.

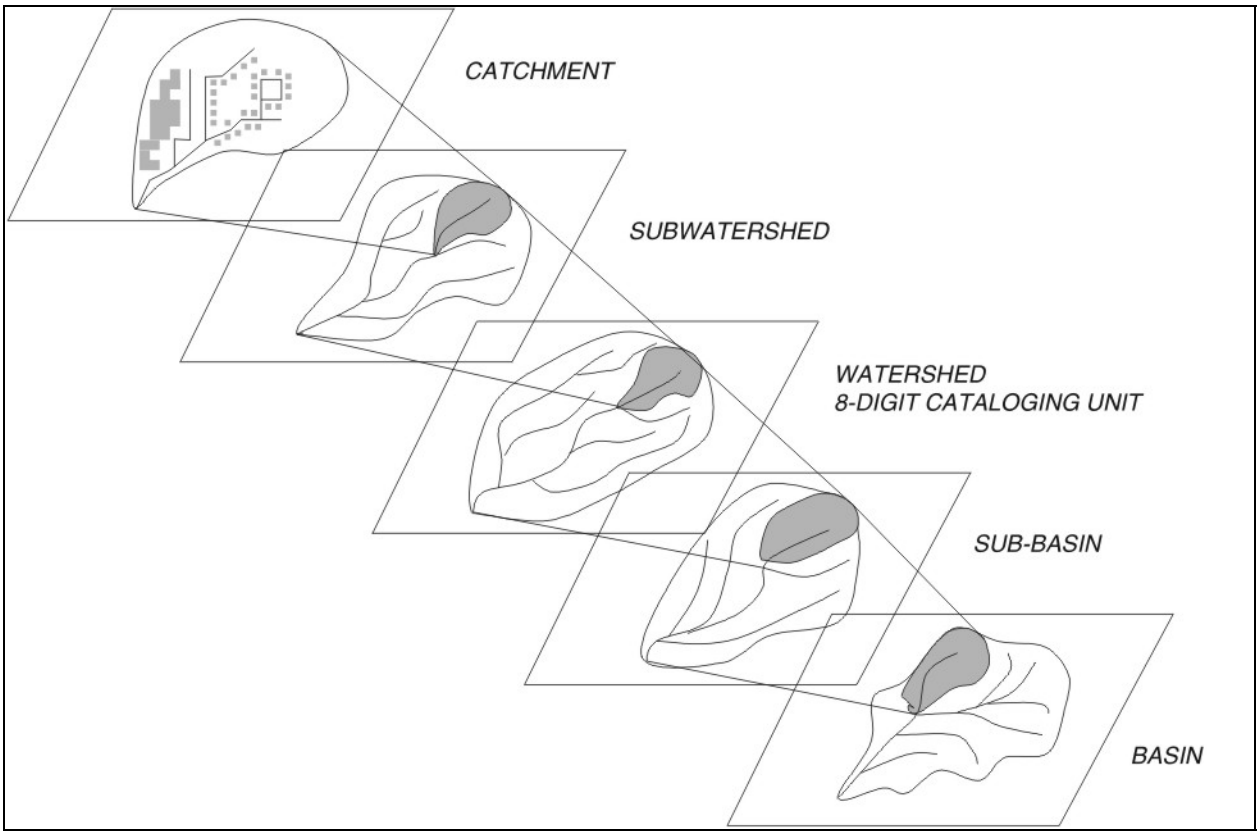

Figure 1.3: Scales of watershed management units (Schueler, 1995).

3. Impervious and Pervious Surfaces in the Urban Landscape

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 of the runoff infiltrates into the soil or it continues to travel downslope 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.

Impervious cover in a watershed or subwatershed can be organized into two 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.

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).

a. 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 and transport systems. It is usually expressed as a percentage of the total watershed or subwatershed area. It can be calculated by direct measurement or by estimating the percentage 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 run 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.

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 about 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.

b. 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 areas, 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.

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 3 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 is 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 BMPs in extending thresholds*. Urban BMPs may be able to extend the threshold of impervious cover, but only modestly if at all.

- *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 nonurban landscapes. However, planners can integrate pervious and impervious areas to greatly reduce effective impervious area and reduce the impact of imperviousness on stream quality.

a. Subwatersheds as the primary management unit

The impervious cover model relies on the subwatershed as the primary management unit. Table 1.4 displays the influence of impervious cover in the context of a hierarchy of watershed-based management units. The subwatershed scale is optimum for planning purposes at the local level for many reasons, including the following:

- The influence of impervious cover on hydrology, channel stability, water quality, and biodiversity is most evident at the subwatershed scale because the receiving waterbody 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 holding 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-in. by 36-in. 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 1.4: 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

b. 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 between 11and 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 26 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 the prevention and removal of urban pollutants so they will not be carried downstream. Restoration of some attributes such as increased biodiversity can sometimes be achieved in limited amounts given the right circumstances. Pollution prevention and retrofitting in existing urban areas are the most frequently used practices.

Table 1.5 describes channel stability, water quality, and biodiversity attributes as well as general resource and water quality objectives associated with each category.

Table 1.5: 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 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 live 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 live history and feeding requirements	– Pollution-intolerant species – Unaltered life history and feeding requirements – Increased number and diversity of species
Rehabilitation Process	Degraded		Improved

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 1.4 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.
- 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

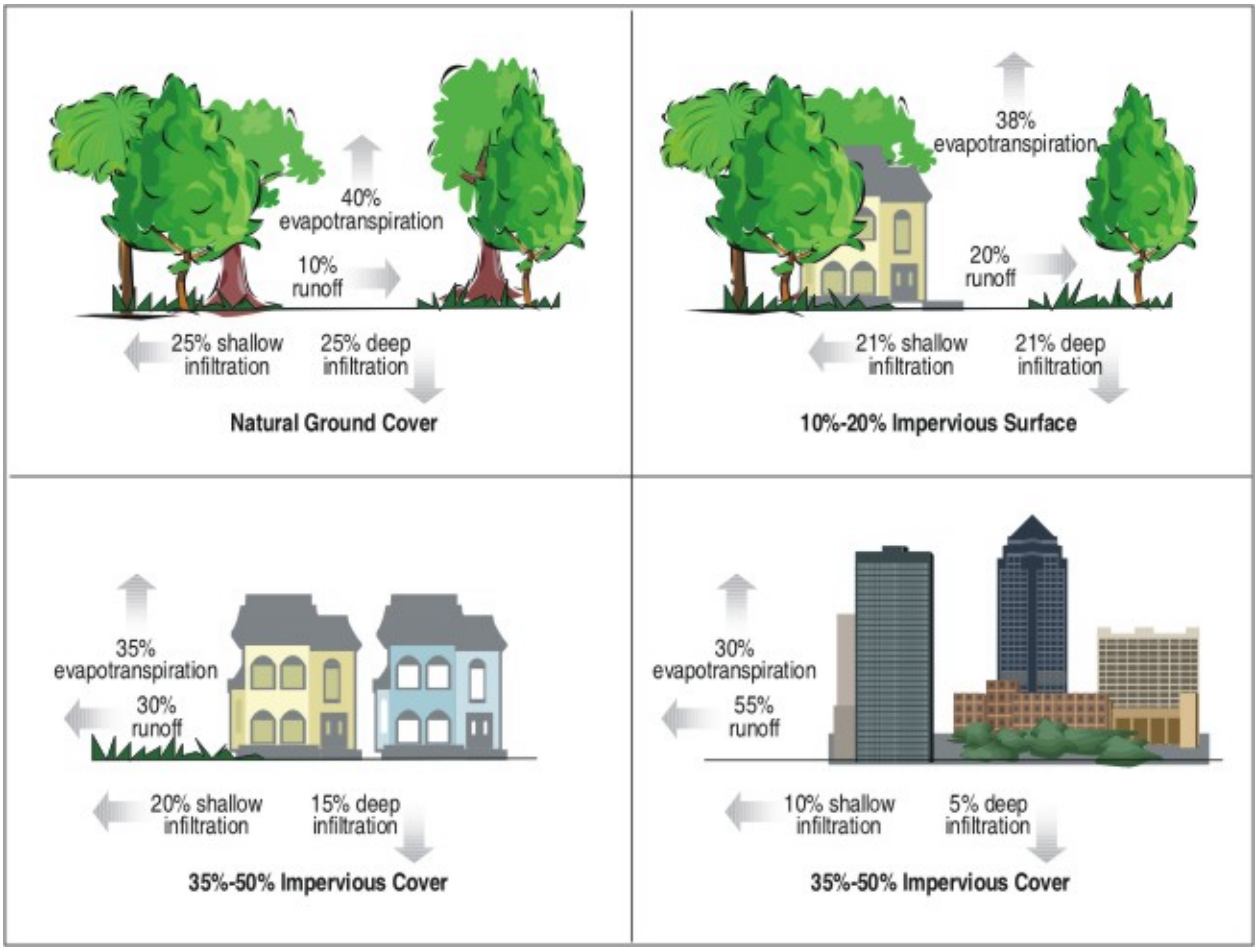

Figure 1.4: Impacts of urbanization on the water cycle (Adapted from FIRSWG, 1998).

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 ten percent can destabilize a stream channel, raise water temperature, and reduce water quality and biodiversity (Schueler, 1995).

Figure 1.5 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.

Development and increased impervious cover also lead to erosion and undercutting of streambanks, channel widening, and in-channel sediment deposition. In addition, decreased base flow occurs in dry weather because a greater portion of runoff flows off the surface, resulting in less infiltration to ground water reserves that normally provide base flow to streams. Figure 1.6 shows changes to stream geometry in response to urbanization (Schueler, 1987).

USEPA (1997) reviewed the literature for case studies that quantitatively examined the relationship between increased impervious surfaces and stream impacts. Table 1.6 lists these relationships, and Table 1.7 summarizes the case studies used to derive the relationships.

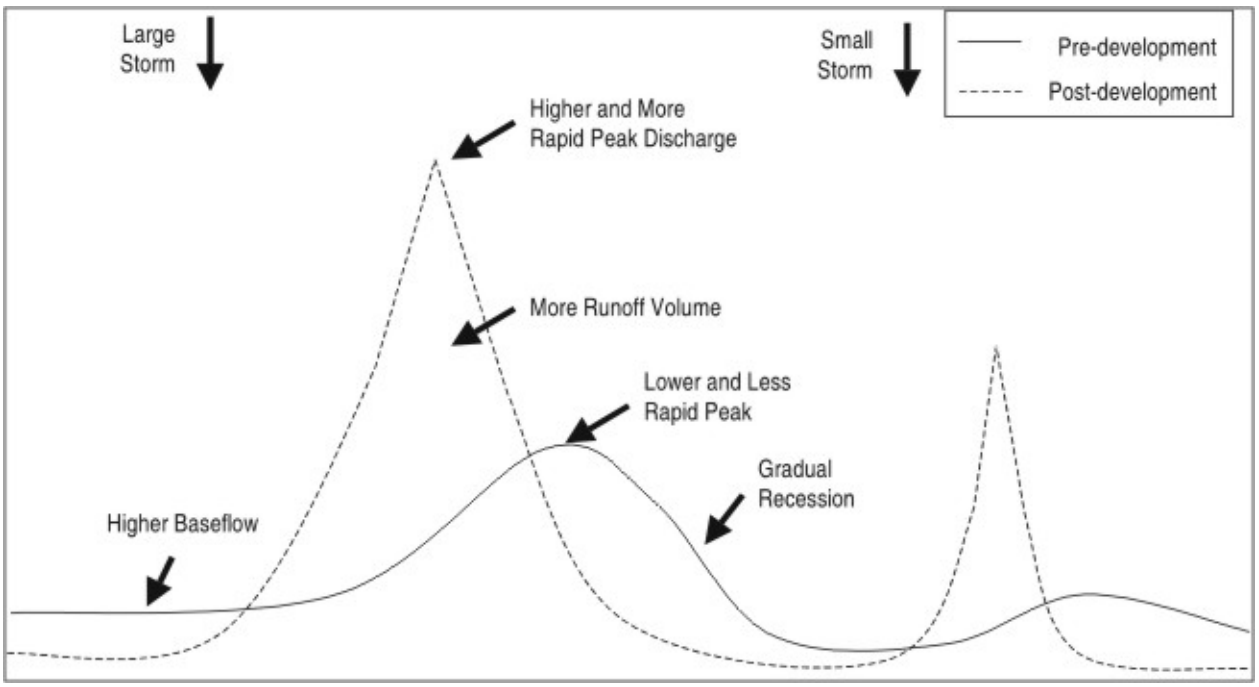

Figure 1.5: Changes in stream flow hydrograph as a result of urbanization (Schueler, 1987).

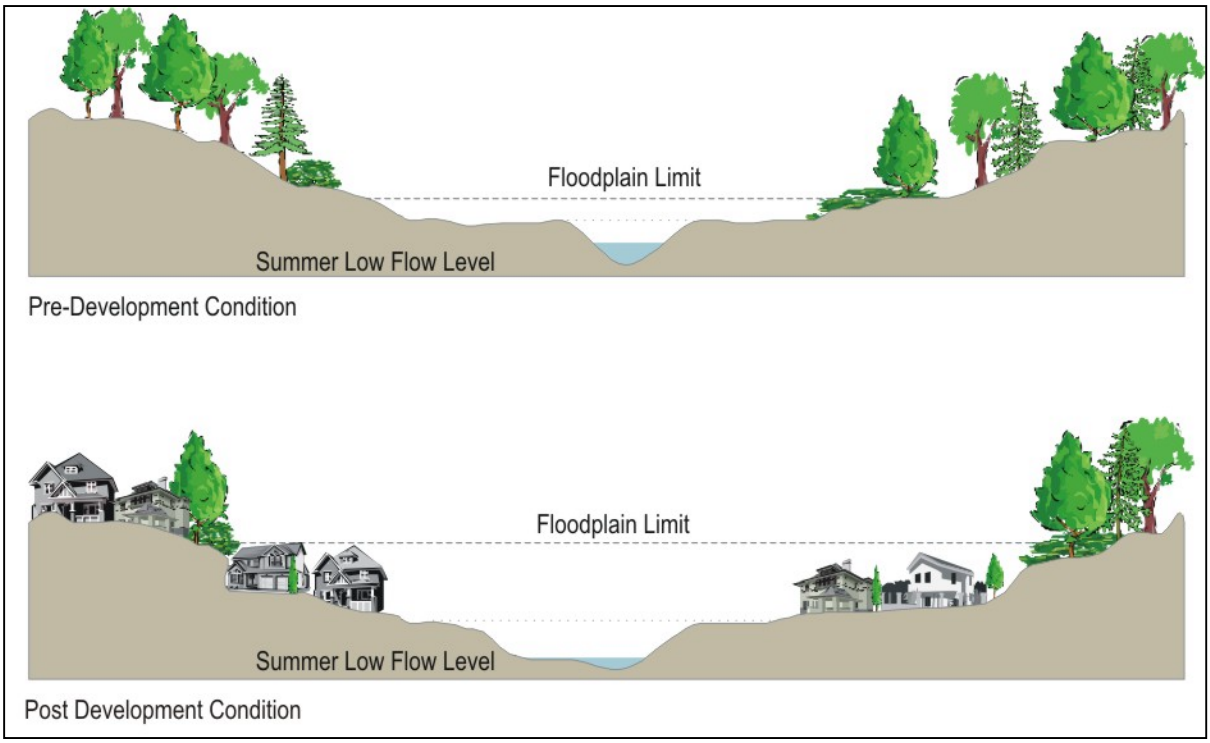

Figure 1.6: Response of stream geometry to urbanization (Schueler, 1987).

Table 1.6: 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	✓	✓	✓	✓	✓

Recent research has shown that streams in urban watersheds have a fundamentally different character than 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).

Table 1.7: 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 stream bank 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

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 had been moved before.

- *Channels enlarge.* The customary response by 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 nonurban 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 into the soil, less flow is available to recharge ground water. Consequently, during extended periods without rainfall, base flow 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 crosssection 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 storm events.

- *In-stream habitat structure degrades*. Urban streams are routinely scored as having poor in-stream 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 directly in 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 storm events 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 to 10 ºF (Galli, 1991). Because temperature plays a central role in the rate and timing of in-stream 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; Schueler, 1995; Shaver et al., 1994). 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 in-stream habitat structure, and barriers that limit natural recolonization.

Figure 1.7 shows the relationship between impervious cover and aquatic insect diversity; Figure 1.8 shows the relationship between imperviousness and fish diversity. Both studies were conducted in Maryland streams (Schueler and Galli, 1992, as cited in Schueler, 1995).

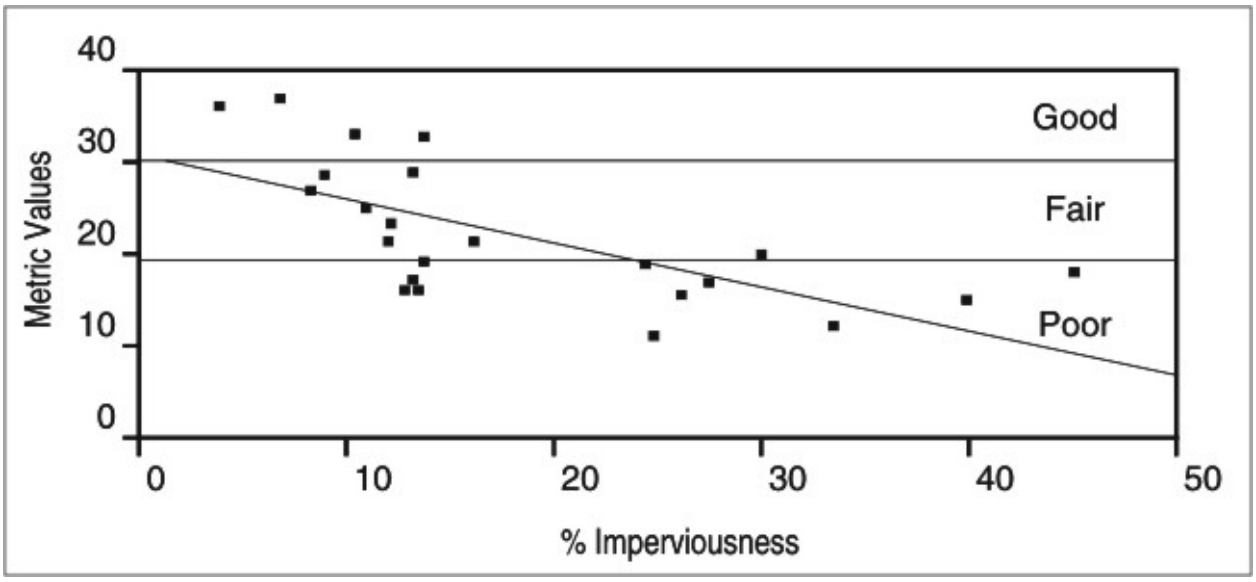

Figure 1.7: Relationship between impervious cover and aquatic insect diversity in Anacostia River subwatersheds (Schueler and Galli, 1992, as cited in Schueler, 1995).

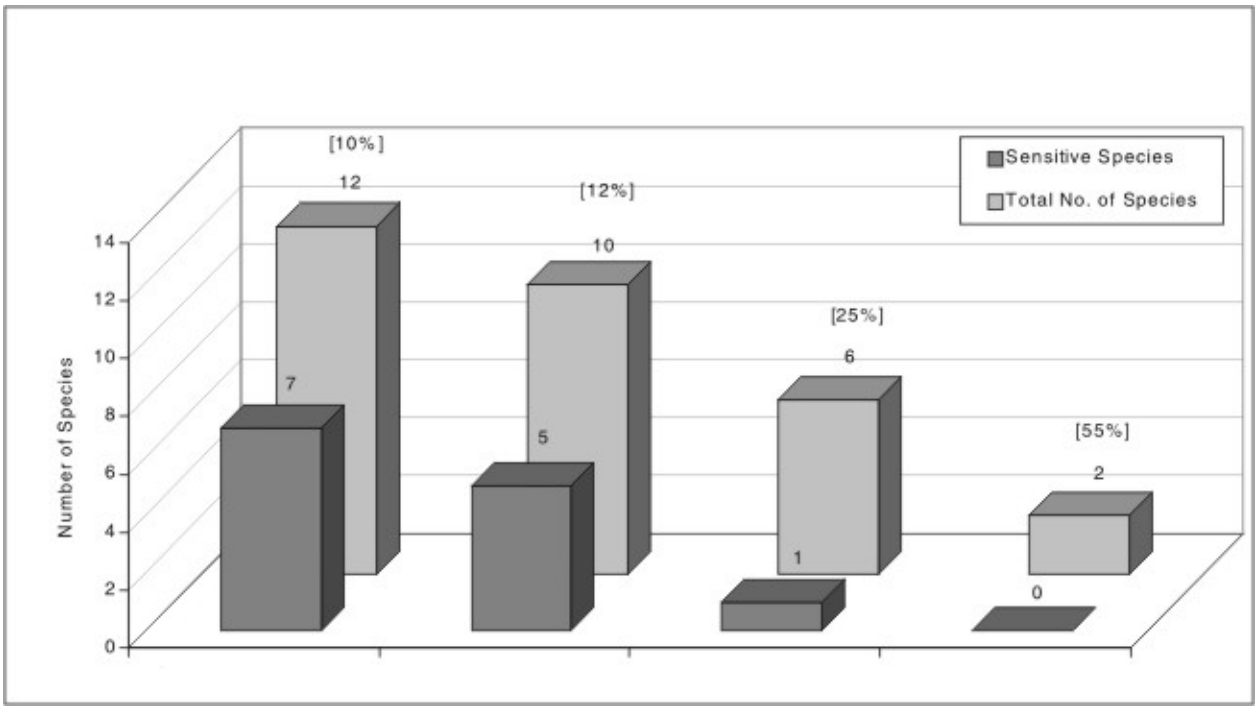

Figure 1.8: Fish diversity in four subwatersheds of different impervious cover in the Maryland Piedmont (Schueler and Galli, 1992, as cited in Schueler, 1995).

6. Nonpoint Source Pollutants and Their Impacts

Urban areas are a source for many different types of pollutants. Table 1.8 shows typical pollutant concentrations found in storm water.

Table 1.8: 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.

The following discussion identifies the principal types of pollutants found in urban runoff and describes their potential adverse effects:

a. Sediment

Excessive erosion, transport, and deposition of sediment in surface waters is a significant form 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 fish food sources, 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: 1998 Report to Congress* (required under section 305(b) of the Clean Water Act), states, tribes, and other jurisdictions surveyed water quality conditions in 23 percent of the Nation's total 3.6 million miles of rivers and streams (USEPA, 2000c). Some 35 percent of these surveyed waters were impaired by various pollution

sources. Sediment was the leading cause of impairment, accounting for 38 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.

A recent study of the economic impact of excessive erosion and transport of sediment in surface water systems estimates the annual costs for 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 damages 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 damage 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 waterbody's shoreline, bank, or bottom.

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.
- 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 waterbody 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.

b. Nutrients

Nutrient over-enrichment 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.

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.

c. 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 waterbody. Data have shown that urban runoff with high concentrations of decaying organic matter can severely depress DO levels after storm events. 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.

d. Pathogens

Urban runoff typically contains elevated levels of pathogenic organisms. The presence of pathogens in runoff may result in waterbody impairments such as closed beaches, contaminated drinking water sources, and shellfish bed closings. 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.

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.

When pet waste is not properly disposed of, it can wash into nearby waterbodies or can 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 waterbody, 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.

e. Road salts

According to a study by the Department of the Interior and USGS (1996), road salt has become a problem for both surface 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 U.S. 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 waterbodies adjacent to salted areas. Additionally, salt is corrosive and may cause damage to roadways, bridges, and vehicles.

f. 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. 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 of time and result in adverse impacts on the diversity and abundance of benthic communities.

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

g. 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 on a study in the Chesapeake Bay that designated urban runoff as the source for 6 percent of the cadmium, 1 percent of the chromium, 1 percent 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 waterbody.

h. 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.

i. 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 storm events (Galli and Dubose, 1990). Elevated temperatures can also be caused by widening and shallowing of streambeds resulting from 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).

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: 1998 Report to Congress* (USEPA, 2000c) reported the following:

Siltation, pathogens, and nutrients are the pollutants most responsible for water quality impairments in the nation's rivers and streams, and agriculture, hydromodification, 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 waterbodies 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 events, and shellfish bed closures in the river have been attributed to loadings from surface runoff and OWTSs (USEPA, 1992).

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 storm events. 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 the 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).

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 waterbodies.

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 into
    - *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.
    - *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.

Information Resources

The Terrene Institute is a non-profit organization dedicated to protecting and conserving natural resources through public education and outreach. The Terrene Institute publishes a newsletter, Nonpoint Sources News-Notes, and coordinates the National Mitigation Banking Conferences. Access to publications, fact sheets, outreach materials, watershed data, and other related materials, can be found at the Terrene Institute website (*www.terrene.org*).

The Center for Watershed Protection is a non-profit organization that provides information concerning watershed restoration, planning, research, and training, stormwater 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 over 15,000 individuals through workshops. The Center for Watershed Protection's website (*www.cwp.org*) provides links to upcoming Center 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 (*www.rivernet.org/welcome.htm*).

The Natural Resources Defense Council (NRDC), an organization with over 500,000 members nationwide, seeks to protect and restore the natural environment. Information relevant to stormwater management and pollution can be accessed at their web site (*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 stormwater management programs employed across the U.S. *Stormwater Strategies* can be downloaded at *www.nrdc.org/water/pollution/storm/stoinx.asp*.

The Watershed Management Institute aims to protect watersheds through educating the private sector, public, elected officials, and citizens, as well as conducting research to better understand watersheds and providing technical assistance through educational services. Projects undertaken by the Watershed Management Institute include workshops on runoff management practices, the Midwest Urban Runoff Workshop, and publications such as *Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation* and *Operation, Maintenance, and Management of Stormwater Management Systems*. Additional information on the Watershed Management Institute can be accessed at *home.att.net/~ericlivingston*.

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 *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 *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 *www.epa.gov/owm* and information specific to the Storm Water program can be accessed at *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 *www.wef.org/applications/periodicals*.

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Management Measure 1
Program Framework and Objectives

A. 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.
- Fosters input from citizens, stakeholders, and technical experts and coordinates with other agencies.

B. Management Measure Description and Selection

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.

a. 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.

b. 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. The following is a list of several 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.

c. 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.

Case Study: 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.

d. 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.

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 of runoff programs; it establishes management measures and how and where management practices will be applied. The program framework should also include the input of citizens, stakeholders, technical experts, and other agencies in the program planning and implementation.

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.

C. Management Practices

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 for other states 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, located at *www.epa.gov/owow/nps/*

ordinance, also has materials that support particular ordinances, such as maintenance agreements and inspection checklists.

The primary focus of the management practices discussed below is on how local governments can increase their ability to manage runoff by developing new, or modifying existing, ordinances or regulations. 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.

a. 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.

Case Study: 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: center@cwp.org.

b. 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, stream bank stabilization, stream temperature control, and 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 the following:

- 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.
- 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 erosion prevention and sediment control practices 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 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.

- 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 further reducing the amount of impervious cover on-site. Open space development reduces the need for clearing and grading by 35 percent to 60 percent and increases opportunities for using the reserved land for a variety of purposes, including conservation, recreation, habitat preserves, and storm water management. Table 2.1 shows a summary of studies that contrasted conventional and open space designs in terms of impervious cover and storm water runoff (CWP, 1998a).

Table 2.1: Redesign analyses comparing impervious cover and storm water runoff from conventional and open space subdivisions (CWP, 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%	-20%	66%
Rapahannock	⅓-acre lots	27%	20%	-24%	25%
Buckingham Greene	⅛-acre lots	23%	21%	-7%	8%
Belle-Hall	High density	35%	20%	-4%	31%

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

(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 their aesthetic qualities. 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 *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).

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 www.epa.gov/owow/nps/ordinance.

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

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

Open Space Development
1. Open Space Development Ordinance from Calvert County, MD
2. Land Preservation District Model Zoning from Montgomery County, PA
3. Open Space Ordinance from Hamburg Township, MI

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

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

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

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

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

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

Case Study: 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 2.2).

Table 2.2: Summary of the Randleman Lake Water Supply Watershed Protection Rules.

Development Option	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 2.1) 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.

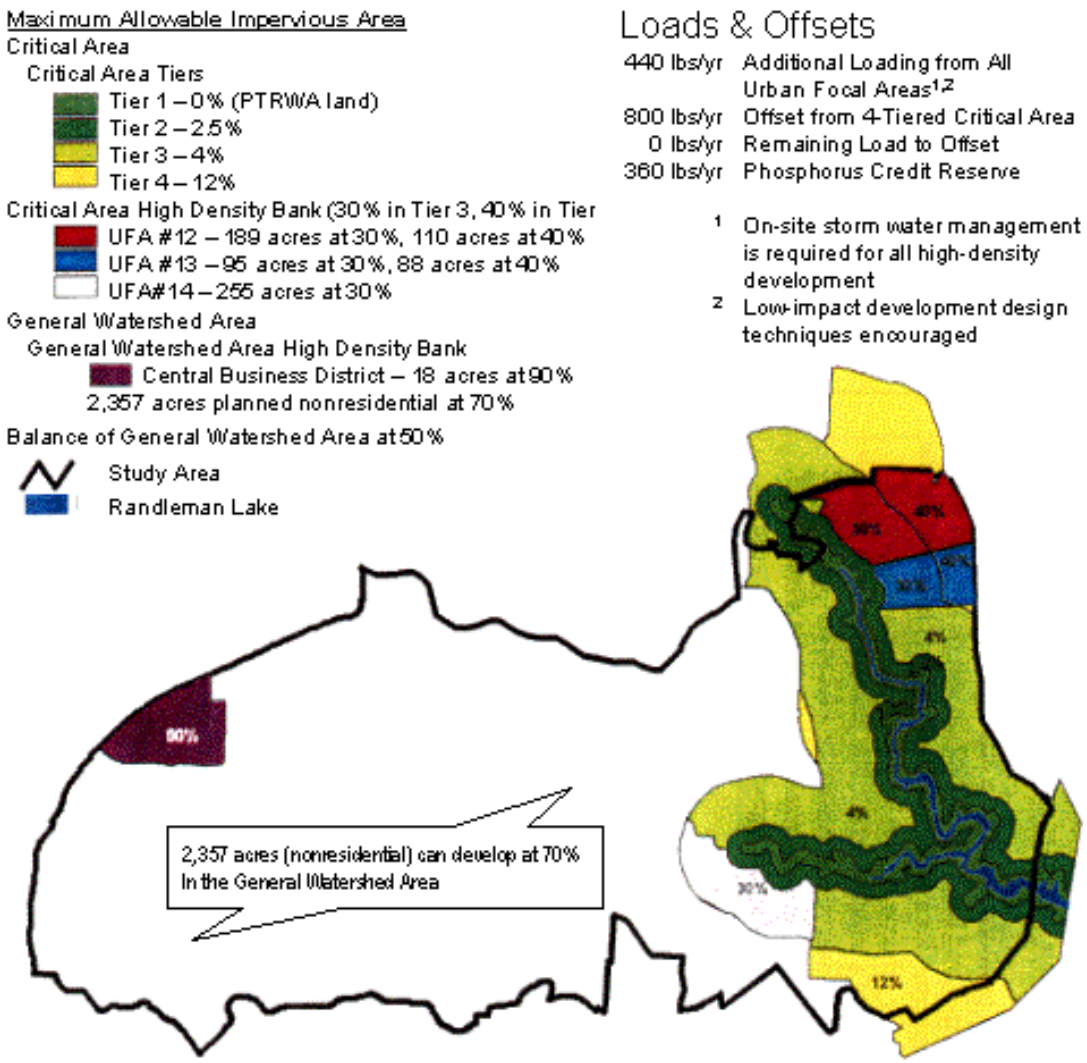

Figure 2.1: Adopted watershed protection plan for the City of High Point, North Carolina.

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.

(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 affect construction site erosion and sediment control 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*. Usually in the form of a surety or cash bond, a guarantee 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 temporary construction site erosion and sediment controls (e.g., silt fences) 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 1 or 2 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 that might be set forth in an ordinance include

- 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 a necessary component 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 require and keep on file all inspection reports. 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) *Miscellaneous ordinances*. Other ordinances capture issues that are important for protection of water resources but do not fall into the other categories of this web site. 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.

- The Wetlands and Watercourses Ordinance of Croton-on-Hudson, New York, protects wetlands by restricting development near wetlands and requiring certain techniques and measures to prevent development impacts on nearby wetlands.

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 small watersheds and primarily to local efforts. State and regional agencies might need to conduct their efforts at a larger scale. Other resources that address establishing a watershed planning framework as applied to larger scales include *Framework for a Watershed Management Program* (Clements et al., 1996) and *Know Your Watershed* (CTIC, 2000).

a. 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 2.2, 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 "imbedded" 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 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 can contribute to the destruction of vegetation through trampling and overgrazing.

In 1994, the Terrene Institute, in cooperation with EPA Region 6, published a bulletin that describes water quality problems associated with stables and backyard livestock pens and presents management techniques to address these agricultural nonpoint sources. These practices include

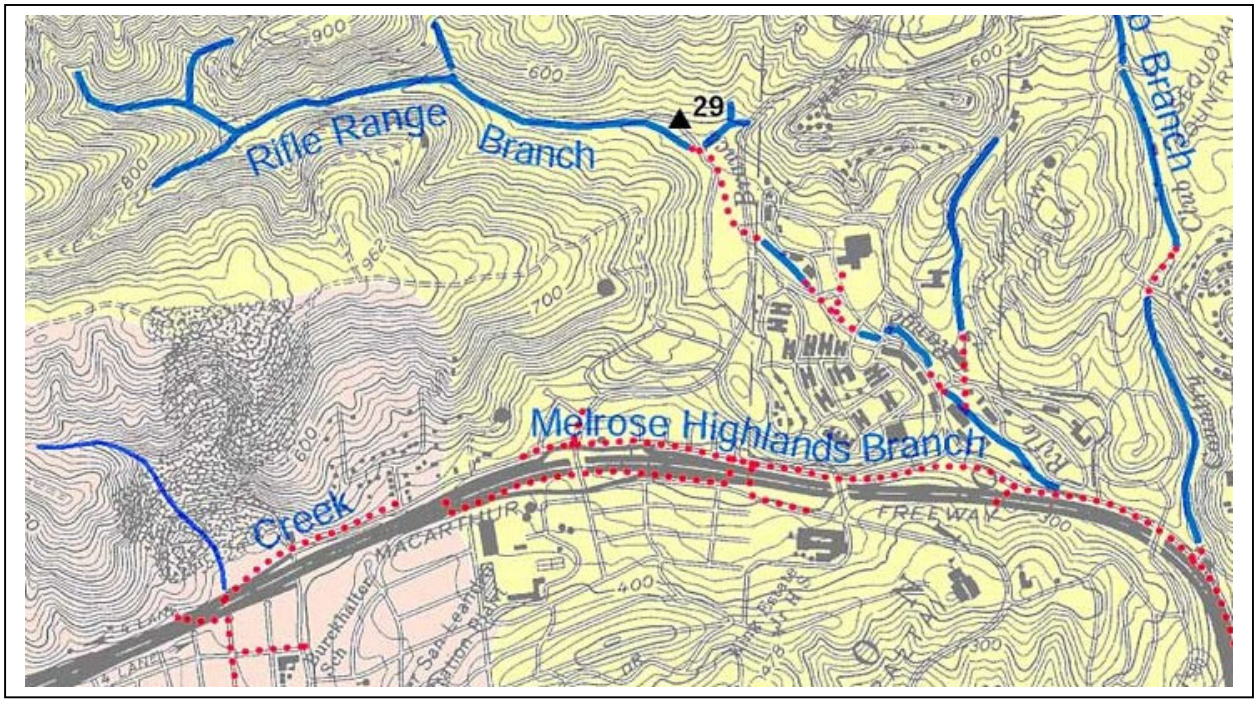

Figure 2.2: Example of part of a subwatershed base map (Oakland Museum of California, No date).

- Siting animal areas to drain away from waterbodies.
- Planting or maintaining as much vegetation as possible between animal areas and waterbodies.
- 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 one or more fenced areas for animal use to protect vegetation.
- Collecting manure and bedding regularly and protecting stored manure from rainfall and runoff.
- 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.

To obtain a copy of this bulletin, contact the Terrene Institute, 1717 K Street, NW, Suite 801, Washington, DC 20006, 202-833-8317. Other sources of information include Local Cooperative Extension Service offices, Soil and Water Conservation Districts offices, and 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 www.ftw.nrcs.usda.gov/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 www.epa.gov/owow.

(3) *Identify possible stakeholders*. Stakeholders are people that

- Are affected by the outcome of the watershed plan.
- Have a responsibility for implementing the plan.
- Have an ability to either impede or assist the implementation of the plan.

The stakeholders have power and a variety of insights that will help determine whether the watershed plan succeeds or fails. See the box 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 local management units are encompassed by larger scales in the watershed hierarchy, 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

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

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

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

Other Citizens
- Local residents
- Schools/teachers

(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 include

- 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.

b. 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 include

- Adequate permanent staff to perform facilitation and administrative duties.
- A consistent, long-term funding source to ensure a sustainable organization.
- Including all stakeholders in planning efforts.
- A core group of persons dedicated to the project that have the support of local governmental agencies.
- Local ownership of the runoff management plan fostered 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 who 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 the goals and carefully lay out the responsibilities and contributions that will be made by each element. Table 2.3 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.

(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.

Table 2.3: 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 from 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 takes 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.
Implementation	Government agencies at the state, local, and federal levels implement the plan.	Local governments implement the plan.	Local governments implement the plan; 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.
Disadvantages	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 overrepresented.	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.

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 or awareness is 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.

c. 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 for 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.

d. 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.

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.

Case Study: 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.

e. 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, BMP regulations, proposed BMP locations, description of proposed new programs, estimates of budget and staff needed to implement the plan, stream buffer widths, or monitoring protocols.

f. 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. As the plan is being developed and afterwards, watershed managers need to work 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.

g. 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.

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 *www.mdsg.umd.edu/EFC* (EFC, 2000).

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

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 *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.

Case Study: 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 *www.ci.lenexa.ks.us/Stormwater/intro.html* (Lenexa, No date).

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

a. 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, nonenvironmental programs. Fees are another method that can generate money for environmental programs. Table 2.4 outlines several kinds of taxes and fees that are appropriate for financing storm water management programs.

Table 2.4: 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.

b. 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.

c. 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.

d. 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.

e. 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.

4. Foster Input From Technical Experts, Citizens, and Stakeholders

Most runoff management institutions require input from three groups of people to plan and implement successful runoff management practices—technical experts, citizens, and stakeholders. 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.

a. 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.

b. Citizen committees

A citizen committee is open to all citizen participation 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.

c. 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. The list of typical stakeholders involved in the watershed planning process includes

- 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.

Case Study: 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).

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 the revision of the plan 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 on its ability to forge all interagency or multijurisdictional 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 actors. Care must be taken to avoid interagency rivalries or miscommunication.

The first step to foster 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 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 include

- 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.

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 also greatly benefit from runoff management education and training. Public awareness of programs 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 cleanups. 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 pollution prevention management measure in Chapter 6.

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 *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 (*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 *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 *www.mdsg.umd.edu/EFC*.

The Florida Association of Stormwater Utilities (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 *www.fasu.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, model purchasing resolution, 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 *www.naco.org/pubs/catalog/environ.cfm*.

The Terrene Institute (1993) published *Clean Water in Your Watershed: A Citizens Guide to Watershed Protection*, which focuses on the citizen's role in protecting watersheds. It is written to help citizen groups work with local, state and federal government agencies to successfully design and complete a watershed protection or restoration project. This publication can be purchased at the Terrene Institute's web site at *www.terrene.org*.

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 *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 may be used to fund watershed projects. The information on funding sources is organized into categories including, for example, 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 may be used to search for funding programs for particular subject areas. The document is available in HTML format at *www.epa.gov/owow/watershed/wacademy/fund.html*.

Model Ordinances to Protect Local Resources (USEPA, 1999b), located at *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 post construction 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 (*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 *www.epa.gov/owow/nps/stormwater.html*.

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Management Measure 2
Watershed Assessment

A. Management Measure

Develop and implement a watershed assessment program to

- Characterize watershed conditions.
- Establish a set of watershed indicators.

B. Management Measure Description and Selection

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 waterbodies using watershed indicators that measure physical, chemical, and biological conditions.

2. Management Measure Selection

In 1999 states developed Unified Watershed Assessments that draw on the full range of information to

- Assess the health of watersheds and identify watersheds in need of restoration (i.e., watersheds that do not now meet clean water and other natural resource goals).
- Identify watersheds that need preventive action to sustain water quality using ongoing state, tribal, and federal programs. Identify pristine or sensitive watersheds on federal lands that need an extra measure of protection.

State pollution control agencies and Indian tribes typically are responsible for watershed assessment and monitoring activities. States, interstate commissions, and tribes monitor water quality and identify waters and watersheds not meeting clean water goals through various programs, including the following:

- 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 2 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 not meeting 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 identifying coastal water quality problem areas as part of efforts to reduce polluted runoff to coastal waters.

Case Study: Pennsylvania Watershed Assessment Objectives

The Commonwealth of Pennsylvania, in 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, the state developed a process to identify the need for data and to obtain committee input to define a schedule for data analysis and interpretation that will ultimately lead to the development of standards for streambank 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.

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

A 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 water quality 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 or implementation of

Planning for Watershed-Scale Monitoring of Freshwater Ecosystems

The Nature Conservancy (TNC, 2000) has developed a document that provides guidance for establishing freshwater ecosystem monitoring at the watershed or landscape scale, particularly for the adaptive management of freshwater biological diversity. Planning for Watershed-Scale Monitoring of Freshwater Ecosystems, which is pending publication, provides a step-by-step process with two sets of guidelines. The first set describes the process for assessing freshwater monitoring needs and includes the following nine steps:

1. Identify and prioritize the conservation questions in the site conservation plan and identify the conservation zone to which each pertains.
2. Identify the level of monitoring intensity needed to address each question and reach a useful answer.
3. For each question, determine which variables or indicators should be monitored.
4. Identify covariates for each of the variables or indicators identified in Step 3.
5. Determine a sampling schedule for each variable, indicator, and covariate.
6. Determine sampling locations for each variable, indicator, and covariate.
7. Determine sampling and measuring methods for each variable, indicator, and covariate.
8. Determine quality assurance and quality control procedures needed for each variable, indicator, and covariate.
9. Integrate the results of Steps 1 to 8 and identify and refine measurement suites.

The second set of guidelines describes the process for developing a monitoring action plan and includes the following four steps:

1. Identify the resources available to support a monitoring program and the major barriers to its implementation.
2. Evaluate the priority for and feasibility of monitoring each measurement suite based on the site's conservation priorities.
3. Identify the amount of short-term and long-term monitoring that can be accomplished.
4. Revise conservation priorities, monitoring needs, and fund-raising and partnership goals until the monitoring plan is feasible, fundable, and institutionally appropriate and meets the conservation needs.

These guidelines allow users to establish a monitoring program that will provide crucial information for guiding management decisions.

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).

C. Management Practices

1. Characterize Watershed Conditions

a. Establish a reference condition

It is important to establish a reference condition that characterizes the relatively unimpaired condition of the waterbody. The reference condition establishes a basis for making comparisons between sites and is essential for detecting impairment. There are two types of reference conditions—site-specific and regional. Site-specific reference conditions are determined from one or more sites upstream from a point source discharge or from a paired watershed, which is a watershed similar in size and characteristics to the watershed of interest. Site-specific reference sites are advantageous because their habitat is often similar to that measured downstream of a discharge, which reduces complications in data interpretation arising from habitat differences. Also, impairments due to upstream influences from other point and nonpoint sources are already factored into the reference condition. However, site-specific reference sites lack broad study design and their capacity for extrapolation is limited. They also have limited variance estimates: because each site of concern typically is represented by one to three reference sites, the result could be an incorrect assessment if the upstream site has especially good or especially poor habitat or chemical quality. In addition, site-specific reference sites involve a substantial assessment effort when considered on a regional or statewide basis.

Regional reference conditions 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.

b. Model pollutant sources and loads

Watershed managers can use models to estimate storm water pollutant loadings to 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 to using published data is that costly, labor-intensive fieldwork can be avoided. One problem associated with using published data, however, is that the measured watershed might not adequately represent the watershed of interest. A major data source is the USEPA National Urban Runoff Program (NURP) database, which contains concentration values measured for 30 cities (USEPA, 1983). Information that is 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 washoff parameters

Calibration/Verification Parameters

- Measured rainfall
- Measured runoff
- Water quality samples

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 pros and cons. 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, models should be calibrated and validated if possible 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.

Watershed managers can choose from several different methodologies depending on the specific goals of the modeling effort, including

- *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 are not likely to 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*. Spreadsheet calculations 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 error; 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 of pollutants. This method is useful for assessing 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 1 year and often 2 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 event 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 intrastorm variations in these measures.

- *Buildup and washoff.* Loading is determined by combining the buildup of pollutants during dry weather and washoff during rainfall events. This method quantifies intrastorm 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 have 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.)

Pollutant fractions or potency factors can be used for pollutants adsorbed to solids because these pollutants can be estimated as a proportion of the total suspended solids concentration or annual

load. This method is most appropriate for metals and organics and can be combined with other models for a more accurate estimate of adsorbed pollutants.

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.
- 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, but they can improve the accuracy of loading estimates. Before they are included, consideration should be given to the level of detail needed for the analysis.

c. 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 both quantity (hydrodynamic) and quality parameters, but some consider these parameters separately. Other receiving water quality models include a surface runoff model that quantifies inputs to the receiving waters.

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 *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 waterbodies. This document is intended to provide watershed managers and other users with information helpful for selecting models appropriate to their needs and resources. Specifically, it 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 nonurban 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. Other publications that can provide watershed managers with modeling information can be found at *www.epa.gov/oiamount/tips/wq.htm* (USEPA, 1998a).

d. 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 there are multiple pathways through which these effects can occur. Also, 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)

Case Study: Application of a FGIS 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.

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 3.1.

e. Estimate the effectiveness of treatment practices

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,

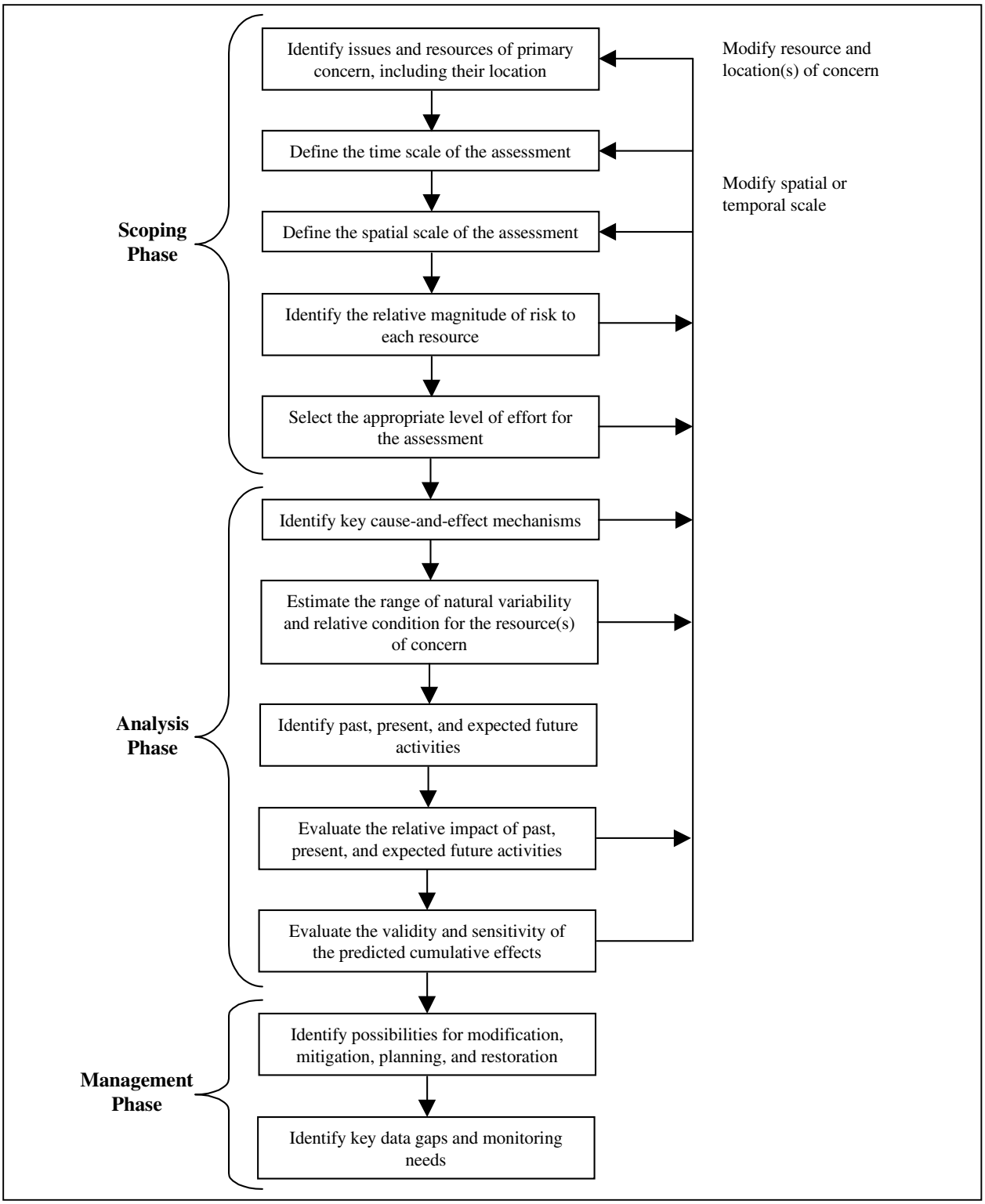

Figure 3.1: Conceptual process for assessing cumulative effects (MacDonald, 2000).

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 *www.cwp.org*.

2. 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

- 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 of time to establish observable trends.
- Be compatible with available financial, personnel, and other resources.

The Center for Watershed Protection and EPA published an excellent 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. It can be ordered on-line at *www.cwp.org*.

a. Establish water quality indicators

Conduct water quality monitoring. This type of monitoring involves measuring pollutants in both runoff and base flow conditions. The most commonly measured constituents are oxygen demand, nutrients, metals, pH, temperature, flow, solids, fecal coliforms, and 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 might be expensive because of labor requirements or equipment costs for automation.

(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 between 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 *www.epa.gov/OST/WET*. Descriptions and guidance on other analytical methods are provided at *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 *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 waterbodies. 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 of time.

(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 and shellfish beds. Tracking the frequency of such closures might indicate that effluent from industrial or municipal facilities, septic systems or runoff from agricultural areas is contaminated. 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 might indicate a developing problem if they become more frequent or might demonstrate the effectiveness of management efforts if they decrease. 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 might not be detected even though they are present at some times (during storm flows). DNA testing is an expensive but effective method for identifying the primary animal (human, duck, dog, etc.) sources of microbes present in the water column. More information on DNA testing can be obtained by contacting Dr. Mansour Samadpour at the Department of Environmental Health, University of Washington, Box 357234, Seattle, Washington; telephone 206-543-5120; e-mail mansour@u.washington.edu (CWP, 1999).

(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 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). 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 community planning by allowing communities to identify areas of pollutant releases when planning economic development and housing projects. The HUD E-MAPS program can be accessed at *www.hud.gov/emaps*.

Case Study: 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 *www.mde.state.md.us/enpa/2000_enpa/envi_indicators*.

b. 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 waterbody's physical, habitat, and hydrological characteristics. Both documents are available on the Internet: the former can be found at *www.epa.gov/owow/monitoring/rbp*, and the latter is located at *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 *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 *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 *www.epa.gov/emap*.

(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*. Physical habitat monitoring 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 assesses the impact of urbanization on base flows, either as compared to a nonurbanized 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 flows as a result of urbanization. Evaluating pipe installations and impervious surfaces in humid regions and water use in arid regions allows this method to identify causes of base flow alteration. This method works well in conjunction with stream widening/downcutting studies. It does not 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, shape, or 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. These maps, called Flood Hazard Boundary Maps (FHBMs), 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) on-line at *www.fema.gov/MSC/product.htm*, 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 identifies areas that would potentially benefit from riparian buffer enhancement and measures 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. Also, some management practices, such as ponds and wetlands, can result in increased temperature.

Case Study: 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.

c. Establish biological indicators

Bioassessments are useful for detecting aquatic life impairments and identifying the causative agent 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.
- Routine biological monitoring is inexpensive relative 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) discusses the advantages of monitoring each community type and presents several methods that can be used for each. Additionally, EPA (2000b) published the *Stressor Identification Guidance Document*, which outlines a process to identify causes of biological impairment. The stressor identification process is outlined in Figure 3.2 and includes 3 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. *Stressor Identification Guidance Document* is available for download in PDF format at *www.epa.gov/waterscience/biocriteria/stressors/stressorid.html* or can be ordered through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

The Biological Assessment of Wetlands Workgroup (BAWWG) (USEPA, 2001b) will provide information for establishing monitoring protocols for wetlands through its series of "state of the science" reports. These reports, which will be available in the spring of 2001, will include

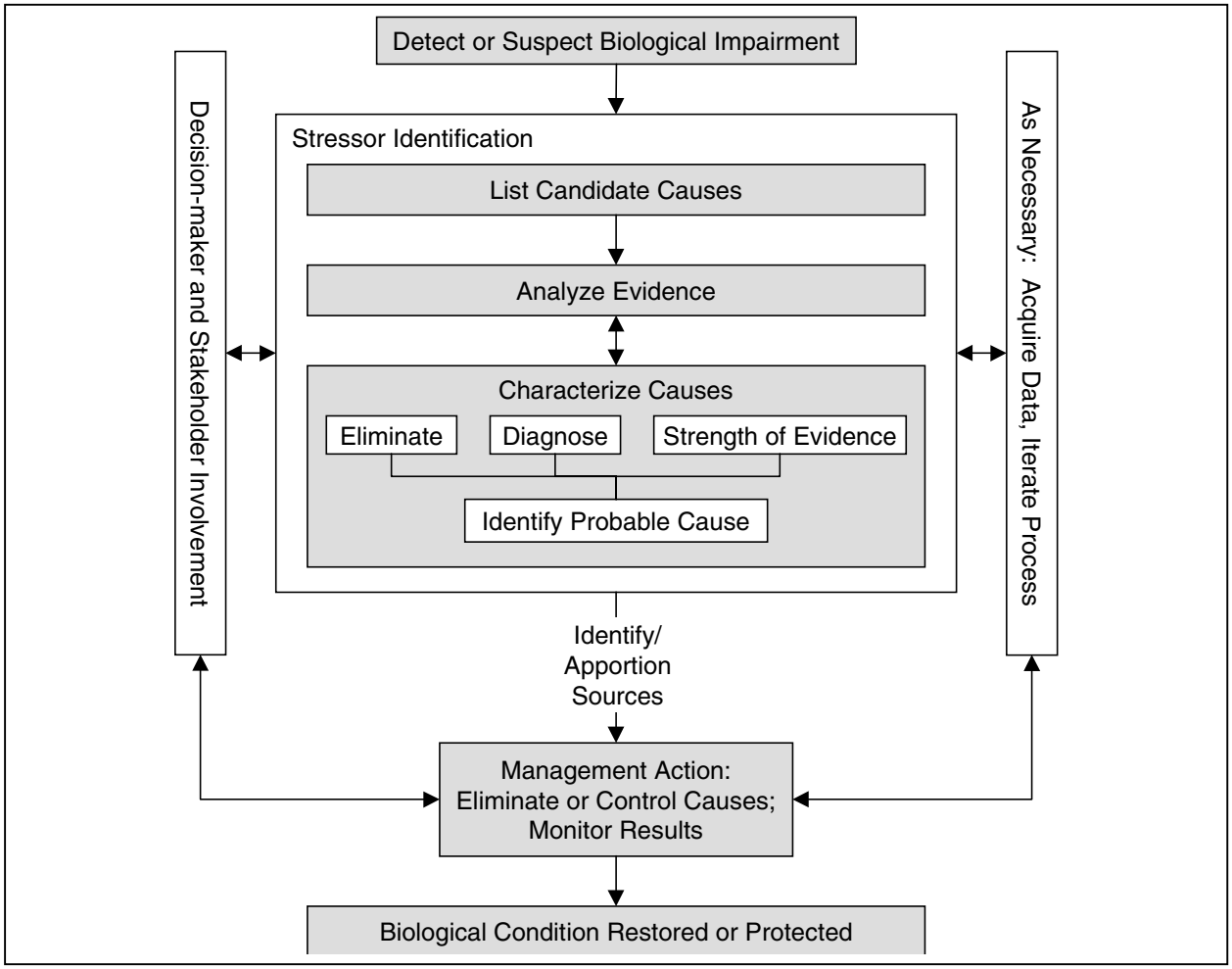

Figure 3.2: Conceptual diagram of the stressor identification process (USEPA, 2000b).

introductory modules on wetland bioassessments and modules on specific methods, such as bioassessment methods for macroinvertebrates. Although the reports will not provide specific prescriptive guidance, they will summarize current knowledge and provide options and recommendations to states for developing wetland bioassessment methods and programs. The modules will also point out limitations of current methods and identify research needs. Information from BAWWG is available at *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 varies seasonally and is highly transient, making it 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, streamflow, 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*. This method includes measurements of fish diversity, species richness, species pollutant tolerance, disease prevalence, and a variety of other metrics that 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 and are usually compared to a regional reference condition to determine the extent of impairment. This method 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 might be affected by conditions in another area, 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.

(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 might skew results, and without corroborating evidence there is no way to prove conclusively that degradation has occurred. Also, focusing on protecting resources necessary for a single species might result in ignoring the management needs of other sensitive 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. Other measurements might be needed to identify sources of degradation.

d. 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 can 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.

e. 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).

Information Resources

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. While 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 *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 downloaded in PDF format at *www.epa.gov/ost/basins1_data_files/docs/npsmodel.pdf* or ordered from the National Technical Information Service at *www.ntis.gov* or by calling 800-553-6847.

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 *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 waterbodies. The publication discusses three major categories of models: watershed loading, receiving water, and ecological. Watershed loading models simulate the generation and movement of pollutants from the source to discharge into receiving waters. Receiving water models simulate the movement and transformation of pollutants through lakes, streams, and rivers. Ecological models 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 *www.epa.gov/ncepihom/index.htm*.

EPA's *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA, 1997b) gives 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 addresses 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 *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 presents methods that have been adapted from those used successfully by existing volunteer programs. The guidance is available in HTML and PDF formats at *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 *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., they 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 *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 and 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 *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 by the kinds of evidence used, from site-specific to more general information. The *Stressor Identification Guidance Document* is available in PDF format at *www.epa.gov/waterscience/biocriteria/stressors/stressorid.html*.

Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures: Urban (USEPA, 2000c) 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 *www.epa.gov/owow/nps/urban.pdf*, or it can be ordered through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

EPA's web site, *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 *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 *www.epa.gov/ost/standards/quality.html*.

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Management Measure 3
Watershed Protection

A. 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 waterbodies and natural drainage systems.

B. Management Measure Description and Selection

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 water quality protection. 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).

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 in the absence of 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 and lacks 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 4.1 is a side-by-side cost comparison demonstrating that it is generally less costly to protect high-quality streams than to restore them.

Table 4.1: 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	$675,000
Total cost per acre	$10.50/acre	$319.90/acre

C. Management Practices

The practices included under the watershed protection management measure fall under the following five categories:

- Identifying critical conservation areas.
- Preserving environmentally significant areas.
- Establishing stream buffers.
- Promoting urban forestry.
- Encouraging development for waterbody and natural drainage protection.

The first category of practices entails identifying properties that if preserved or enhanced could maintain or improve water quality and reduce the impacts of urban runoff. The second group, which involves preserving environmentally significant areas, includes land acquisition, easements, and development restrictions of various types. The third group of practices describes steps important for protecting or establishing riparian buffer zones to enhance water quality and pollutant removal. Next, a discussion of urban forestry practices is presented, followed by descriptions and applications of zoning techniques that can be used to limit development density or redirect density to less environmentally sensitive areas.

1. Identify Critical Conservation Areas

Achieving the first two elements of this management measure, which are (1) to avoid developing areas especially susceptible to erosion and sediment loss and (2) to preserve areas that provide important water quality benefits, usually requires implementation of management practices aimed at preserving and managing lands that mitigate runoff impacts and support critical ecosystem functions. These types of lands are described in Table 4.2.

An initial step for incorporating targeted land conservation into a runoff management program is to identify critical conservation areas on a watershed map and then superimpose this information on a tax map. Owners of potential conservation lands could include a mix of individuals, corporations or other business entities, homeowner associations, government agencies, and land trusts.

Table 4.2: 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

2. Preserve Environmentally Significant Areas

Land conservation includes more than simply preserving land in its current state. It also means that an individual or organization should take 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 *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 *www.lta.org*.

Additionally, The Conservation Fund web site, at *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. Their web site, at *www.natlands.org*, provides information and resources pertaining to land preservation and land use planning.

The following land conservation management practices are discussed in this subsection:

- Exclusive management, which involves voluntary landowner stewardship.

- Nonexclusive management, including conservation easements, leases, deed restrictions, covenants, and transfer of development rights (TDRs).

- Sale of privately owned conservation land to a government entity or qualified nonprofit organization.

- Donation of privately owned conservation land to a government entity or qualified nonprofit organization.

Figure 4.1 presents these alternatives in the form of a decision tree that incorporates the four basic questions landowners must ask themselves before deciding how to best conserve land. Each option is briefly discussed below.

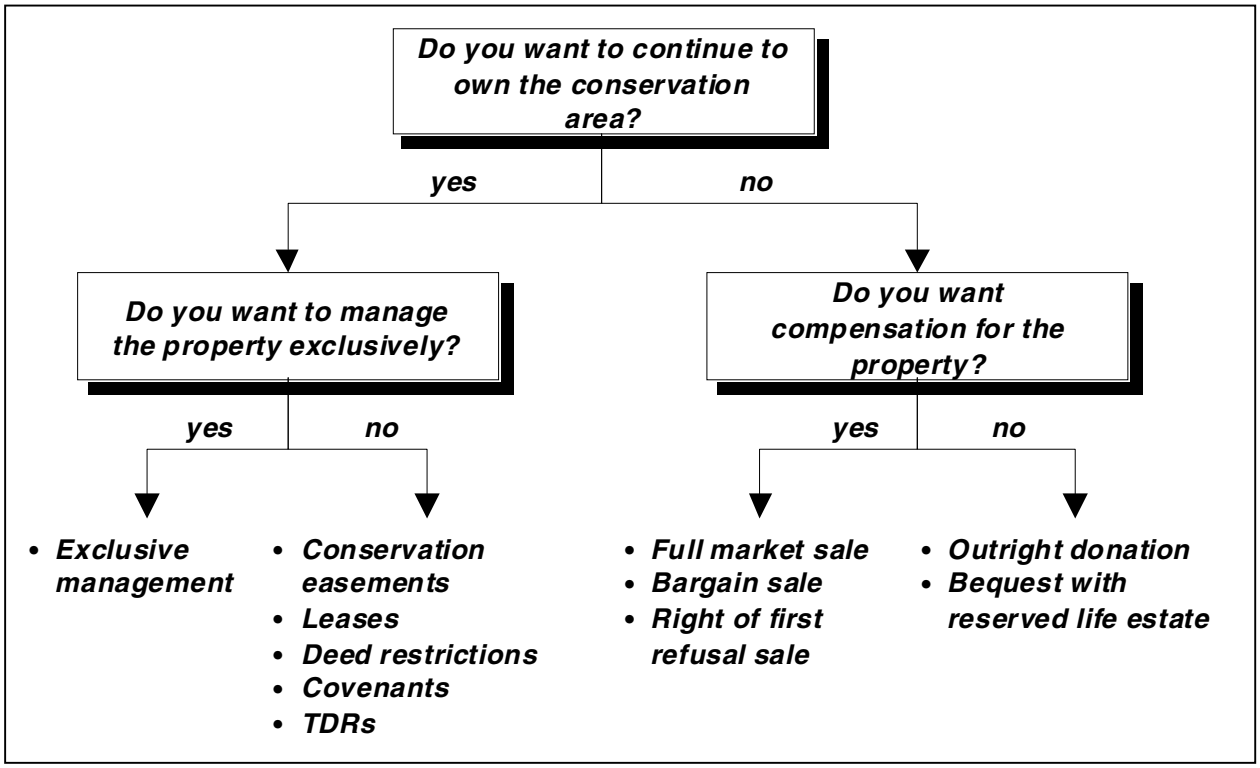

Figure 4.1: Landowner alternatives for conservation area land management (adapted from Cwikiel, 1996).

a. Continue to own the property

(1) *Exclusive management*. Many of the land conservation practices discussed in this section focus on techniques for transferring the responsibility of protecting and maintaining conservation areas from private landowners to a government agency, land trust, or other entity. In some cases, however, landowners are capable stewards of ecologically important areas. Therefore, voluntary stewardship is a concept that should be encouraged throughout the community through education, outreach, and cost-sharing. Owners of environmentally significant natural areas are often candidates for funded projects that will improve or maintain site conditions. The following are general approaches communities can use to promote stewardship of privately owned conservation lands:

(a) *Watershed advocacy*. Promoting watershed advocacy through an education and outreach program lays the foundation for public awareness and support, which are critical elements in any runoff management program. One of the most important investments a community can make toward runoff control is to support nongovernmental organizations, which can be forceful advocates for management of natural areas. They also have an

ability to develop broad-based popular support for watershed programs, especially where local governmental resources are limited.

(b) *Public education*. There is no shortage of public and private organizations eager to dispense information and offer technical assistance in managing conservation lands. National and state program leaders can form partnerships with local conservation districts (for more information on local conservation districts, see the National Association of Conservation Districts web site at www.nacdnet.org) or individuals for the distribution of educational materials and stewardship training. In some cases, this partnership is formalized through a nonregulatory agreement that outlines the responsibilities of each partner. In addition to developing education materials, communities can help broker partnerships and become partners themselves.

(c) *Volunteer monitoring*. Land stewards should be aware of environmental conditions in conservation areas over time. Communities can foster this awareness by establishing a local volunteer monitoring program or encouraging residents to participate in an established regional or state-level volunteer monitoring program. EPA's Volunteer Monitor provides more information about volunteer wetland monitoring at *www.epa.gov/volunteer/spring98/index.html* (USEPA, 1998).

Case Study: Michigan Natural Areas Registry

The Michigan chapter of The Nature Conservancy promotes land conservation stewardship education through the Michigan Natural Areas Registry. Candidate lands for the Registry are selected from the Michigan Natural Features Inventory, a state program that identifies significant natural areas in the state. Landowners are contacted and if they wish to participate, a nonregulatory agreement is created with The Nature Conservancy. The Conservancy provides training and management information to the owners of these areas so they can learn effective stewardship techniques and activities. More information about The Nature Conservancy and its stewardship programs can be found at nature.org (TNC, 2001).

(2) *Nonexclusive management*. There are several options for landowners that would like to retain ownership of the parcel but relinquish stewardship and conservation management to another organization. These options, discussed below, include establishing conservation easements, leases, deed restrictions, covenants, or TDRs.

(a) *Conservation easements*. A conservation easement is a legal agreement that transfers specific rights concerning the use of land by sale or donation to a government agency (municipal, county, or state), a qualified nonprofit organization (e.g., land trust or conservancy), or other legal entity without transferring title of the land (Cwikiel, 1996). This transfer of rights is registered with appropriate local officials, such as the registrar of deeds. The agreement 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.

(b) *Leases*. 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.

(c) *Deed restrictions*. 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, deed restrictions 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.

(d) *Covenants*. 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.

(e) *Transfer of Development Rights*. The concept of TDRs as a watershed protection tool is based on the premise that ownership of land includes a "bundle" of property rights. One of these rights is the right to develop the property to its "highest and best use." Although this right can be restricted by zoning building codes, environmental constraints, and other types of restrictions, the basic right to develop remains. A TDR system creates an opportunity for property owners to transfer development potential or density at one property, called a sending area to another property, called a receiving area. In the context of watershed planning objectives, TDR programs can be an effective way to transfer development potential from sensitive subwatersheds to subwatersheds that can better deal with increased imperviousness. In contrast to the conventional down-zoning approach, which witholds from landowners the value associated with the right to develop, TDR systems allow an opportunity for a landowner to be compensated for that value.

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 downzoned 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, downzoning 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.

- *Provide adequate resources*. A TDR program does not run itself. It needs staff and resources to administer and manage the program.

Case Study: 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 (Simms, 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.

b. Relinquish ownership of the property

(1) *Sale*. A property owner can choose to sell a property to a government agency or conservation organization. There are several options for selling, including selling the property for *full market value*, which allows the property owner to receive a price comparable to what would be received from a developer. The property can also be sold at a *bargain price*, which conveys the property to an agency or nonprofit organization at a price below market value. Thus, for tax purposes the transaction is considered part donation and part sale.

Landowners who want their land conserved but do not wish to sell it right away can make arrangements to give a *right of first refusal* to a specific agency or organization. Under this agreement, when the owner decides to sell his or her land, the designated agency or organization can exercise the right to match any offer received by the owner and obtain the property. Some communities have formalized this concept through an official map of land areas desired for conservation purposes (National Lands Trust, 1997). Owners are notified that their lands are on the map and earmarked for possible future public acquisition. When such owners decide to build, subdivide, or otherwise develop the land, the municipality is legally obligated to purchase the land at fair market value in a specific period of time. If the municipality fails to initiate the purchase or begin condemnation proceedings to acquire the land, the conservation designation on the official map is declared null and void and the owner can proceed with his or her plans for developing the property, subject to zoning and other regulations.

(2) *Donation*. The donation of conservation land to a government agency, land trust, or other qualified nonprofit organization is another option for landowners. As with conservation easements, an owner can realize substantial tax benefits; the difference is that with donation the owner gives up title to the land. There are several donation scenarios other than *outright donation* that can be attractive to landowners that desire to continue to occupy, use, or otherwise realize some gain beyond tax benefits for their donation. These scenarios include the following:

- *Donation with reserved life estate*. This approach allows the owner to donate his or her property to an agency or nonprofit organization while retaining the right to occupy and use the property during his or her lifetime. Full title and control of the property is conveyed only after the death of the donor.

- *Donation by will.* This approach conveys the property to a government agency or conservation organization upon the death of the owner.

- *Charitable gift annuity*. This option allows an eligible charity, such as a land trust, to make regular annuity payments to one or two specific beneficiaries in exchange for the property.

- *Charitable remainder unitrust*. This scenario involves executing a conservation easement on the property and then putting the land into a trust. The trustee sells the land and invests the net proceeds of the sale. These monies provide for an annuity payment to one or two specific beneficiaries.

3. Establish and Protect Stream Buffers

Stream buffers should be protected and preserved as a conservation area because these areas provide many important functions and benefits, including

- Providing a "right-of-way" for lateral movement.
- Conveying floodwaters.
- Protecting streambanks from erosion.
- Treating runoff and reducing drainage problems from adjacent areas.
- Providing nesting areas and other wildlife habitat functions.
- Mitigating stream warming.
- Protecting wetlands.
- Providing recreational opportunities and aesthetic benefits.
- Increasing adjacent property values.

Factors to consider when designing new buffer systems include the quantity and velocity of runoff entering the buffer, the slope of the riparian area, soil types and infiltration capacity, and the density of development adjacent to the riparian corridor. 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 be problematic and 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 and should include the 100-year floodplain, 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

Case Study: Controlling Runoff from Nonpoint Sources in Wisconsin

Wisconsin is considering new regulations that would require more stringent, mandatory nonpoint source controls for both urban and agricultural sources (Barrett, 2001; Sandin, 2001a, 2001b). Although voluntary nonpoint source control programs have been in place for 20 years, participation was too low to improve water quality. Under the revised proposal, farmers would have to meet standards for applying fertilizer, controlling soil erosion from cropland, and managing manure. Buffers at least 20 feet wide would be required along all lakes and rivers bordered by cropland, barnyards, or feedlots whenever state dollars are available to pay 70 percent of the buffer costs. Similar buffers or retention areas would be required to control runoff to nearby streams from new or expanded state, county, or municipal roads. Additionally, bridges rebuilt over sensitive waters would need to be designed to channel runoff into detention ponds or chambers. Finally, owners and operators of golf courses, parks, and corporate lawns greater than 5 acres would be required to reduce fertilizer and pesticide applications.

Critics contend that financing constraints could limit implementation and burden local governments unless state grants were made available. Others question whether loopholes in the rules would exempt construction sites from installing vegetated buffers to capture runoff. If implemented successfully, however, the regulations would put Wisconsin ahead of other states on meeting standards and might provide an economic advantage in the future when other states might be struggling to meet those standards. The draft rules can be viewed at *www.dnr.state.wi.us/org/water/wm/nps/admrules.html*.

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.

a. Establish a 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.
- Direction on allowable uses and public education.

A model ordinance and examples of buffer ordinances from across the country can be found at *www.epa.gov/owow/nps/ordinance*. Buffer ordinances and other water-resource-related ordinances are described further in Management Measure 1.

Case Study: Stream Buffer Ordinances in Apex and Cary, North Carolina

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 also 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 in to vote on the new regulations.

b. Develop 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 system covers, permanent structures, or impervious covers. A depression incorporated into the design of the upland zone can detain runoff during storm events. This runoff is released slowly to the middle zone as sheet flow, which is then transferred to the dense streamside zone, designed to have zero discharge of surface water to the stream.

c. Establish 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.

d. Integrate structural runoff management practices where appropriate

Depressions can be incorporated into the upland part of a stream buffer to provide runoff detention during storm events 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.

e. Develop 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 streamwalks, 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 "bufferwalks" to determine the extent of encroachment, devegetation, erosion, or excessive sediment deposition.

4. 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.

Several organizations dedicated to promoting urban forestry can provide information and other resources to interested groups or individuals. For example, American Forests (*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. Information about the software is available at *http://www.nrcs.usda.gov/technical/land/pubs/97highlights.html*.

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 *www.cyberjava.com/earth/tree/tree1.htm*.

Case Study: 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.

5. Encourage Waterbody and Natural Drainage Protection When Siting Developments

To meet the third element of this management measure, communities should implement management practices that guide future development and land use activities. This can be accomplished through zoning for natural resource protection. Several zoning techniques are described below. More details about these techniques and case studies can be found in *Protecting Wetlands: Tools for Local Governments in the Chesapeake Bay Region* (Chesapeake Bay Program, 1997).

Case Study: Creating a Uniform Storm Water Pollution Policy in Missouri

Officials in Columbia, Missouri, are 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 recommends 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 of what is expected of them.

a. Use cluster zoning and planned unit development

Cluster zoning, also known as open space zoning, requires developers to set aside larger areas of open space to protect sensitive site features such as wetlands or steep slopes and to concentrate development on a smaller portion of the site. 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. Advantages of cluster development include

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

b. Consider resource protection zones

Resource protection zones prohibit or limit the development or use of lands where the use has the potential to contribute to resource degradation. For example, authorized uses in an area adjacent to a waterbody could include hunting and fishing, conservation activities, or other low-intensity practices. Construction of permanent structures or siting of waste disposal areas would be

prohibited. Intermediate uses are typically approved on a case-by-case basis under a conditional use permit. Riparian buffer zones are an example of this type of zoning. It is important that the relationship between the quality of the resource and the protection zone, as well as the importance to the community of the resource itself, be well defined for resource protection zones to be accepted by the public, especially when the uses of private property are restricted.

c. Practice 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 a 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 natural resource protection 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.

d. Establish overlay zones

Overlay zones superimpose additional restrictions over 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.

e. Establish 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 the developer in return 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 receiving additional density credits and cannot be relied on to protect natural resources. However, bonus or incentive zoning can successfully encourage voluntary and economically beneficial protection for open space and sensitive features.

f. Consider large lot zoning

Large lot zoning establishes a very low density of development; individual dwellings are built on lots of 5 acres or more. 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.
- Excluding lower-income residents who cannot afford to purchase large parcels of land.

Although used in many areas, large lot zoning is not considered to be any more protective than other zoning tools.

g. Practice agricultural protection zoning

Many communities consider forestry and agriculture 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 5 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 remaining part 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.

h. Use 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).

Case Study: King County, Washington, Growth Management Initiatives

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 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 tightened subdivision requirements for rural lands. These efforts will ensure that new development is consistent with current environmental and development standards.

King County strives to promote agriculture and protect farmlands. Some of 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.
- 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 page at *www.metrokc.gov/smartgrowth/rural.htm*.

i. Delineate urban growth boundaries

Urban growth boundaries are used to define urban and suburban development. The goal of these boundaries is to protect from development lands currently used for agriculture, forestry, and open space. 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 life span 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.

Case Study: Balancing Development with Preservation in Southern California

As one of the nation's fastest growing regions, southern California is seeking to balance development with preservation (Verden, 2000). Local, state, and federal officials recently approved the Riverside County Plan, which involved multiagency cooperation in identifying where development may occur and where land should be preserved. 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.

Case Study: Urban Growth Boundaries in Oregon

Oregon uses urban growth boundaries to protect rural lands from urban sprawl. The area between the urban growth boundary and the city limits is urbanizable land or land that will accommodate a city's future growth over a 20-year period. Zoning prohibits urban development on land outside the urban growth boundary. Most of this land will continue to be used for forestry, farming, or low-density residential development (University of Oregon, 1995).

Determining urban growth boundaries is a cooperative process between the cities, counties, districts, and citizens affected by the boundary. The amount of land included in the boundary depends on future growth expectations (how much vacant land is needed to accommodate expected growth). Once land needs are determined, the amount of vacant land available within the current city limits is subtracted from the amount of land necessary for growth. The remainder is the amount of land outside the city limits that is needed to accommodate future growth. The city must then determine which areas to include within the boundary based on three main factors: efficient use of land, protection of agricultural land at the city's edge, and cost-effective public services. In some cases, urban growth boundaries can be modified. To modify a boundary, a proposal must be submitted and the community must determine the best location at which to change the boundary (University of Oregon, 1995).

Urban growth boundaries in the Portland metropolitan area include approximately 369 square miles and include 24 cities, including the urban portions of Washington, Multnomah, and Clackamas counties and a reported 1.3 million people. Portland's urban growth boundary has been the subject of much controversy. In the past 20 years, the boundary has been moved more than 30 times. Supporters of Portland's urban growth boundary argue that it has helped to control urban sprawl, while opponents argue that it has caused land and housing price inflation. Both topics have been researched in great detail and remain controversial (Multnomah County, 2001).

More information about Oregon's urban growth boundaries is available at *www.multnomah.lib.or.us/metro/growth/ugbursa/ugbursa.html* and *darkwing.uoregon.edu/~pppm/landuse/UGB.html*.

Case Study: Curbing Growth in the Phoenix Area

Political leaders in Arizona are striving to manage development in light of mushrooming growth, especially in the Phoenix area (Morrison, 2000). Governor Jane Dee Hull called a special session of the legislature in February 2000 to address the pressing issue of development with a package of growth-management bills. One part of these bills will give county governments the ability to make development agreements and to charge developers fees for services. Another part of the bills placed an initiative on the ballot that would protect from development up to 3 percent of state trust land. The Sierra Club plans to propose another ballot measure that requires cities of more the 2,500 people to draw development boundaries only large enough to accommodate a decade of population growth.

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 (*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 *www.chesapeakebay.net*.

The Conservation Fund's web site, located at *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 *www.riparian.net/correll.htm*.

The Delaware Department of Natural Resources and Environmental Control, Division of Soil and Water Conservation, has produced the document *Delaware's Riparian Buffers* (no date).

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 *www.islandpress.org/ecocompass/community/sprawl.html*.

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 *www.natlands.org*.

Schueler's (1995) manual, *Site Planning for Urban Stream Protection*, is available for purchase from the Metropolitan Washington Council of Governments' web site at *www.mwcog.org/ic/95708.html*.

The Smart Growth Network is a nationwide effort coordinated by EPA's Urban and Economic Development Division (International City/County Management Association, 2000). EPA is working through cooperative partnerships with a diverse network of organizations 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 *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 *www.marc.org/transportation*.

The Local Government Commission (*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. They provide guidelines and resources for communities to improve community design, transportation, economic development, environment, energy, and waste prevention. A list of publications can be found at *www.lgc.org/bookstore/land_use/publications/index.html*.

The Northeastern Illinois Planning Commission (1988) 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 their web site at *www.nipc.cog.il.us/pubslist.htm*.

The National Association of Conservation Districts web site (*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 *www.nga.org* or downloaded in PDF format at *www.nga.org/cda/files/072001NCDFull.pdf*.

The concept of creating and maintaining an interconnected network of protected land and water, called Green Infrastructure, is presented at *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.

EPA's Green Communities Program encourages successful community-based environmental protection and sustainable community development. The Green Community Assistance Kit provides technical assistance and training for planning green communities. Information about the Green Communities Program can be found at *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 *www.epa.gov/ncepihom* or by calling 800-490-9198.

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Management Measure 4
Site Development

A. 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 increases of impervious areas unless predevelopment site hydrology is maintained.
- Limit land disturbance activities, such as clearing and grading and cut-and-fill, to reduce erosion and sediment loss.
- Limit disturbance of natural drainage features and vegetation.

B. Management Measure Description and Selection

1. Description

The goals of this management measure are to reduce the generation of nonpoint source pollution, maintain natural 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 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.

- Programs designed to control increased runoff and nonpoint source pollution resulting from site development should include
- Predevelopment planning to match the goals of the developer to the attributes of the site.

- Guidance on creating site designs that closely maintain predevelopment hydrologic functions.
- Appropriate pollution prevention practices to be incorporated into site development and use.
- Site plan review and conditional approval to ensure that the integrity of environmentally sensitive areas and areas necessary for maintaining natural hydrology and water quality will not be lost.
- 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 minimize erosion and sediment loss.
- Protect and retain existing vegetation to decrease concentrated flows, maintain site hydrology, and control erosion.
- Minimize imperviousness to the extent practicable.
- Properly manage all maintained landscapes 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.

The use of site planning and evaluation can significantly reduce the size of controls required to retain 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).

2. Management Measure Selection

This management measure was selected because the practices associated with it have been shown to be effective at 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 minimize environmental damage caused by that development while allowing for population and economic growth.

Increasing Housing Prices and Environmental Regulation

Laquatra and Potter (2000) undertook a study to determine whether there is a linkage between the costs of complying with environmental regulations and increasing housing prices. In their study, they provide evidence challenging the notion that the decline in homeownership since the 1960s can be attributed to increasing housing prices resulting from the financial burdens being imposed on land developers by environmental regulations.

In response to the belief that increasing environmental compliance costs have led to rising housing prices, the authors point out that the period from 1963 to 1973, when very few environmental regulations were in existence, witnessed an increase in the price of new homes. In addition, the authors explain that in the northeastern region of the United States, real house prices actually declined from 1973 to 1983, even though a number of new environmental regulations were being implemented during that time. However, real house prices in the South and West (excluding the west coast) increased during the same period despite the fact that these regions are considered less environmentally progressive than the Northeast.

The authors cite another study that examines the economic impacts of the federal Endangered Species Act (ESA) on building costs and home prices in the Pacific Northwest. The study analyzed the relationship between the listing of the spotted owl as an endangered species and prices for lumber and new homes. The results indicated that no significant relationship existed between the spotted owl listing and increases in the average cost of a new home.

Other factors to which the authors attribute the reduction in homeownership rates include

- Changing demographics, most notably the delaying of marriage and the age when couples begin having families, as well as the rise in the number of single-household families.
- A decline in housing affordability, which stems from income levels that have failed to keep pace with rising home prices. Incomes became stagnant or began to decline with the onset of globalization, which resulted in the transferring of manufacturing jobs overseas. These manufacturing jobs were replaced by lower-paying jobs in the service industry.
- Rapid inflation during the 1970s and 1980s that prevented many Americans from purchasing homes.
- The inability of first-time homebuyers to make down payments because of increasing levels of consumer debt and low personal savings rates. These financial shortcomings force many potential homebuyers to wait longer before they are able to purchase a home.

Many researchers agree that housing price increases are primarily due to factors related to improvements in the quality of housing, such as the building of larger homes and enhancements in amenity features of new homes. Other housing researchers point out that local zoning and subdivision ordinances contribute to increasing housing costs. The authors conclude that there are insufficient data to support the argument that the costs of complying with environmental regulations have resulted in higher home prices. Housing affordability problems are more likely the result of demographic trends, declining incomes, lifestyle and societal changes, inflation, and rising interest rates.

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. Instead of allowing storm water to run from a downspout down a driveway and into a storm sewer, water is directed 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). 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 might 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. Practices and natural landscape features work together 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 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.

Better Site Design and the Site Planning Roundtable

The Site Planning Roundtable, consisting of a national cross-section of diverse planning, environmental, homebuilder, fire, safety, public works, and local government personnel, developed 22 "model development principles" in an effort to encourage environmentally sensitive, economically viable, and locally appropriate development. The resulting manual, Better Site Design: A Handbook for Changing Development Rules in Your Community (Brown et al., 1998), describes each principle, contrasts current and recommended practices for each, estimates economic benefits, and provides case studies where recommended practices were implemented. The Consensus Agreement on Model Development Principles to Protect our Streams, Lakes, and Wetlands (Site Planning Roundtable, 1998) provides a summary of the Roundtable's findings, including key points of consensus and a list of the 22 model development principles. Both documents can be ordered from the Center for Watershed Protection's web site at *www.cwp.org*.

C. Management Practices

The majority of management practices in this section are included in "better site design," which is a suite of site planning techniques that modify the layout of new developments to reduce the total paved 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 scrutinized to identify areas that should be preserved or restored. Better site design techniques are used to identify the most efficient building and infrastructure layouts and to develop a comprehensive strategy to reduce the quantity of runoff leaving the site and curb 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 the plan approval process. Also, site designs that preserve community open space reduce the burden on the local government to provide recreational areas. Economically, better site design techniques reduce the amount and cost of infrastructure, which also reduces engineering and maintenance costs. 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 their value appreciates more than lots in traditional subdivisions (Arendt, 1996). For example, lots in an open space subdivision in Amherst, Massachusetts, experienced a 13 percent greater appreciation in value over a comparable traditional development after 20 years, even though the lots in the traditional 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 traditional developments and can be implemented in most communities. In some cases, however, outdated development rules might 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. The Center for

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 *www.basmaa.org* (BASMAA, no date).

1. Site Planning Practices

a. Fit the site to the natural gradient

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.

b. Practice site fingerprinting

The total amount of disturbed area in a site can be reduced by fingerprinting development. Fingerprinting places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces, areas with trees to be saved, future restoration areas, 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 divides, and disconnecting impervious areas (Prince George's County, Maryland, Department of Environmental Resources, 2000a).

c. Use cluster development

Cluster development is used to concentrate development and construction activity on a limited portion of a site, leaving the remaining portion undisturbed. Figures 4.2 and 4.3 show schematics of a residential cluster development and a rural cluster development, respectively. This practice allows for the design of more effective erosion and sediment control and urban runoff management plans. It also provides a mechanism to preserve environmentally sensitive areas and reduce road lengths and impervious parking areas.

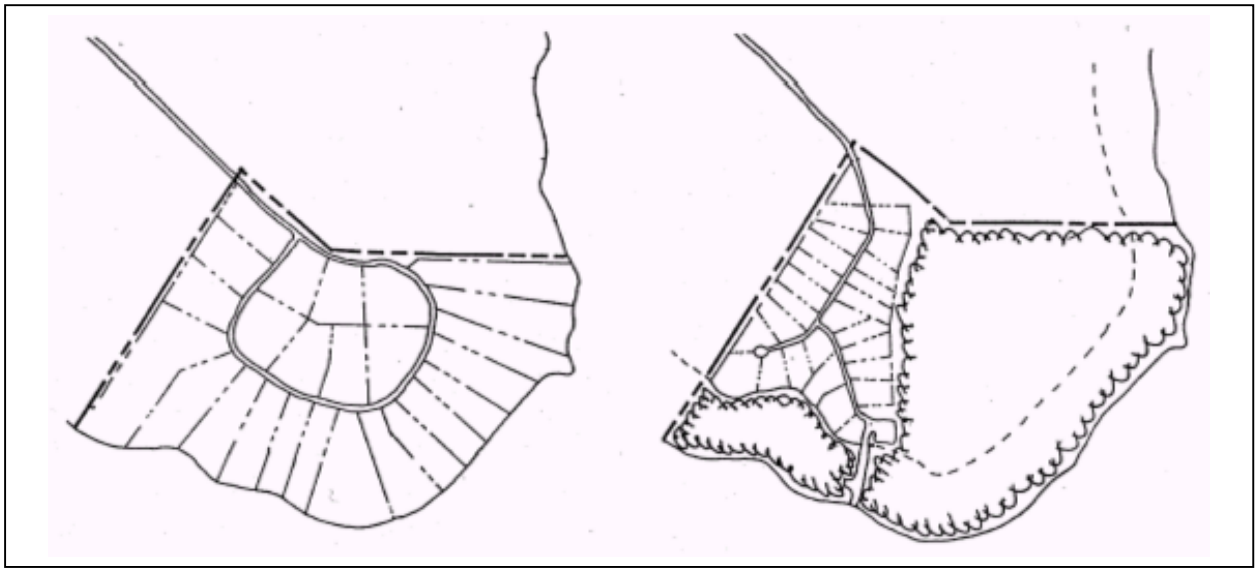

Figure 4.2: Schematic of a residential cluster development (Schueler, 1995).

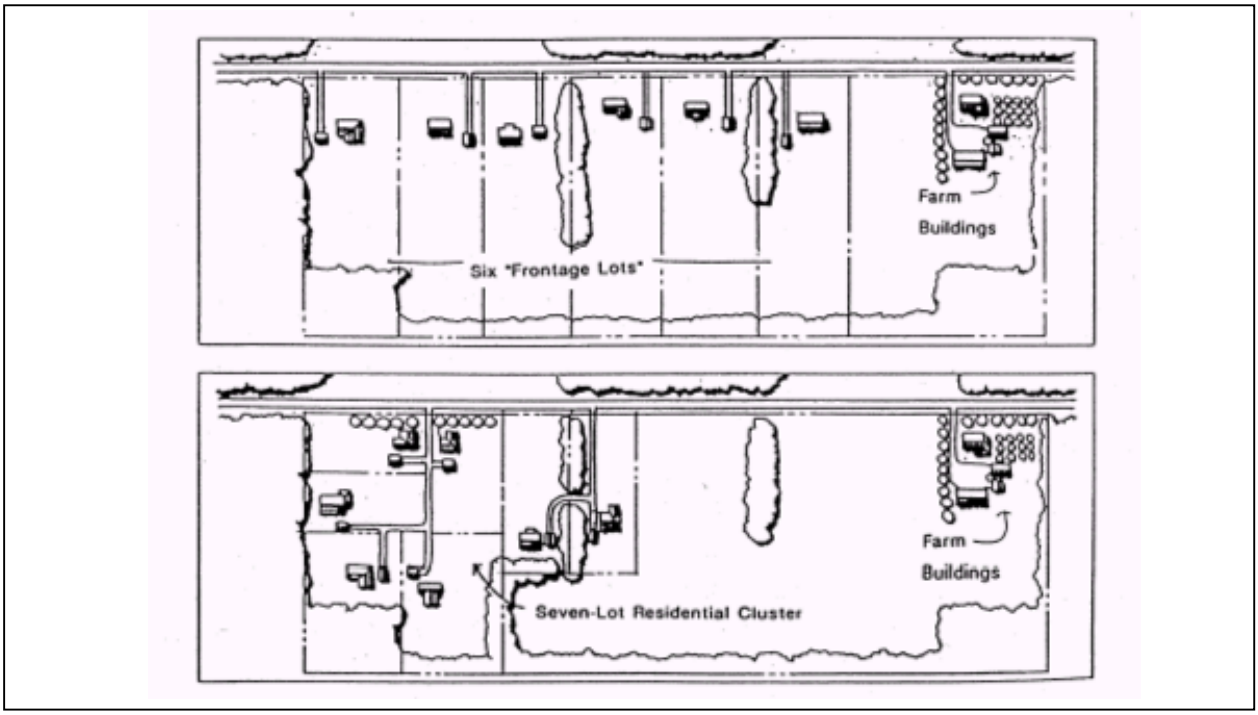

Figure 4.3: Schematic of a rural cluster development (Schueler, 1995).

Although a common belief is that low-density development is more environmentally sound because it results in increased open space, minimum lot size requirements can result in suburban sprawl. Many of these areas are heavily landscaped and therefore have the potential to contribute significant loadings of nutrients and pesticides to surface waters. Often, clustering and infill development are more environmentally sound and can result in a cost savings for municipalities because clustering and infill development typically require less new infrastructure, including urban runoff treatment systems. The imposition of density controls might 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 traditional suburban development.

d. 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 use recreational facilities, such as pedestrian paths, picnic areas, and athletic fields.

The following are some techniques for conserving open space:

- *By-right open-space development*. This technique allows for 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*. These credits take into account implementation of source controls that reduce runoff volumes and pollutant concentrations before the 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 they allow for the fact that removals already occurred through source controls.
- *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.

Case Study: Jordan Cove Urban Watershed National Monitoring Project

A study is being conducted by the Jordan Cove Urban Watershed National Monitoring Project in cooperation with EPA, Connecticut DEP, a University of Connecticut researcher, the town of Waterford, Connecticut, and a local landowner to compare the differences in runoff quantity and quality emanating from two sites, a traditional development and an environmentally sensitive development (Cote et al., 2000). Preconstruction monitoring revealed that the two sites could be used for a paired watershed monitoring design. This project has a treatment period that will occur in two phases—during construction and after construction when the runoff control practices are fully operational. Runoff quality and quantity are being measured at the outlets of each of the neighborhoods and in the control watershed. The runoff is analyzed weekly for suspended solids, phosphorus, and nitrogen. Grab samples are analyzed for fecal coliforms and 5-day biological oxygen demand (BOD_5), and monthly analyses are conducted for copper, lead, and zinc. Supplemental monitoring will be conducted on selected management practices to evaluate their effectiveness.

Preliminary findings include the following:

- An indication that construction of the traditional neighborhood is converting the watershed's topography from a "knoll" to a "bowl," which has caused a significant change in hydrologic response.

- Increased nitrate and lead concentrations in runoff.

- No increases in sediment and sediment-associated nutrients in runoff.

- A decline in total Kjeldahl nitrogen concentrations during construction.

Preliminary results suggest that increased runoff, rather than erosion, is the cause of increased pollutant export from the construction site.

Case Study: 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. 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 were the predominant source of exported nutrients.

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 4.3 shows a 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.

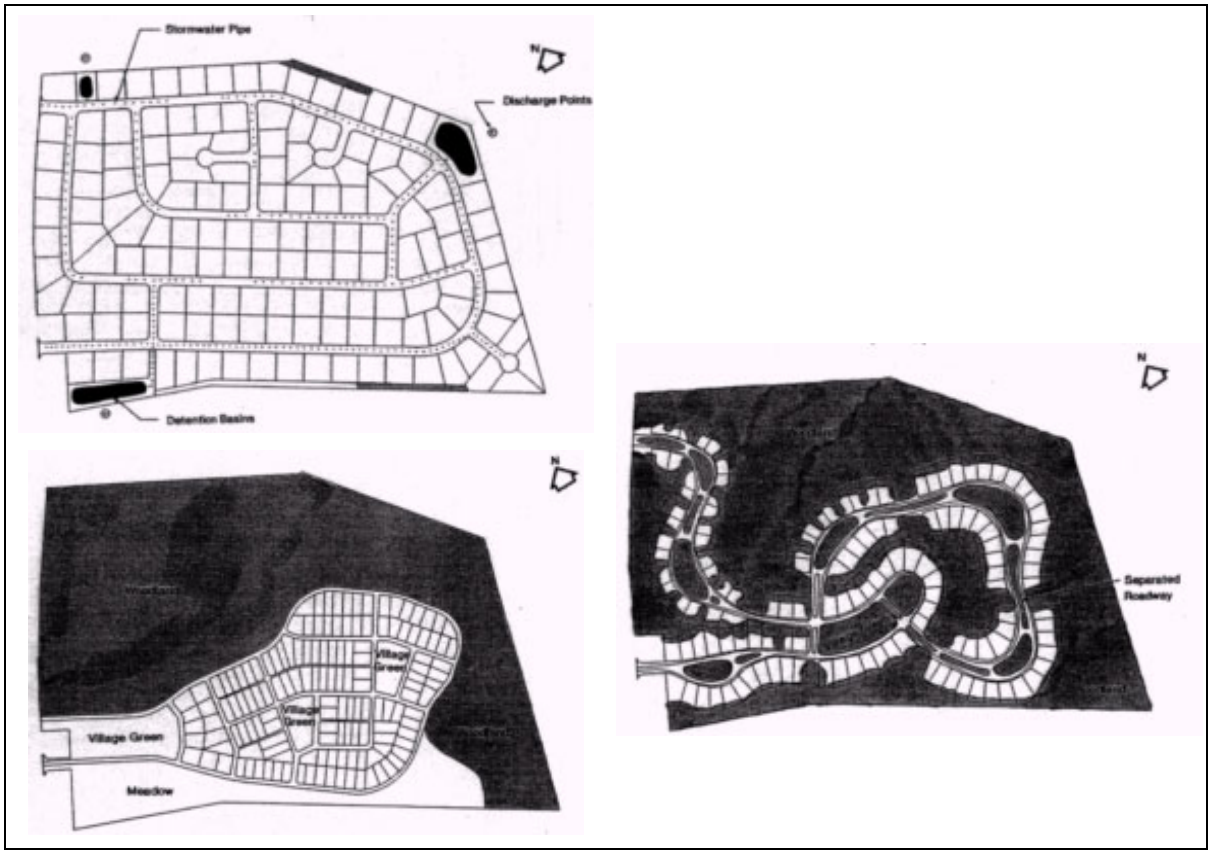

Figure 4.4: Schematic drawings of conventional (a), parkway (b), and clustered (c) development scenarios for the Chapel Run subdivision (Delaware DNREC and the Brandywine Conservancy, 1997).

Comparison of Traditional and Low-Impact Development Scenarios in Delaware (continued)

Table 4.3: 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	½-acre	⅛-acre	¼-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	114,082,682	114,082,682	114,082,682
Runoff	31,584,217	21,812,868	17,782,776
Recharge	31,280,103	34,001,079	35,502,938
Evapotranspiration	51,223,261	58,208,796	60,802,278
Costs			
Total	$2,460,200	$1,174,716	$888,735
Per lot	$27,325	$8,273	$6,259

[a] From USDA-NRCS's TR-55 model.

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.
- Model ordinance provisions.

Arendt's multistep process for creating conservation subdivisions involves two stages. The first stage, 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 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 primary and secondary 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. Primary conservation areas are legally or logistically unbuildable and therefore must be avoided. Secondary conservation areas are typically legally buildable but are historically or ecologically significant or desirable and therefore should be avoided when other land is available for development. The site analysis should include site visits and identify the following primary conservation areas:

    - *Wetlands*. Tidal and nontidal saltwater and freshwater wetlands and the dry upland buffers surrounding them should be identified as areas to be conserved because they function to 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 (see Management Measure 2), should not be developed to preserve a continuous riparian greenway and to prevent damage to property from flooding. To preserve views to 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 secondary conservation areas should also be identified.

- *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. Developers typically want to site buildings to take advantage of attractive views, siting buildings in areas where they are easily seen from the surrounding landscape. 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 with limited cutting of trees to create "view tunnels" or trimming lower limbs to create "view holes" through the foliage.

- *Aquifers and their recharge areas.* Ground water aquifers are typically recharged at low points in the landscape or through sandy or gravelly soils. These areas, though generally buildable, should be conserved as open space to maintain ground water recharge. These areas 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 secondary conservation areas need to be sacrificed to achieve the development objectives, decisions will need to be made that rank the secondary conservation areas with respect to how special, unique, irreplaceable, environmentally valuable, historic, or scenic they are compared to similar features. Figure 4.5 shows an example site before development, developed with a conventional strategy, and developed with consideration of locational context and conservation areas (Arendt, 1996).

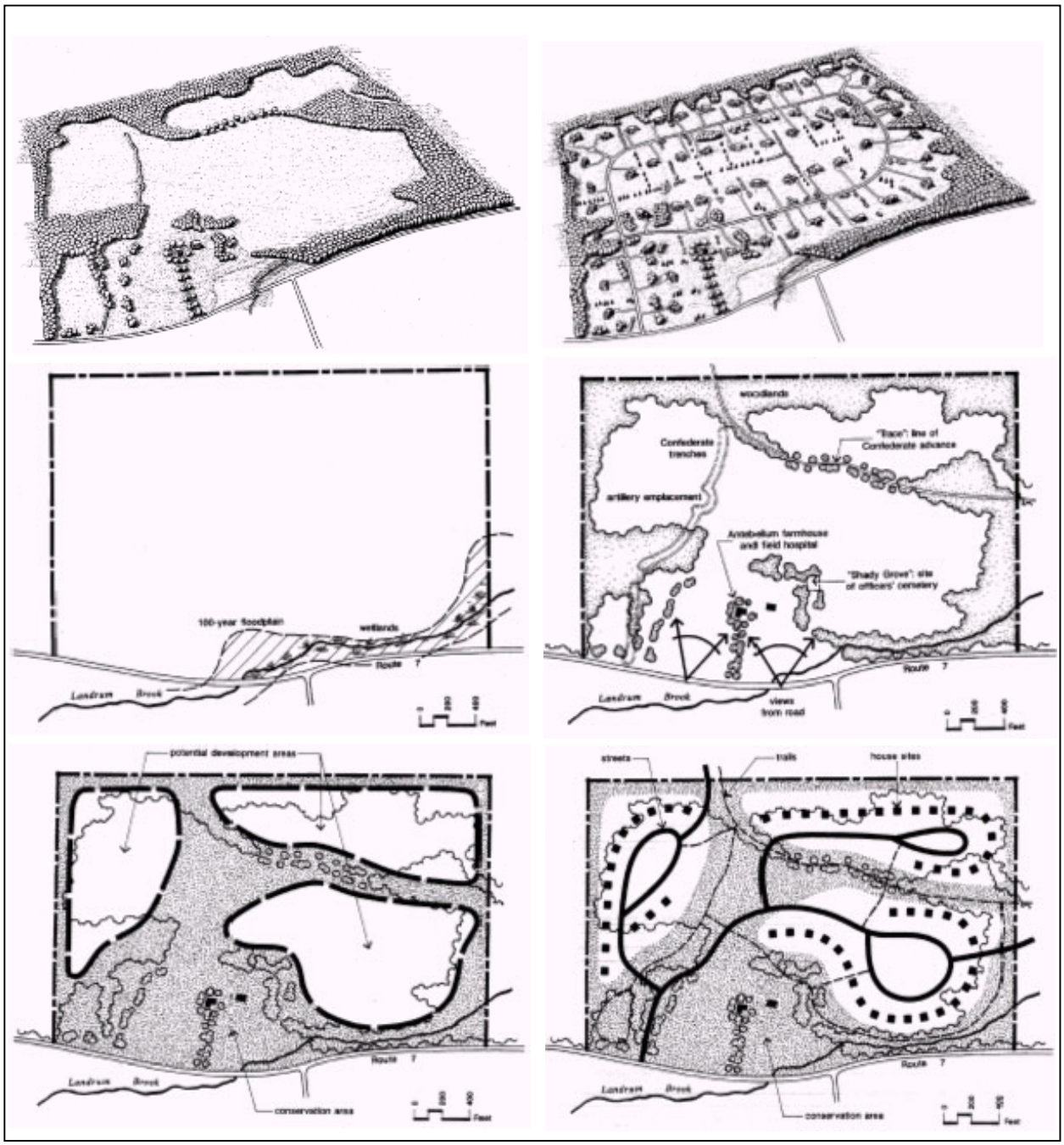

Figure 4.5: Development of a conservation subdivision. The site before development (a) and as designed with conventional development (b and c); identification of primary (d) and secondary (e) conservation areas; and delineation of potential development areas (f) (adapted from Arendt, 1996).

Pedestrian Paths Improve Neighborhood "Walkability"

Communities can improve the transportation infrastructure of neighborhoods by providing paths for pedestrians (Kiesling, 1999). This practice reduces automobile traffic, decreases the demand for parking, and promotes socializing among members of the community. Neighborhood paths reduce walking distances by offering quick "shortcuts" and improve safety by separating pedestrians from traffic.

There are several options for communities to incorporate pedestrian paths into neighborhood layouts, from making short connections between cul-de-sacs and major streets to creating extensive networks of pedestrian pathways. Pedestrian walkways also can be incorporated into the design of commercial parking areas, along riverfronts, in urban parks, and within plazas between buildings. Figure 4.6 shows how pedestrian paths can improve the "walkability" of a standard suburban neighborhood.

Figure 4.6: Pedestrian paths (bold lines) can add to the "walkability" of a neighborhood when compared to the sidewalk route (dotted lines).

2. On-Lot Impervious Surfaces

a. Reduce the hydraulic connectivity of impervious surfaces

Pollutant loading from impervious surfaces can be reduced if the impervious area does not connect directly to an impervious conveyance system. This can be done in at least four ways:

(1) Route runoff over lawn areas to increase infiltration.

(2) Discourage the direct connection of downspouts to storm sewers or the discharge of rooftop downspouts to driveways, parking lots, and gutters.

(3) Substitute swale and pond systems for curbs and gutters to increase infiltration.

(4) Reduce the use of storm sewers to drain streets, parking lots, and backyards.

Figure 4.7 shows schematic representations of impervious areas that are directly connected and not directly connected (BASMAA, 1997).

b. 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. The coir fiber mat absorbs rainfall, the mineral substrate provides the plants with nutrients, and the synthetic matrix promotes drainage. Mats can be used

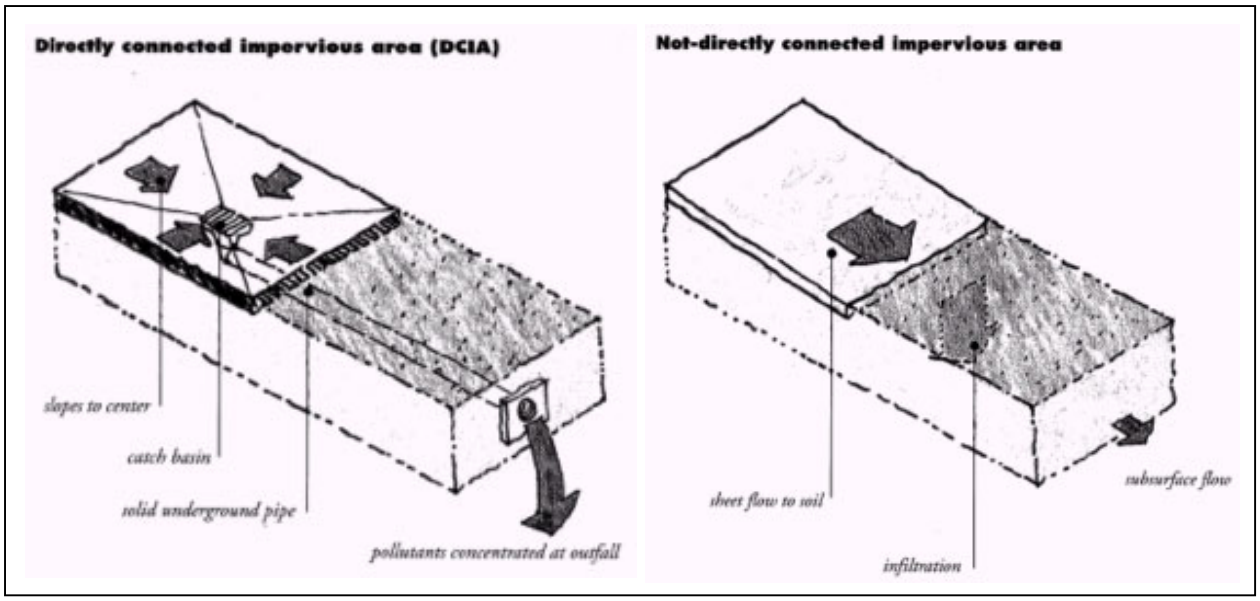

Figure 4.7: Schematic representation of directly connected and not-directly connected impervious areas (BASMAA, 1997).

on roofs with slopes of up to 30 degrees and are capable of reducing runoff by two-thirds. These mats provide benefits other than runoff reduction, including

- Visual aesthetics.
- Protection of roofs from damaging radiation, wind, and precipitation.
- Insulation.
- Noise reduction.
- Habitat for wildlife.
- 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.

Building Green: A Guide to Using Plants on Roofs, Walls, and Pavements (Johnston and Newton, no date) is a reference for planting turf, gardens, and trees on roofs and walls. The book provides information on the effectiveness of ultra-urban greening at reducing runoff and energy consumption and on design techniques and plant suggestions, as well as European case studies where these practices have been successfully implemented. This publication is available from The London Ecology Unit, Bedford House, 125 Camden High Street, London, NWI 7JR; phone 071-267-7900.

Case Study: 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. The distinguishing features of this rooftop meadow are

- A synthetic underdrain layer that promotes rapid drainage of water from the surface of the roof deck.
- A thin, lightweight growth medium that permits installation on existing conventional roofs without the need for structural reinforcement.
- 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 existing structures can be retrofitted to reduce runoff.

c. Relax frontage and setback requirements

Open-space developers 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, and shorter front yard setbacks lead to shorter driveways and sidewalks.

d. Modify sidewalk standards

Many traditional 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:

- Reducing sidewalk width to 3 feet.
- Allowing sidewalks on only one side of the street, eliminating them altogether, 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.
- Grading sidewalks so that runoff drains to the front yard rather than toward the street.

Case Study: Greenways

A survey was conducted in the Chicago area to determine people's use and perception of greenway trails, which are natural or landscaped paths designed for recreational uses such as walking, jogging, and biking (Adams, 1999). Paul Gobster of the USDA Forest Service identified several factors that influence people's opinion of trails, including location, design, and management. He found that small, local trails were used repeatedly by local residents and that trails located close to home (within 8 km) were used most frequently. Most metropolitan area users preferred paved, landscaped trails with drinking water and clean restrooms located at reasonable intervals along the trail. Maintenance of the trail surface, crowding, use conflicts, and personal safety were other factors affecting people's use and perception of trails.

Based on the survey responses, siting trails close to residential areas, diligent maintenance of trail surfaces and facilities, planting and management of vegetation, and regular safety patrols would improve the perception and use of greenways by metropolitan area residents. In addition to recreational benefits, communities also provide habitat protection and preservation of biodiversity by establishing and maintaining greenways.

e. Modify driveway standards

In a sense, driveways are small-scale parking lots that are designed to accommodate two to four cars. When combined with areas needed to drive in and park, driveways can easily 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.
- 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.

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 focus 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.

a. 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 forcing 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.
- Eliminating long streets that serve only a small number of homes.

b. 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.)
- Reducing street and sidewalk widths.

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 queuing lanes. Cars wait between parked cars in the queuing lanes until approaching traffic passes before proceeding to the travel lane. This approach also helps slow traffic, which can improve safety.

Case Study: 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 *www.sustainable-communities.agsci.ubc.ca/projects/Headwaters.html*.

c. 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.
- Incorporating a pervious cover island in the center of the turnaround bulb that accepts runoff.

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).

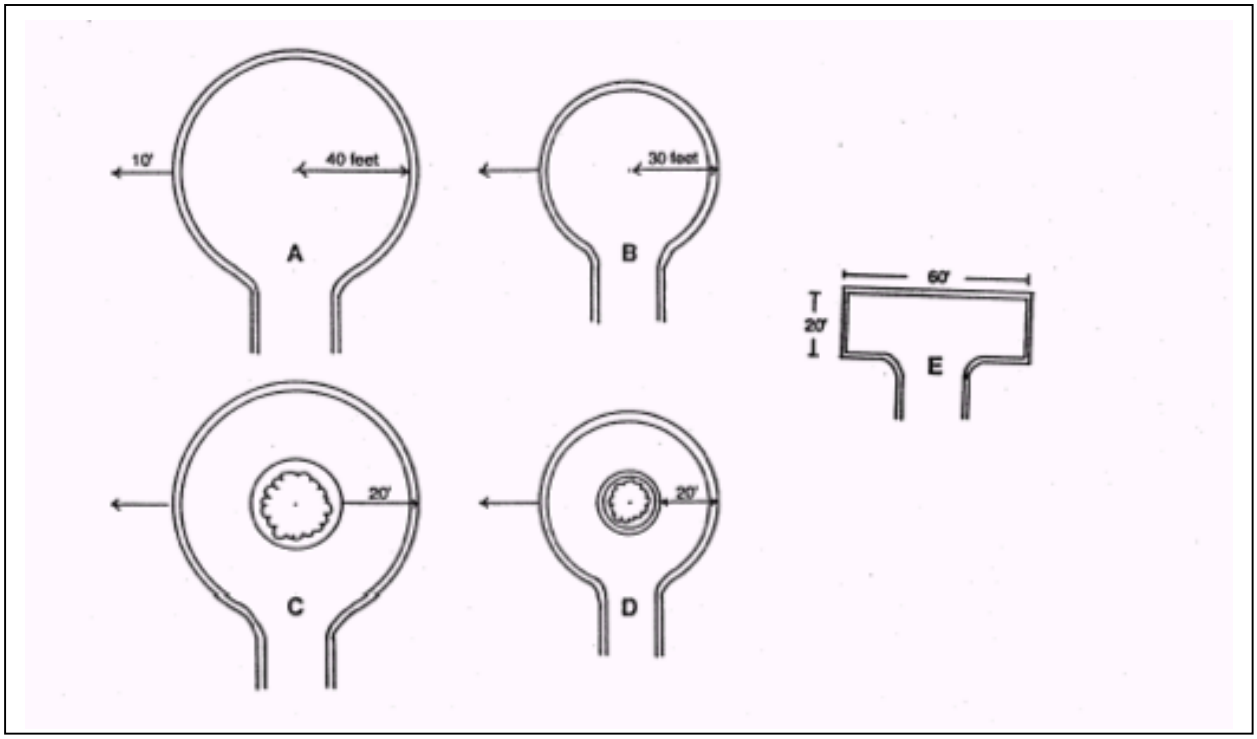

Figure 4.8: Five turnaround options at the end of a residential street (Schueler, 1995).

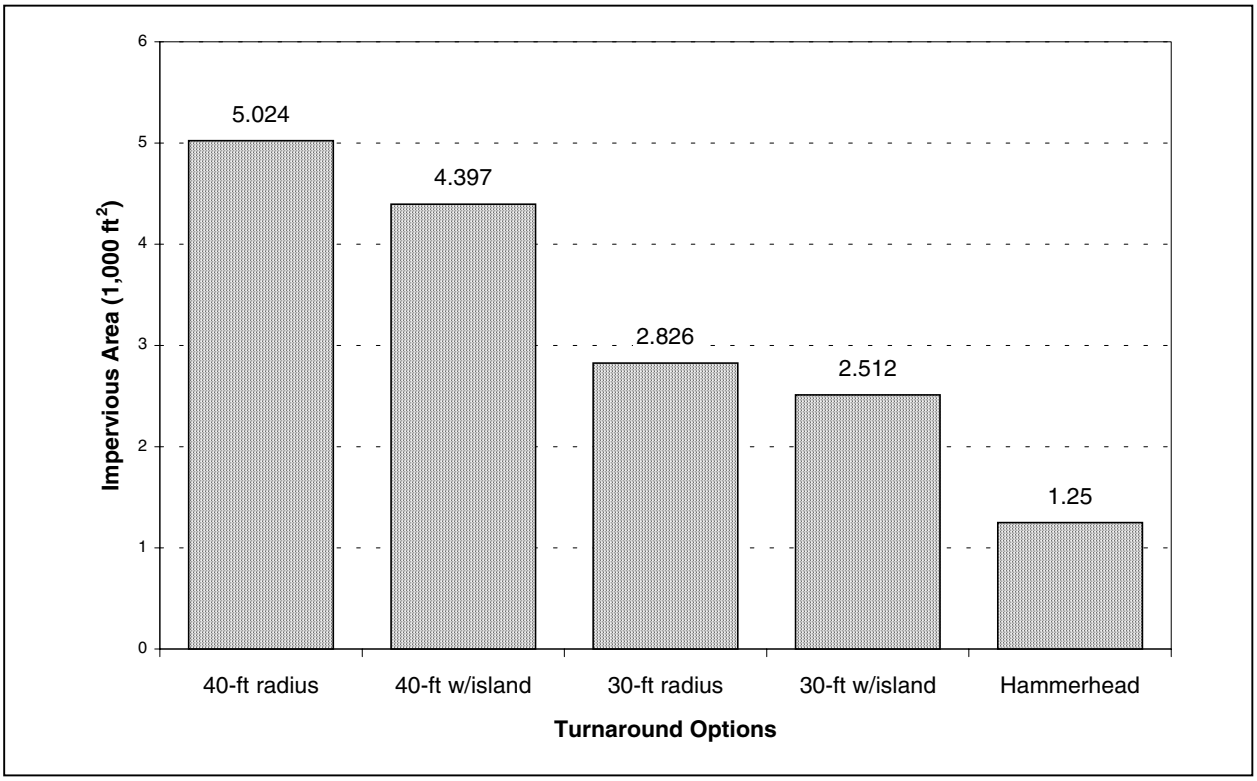

Figure 4.9: Impervious cover created by each turnaround option shown in Figure 4.8 (Schueler, 1995).

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, exacerbating erosion problems, but they also act as a repository for pollutants associated with automobiles, which include nutrients, trace metals, and hydrocarbons.

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 several better site design practices, including

- 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 adjacent localities 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.)

- Converting parking lot islands to bioretention areas (see Management Measure 5).

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.

Case Study: 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.

5. Xeriscaping Techniques

Xeriscaping is a landscaping concept that maximizes water conservation by using site-appropriate plants and an efficient watering system. It also involves the use of landscaping plants that need minimal watering, fertilization, and pesticide application. Xeriscaping can reduce the contribution of landscaped areas to nonpoint source pollution and 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.
- Reduction of fertilization through soil preparation.

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.
- Monitoring programs for ordinance implementation and compliance.

Case Study: 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.

The law also includes a provision requiring local governments and water management districts to promote the use of xeriscape practices in already developed areas through public education programs. California has passed a law requiring all municipalities to consider enacting water-efficient landscape requirements.

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, home builder, fire, safety, public works, and local government personnel, and details basic rationale for their implementation. The *Consensus Agreement* can be purchased at *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 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 *www.cwp.org*.

The Metropolitan Washington Council of Governments published *Clearing and Grading Strategies for Urban Watersheds* in 1995 to assist land planners and developers in preventing the adverse effects that result from clearing and grading of construction sites, especially those related to excessive erosion and high sediment loads in runoff. This document can be purchased from the Metropolitan Washington Council of Governments web site at *www.mwcog.org/ic/publist.html*.

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 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 *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 *www.natlands.org/pdffiles/growinggreener.pdf*.

The Watershed Management Institute published *Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation,* which 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. To order, send a check, money order, or purchase order to Watershed Management Institute, Inc., 410 White Oak Drive, Crawfordville, Florida, 32327. For more information, please contact Eric Livingston at 850-926-5310 or Earl Shaver at 410-758-2731.

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 *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 *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 includes 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, phone (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 for both people and cars. This publication can be purchased from the Local Government Commission's Center for Liveable Communities web site at *www.lgc.org/bookstore/land_use/publications/healthystreets.html*.

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 *www.sonic.net/abcaia/narrow.htm*.

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Management Measure 5
New Development Runoff Treatment

A. Management Measure

By design or performance, after construction has been completed and the site is permanently stabilized: (a) reduce the average annual total suspended solids (TSS) loadings by 80 percent,[a] or (b) reduce the postdevelopment loadings of TSS so that the average annual TSS loadings are no greater than predevelopment loadings.[b]

Maintain the postdevelopment average volume and peak runoff rate at levels that are similar to predevelopment levels, or by planning and design detain and/or retain an appropriate rainfall amount on-site to meet hydrologic requirements established for receiving waters integrated with downstream drainage systems.

Maintain temperatures in runoff at levels similar to predevelopment levels, or at levels to sustain aquatic life in receiving waters integrated with downstream drainage systems.

[a] Based on the average annual TSS loadings from all storms less than or equal to the 2-year/24-hour storm. TSS loadings from storms greater than the 2-year/24-hour storm are not expected to be included in the calculation of the annual TSS loadings.

[b] The first element of the measure focuses on TSS loadings that are generated after construction has ceased and the site has been properly stabilized using permanent vegetative and/or structural erosion and sediment control practices. The second element is not intended to be used as an alternative to achieving an adequate level of control in cases where high sediment loadings are the result of poor management of developed sites (not "natural" sites such as farmlands where the erosion control components of the USDA conservation management system are not used or sites where land disturbed by previous development was not permanently stabilized). The term "predevelopment" refers to the sediment loadings and runoff volumes/velocities 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.

B. Management Measure Description and Selection

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 topsoil compaction by construction equipment.
- Impermeable surfaces (paving and rooftops) increase.
- Artificial conveyances such as pipes and concrete channels are constructed.
- Slopes increase.

- Vegetative cover decreases.
- 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). In addition, destruction of in-stream and riparian habitat and increases in water temperature, streambed scouring, and downstream sedimentation of streambed substrates, riparian areas, and estuarine habitats may occur.

Additionally, everyday activities that occur after development result in pollutants in runoff that can have harmful effects on waters and habitat. Vehicle petroleum and coolant leaks and overflows, tire and brake wear, pet waste, pesticides, and fertilizers can all reach streams, rivers, and lakes through runoff. Soils and sediment can constitute a significant fraction of the solids on urban surfaces. Atmospheric transport of eroded soil by wind and rain contributes to these solids. Other sources of solids on urban surfaces include wear of automotive parts (brake pads, tires), engine 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 hydrological conditions to closely resemble those of the predisturbance condition (surface and groundwater).
- 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.
- Reduce thermal impacts of increased impervious surfaces.

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. In combination, these three management measures applied on-site and throughout watersheds can be used to provide increased watershed protection and help prevent severe 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.

a. Pollutants and total suspended solids

Many pollutants are highly associated with particulates. Particulates include suspended, settleable, and bedload solids, and the associated pollutants can include heavy metals, phosphorus, nitrogen, pesticides, trash and debris, and oxygen-demanding substances. Although many pollutants are highly associated with particulates, the correlation between TSS and specific pollutants varies (URS Greiner Woodward Clyde, 1999).

Sansalone and Buchberger (1997) found that the mass of zinc, copper, and lead in highway runoff and snowbank samples increased with decreasing particle size. The effect was attributed to the increase in particle-specific surface area with decreasing particle size. In another investigation, Sansalone and coworkers (1998) found that the specific surface areas of solids found in runoff were approximately three orders of magnitude greater than the specific surface area calculated for spherical particles. The study also established a pollutant mass-particle size relationship for runoff and street surface materials. The greatest mass of contaminants in highway runoff originated from particles in the 425 to 850 micron (µm) range, which was also the median particle size range. Because TSS is captured using filters with pore sizes of less than 10 µm, it is readily apparent that many pollutants have a direct association with TSS.

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.

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 storm events or dry weather periods preceding the sampling.
- Flow velocity, turbulence, and other conditions that promote the suspension of solids in the water column.
- The sampling techniques employed.

Generally, individual particles found in a TSS sample are 62 µm (0.062 mm) or less in diameter and classified as either silts or clays (Table 4.4). Solids greater than 62 µm can also be found in the water column if conditions are turbulent enough to keep them in suspension.

Table 4.4: 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 events. These events vary in magnitude through time, with large events occurring less frequently than small events. Collectively, all the rainfall events occurring during the year contribute 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 2-year/24-hour storm. This eliminates the impacts of larger infrequent storms from 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 1-year period from precipitation events less than or equal to the 2-year/24-hour storm. The 80 percent standard can be achieved by reducing, over the course of the year, 80 percent of these loadings.

EPA suggests considering monitoring turbidity in urban runoff because it has the advantage of being able to be conducted in-situ using continuous methods (e.g., Secchi disk). It should be noted, however, that using turbidity as a surrogate for TSS might 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.

Gray et al. (2000) examined the comparability of suspended-sediment concentration (SSC) and total suspended solids (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 relation between SSC and TSS. As sand-size material in samples exceeded nearly a quarter of the dry sediment mass, SSC values tended to exceed their corresponding paired TSS values.

Gray et al. indicate that the TSS method is unreliable for analyzing natural water samples because it was developed as an analytical method for wastewater, presumably for samples collected after a settling step at a wastewater treatment facility. Conversely, 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).

b. Runoff

Traditionally, runoff management programs have focused on the flood protection aspects of development. Consequently, performance standards typically involve limiting postdevelopment peak discharge rates to predevelopment rates for a single specified large storm (e.g., 2- or 20-year storm). Controlling total runoff volume from the entire storm is also an important objective. However, only a few programs have adopted performance standards that reflect this runoff characteristic.

The management measure incorporates both peak runoff rates and average volume objectives with the intent of limiting postdevelopment runoff to predevelopment runoff levels. USEPA recommends basing structural designs on the 2-year, 24-hour storm. State and local governments should determine an appropriate storm size to control based on local hydraulics, hydrology, meteorology, and other regional and local factors. Watershed managers should consider implementing volume-based controls rather than peak discharge controls to address problems associated with the frequency and duration of erosive flows (MacRae and Rowney, no date). For example, low-impact development (LID) techniques are promising for stabilizing and protecting stream channels (Prince George's County, Maryland, Department of Environmental Resources, 2000a, 2000b).

State and local governments should also determine whether they wish to consider the receiving waters that are integrated with downstream drainage areas as part of the management practice, thereby using the alternative approach to manage the streambanks, riparian zones, and channels to prevent additional degradation of the receiving waters.

Urbanization and channel enlargement

MacRae (1996) studied the effects of urbanization on channel morphology and examined how runoff management practices that target peak flow rate affect this dynamic. He agreed with the general paradigm that channel enlargement occurs as a result of increased watershed imperviousness from urbanization. He also concluded that traditional runoff control ponds do little to minimize the erosive effects of increased runoff volume and velocity because they are designed based on generic flow values and do not take into consideration site-specific variables like the erosivity of stream bank substrates. In fact, runoff control ponds tend to prolong the duration of mid-bankfull and bankfull flows, which can result in a higher rate of erosion depending on stream bank materials. MacRae suggested that runoff control practices be designed with multiple criteria that consider discharge and boundary material characteristics.

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."

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 4.5 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.
- The control of postdevelopment volume and peak runoff rates to reduce or prevent streambank erosion and stream scouring and to maintain predevelopment hydrological conditions can be accomplished using a number of flood control practices. Table 4.6 presents peak discharge and volume standards and design criteria for select local runoff management programs.
- Urban streams often experience elevated temperatures due to the increase in impervious areas and the 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 4.5: Select local and state programs with TSS performance standards (adapted from WMI, 1997a).

Community/State	Standard	Criteria
Olympia, WA	80 percent removal of suspended solids.	Treat runoff volume of 6-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.
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 2 hours or the 1 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 4.6: 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 2-yr and 10-yr, 2-hr storm.	None
Austin, TX	Postdevelopment rate cannot exceed predevelopment rate for 2-, 10-, 25-, and 100-yr, 24-hr storm.	None
Bellevue, WA	Postdevelopment rate cannot exceed predevelopment rate for 2- and 10-yr, 2-hr storm.	Multiple release rate for detention systems.
Olympia, WA	Postdevelopment rate cannot exceed predevelopment rate for 2-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 2-, 10-, and 100-yr, 24-hr storm.	None
Clark Co., WA	Postdevelopment rate cannot exceed predevelopment rate for 2-, 10- and 100-yr, 24-hr storm.	Postdevelopment vol. cannot exceed predevelopment vol. for 2-yr, 24-hr storm.
SW Florida Water Management District	Postdevelopment rate cannot exceed predevelopment rate for 25-yr, 24-hr storm.	Postdevelopment vol. cannot exceed predevelopment vol. for 25-yr, 24-hr storm.

Case Study: 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.

3. General Categories of Urban Runoff Control

Structural practices to control urban runoff rely on several basic mechanisms:

- Infiltration.
- Filtration.
- Detention/retention.
- Evaporation.

a. 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.

- Augments ground water reserves by facilitating aquifer recharge. During dry weather, ground water recharge helps to assure minimum necessary baseflow to maintain biological populations in streams.

Treatment effectiveness depends on whether the facility is sited on-line or off-line, and the sizing criteria used to design the facilities. Off-line infiltration practices prevent 100 percent of TSS and other pollutants 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, generally around 75 percent (WMI, 1997b).

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 or steep slopes.
- In areas where ground water contamination might be an issue.
- In areas where there is a risk of hazardous material spills.

The effect on ground water quality of infiltration practices is unknown, 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 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.

The presence of volatile organic compounds (VOCs) in ground water is another concern. A U.S. Geological Survey 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).

b. 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.

Biofiltration refers to practices that use vegetation to capture sheetflow from impervious areas and treat runoff through filtration, infiltration, adsorption, ion exchange, and biological uptake of pollutants.

c. Detention/retention practices

Runoff detention facilities provide pollutant removal by delaying the runoff from entering receiving waters and allowing particulate matter to settle. Retention facilities are off-line systems that dispose of runoff through withdrawal or evaporation. Both types of facilities can use biological uptake as a mechanism for pollutant removal. Runoff management ponds can be designed to control the peak discharge rates, thereby preventing excessive flooding and downstream erosion.

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 loading to surface waters. They can be designed with extended detention. Where site-specific conditions allow, constructed wetlands or sediment retention basins should be located to minimize the impact on the surrounding areas.

d. Evaporation practices

Runoff detention and retention facilities not only provide pollutant removal through settling but also have an additional runoff management benefit—evaporation—that reduces the quantity of runoff released to waterbodies. In warm, dry climates, evaporation from runoff detention areas such as rooftops, streets, basins, and ponds can be an important mechanism for runoff management.

C. 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, location, and climate. Thus, practices that by themselves do not achieve the 80 percent TSS removal criterion can be combined with other practices to achieve 80 percent removal (such that x + y + z = 80 percent). The seven categories include

- Detention ponds or vaults.
- Ponds.
- Wetlands.
- Infiltration practices.
- Filtering practices.
- Open channel practices.
- Structural practices that do not meet the 80 percent TSS removal criterion.

Some advantages, disadvantages, and costs of specific runoff control practices under the seven categories are listed in Table 4.7. Site-specific information, regional limitations, operation and maintenance burdens, and longevity for these practices are listed in Table 4.8.

Table 4.7: 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 resuspension 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 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	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 rock and water table – Fairly high failure rate – If not adequately maintained, can be and eyesore, breed mosquitoes, and create undesirable odors – Regular maintenance activities cannot prevent rapid clogging of infiltration basin	Construction cost moderate but rehabilitation cost high
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 rock 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

Table 4.7 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
Infiltration practices (continued)			
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 rock 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 stormwater through sedimentation to prevent filter media from prematurely clogging	Information not available
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 fully meet the 80% TSS requirement			
Vegetated filter strip	– Low maintenance requirements – Can be sued 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
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

Table 4.7 (continued).

Practice	Advantages	Disadvantages	Comparative Cost[a]
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 4.8: 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 groundwater 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 groundwater 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

Table 4.8 (continued).

Management Practice and Specifications	Cold Climate Restrictions (Caraco and Claytor, 1997)	Arid and Semi-Arid Regional Restrictions (Schueler, in press)
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
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 4.9 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 4.9: 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

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 *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 *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 *www.epa.gov/etv* and *www.hsf.org/etv*, respectively. More information about the program is available at *www.wateronline.com/content/news/article.asp?docid={17DDF263-29B8-11D5-A770-00D0B7694F32}* (Water-Online, 2001).

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 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 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 should be used to improve data transferability.

Table 4.10 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 4.10: 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 4.10 (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 to 2000 dollars using the Bureau of Labor Statistics Consumer Pricing Indexes Inflation Calculator (BLS, 2000).
[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.

National Stormwater Best Management Practices Database

The American Society of Civil Engineers, in cooperation with EPA, has compiled the *National Stormwater Best Management Practices Database*, which contains performance data from more than 113 BMP 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 www.bmpdatabase.org.

1. Detention Ponds or Vaults

These practices temporarily detain runoff to ensure that the postdevelopment peak discharge rate is equal to the predevelopment rate for the 2-, 10-, or 25-year design storm event. 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 1-year storm). ***These practices do not meet the 80 percent TSS criterion unless combined with source controls.***

Extended detention (ED) ponds (Figure 4.10) 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 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 antivortex trash rack on top to control large floating solids.

2. Ponds

These practices combine 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.
- Multiple pond systems.
- "Pocket" ponds.

Ponds (Figure 4.11) 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 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 antivortex trash device, is a common design modification. "Pocket" ponds are appropriate for sites with small drainage areas because they are built below the water table, which allows a permanent pool to be maintained with a combination of runoff and ground water (MDE, 2000). Table 4.11 presents several design considerations for ponds.

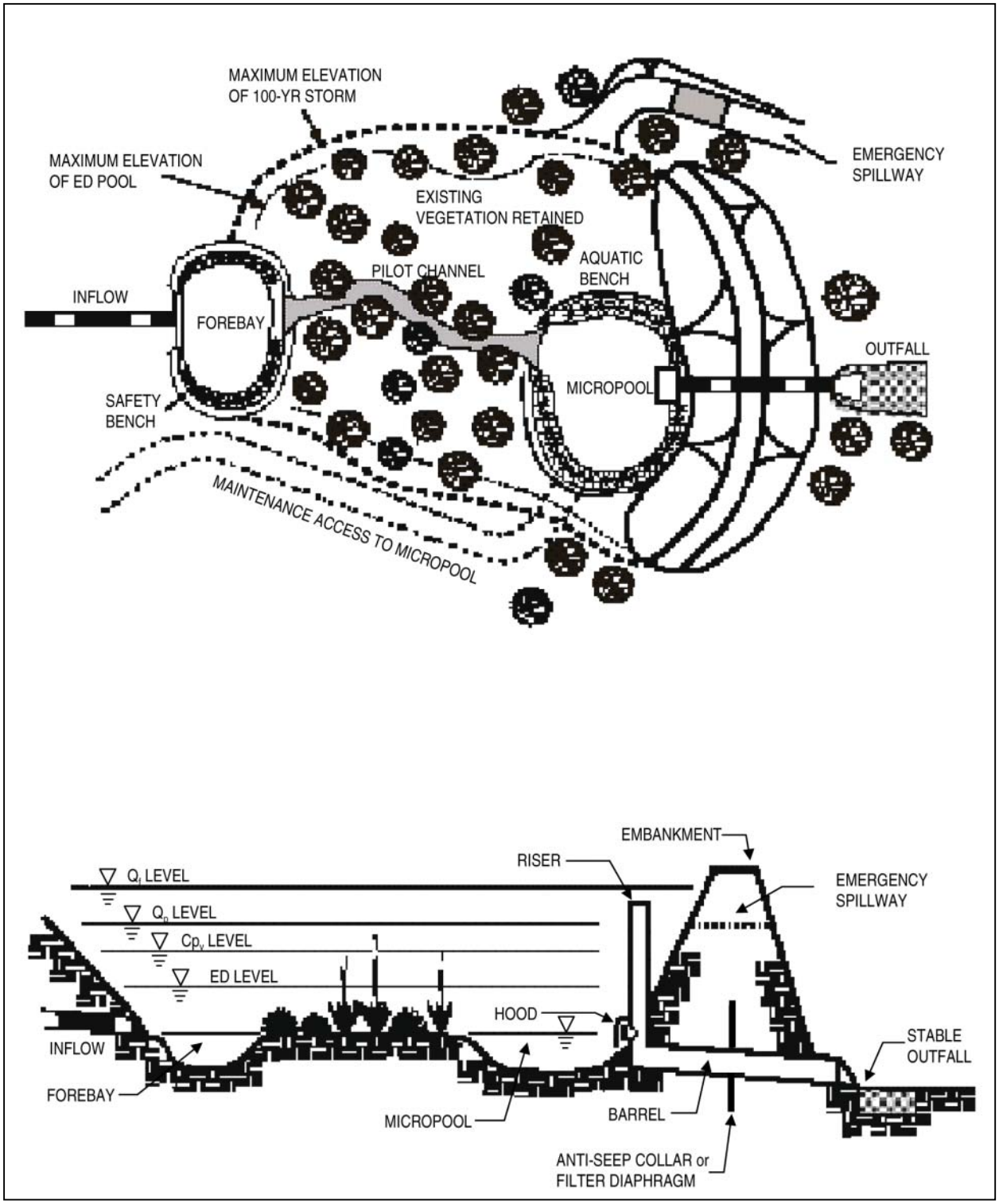

Figure 4.10: Schematic of a dry extended detention pond (MDE, 2000).

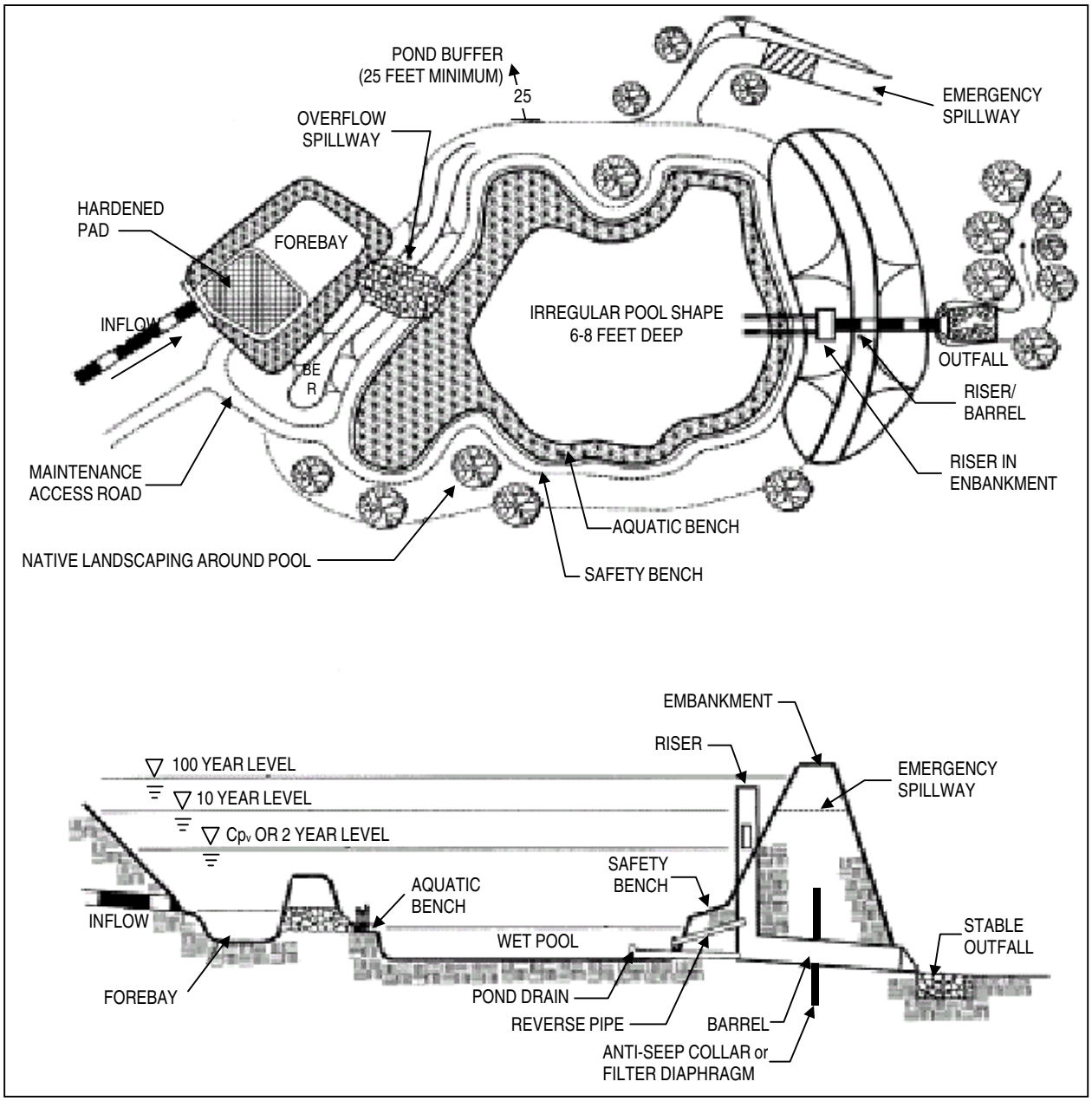

Figure 4.11: Schematic of a wet pond (MDE, 2000).

Table 4.11: Design considerations for ponds and wetlands, continued (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 offline 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 dieoff.
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

3. Wetlands

These practices, often referred to as constructed wetlands, include significant shallow marsh areas to store and treat runoff but often may also incorporate small permanent pools and extended detention storage. The different types of wetlands include

- Shallow wetlands.
- ED shallow wetlands.
- Pond/wetland systems.
- "Pocket" wetlands.

Constructed wetlands (Figure 4.12) are feasible to use 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 4.11.

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 increased 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. Static water depths should not exceed 2 to 3 feet for growth of emergent vegetation. 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 of water greater than 4 feet. In general, 50 percent of the pond should have depths less than one foot, 30 percent of the pond should be 1 to 2 feet deep, and 20 percent of the pond surface area should be 2 to 4 feet deep. Greater depths are allowable for the inflow forebay and around the outlet structure.

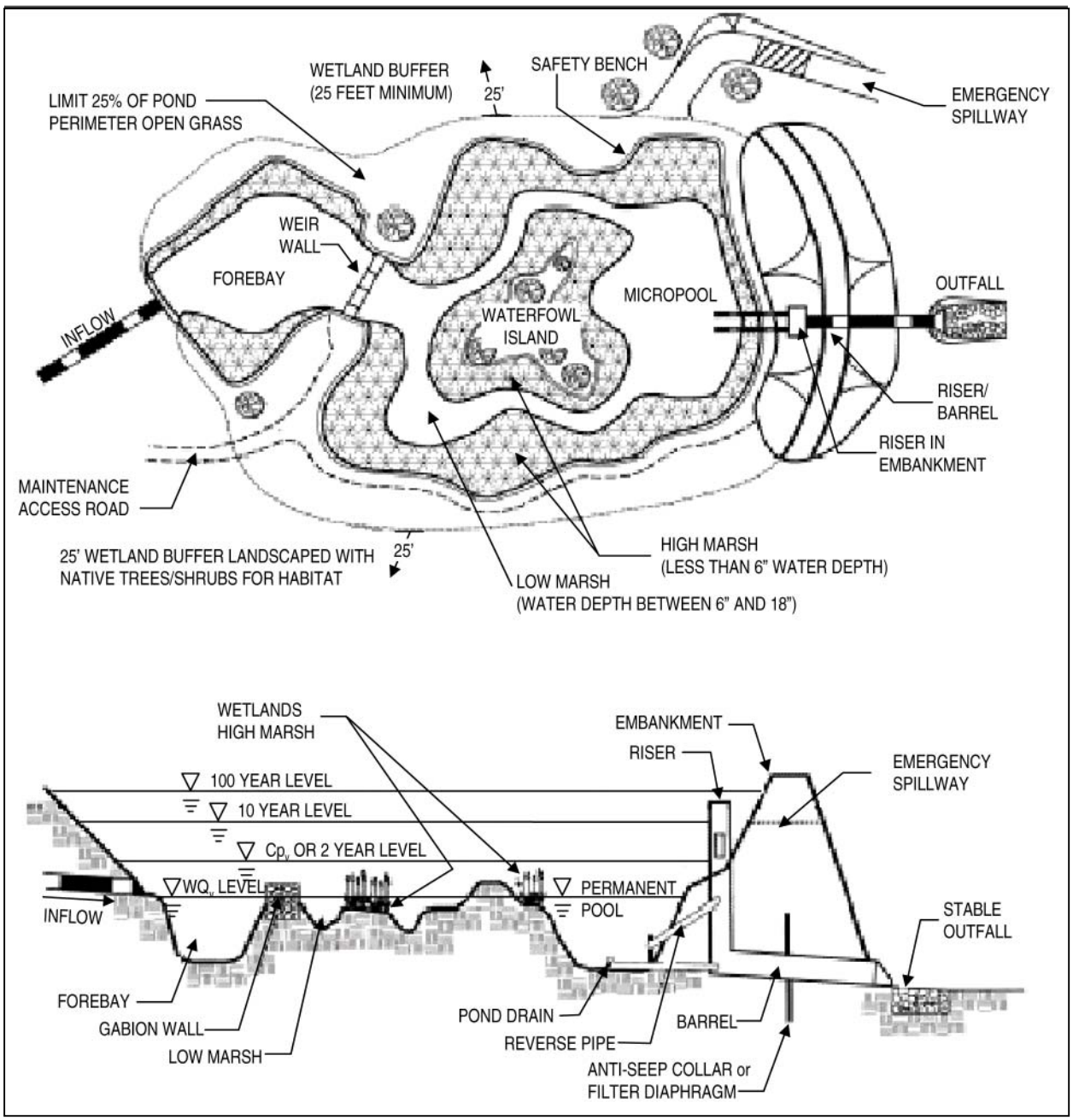

Figure 4.12: Schematic of a shallow wetland (MDE, 2000).

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 2- 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. If a liner is needed, it should have at

Case Study: 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.

least one foot of clean fill material placed on top of it for wetland plant growth (the fill material will reduce the potential for puncture).

An island within 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 the elevation that storage of the first inch of runoff would reach.

Habitat for geese should be avoided in the typical constructed wetland. Because most runoff management ponds are fairly small compared with a natural marsh system, planting woody vegetation or allowing areas around the pond to grow without mowing tends to discourage goose residency. They typically prefer a long glide path for landing and taking off.)

The following are several 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.

The cleanout frequency of sediment forebays depends on the sediment load entering the constructed wetland. Each forebay should be inspected on an annual basis to ensure that

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 might 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, outlet clogging can occur from algae where small orifices are needed for extended detention. Having a below-surface withdrawal structure may reduce or eliminate the problem.

(4) *Transition zone*. The maximum slope of the transition zone 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 improve wildlife utilization. The transition zone should be mowed no more than once a year in late fall. Optimally, the transition area should not be mowed at all to promote the growth of woody vegetation unless the pond is an embankment pond, in which case it should be mowed once annually to prevent woody vegetation from establishing on the embankment.

(5) *Vegetation*. Placement of organic soils on the bottom of the pond will provide for a more rapid growth of planted or volunteer vegetation. Constructed wetlands should initially be planted with emergent plants and woody shrubs and 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 and should propagate by seed.

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 can help to design a maintenance schedule based on vegetation requirements.

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 australus* (common reed), *Lythrum salicaria* (purple loosetrife), and *Phalaris arundinacea* (reed canary grass). Periodic inspections will be 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, planting cattail in urbanized areas addresses the fact that 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 the 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 U.S. where plant growth is the most important mechanism for nutrient uptake. Harvesting is not needed where microbial activity is the dominant pollutant removal mechanism.

Case Study: 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 help 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).

4. 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.
- Porous pavements.

a. Infiltration basins

Infiltration basins are impoundments created by excavation or creation of berms or small dams (Figure 4.13). 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, so that aerobic conditions are maintained and to 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 to treat the peak discharges of the 2-year storm event.

The key for 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 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.

b. Infiltration trenches

Infiltration trenches are shallow (2 to 10 feet deep) excavated ditches with relatively permeable soils that have been backfilled with stone to form an underground reservoir (Figure 4.14). 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 three to four 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.

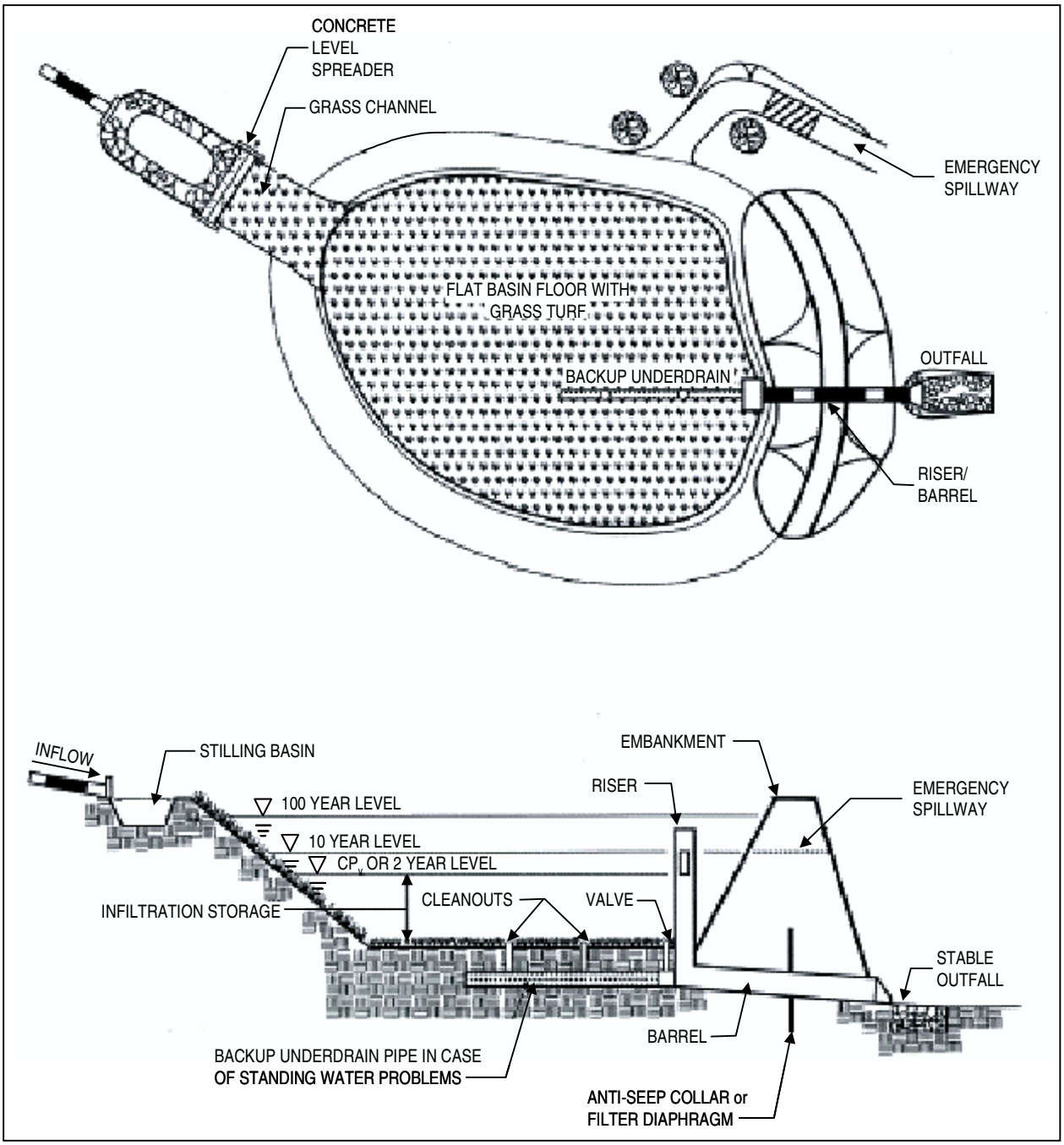

Figure 4.13: Schematic of an infiltration basin (MDE, 2000).

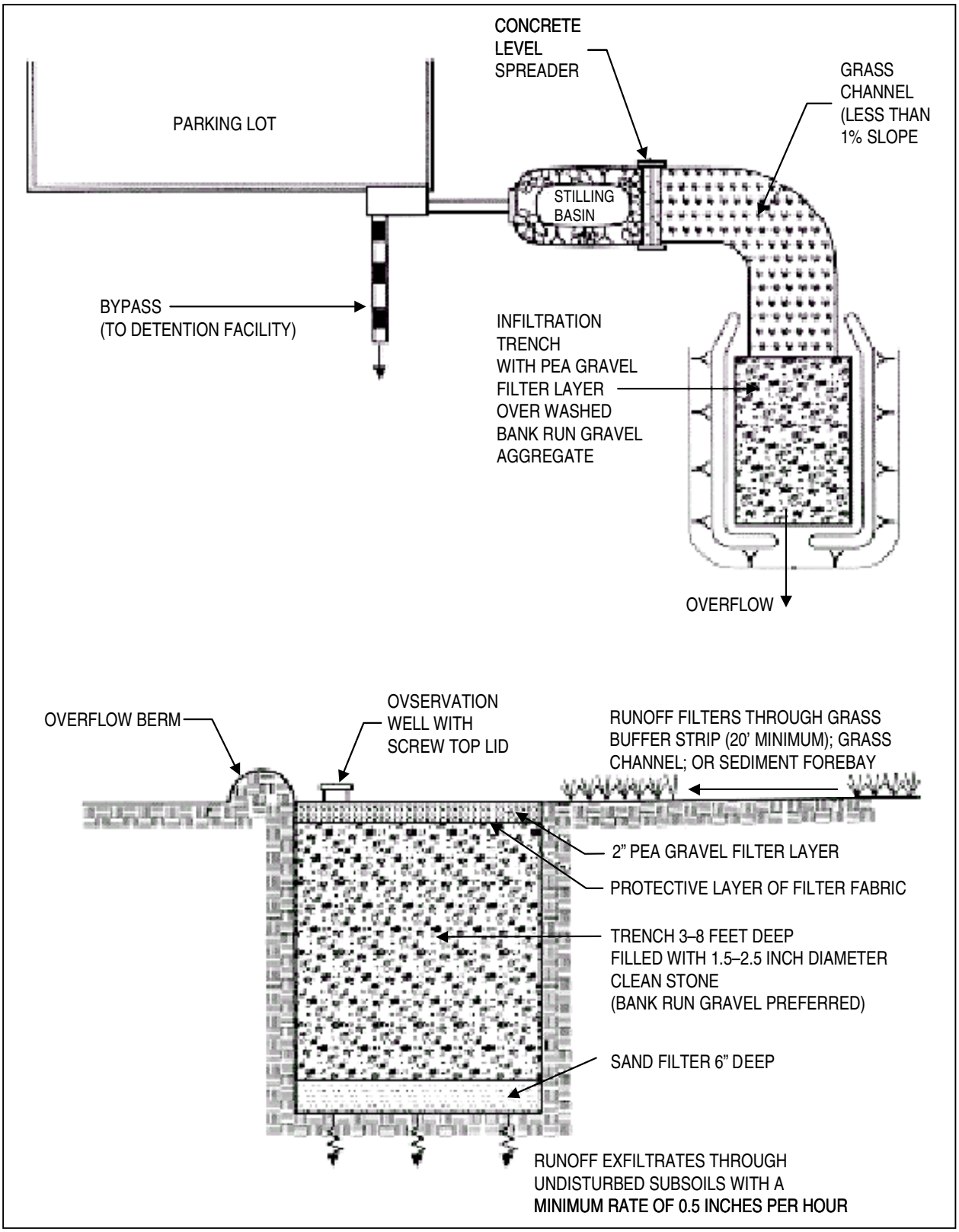

Figure 4.14: Schematic of an infiltration trench (MDE, 2000).

c. Pervious and modular pavement

Pervious pavement has the approximate strength characteristics of traditional pavement but allows rainfall and runoff to percolate through it. The key is the elimination of most of the fine aggregate found in conventional pavements. 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 4.15 shows several types of porous pavement.

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 that provides structural strength. Filled with sand and sodded, it provides a completely grassed parking area.

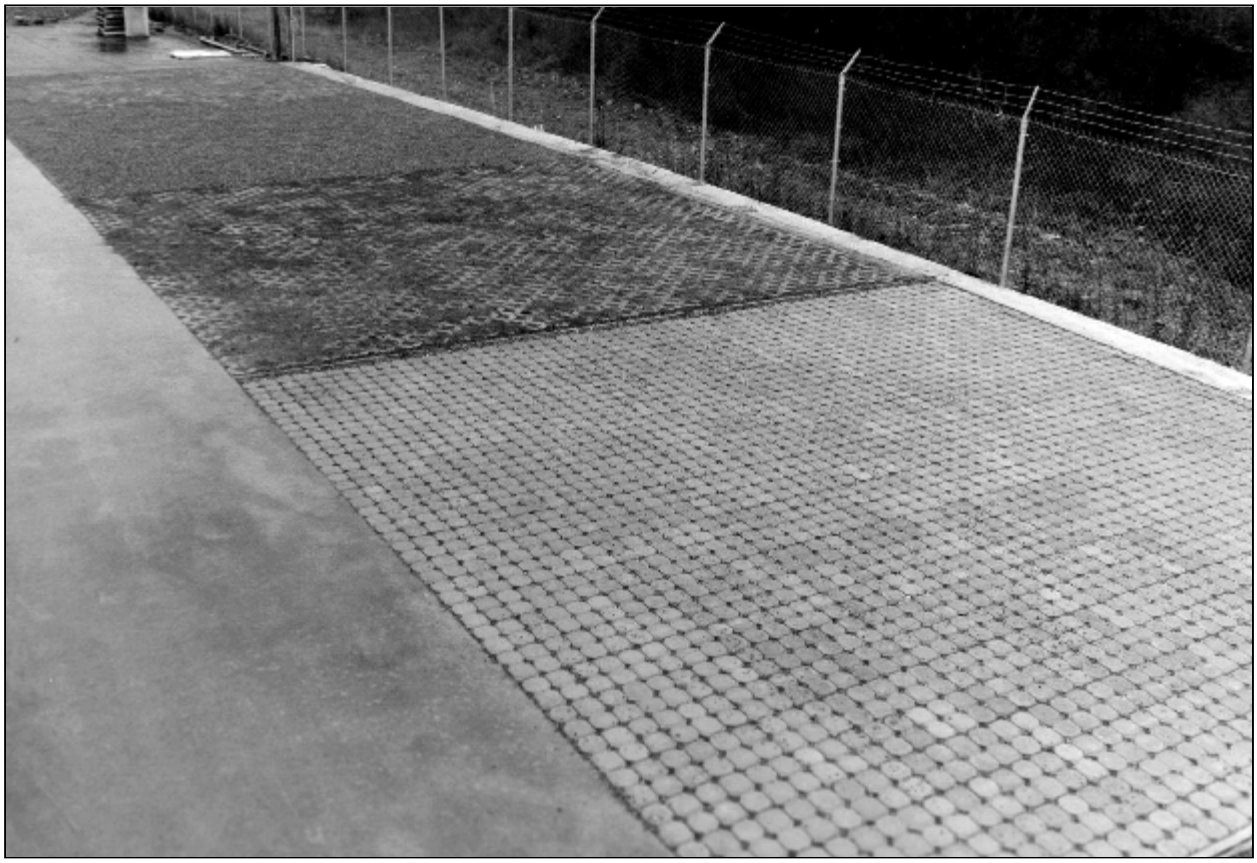

Figure 4.15: Photo showing several types of pervious modular pavement installations.

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 installed, a vacuum-type street sweeper should be used regularly to maintain pavement 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 less than 5 percent, and no heavy vehicle traffic. Pervious pavement has limited use in regions with cold climates, arid regions with high wind erosion, and areas with sole-source aquifers.

Case Study: 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 underdrains 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 underdrain/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 *www.stormwater-resources.com/Library/103BFloridaRetrofits.pdf*.

5. Filtering Practices

These 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.
- Bioretention areas.

a. Filtration basins and sand filters

Filtration basins are impoundments lined with filter medium such as sand or gravel. Runoff drains through the filter medium and through perforated pipes into the subsoil. Detention time is typically 4 to 6 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 chamber 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 several design variations for sand filtration devices:

(1) *Surface sand filter*. The surface sand filter (Figure 4.16) is the original sand filter design. In this practice both the filter bed and the sediment chamber are aboveground. The surface sand filter is designed as an off-line practice, where 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 4.17) 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 the smaller water quality events. Underground sand filters are expensive to construct but consume very little space. They are well suited to highly urbanized areas.

(3) *Perimeter sand filter*. The perimeter sand filter (Figure 4.18) 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, with all flows entering the system but larger events bypassing treatment by entering an overflow chamber. One major advantage to 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 4.19) are essentially the same as surface filters, with the sand medium replaced with or supplemented by another medium. Two examples are the peat/sand filter (Galli, 1990) and the compost filter system. The assumption is that these systems will have enhanced pollutant removal for many compounds because of the increased cation exchange capacity achieved by increasing the organic matter content.

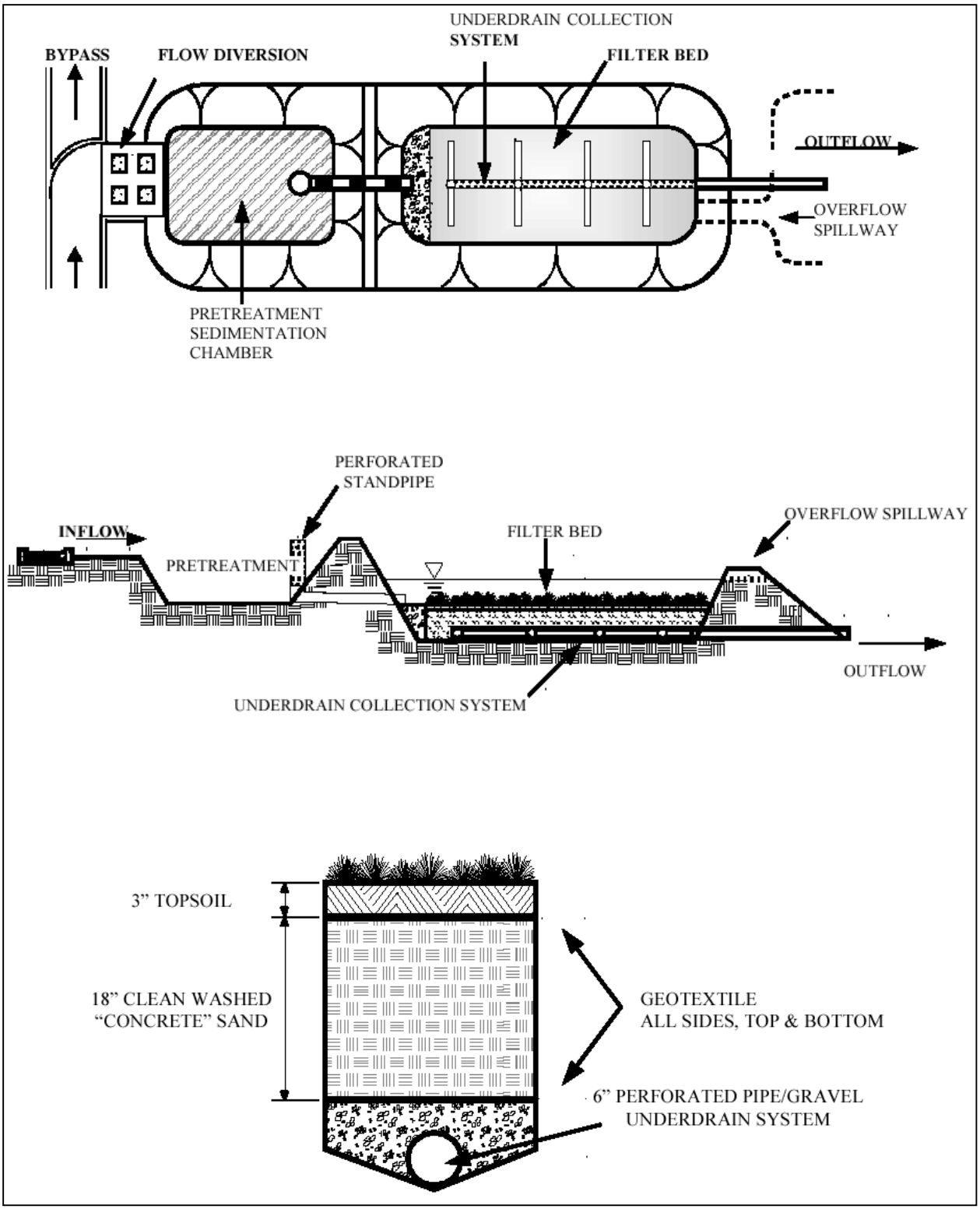

Figure 4.16: Schematic of a surface sand filter (MDE, 2000).

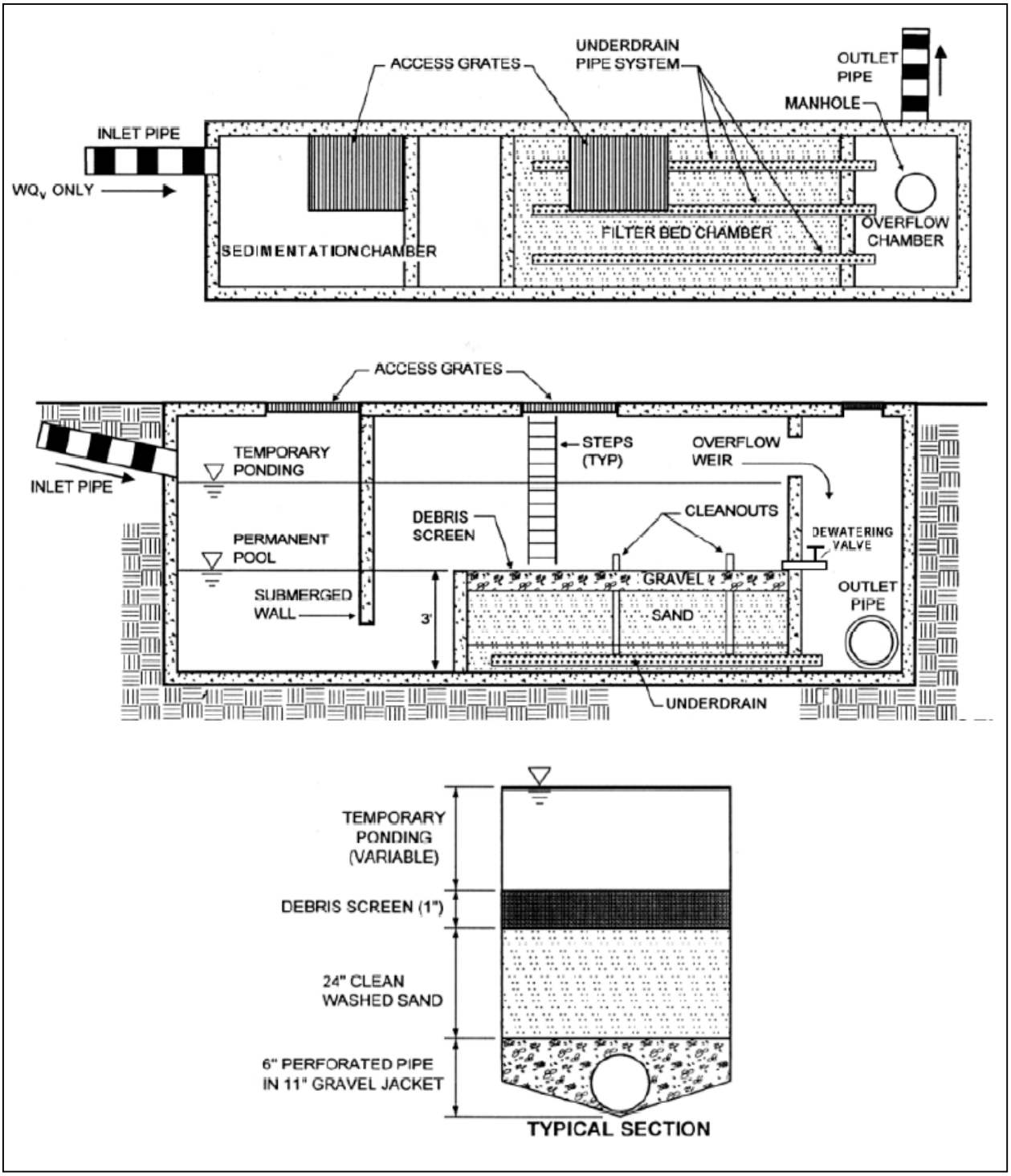

Figure 4.17: Schematic of an underground sand filter (MDE, 2000).

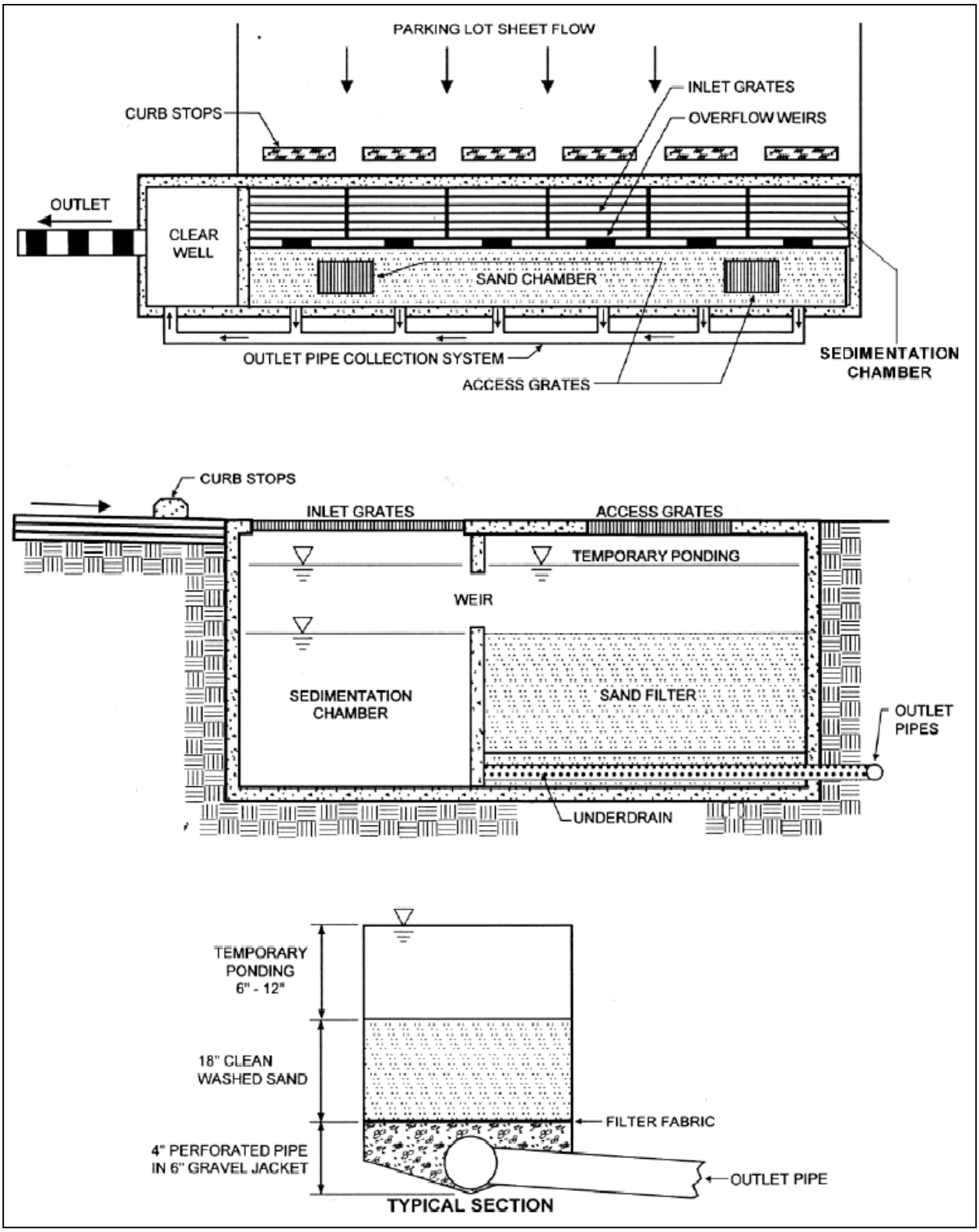

Figure 4.18: Schematic of a perimeter sand filter (MDE, 2000).

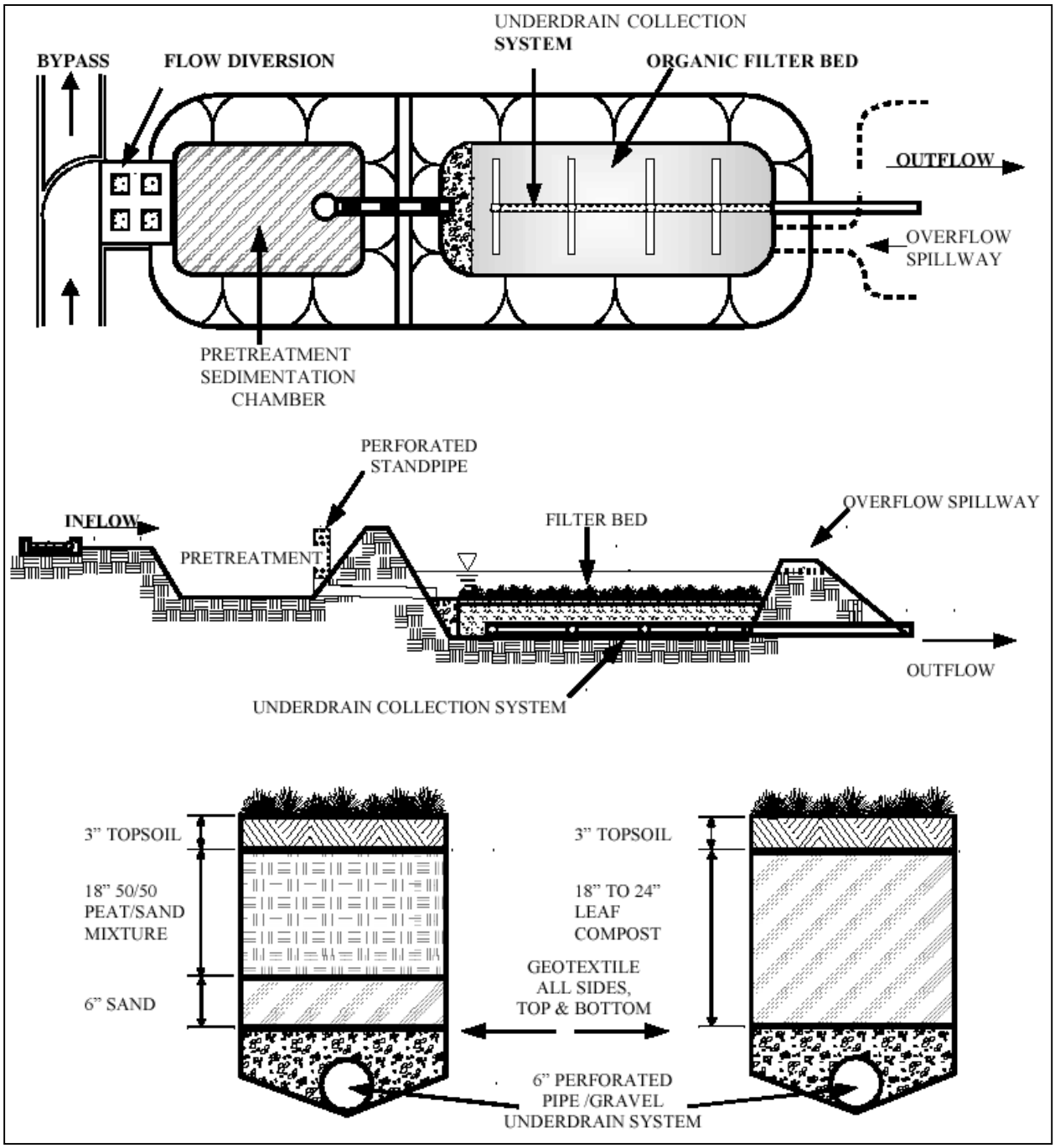

Figure 4.19: Schematic of an organic media filter (MDE, 2000).

(5) *Multi-chambered treatment train*. The multi-chambered treatment train (Figure 4.20) 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.

b. Media filtration units

Similar to wastewater treatment technology, passive filtration units can be used to capture pollutants from runoff. Existing media filtration practices commonly use trenches filled with sand or peat. Excess runoff bypasses the filter and is untreated. A newer technology for runoff management is the complete treatment of all runoff through filter media. A basin collects the runoff and gradually discharges through a pipe to cartridges filled with composted leaf media.

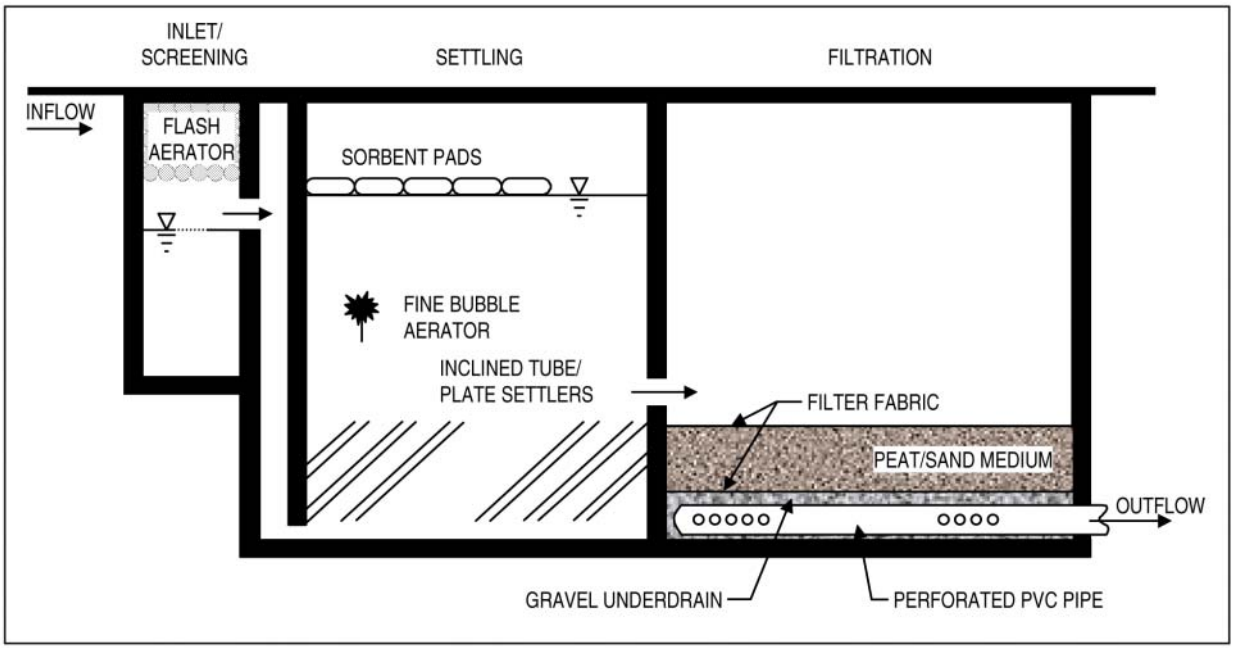

Figure 4.20: Schematic of a multi-chambered treatment train (Pitt, 1996).

The 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), according to the Unified Sewerage Agency of Washington County in Oregon (WEF, 1998). Similar types of systems with various filter media are available commercially.

The technology is most practical where space is limited, as it uses less than 10 percent of the land required for a comparable water quality pond or grassed swale. The system costs $7,000 to $100,000 depending upon the number of media cartridges required. A 100-cartridge system can treat 1,500 gallons per minute.

c. Bioretention systems

Bioretention systems (Figure 4.21) 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.
- Swales or depressional 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 pretreat sheet flow before it is channelized or collected in an inlet structure.

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.
- 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 4-day maximum ponding period (appropriate for the Mid-Atlantic region). This 4-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,

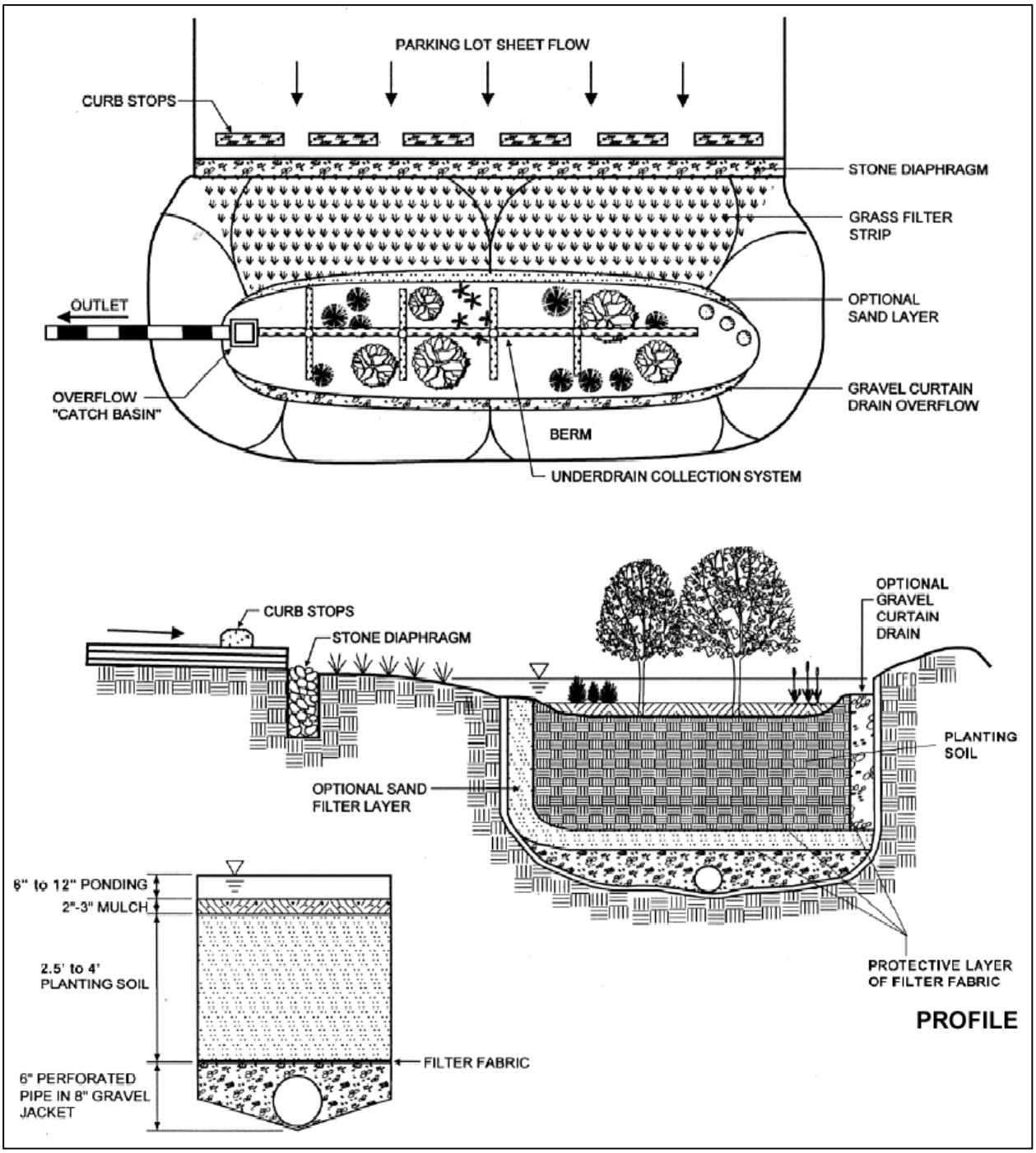

Figure 4.21: Schematic of a bioretention system (MDE, 2000).

planting soil that provides the desired infiltration rate, and an underlayer 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).

Case Study: 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 realized 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 using 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 that 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).

6. Open Channel Practices

Vegetated open channels are explicitly designed to capture and treat runoff within an open channel, through infiltration, filtration, or temporary storage. Design variants include

- Dry swales.
- Wet swales.
- Biofiltration swales.

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. Two types of channels are typically used in residential landscapes:

- *Grass channels*. These have dense vegetation, a wide bottom, and gentle slopes, as shown in Figure 4.22. Usually they are intended to detain flows for 10 to 20 minutes, allowing sediments to filter out.

- *Dry swales*. This practice provides more complete runoff treatment than grass channels. A schematic diagram of a dry swale is shown in Figure 4.23. As in grass channels, runoff flows into the channel and is subsequently filtered by surface vegetation. 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 to 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.

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 less 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.

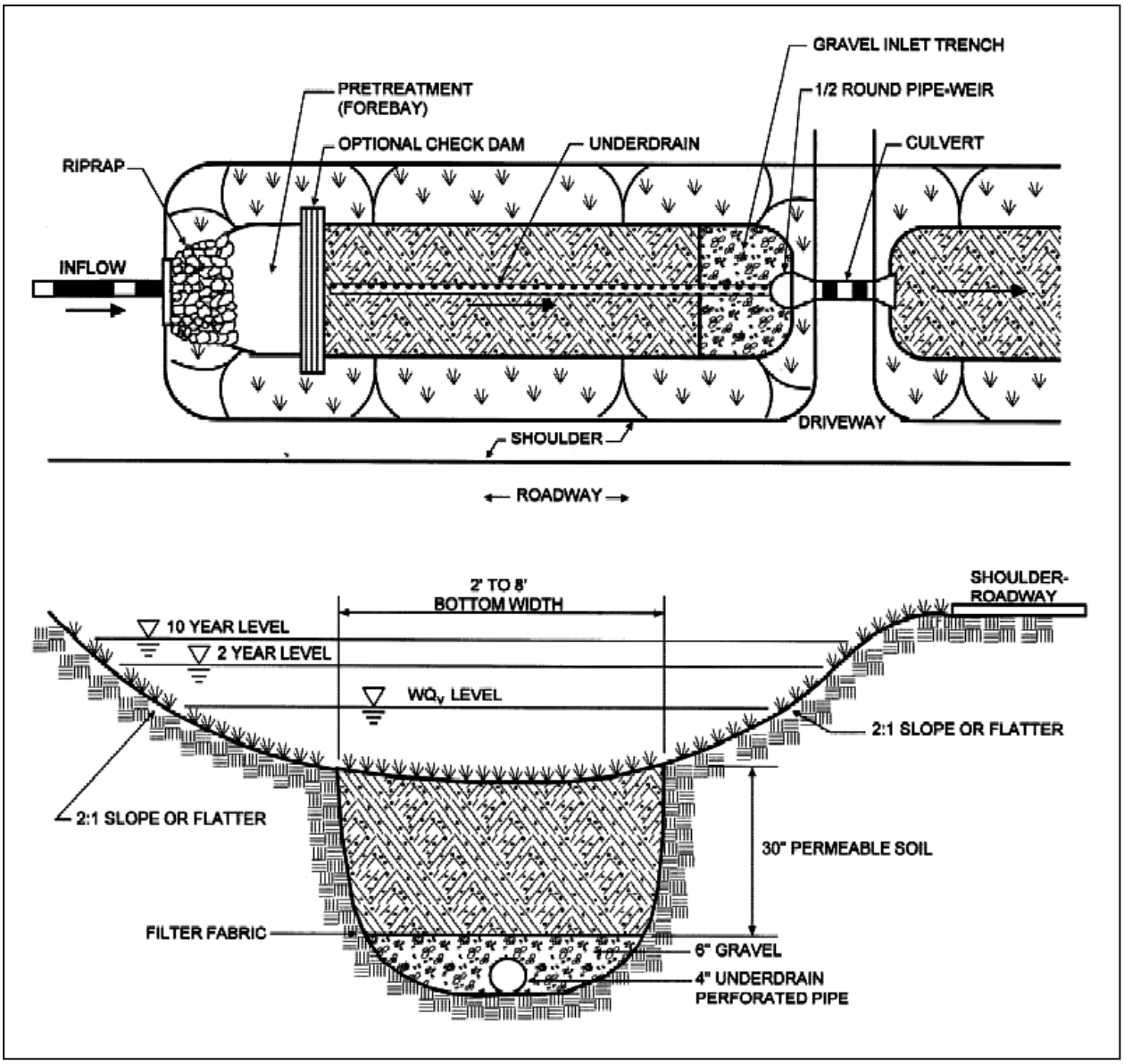

Figure 4.22: Schematic of a grass channel (Claytor and Schueler, 1996).

J.F. Sabourin and Associates concluded that infiltration capacities of grass swales were optimum, as 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.

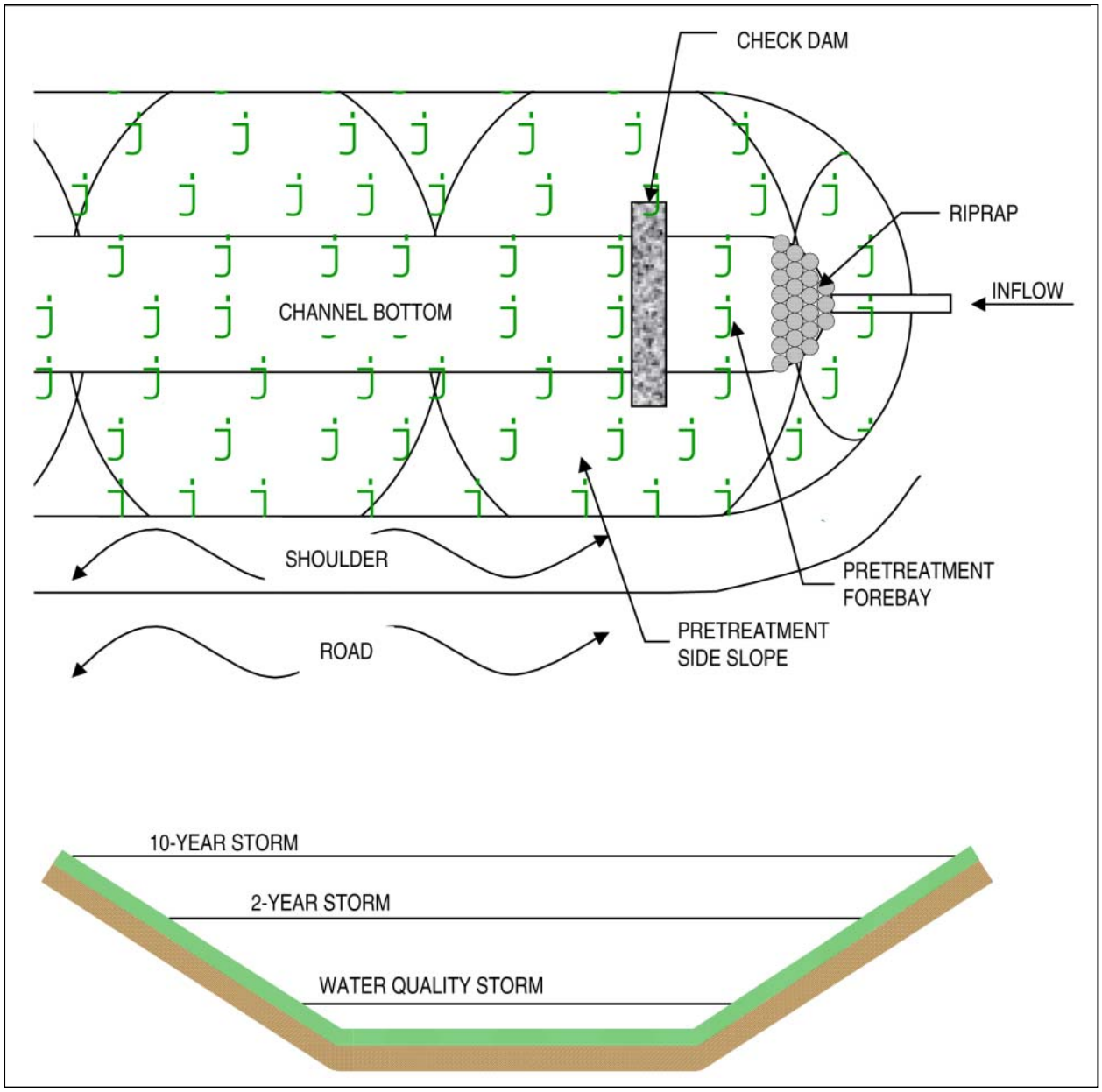

Figure 4.23: Schematic of a dry swale (adapted from MDE, 2000).

7. Miscellaneous Practices

Many practices used alone do not meet the criteria for being an effective structural practice due to poor longevity or inability to meet the 80 percent TSS removal criterion at a site. Some of these practices that *do not meet the 80 percent TSS removal criterion* include

- Water quality inlets.
- Hydrodynamic devices.
- "Baffle boxes."
- Catch basin inserts.

- Vegetated filter strips.
- Street surface storage.
- On-lot storage.

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, a vegetated filter strip installed upslope of a wet pond will help remove a portion of the pollutants present in runoff before it enters the pond. The filter strip improves runoff quality and can help extend the longevity of the wet pond.

a. Water quality inlets

Water quality inlets are underground retention systems designed to remove settleable solids. Several designs of water quality inlets exist. 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. A high frequency of maintenance and disposal of trapped residuals and hydrocarbons must occur for these devices to work.

b. 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 are sometimes present to trap oil and other floatables. Typically these devices are premanufactured 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. These functions are typically conducted by using a vacuum truck. Cleaning of the device usually costs approximately $250 per unit per cleanout exclusive of waste disposal costs. Disposal costs are typically between $300 and $500.

A second hydrodynamic device uses centrifugal motion to remove litter and debris from runoff and potentially larger sediment particles. This technology is designed to capture trash rather than pollutants and therefore 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 from 3 to 300 cfs. The devices are constructed so that a vacuum truck can regularly remove the floatable and settleable debris collected in the treatment chamber. Installation costs are site specific but could range from $2,300 to $7,200 per cfs capacity (WEF, 1998).

Because limited data are available on their performance, and independently conducted studies suggest marginal fine particle and soluble pollutant removal, swirl separators should not be used as a stand-alone practice for new development. Also, this practice has a high maintenance burden. Swirl separators are best installed on highly impervious sites. The best application of these products is as pretreatment to another runoff treatment device or in a retrofit situation where space is limited.

The specific design of swirl concentrators is specified by product literature available from each manufacturer. For the most part, swirl concentrators are a rate-based design. That is, they are sized based on the peak flow of a specific storm event. This design contrasts with most other runoff management practices, which are sized based on capturing and storing or treating a specific volume. Sizing based on flow rate allows the practice to provide treatment within a much smaller area than other runoff management practices.

A typical swirl separator costs between $5,000 and $35,000, or between $5,000 and $10,000 per impervious acre. This cost is within the range of some sand filters. Swirl concentrators usually require quarterly maintenance. Maintenance most often is performed using a vactor truck, a device that costs between $125,000 and $150,000. This initial cost may be high for smaller communities. However, it may be possible to share a vactor truck with another community.

In some regions, it might be difficult to find environmentally acceptable disposal methods. The sediments might not always be land-filled, land-applied, or introduced into the sanitary sewer system due to hazardous waste, pretreatment, or ground water regulations. This is particularly true when the devices drain runoff from “hot spot” areas. Depending on the rules within a community, disposal costs of the sediment captured in swirl separators might be significant.

c. 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 that are typically 10 to 15 feet long and 6 to 8 feet high and 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 a 28 percent removal efficiency for fly ash at the same velocity. Installation costs for most baffle boxes ranges from $20,000 to $30,000 depending on the extent that existing infrastructure needs to be modified or relocated. Baffle box designs can be modified to serve as a retrofit installation at curb or

manhole inlets or beneath grates. Regular maintenance, especially sediment and debris removal, is essential to maintain the effectiveness of this practice.

d. Catch basin inserts

Catch basin inserts consist of a frame that fits below the inlet grate of a catch basin that 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, activated carbon for organics, fertilizers and pesticides). The design can allow for overflow of clogged trays, and the device is designed to accept the design flow rate of the inlet grate. The media require routine maintenance for replacement, cleaning, or regeneration. Catch basin inserts are typically used for smaller watersheds. Typically the media needs replacement at least on a quarterly basis.

Costs for these devices are approximately $400 to $2,000 per catch basin depending on the number of trays and size of the catch basin and media selected. Maintenance costs are typically less than $25 per installation or less than $100 per year if media needs to be replaced.

e. 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.

f. Vegetated filter strips

Vegetated filter strips (Figure 4.24) are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. They may closely resemble many natural ecological communities such as grassy meadows or riparian forests. 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, filter strips 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

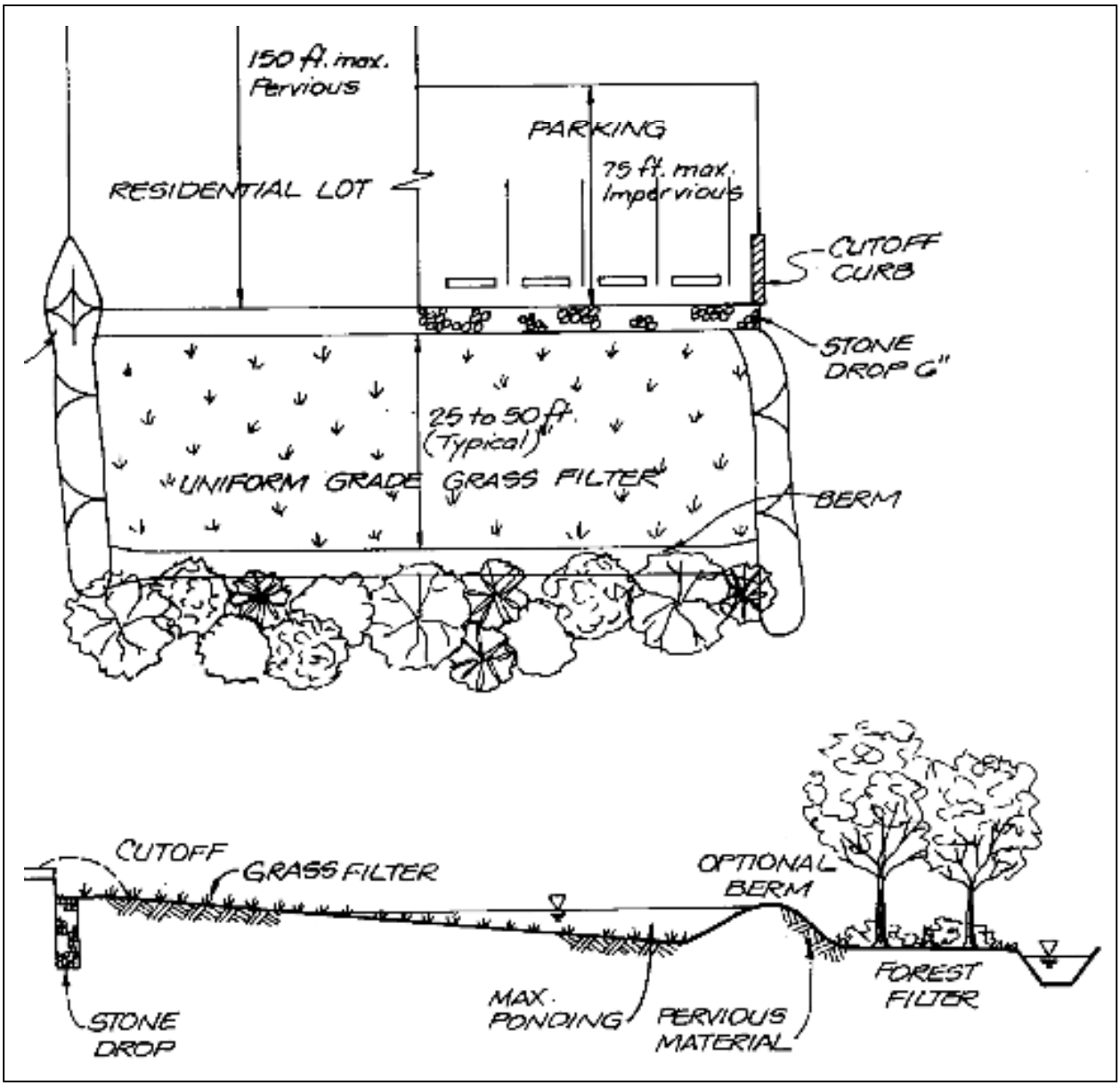

Figure 4.24: Schematic of a vegetated filter strip (Claytor and Schueler, 1996).

and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip.

Filter strips should be designed on slopes between 2 and 6 percent. Greater slopes than this would encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff would pond on the surface on slopes flatter than 2 percent, creating potential mosquito breeding habitat. Filter strips should not be used on soils with a 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 the filter strip does not remain wet between storms.

Filter strips are a minimal design practice 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.

- 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.

g. Street surface storage

Runoff can be temporarily stored on and below the surface of streets in urban areas, as shown in Figure 4.25, to reduce peak flows to the storm sewer system (Carr et al., 1999). Runoff can be retained within 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 more gentle; 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 to surface storage 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. They also reduce peak flows at wastewater treatment plants and help prevent nonpoint source pollution. 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 some new storm and combined sewers. 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.

Figure 4.25: Runoff pooling on a street surface designed for temporary storage.

h. 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 primary purpose of most on-lot practices is to manage rooftop runoff. Rooftop runoff, particularly in residential areas, generally has low pollutant concentrations compared with other urban sources (Schueler, 1994). The primary advantage of managing runoff from rooftops is to disconnect these impervious surfaces, reducing the effective impervious cover in a watershed.

Although there is a variety of on-lot treatment options, they can all be classified into one of three categories: (1) practices that infiltrate rooftop runoff, (2) practices that divert runoff or soil moisture 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 homeowner.

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.

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, 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, as opposed to flowing directly to the street, and thus the storm drain system.

Practices that store rooftop runoff, such as cisterns and rain barrels (Figure 4.26), are the simplest in design of all of the 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.

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. Information about building a simple rain barrel is available from the Maryland Green Building Program at *www.dnr.state.md.us/programs/greenbuilding/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.

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 site 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 site design constraints and the preferences of the homeowner. On-lot infiltration practices

Figure 4.26: A rain barrel that collects runoff from a roof gutter downspout.

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 practices are simple compared with many other runoff management practices, the design needs to incorporate the same basic elements of any runoff management practice. Pretreatment is important for all of these practices to ensure that they do not become clogged with leaves or other debris. Infiltration practices may 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 set at the bottom of the device so the homeowner can use the stored water for irrigation or other uses by attaching this hose to a standard garden hose and controlling flow with an adjustable valve.

One important design feature of on-lot infiltration practices is that the infiltration area be located sufficiently far from the house's foundation to prevent undermining of the foundation or seepage into basements. The infiltration area should be separated from the house by at least 10 feet to prevent these problems.

Infiltration practices require regular removal of sediment and debris settled in the pretreatment area and need to be replaced when the practice 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 a cost per unit area treated basis, 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. For many of these practices, homeowners can reduce costs by creating their own on-lot practice rather than purchasing a commercial product.

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, including 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.

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 *www.dot.ca.gov/hq/construc/stormwater.html*.

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 *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 of detailed technical information on runoff control practices, including step-by-step design examples. Both volumes of the manual are available for download at *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, the concentration of development, headwater streets, stream buffers, green parking lots, and other land planning topics. The document is available for purchase from MWCOG at *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 *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 *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 *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 *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 *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 site, accessible at *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 *www.ecy.wa.gov/programs/wr/sw/if-ver12.pdf*.

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Management Measure 6
New and Existing On-site Wastewater Treatment Systems

A. Management Measure

Develop or maintain on-site wastewater treatment system (OWTS) permitting and installation programs that adequately protect surface 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 cause surface or ground water impairment.
- Requirements for system selection, siting, design, and installation based on performance requirements, prescriptive technologies, protective setbacks, and separation distances that protect surface and ground water resources.
- Education, training, licensing, and/or certification programs for system designers, site evaluators, permit writers, installers, inspectors, and other service providers.
- 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:

- Development of system inventories and assessments of maintenance needs to provide management information regarding the types of systems in use, 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 the 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) is reused or disposed of in a manner that does not present significant risks to surface waters or ground resources.

B. Management Measure Description and Selection

1. Description

When properly planned, designed, installed, operated, and maintained, OWTSs can effectively remove or treat contaminants such as pathogens, 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 4.12). 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, biochemical oxygen demand (BOD), and other chemicals described in Table 4.13.

Table 4.12: 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.
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.

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 overenrichment 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, 2002a).

Table 4.13: 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.

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).

OWTSs can generally be divided into two categories: conventional systems and alternative or innovative systems.

Conventional systems (see Figure 4.27) 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 or perforated pipe wrapped in 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 profiles. 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

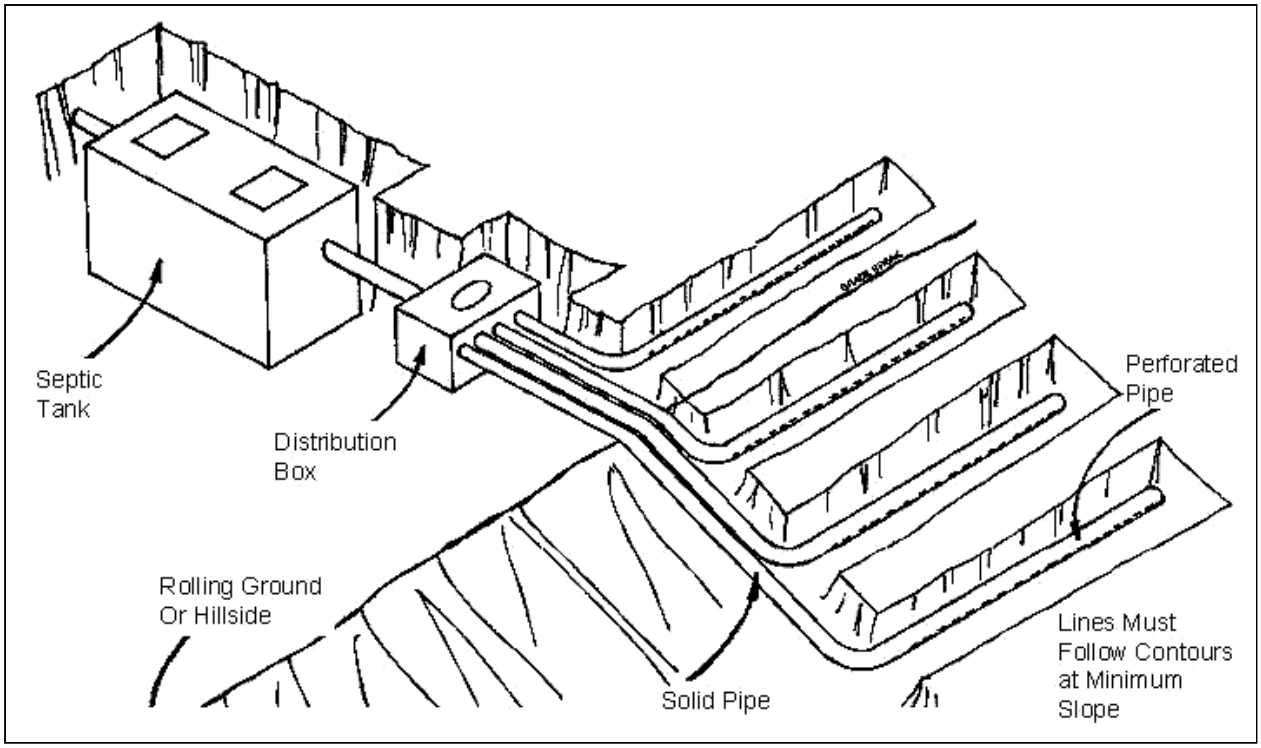

Figure 4.27: Conventional on-site wastewater treatment system.

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, see *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 and the density and cumulative discharge of existing and future 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, including 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 recently issued draft *EPA Voluntary National Guidelines for Management of Onsite/Decentralized Wastewater Treatment Systems* (USEPA, 2002a), 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 draft 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/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 urbanized areas, require periodic attention and regular servicing to ensure that treatment levels meet established performance requirements. Management programs must ensure continuous compliance with performance requirements by ensuring that sludge is pumped from tanks periodically, failed or failing systems are detected promptly and repaired or replaced, and undersized or underperforming systems are upgraded when necessary.

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, "blue-baby" syndrome, nutrient enrichment, dissolved oxygen loss). This management measure supports a performance-based approach to

system management and is consistent with the *EPA Voluntary National Guidelines for Management of Onsite/Decentralized Wastewater Treatment Systems* (USEPA, 2002a) and the *Onsite Wastewater Treatment System Management Handbook* (USEPA, 2002b).

C. Management Practices

The following management practices correspond to the management measures listed in Part A of Management Measure 6.

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 not all on-site regulatory agencies or management programs will have the ability to implement performance-based approaches because of a lack of staff expertise, assessment data, regulatory infrastructure, public support, and other resources needed to implement such an approach.

Therefore, alternative approaches, which include prescriptive standards that provide appropriate levels of human health and water resource protection, are included among the acceptable management practices summarized in this section. These standards, which 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) will be considered acceptable management practices if they are demonstrated to provide reasonable assurances that they will protect 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 Part A of this section.

a. 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, including a wide range of environmental characteristics (e.g., ground water, topography, soils, climate, sensitive ecological resources), the locations and types of facilities that might be part of an overall wastewater management plan, the organizational and institutional structures that exist or might need to be created, and financial support for their development and implementation. At a minimum, planning should include the identification of areas where installation of conventional systems can be allowed at specified densities, areas where alternative systems might be required, and areas where on-site systems might be permitted only under strict design and performance requirements and assurances for long-term monitoring and maintenance.

(1) *Comprehensive planning*, if available in the area, 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 requirements that

- Specify prescriptive or performance requirements for individual or clustered systems installed in unsewered areas, preferably by watershed, subwatershed, or ground water recharge areas.

- Limit, manage, or prevent development on sensitive natural resource lands or in designated critical areas (e.g., wellhead protection zones, shellfish habitat runoff catchments, near nutrient-sensitive waters and wetlands).

- Encourage development within urban growth areas serviced by sewer systems, if adequate capacity exists.

- Consider factors such as system densities, hydraulic and pollutant output, proximity to waterbodies, soil and hydrogeological conditions, and water quality in planning and zoning decisions. Large numbers of soil-based on-site systems discharging to a confined area (e.g., high-density subdivision developments) can overwhelm the capacity of soils to assimilate and treat wastewater (i.e., remove pollutants of concern such as nutrients and pathogens).

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 type of information needed for on-site system management. Some of these offices have the capability 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. Working with planning offices to designate ecologically sensitive areas and areas 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.

(2) *Wastewater treatment continuum concept.* Decisionmakers 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 the technology used, operational factors, system maintenance, and site-specific conditions (e.g., combined sewer overflows, bypasses, and nutrient removal requirements for centralized systems; 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 contained within the confines of each residential or facility lot.
- Better performing alternative on-site systems for each lot. Examples include sand filters, aerobic treatment units, or 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.
- 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 management entity should be charged with the responsibility for keeping collection and treatment systems working. The responsible management entity 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.

(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 only considered connecting to a regional POTW or constructing a treatment facility. Factors to consider other than costs when deciding whether it is beneficial to construct a new treatment plant or extend service lines of a nearby system include the following:

- Age and operational history of existing OWTSs.
- Future housing and other development trends based on land use planning information.
- Proximity and carrying 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.

- Hydrological impacts and catastrophic risk assessment due to failure of collection systems and POTWs.

b. 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 that discharge pathogens to 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 3 years were suggested to assist homeowners with increased system costs. Existing systems would only require nitrate removal in these areas when replacement was required.

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).

(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.
- 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 waterbodies, 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.

(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, 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 waterbody that ultimately receives treated wastewater effluent (ground water or surface water) and the present or projected uses of that waterbody (e.g., drinking water source, shellfish habitat, contact recreation). An example 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 the resource 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. 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 waterbodies, 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).

- Biochemical oxygen demand (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).

- Safety for operators and inspectors (e.g., protective gloves).

- 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. In other cases a combination of chemical and biological monitoring might also be used, as defined by the management program.

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 performance goals. 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.

(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 it 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 and 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 concentration 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.

(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), the sensitivity of aquatic

resources, and the 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 and 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. Lack of available concentrations of certain metals that retard phosphorus movement to nearby surface waters is one example.

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 bacteria, nitrogen, and phosphorus concentrations below requirements established to protect water quality can be sited closer to water resources if impact analyses determine that contamination risk is unlikely.

(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 the use of one or more of three evaluation approaches. These approaches can be classified as follows:

(a) *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 subwatershed. 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 is best accomplished in a backhoe pit 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 later with distribution piping and absorption trench stability and the disturbance could modify subsequent soil system performance.

(b) *Hydrogeologic-based*. Surface 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 that 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 long site visits to perform tests. 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.

(c) *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 be centrally managed to assure 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 research of soil surveys, geology, topography, surface 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 4.14 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 (*www.astm.org*). Surface and some subsurface characterization practices are shown in Table 4.15. The ASTM standard practice for characterizing subsurface conditions through test pit inspection is summarized in Table 4.16. These practices can be specified when hiring contractors and consultants.

Table 4.14: 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, waterbodies, 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
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 4.15: 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
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

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 (*www.dep.state.fl.us/gis/datadir/program2.htm*). 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 (*www.statlab.iastate.edu/soils/nssc*) provides county-level soil information nationwide. Regional soil permeability information and links to more detailed sites can be found at *www.epa.gov/nwapsurf/1999sept/iv20usmap.html*.

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 buildout, and other parameters (*www.buzzardsbay.org/nitrmang/bbploadcalc.xls*).

Table 4.16: 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

c. 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

Table 4.17: Survey of state certification and licensing programs (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
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.

from having compliance enforcement staff design systems that are under their jurisdiction, which is inherently bad practice for a regulatory agency.

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 4.17). Florida requires installers to meet certain minimum requirements, demonstrate experience, provide references, pass an examination, and complete 6 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 1 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 4.17). In addition, some states issue permits or grant exemptions that allow homeowners to design and install on-site treatment systems at their primary residence. 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 1 year of experience or a high school diploma or equivalent and 4 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.

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.

d. Inspection of new on-site wastewater treatment systems

Ensuring 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 that ensure proper installation include reviews of site evaluation procedures and findings and inspections of systems during and after installation. The review and inspection process should include the following:

- Preconstruction meeting of the owner, designer, regulator, and contractor.
- Inspection after delivery of components.
- Inspections during and after construction (e.g., during excavation, during installation of components, and after backfilling).
- Issuance of a permit to operate the system as designed and built.

Inspections should be conducted at several stages during the system installation process to ensure compliance with regulatory requirements. 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 to accommodate weather events, as construction during wet weather may compact, smear, or otherwise alter soil structure.

e. 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 water quality requirements of the water(s) receiving on-site system effluent. Design, operation, and maintenance information for these devices can be found in the *Design Manual: Onsite Wastewater Treatment and Disposal Systems* (USEPA, 1980) and the *Onsite Wastewater Treatment System Management Handbook* (USEPA, 2002b). Table 4.18 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 4.28, and a SWIS. Septic tanks perform the following four important functions:

- Removal of settleable and floatable solids, oils, and grease from raw wastewater.
- Storage of the removed solids.
- Partial anaerobic digestion (liquefaction) of settled organic matter.
- Flow attenuation.

Table 4.18: 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.

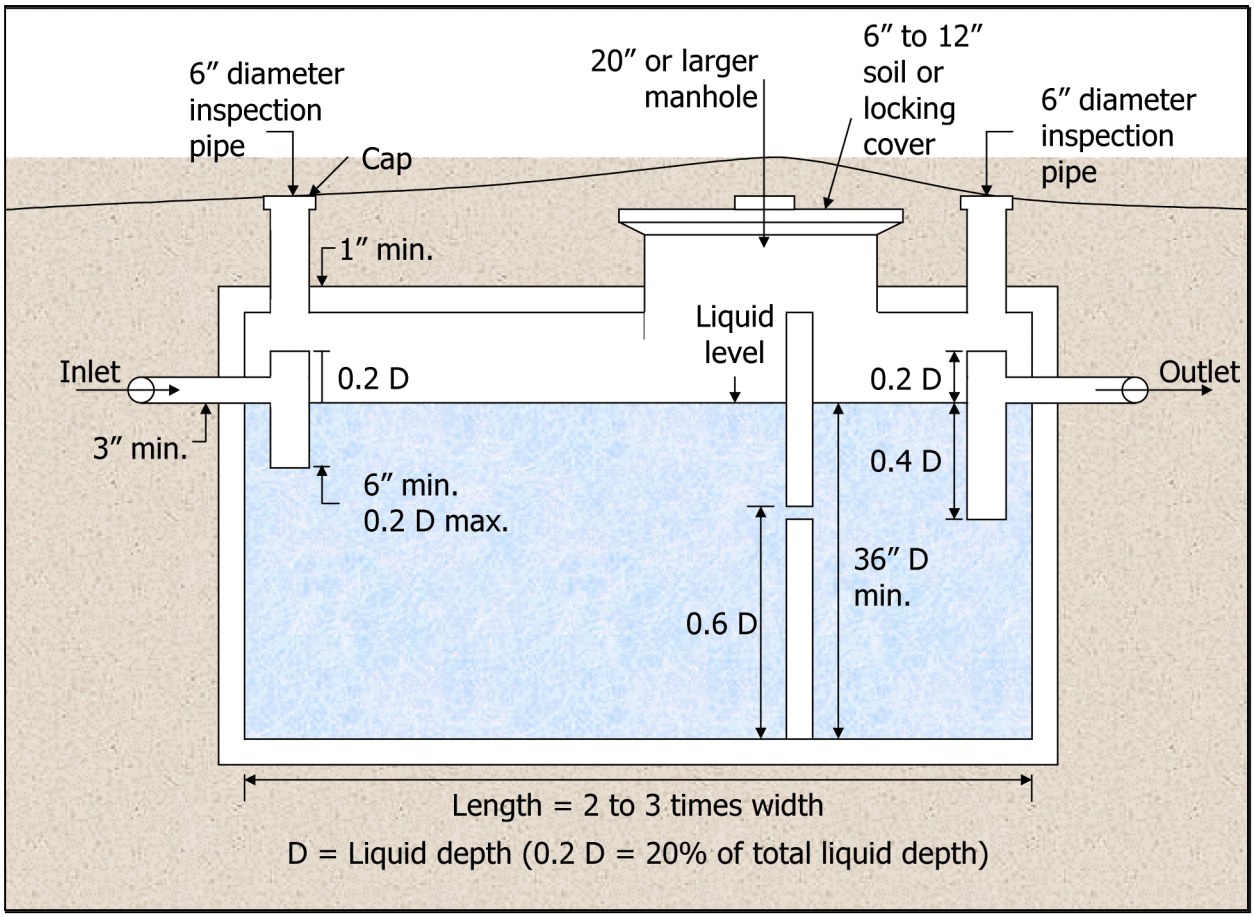

Figure 4.28: Septic tank detail (University of Missouri Extension Service, 1997).

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. 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-fed 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 the system. 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 design 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.

(1) *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 increased 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 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 tanks and polyethylene tanks are preferred over tanks constructed of metal, redwood, concrete block, brick, or other materials, unless the latter are lined 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 be extended 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 waterbody, but this setback might not be adequate in some cases (e.g., high-porosity soils, high water tables).

(2) *Subsurface wastewater infiltration systems*

Infiltration trenches are the most widely used method for treating and dispersing septic tank effluent. 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 siphon after a predetermined quantity of effluent has accumulated. Uniform application similarly 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 that 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 6 months to a year to restore their effectiveness.

Most SWISs are designed to oxidize carbonaceous organics and to convert the ammonium in septic tank effluent to nitrate by providing an aerobic environment. Nitrogen removal capabilities of SWISs are minimal and are partly dependent 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 organics or minerals, 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 5 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. Seepage from the SWIS that reaches the ground water where unsaturated soil depth is inadequate 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.

(3) *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 one-half-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 recirculating sand filters (Table 4.19), which have been shown to normally remove approximately 50 percent of the total nitrogen from residual wastewater (USEPA, 1993b and 2002b). Other innovative and alternative systems have been developed to address a number of 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 entering 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 media. Table 4.19 presents an estimated performance summary for a variety of treatment technologies.

Table 4.19: 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 STEa	Domestic STE with N-removal recycleb	Aerobic unit effluent	Recirculating sand filter effluentc	Recirculating foam or textile filter effluentc	
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.

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) 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).

(4) *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 for "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 2 years.

More information on the alternative technologies described below is available from the National Small Flows Clearinghouse Environmental Technology Initiative (*www.estd.wvu.edu/nsfc/NSFC_ETI.html*) and EPA (*www.epa.gov/owm/decent/treat.htm*). An extensive list of links to public and private sector OWTS resources can be found at *www.dal.ca/~cwrs/cdwt/links.htm*. For information on loading rates, design, and performance capabilities for conventional and alternative treatment systems, refer to the *Onsite Wastewater Treatment System Management Handbook* (USEPA, 2002b). Table 4.20 provides a summary of capital and maintenance cost data for selected OWTS technologies that are summarized in the following section.

Table 4.20: Summary of estimated capital and operation and maintenance costs for OWTSs (Hoover, 1997).

System Type	Costs (dollars)					
	Total materials & installation	Present value of total O&M	Total over life of system	Amortized monthly materials & installation	Average monthly present value of O&M	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

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.

Table 4.20 (continued).

System Type	Costs (dollars)					
	Total materials & installation	**Present value of total O&M**	**Total over life of system**	**Amortized monthly materials & installation**	**Average monthly present value of O&M**	**Average monthly over the life of the system**
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
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

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.

Regardless of the type of soil, sand, or other medium used for the absorption field, some sort of minimal maintenance is often required. In addition to periodic tank pumping, 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.

(5) *Elevated systems*

Mound systems are alternative soil absorption systems that are typically used at sites where insufficient ground water separation distances or slow-permeability soil conditions exist (see Figure 4.29). 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 that 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 site conditions than sites where mounds would be needed (Converse and Tyler, 2000).

Pollutant removal effectiveness and operation and maintenance is similar to conventional systems with pressurized distribution (see Tables 4.8 and 4.9). Installation of a mound system is more expensive than a typical soil absorption trench system. Costs for a complete mound system, including a septic tank, are 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,

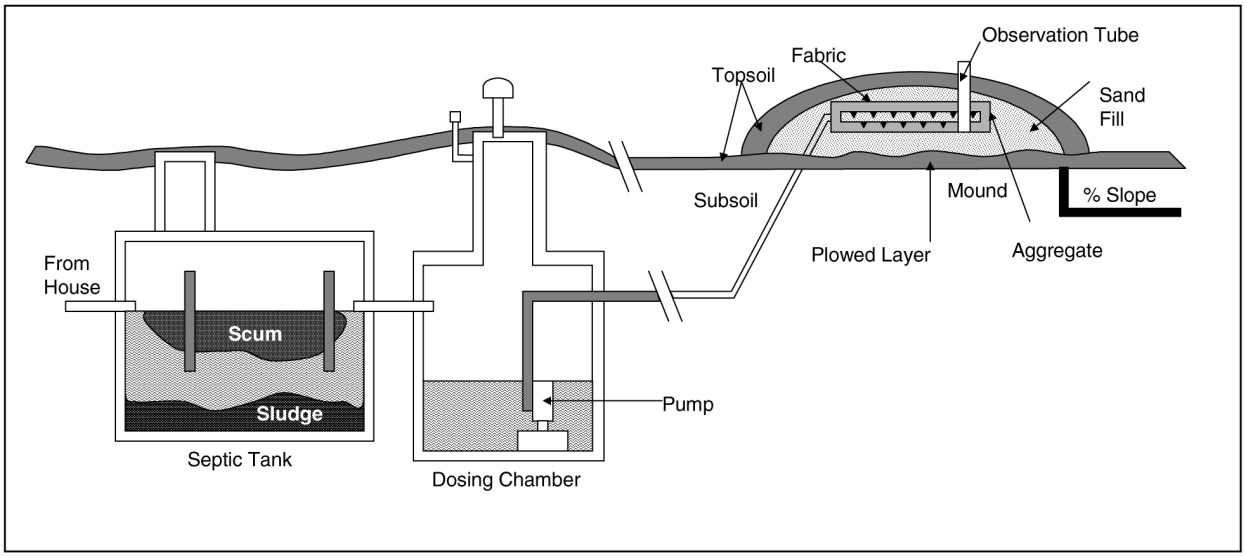

Figure 4.29: Schematic of a typical mound system (Ohio State University, no date).

float switches, tank, and dosing chamber; and maintenance of vegetative cover (i.e., grass) to prevent erosion.

(6) *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 include insulation in cold and wet weather regions.

Intermittent media filters might become clogged as the pore space between the grains of the medium begins to fill with inert and excessive amounts of 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 3 to 4 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, 2002b). Installation costs range 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.

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).

(7) *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 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 retrofit 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 effluent monitoring, 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.

(8) *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

Case Study: 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.

conditions) to the bottom of the AUF and up through the filter to the top, where a collection pipe transports the effluent to a dosing chamber 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.

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. Costs for the filter vary by manufacturer and are 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.

(9) *Cluster systems*

For the purposes of this guidance, a cluster system is defined as a collection of individual on-site systems where primary treatment occurs in septic tanks at each site. Septic tank effluent is collected and routed to another site for further treatment. Other designs where 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 because of inadequate area at individual homes or availability of better soil at a neighborhood location.

(10) *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 4.30), are designed primarily to reduce BOD and suspended solids concentrations in wastewater effluent from the septic tank. VSBs are usually underlain with an impermeable liner (e.g., plastic sheeting), are horizontal flow gravel filters with wetland-type vegetation (e.g., cattails, canna lilies). 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 incorporate 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

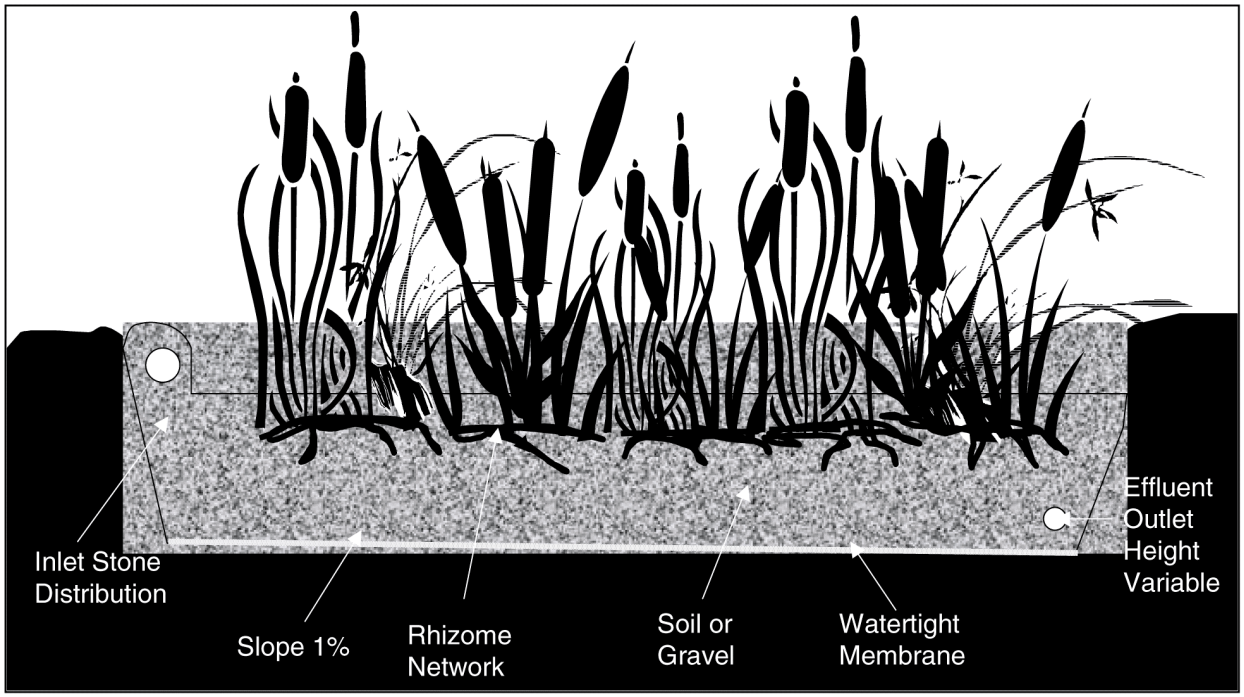

Figure 4.30: Components of a vegetated submerged bed.

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). Costs for VSBs can be estimated at 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 that wastewater levels do not rise above the filter medium.

(11) *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 deliberations 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. While SBR cost, operation, and maintenance requirements are greater than those of conventional on-site systems, they might be suitable alternatives for sites where high-density development and/or unsuitable soils preclude

adequate treatment of effluent by conventional systems. SBRs for on-site use can be purchased in package plant modules.

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.

(12) *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 might 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 3 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 a 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 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.

(13) *Fixed film systems*

Fixed film systems feature media (plastic disks, pellets, gravel) 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 medium) 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.

(14) *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, which provides for 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 distributors are plowed in at even more shallow depths and should be preceded by pretreatment greater than a septic tank to prevent clogging of emitters (USEPA, 2002b).

(15) *Evapotranspiration*

Evapotranspiration (ET) systems are designed to remove wastewater through evaporation and transpiration and are used mostly in dry climates (e.g., Arizona, New Mexico). They have been used in wetter climates for several homes 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 and for use by plants or it 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. Costs for installation are $10,000 to $15,000, but operation and maintenance costs are generally quite low.

(16) *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. 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. Prior to spraying, it is recommended that effluent be treated to remove most BOD to prevent odors. Spray devices should not be activated during wet weather,

freezing temperatures, or saturated conditions. Large buffer areas around the spray sites are usually required, so that land requirements are quite large, limiting this option to only very large lots.

(17) *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 the system's 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 required. 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 a high quality influent (BOD of 30 mg/L and TSS of 30 mg/L or better) to have 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 UV bulb replacement 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.

(18) *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 10 to 20 cents/gallon for pumping and hauling.

(19) *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 when used. These systems require frequent pumping, which can be expensive if the total wastewater flow is contained.

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 be 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 public health and environmental resource protection, 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 accomplished only under 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 be dependent 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 3-month period during 1997, with 31,000 reports of four or more breakdowns at the same home. Typical reported failure 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). In some areas of Connecticut it has been estimated that 4 percent of on-site systems fail each year. The failure rate might be greater because many on-site systems are approved in areas with unsuitable soil conditions.

Reported failure rates may underestimate the 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 partial and total system failure rate estimates in some states range as high as 50 percent and more in some cases, but definitions of failure were highly variable, including all systems that were not designed by their 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 public health and water quality protection. 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, system technologies, and case studies from across the nation is available from EPA at *www.epa.gov/owm/decent* and from the National Small Flows Clearinghouse at *www.estd.wvu.edu/nsfc/NSFC_NODP.html*. A model framework for management programs and other information on OWTS issues is posted by the National On-site Wastewater Recycling Association at *www.nowra.org*.

a. Development of system inventories and assessment of maintenance needs

Comprehensive planning based on inventories of existing systems and planned locations for new ones can provide valuable information and support for on-site system management. At a minimum, planning should include the identification of the planning region; program goals; location of on-site systems and supplemental information; and coordination of multiple agencies involved in health, resource protection, and economic development activities.

Inventories of systems with supplemental information (e.g., owner, contact information, system type, location, installation date, design capacity, date of last service) are recommended to ensure that all owners receive operation and maintenance information. 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 included advisory groups, homeowner education meetings, news media 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 5 years old unless a complaint or other reports 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).

Some data necessary for on-site system management might 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 management agency should ensure that data on existing systems are available to health and water resource organizations so that their activities and analyses reflect this important aspect of public health and environmental protection.

Under management programs that rely on homeowners for system O&M, education initiatives for system owners are an important component of the outreach program. These 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 O&M 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 the following:

- 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 O&M practices, procedures, and timetables.
- How delaying septic tank pumpout can cause solids to clog infiltration systems.
- 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 and help target remediation and prioritization actions to sources primarily responsible. Models can also be constructed that predict impacts from proposed development and suggest guidance on performance requirements for on-site systems in proposed development areas.

b. Management, operation, and maintenance policies

There are three basic approaches for developing and implementing a management program (see below). In addition, EPA has proposed and will soon finalize *EPA Voluntary National Guidelines for Management of Onsite/Decentralized Wastewater Treatment Systems* (see *www.epa.gov/owm/decent/index.htm* 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 4.21). Adoption of the guidelines as appropriate to the level of risk and value of resources affected by on-site systems is strongly recommended. Table 4.22 shows an example matrix of different on-site system management program elements and functional responsibilities.

Management options for on-site systems are as follows:

(1) *Voluntary.* An effective voluntary program develops recommended guidelines and educational materials and to distribute 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 *www.extension.umn.edu/distribution/naturalresources/DD6583.html*. Another equally useful guide can be found on the North Carolina Cooperative Extension web site at *ces.soil.ncsu.edu/soilscience/publications/Soilfacts/AG-439-22*.

Table 4.21: 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 O&M needs	– Owner awareness of permitting program, installation, and O&M needs – Compliance with codes and regulations	– Only conventional systems allowed – Prescriptive design and site requirements – Owner education to promote O&M – 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 O&M requirements – Allowances for approved alternatives – O&M 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 of change of use triggers compliance assurance inspection
Utility O&M	Public or private utility/entity assumes O&M 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 O&M responsibility
Utility ownership	– Public or private utility/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 – Utility responsible for O&M – Utility finances installation, repairs

(2) *Regulatory*. Under this approach, the regulatory authority—typically a district or local health department—oversees and enforces an on-site system design, permitting, installation, operation, and maintenance program 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 the case in Washtenaw County, Michigan (Washtenaw County, 1999), the Code of Massachusetts Regulations, or other state and local statutes. Financial incentives and disincentives usually aid compliance and 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.

Table 4.22: Program elements and functional responsibilities example matrix.

Program Element	Responsible Party							Comments
Planning								
Stakeholder involvement process								
Watershed assessments								
Sensitive 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 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 O&M 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

(3) *Direct management*. Another option for managing and maintaining on-site systems is through a wastewater 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 being responsible for system O&M, is a means to ensure that small wastewater systems in a designated area function properly and do not threaten ground water or surface water resources. State legislation that enables the creation of 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.

Case Study: 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.

On the other hand, the regulatory authority 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 charge 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 Administrative Code, 1997). Procedures that can be used to apply the wastewater management district concept to a specific problem area include the following:

- Research relevant legal and regulatory issues.
- Conduct a thorough site investigation.
- Identify the specific geographic area to be included within the wastewater management district.
- Select the performance standards to be met and typical means of attaining them.

- Prepare accurate cost estimates.
- Receive approval from ratepayers within the proposed district for the creation of the management district.
- Prepare and adopt regulations, as needed, to establish the wastewater management district.
- Adopt a management strategy (including operational, administrative, and financial processes).

A variety of resources are available to help management entities explore the concept of establishing an on-site wastewater management district. The National Small Flows Clearinghouse (1997) has published a series of overview documents outlining issues to consider in management district development (see *www.estd.wvu.edu/nodp4/index.html*). Also, the city of Austin, Texas, provides online resources related to its study of management district establishment (see *www.ci.austin.tx.us/wri/altern.htm*).

Case Study: 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.

c. Inspection and monitoring programs

On-site management programs should ensure that on-site system impacts are considered by regional planners, water resource management agencies, source water protection programs, and economic development interests. It is difficult to discuss current and likely future on-site wastewater impacts without a means of inventorying existing and new systems, conducting inspections, providing monitoring data, or responding to treatment failures. 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 clicking onto 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.

(1) *System inspections*

In general, basic on-site system operation and performance inspections should check for the following (USEPA, 2002b):

- 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 since the system was installed.
- Surface drainage patterns in the area of the tank and infiltration field.
- Broken or open tank access covers or doors.
- Sludge or scum buildup in septic tank; clogging of tank filters (if present).

More detailed inspections of the system are recommended if there is evidence of a problem. A detailed system performance monitoring inspection 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 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. 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 their inspection requirements are less stringent than other states. Inspections are discussed further in *EPA Voluntary National Guidelines for Management of Onsite/Decentralized Wastewater Treatment Systems* (www.epa.gov/owm/decent).

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 O&M 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 that property transfers be accompanied by a 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 3 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 that inspectors be certified. New Hampshire requires an assessment and 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

Case Study: 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).

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).

water and ground water monitoring. If indicator pollutants (e.g., fecal coliform as an indicator of potential pathogen contamination) are found during the monitoring, nearby on-site systems should be inspected to determine whether they are the 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 lake 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.

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 *www.state.ri.us/dem/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 *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 *www.dal.ca/~cwrs/cdwt/links.htm*. The Wayne County (Ohio) Health District also has an extensive list of links on its site (*wchd.neobright.net/wc_wastewater_tx2.html*).

(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 also 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 have public health impacts 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 4.23). Several states have implemented specific water conservation practices (USEPA, 1998). 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 4.23: Comparison of current and federally mandated flow rates and flush volumes (USEPA, 1998).

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 4.24) 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 4.24: 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%)

d. 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 O&M. 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 decreasing 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 3 to 5 years in lieu of a regular inspection program. Failure will not occur immediately if a septic system is not pumped out regularly. However, continued neglect will cause the SWIS to fail because it is no longer protected from greases, oils, and solids and might need to be replaced, often at considerable expense.

Responsibility for ensuring proper O&M 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 system owners understand their responsibilities. 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 *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 of septage 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 *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 decisionmaking 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 resources to potentially toxic or hazardous chemicals and pathogenic organisms found in septage. Other key areas of residuals management programs include tracking or manifest systems that identify septage sources, pumpers, transport equipment, final destination, and treatment, along with procedures for controlling human exposure to residuals, including vector control, wet weather runoff, and access to disposal sites.

Information Resources

The *Onsite Wastewater Treatment System Management Handbook* (EPA, 2002b) 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 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; (5) ownership and management by a public or private management entity. Each of these model programs include 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 *www.epa.gov/owm/decent/index.htm*.

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 *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 (*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 their publications page (*www.asae.org/pubs/pubcat/waste.html*). ASAE also has a searchable library of technical articles (*asae.frymulti.com*), many of which pertain to OWTSs.

The National Onsite Wastewater Recycling Association (NOWRA) web site, which can be accessed at *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.

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Management Measure 7
Bridges and Highways

A. Management Measure

Plan, design, operate, and maintain highways and bridges to

- Protect sensitive ecosystems, including wetlands and estuaries, by minimizing road-building mileage in those systems, minimizing the number of water crossings, and establishing protective measures including setbacks during construction.
- Limit runoff of pollutants through the use and proper maintenance of structural controls.
- Limit generation of pollutants from maintenance operations by minimizing the use of pesticides, herbicides, fertilizers, and deicing salts and chemicals.
- Limit generation and runoff of pollutants during highway and bridge repair operations by reducing the use of hazardous materials and incorporating measures to prevent spillage into sensitive areas.

B. Management Measure Description and Selection

1. Description

Motor vehicles generate runoff pollutants through emission and deposition of automobile exhaust and through discharges of both fluids and solid particles during travel and while braking. In a study of traffic-generated particulates in Cincinnati (where the average daily traffic 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 and control of petroleum hydrocarbons in urban runoff from four land uses: all-day parking lots, streets, gas stations, and convenience commercial areas. Shepp found that convenience commercial areas had the highest hydrocarbon concentration (see Figure 4.31). Evaluation of the observations 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.

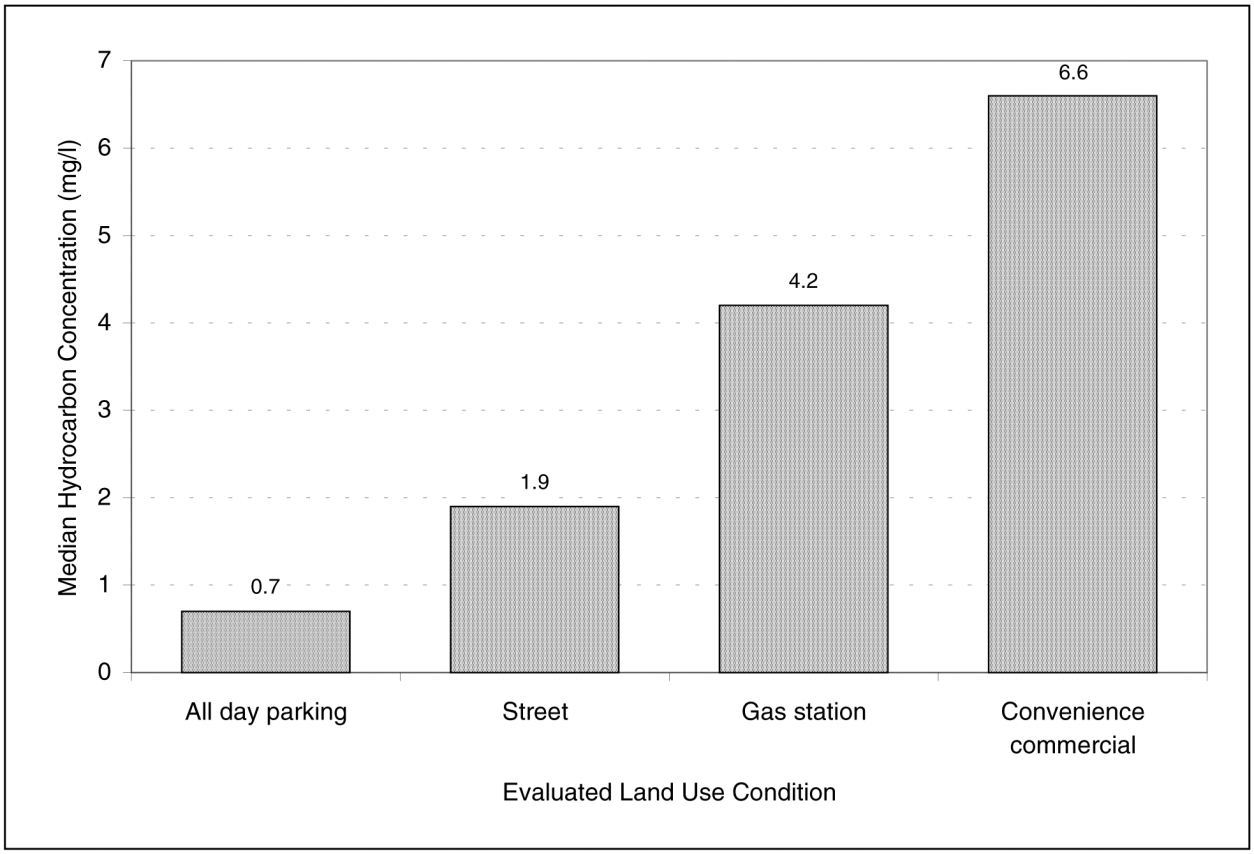

Figure 4.31: Median hydrocarbon concentrations by land use (Shepp, 1996).

The National Water Quality Assessment Program (NAWQA) of the U.S. Geological Survey 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).

Roads tend to accumulate particulate matter from roadsides, salting and sanding, dirty cars, brake pad dust, aerial deposition, and road 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 long-duration, high-intensity events but 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 a carrier for other pollutants that adhere to particle 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 c).

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 predominately dissolved in highway runoff, a phenomenon they attributed to low urban rainfall pH and alkalinity and relatively short pavement residence times. Other metals predominately found in the dissolved phase in highway runoff were zinc, cadmium, and copper (Sansalone and Buchberger, 1997; Sansalone and Glenn, 2000).

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 are shown in Table 4.25 along with their likely sources. 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 4.26 shows the range of values for highway contaminants presented by Newbry 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 4.25: 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 4.26: Range of average values for runoff contaminant concentration for selected highway contaminants (Newbry 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.

- *Polycyclic aromatic hydrocarbons (PAHs)* include compounds such a 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).

Paved roadways often generate higher loads of metals and toxicants than other nonpoint source pollutants. Nutrient loadings from highways tend to be of concern when they are located upstream of a reservoir or estuary. It should be noted that several recent studies cited by the Federal Highway Administration 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).

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 unpublished studies, Sansalone and Glenn (unpublished a, b, and c) examined the characteristics of snowbanks and snowmelt. Table 4.27 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 predominately 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 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 and 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 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 4.27: Results of three studies that analyzed chemical and physical parameters of snowmelt (Sansalone and Glenn, unpublished a, b, and c).

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 gradually 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.

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 watershed protection; site development; new development runoff treatment; and construction site erosion, sediment, and chemical control management measures (Management Measures 3, 4, 5, and 8) discussed previously are also applicable to the planning and constructing of highways and bridges.

C. 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.

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 to minimize mileage through sensitive environments, such as wetlands and estuaries. River crossings should be minimized, and sufficient setbacks should be established during construction to minimize disturbance of the surrounding environment.

Highway development is most disruptive in wetland areas because it increases sediment loss, alters surface drainage patterns, changes the subsurface water table, and results in loss of wetland 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.

2. Structural 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 readily. Installation of bioengineering practices can be labor-intensive, and periodic inspection and maintenance, especially after large storm events, is necessary to repair slumps and replace dead vegetation. Several kinds of soil bioengineering practices are described by the U.S. Department of Agriculture (USDA, 1992):

a. 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 by 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.

b. 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.

c. 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.

d. 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 greater than 4 feet deep or 5 feet wide.

e. 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.

f. 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.

g. 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.

h. 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.

i. 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.

j. Other runoff and sediment controls for highways

Other runoff controls, such as grassed swales, wet ponds, extended detention dry ponds, storm water wetlands, and grassed filter strips, 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.

Low Impact Development along Highway Rights-of-Way in Lenexa, Kansas

The City of Lenexa, Kansas, has proposed to treat nearly 100% of the first inch of runoff from the Prairie Star Parkway using a combination of bioretention areas, a constructed wetland, and a wet pond. Off-site drainage from upstream development will bypass the bioretention areas, be directed into a sediment forebay, and eventually be treated by the constructed wetland.

3. Structural Runoff Controls for Bridges

a. 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. More recently, bridge designs have taken into account potential effects of runoff pollutant loadings, especially on waterbodies. 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 Federal Highway Administration (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 following:

- 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 have often created more problems than they have prevented.

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 might not be a cost-effective approach to minimizing the impacts of bridge runoff. 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. 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. 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 might be more cost-effective when a watershed approach is used.

b. 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 might be more cost-effective than others.

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 is required to prevent corrosion, can be a significant source of pollutant loads if proper management practices are not used.

Although most construction activities take place away from waterbodies, bridge operation and maintenance activities occur within close proximity to a waterbody. Therefore, management practices to minimize potential adverse effects on the surrounding environment are recommended.

a. Enclosures

The following types of enclosures can be used to collect pollutants during bridge maintenance activities:

(1) *Free-hanging enclosures*. Free-hanging enclosures include tarps, drapes, plastic sheeting, screens, and rigid panels in which only two corners or one side of the sheeting or panel is supported. Free-hanging tarps generally result in 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, the structural adequacy of the enclosure, portability, and reusability. Enclosures may 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 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 structure 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.

b. Containment and collection

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 waterbody.

(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).

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 a precipitation event. 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.

a. Eliminate curbs

Curb systems act as traps for particulates and other pollutants. 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 direct runoff to pervious areas. The advantage to curbs is that they trap pollutants on the paved surface, and when combined with regular vacuum street sweeping programs (where available), they can be effective at removing pollutants prior to mobilization in runoff.

b. 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 waterbodies. 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.
- 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.

c. Manage pesticide and herbicide use

Overapplication of pesticides and herbicides results in excess chemicals being readily leached from the soil by rainfall into surface runoff or underlying ground water. 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, 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 waterbodies.

d. 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 C.2).

e. 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.

f. 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.

g. Practice spill prevention and control

Prevention and control of spills eliminates or minimizes the discharge of pollutants to waterbodies. Waterbodies 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 can be used in an emergency to contain a spill.

h. 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 waterbodies 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.

i. 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 the 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.

j. 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 the Transportation Research Board (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 such that they come in contact with precipitation or runoff. Chemicals can also enter receiving waters if chemically treated, plowed snow is piled in areas that are connected to receiving waters via impervious surfaces. For example, piling salted snow on a parking lot surface can result in runoff of the chloride-laden water directly to a stream or runoff treatment pond. 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 impacts 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 that they can reduce 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 prewetting 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 against savings in labor and materials. Successful use of the RWIS leads to fewer applications of deicing materials and fewer snowplow trips. 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.

(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 4.28). 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.

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.

Table 4.28: 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 – Corrosivity
Alternative deicing chemicals	– Reduced corrosivity – Reduced impact on the environment – $CaCl_2$ can be used in very low temperatures (-20ºF)	– Higher cost (from a couple hundred dollars per ton to a couple thousand per ton) – CMA starts to act at a slower rate than salt

(3) *Proper deicing chemical storage.* Storage buildings for deicing chemicals minimize the likelihood of polluting surface and ground waters with contaminated runoff and eliminate the economic cost of 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.

Information Resources

The California Regional Water Quality Control Board produced *the Erosion and Sediment Control Field Manual* for the San Diego Region in 1998. To order, send a printable order form, which is available at *www.swrcb.ca.gov/stormwtr/orderform.html*, along with payment, to P.O. Box 791, Oakland, California 94604-0791.

The Federal Highway Administration 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 stormwater 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*, which is 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 *www.qc.dfo_mpo.gc.ca/iml/en/env/habitat/pont.htm*.

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 *www.novaregion.org/pdf/NVBMP_Handbook.pdf*.

Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs (Schueler, 1987), is available for purchase from the Metropolitan Washington Council of Governments at *www.mwcog.org/ic/87703.html*.

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 *trb.org*.

The Transportation Research Board has published several studies that investigate the environmental impacts of activities related to transportation infrastructure. These publications are available at *www4.trb.org/trb/onlinepubs.nsf*.

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 *www.engr.colostate.edu/~cwatson/ce_old/CE_610_class_notes_S02/scs_1992.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 *isddc.dot.gov*.

The Federal Highway Administration (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 conditions 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, 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 *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 *www.mdot.state.mi.us/mappub/deicing*. More information on alternative deicers can be found at *www.betterroads.com/articles/prod801.htm*, *www.forester.net/xw_0106_deicing.html*, and *www.wsdot.wa.gov/fossc/maint/pns/htm/resources.htm*.

The Pacific Northwest Snowfighters Association web site (*www.wsdot.wa.gov/fossc/maint/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).

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Management Measure 8
Construction Site Erosion, Sediment, and Chemical Control

A. Management Measure

- 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.

B. Management Measure Description and Selection

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. These pollutants include sediment; pesticides (insecticides, fungicides, herbicides, and rodenticides); 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. For example, potential pollution associated with fertilizer use might be greater along a highway or at a housing development than it would be at a

shopping center development because highways and housing developments usually have greater landscaping requirements.

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 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.

a. 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 5.1 illustrates some of the sediment loading rates associated with construction activities across the United States. As shown in Table 5.1, 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 combat pests and diseases. First, losses of nutrients and nutrient holding capacity result in a less fertile environment for lawns and plants. Second, lost organic matter results in increased soil density and compaction, which can reduce the available water-holding capacity on-site. This reduction results in poorer plant growth and reduced infiltration of fertilizers and pesticides, which contribute to the transport of these chemicals by runoff into nearby lakes and streams. Third, organic matter is a food source and habitat for beneficial microorganisms and invertebrates. If organic matter is lost, 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 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). Finally, excessive erosion and sedimentation can reduce the capacity of reservoirs.

Case Study: 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.

The Miami River in Florida has been severely affected by pollution associated with upland erosion. This watershed has undergone extensive urbanization, which has included the construction of many commercial and residential buildings, over the past 50 years. Sediment deposited in the Miami River channel contributes to the severe water quality and navigation problems of this once-thriving waterway, as well as to Biscayne Bay (SFWMD, 1988).

Table 5.1: 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

b. 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. Overapplication of pesticides on revegetated areas can lead to contamination of soils and subsequent contamination of surface and ground water. The use of pesticides is controlled by federal or state regulations.

c. 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).

d. 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.

e. 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.

f. Construction chemicals

There are several sources of chemicals at construction sites. For example, chemicals like paints, acids for cleaning masonry surfaces, cleaning solvents, asphalt products, soil additives used for stabilization, and concrete-curing compounds might be used on construction sites and 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, might also be present and contribute to nonpoint source pollution. Improperly stored construction materials, such as pressure-treated lumber or solvents, can lead to leaching of pollutants to surface water and ground water. Persons disposing of construction chemicals should follow all applicable state and local laws, which may require disposal by a licensed waste management firm.

Improper fueling and servicing of vehicles can lead to significant quantities of petroleum products being dumped 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 might 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. These pollutants can be nearly impossible to control once present in runoff other than by the use of very costly water treatment facilities (Washington Department of Ecology, 1991).

After spill prevention, one of the best methods to control petroleum pollutants is to retain the sediments that contain the chemicals on the construction site through use of erosion and sediment control practices. Improved maintenance and safe storage facilities reduce the chance of contaminating a construction site. One of the greatest concerns related to 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.

g. Contaminated soils

Contaminated soils can be encountered during excavation activities that uncover previously known or unknown site contamination. Also, new contamination can result from a spill or leak of a hazardous material used at the construction site (a release from a material or waste storage area). If previously unknown contamination is encountered, the nature of that contamination might not be immediately known. Sampling and analysis will be required to determine what types of contaminants are present and, therefore, how the contaminated soil needs to be handled. Furthermore, extensive investigations might need to be implemented to determine the extent of contamination present.

2. Management Measure Selection

This management measure was selected to minimize sediment being transported outside the perimeter of a construction site by reducing erosion and retaining sediment on-site. Additionally, the management measure was selected because construction activities have the potential to contribute to increased loadings of toxic substances and nutrients to waterbodies. 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 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 ESCs specify designs and proper placement of practices, including soil stabilization, and procedures for installation and maintenance of practices, and they have been proven to be effective when followed at construction sites.

Case Study: Eugene, Oregon's goals for erosion and sediment control on construction sites

The City of Eugene, Oregon, requires all construction sites to employ, to the maximum extent feasible, management practices that meet a specified set of outcomes, 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.

- Current practice 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.

C. Management Practices

1. Erosion and Sediment Control Programs

a. Prepare erosion and sediment control plans

In many municipalities, erosion and sediment control plans are required under ordinances enacted to protect water resources (Table 5.2). 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 5.2: 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 waterbody. Stabilization must occur at completion or if no construction activity is to occur for 7 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 waterbody. 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 7 days of final grading or when there is no construction activity for 45 days.
Oklahoma	ESC plans required for sites over 5 acres.
Pennsylvania	ESC plans required for all sites, but the state reviews only plans for sites over 25 acres. Permanent stabilization must occur as soon as possible after final grading. Temporary stabilization is required within 70 days if construction ceases for more than 30 days. Permanent stabilization is required if the site will be inactive for more than 1 year.
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 7 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 7 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 might 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 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 basin 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.

ESC plans ensure that provisions for control measures are incorporated into the site planning stage of development, 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

- Planning and designing the development within the natural constraints of the site.
- Minimizing the area of bare soil exposed at one time (phased grading).
- Providing stream crossing areas for natural and man-made areas.
- Stabilizing cut-and-fill slopes caused by construction activities.

Structural controls include

- Installing perimeter controls.
- Mulching and seeding exposed areas.
- Installing sediment basins and traps.
- Using silt fences or filter fabrics.

Some erosion and soil loss is unavoidable during land-disturbing activities. Although proper siting and design help prevent areas prone to erosion from being developed, construction activities invariably produce conditions where erosion can occur. To reduce the adverse impacts associated with construction, the construction management measure suggests a system of nonstructural and structural erosion and sediment controls for incorporation into an ESC plan. Erosion controls have distinct advantages over sediment controls. Erosion controls reduce the amount of sediment transported off-site, thereby reducing the need for sediment controls. When erosion controls are used in conjunction with sediment controls, the size of the sediment control structures and associated maintenance may be reduced, decreasing the overall treatment costs (SWRPC, 1991).

b. Provide education and training opportunities for designers, developers, and contractors

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; more informally, municipalities can hold mandatory preconstruction or prewintering 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 for water quality

Case Study: 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*.

Case Study: 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.

protection; developing and implementing ESC plans; the importance of proper installation, regular inspection, and diligent maintenance of ESC practices; and recordkeeping for inspections and maintenance activities.

c. 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.
- 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.

d. 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 show 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.

e. 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.
- Revision and update of the local ESC manual.

An allowance item that acts as an additional "insurance policy" for complying with the erosion and sediment control plan 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 events, windblown objects, fallen trees or limbs, or high-velocity, short-term rain events 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 being in compliance 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 steam 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 were sampled in addition to several water chemistry variables and leaf litter decomposition rates. The researchers found the following 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.

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 5.3 shows cost and effectiveness information for several erosion control practices.

a. Schedule projects so clearing and grading are done during the time of minimum erosion potential

Often a project can be scheduled during the time of year that 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 6-month dry season (May 1 to October 31), temporary erosion and sediment controls might not be needed. In addition, in some parts of the country erosion potential is very high during certain parts of the year such as the spring thaw in northern and high-elevation areas. During that time of year, 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-site. Therefore, in the north, limitations should be placed on clearing and grading during the spring thaw (Goldman et al., 1986).

b. Phase construction

Construction site phasing involves disturbing only small portions of a site at a time to prevent erosion from dormant parts (CWP, 1997c). Grading activities and construction are completed and soils are effectively stabilized on one part of the site before grading and construction 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 accommodated.

- Determining the fate of already completed downhill phases.

– 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 5.3: Cost and effectiveness for 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 stabili-zation	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, that will be the only zone affected by enforcement. This approach can help to minimize liability exposure and protect the contractor financially (Deering, 2000b).

c. Practice site fingerprinting

Often areas of a construction site are unnecessarily cleared. Site fingerprinting involves clearing only those areas essential for completing construction activities, leaving other areas undisturbed. Additionally, 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.

d. Locate potential pollutant sources away from steep slopes, waterbodies, and critical areas

Material stockpiles, borrow areas, access roads, and other land-disturbing activities can often be located away from critical areas such as steep slopes, highly erodible soils, and areas that drain directly into sensitive waterbodies.

e. 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.

f. 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 so that construction equipment is kept away from the tree. A tree's drip line is the minimum area around the tree in which the tree's root system should not be disturbed 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 or the quantity of fill placed over the tree's roots.

g. Stockpile topsoil and reapply to revegetate site

Because of the high organic content of topsoil, it cannot be used as fill material or under pavement. After a site is cleared, the topsoil is typically removed. Since topsoil is essential to establish new vegetation, it should be stockpiled and then reapplied to the site for revegetation, if appropriate. Although topsoil salvaged from the existing site can often be used, it must meet certain standards, and topsoil might need to be imported onto the site if the existing topsoil is not adequate for establishing new vegetation.

h. Cover or stabilize soil stockpiles

Unprotected stockpiles are very prone to erosion, and therefore stockpiles 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.

i. Use wind erosion controls

Wind erosion controls limit the movement of dust from disturbed soil surfaces and include many different practices. Wind barriers block air currents and are effective in controlling soil blowing. 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.

j. Intercept runoff above disturbed slopes and convey it to a permanent channel or storm drain

Earth dikes, perimeter dikes or 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 of a slope to the bottom of the slope to convey concentrated runoff down the slope without causing erosion (Delaware DNREC, 1989).

k. 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. This keeps water from proceeding down the slope at increasing 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.

l. Use retaining walls

Often retaining walls can be used to decrease the steepness of a slope. If the steepness of a slope is reduced, the runoff velocity is decreased and, therefore, the erosion potential is decreased.

m. Provide linings for urban runoff conveyance channels

Often construction increases the velocity and volume of runoff, which causes 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 installed. The first choice of lining should be grass or sod because it reduces runoff velocities and provides 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.

n. 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.

o. Use seeding

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 areas where vegetation can be established. In very flat, nonsensitive areas with favorable soils, stabilization may involve simply seeding and fertilizing. The Soil Quality Institute (SQI, 2000) recommends that soils that have been 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. 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 (*www.reeusda.gov*) or Natural Resources Conservation Service (*www.nrcs.usda.gov*) office.

p. Use mulches

Newly established vegetation does not have as extensive a root system as existing vegetation and therefore 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 or other suitable materials on disturbed soil surfaces. Mulches and mulch mats used include tacked straw, wood chips, and jute netting and are often 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 2 to 6 months. Mulching

and/or sodding may be necessary as slopes become moderate to steep, as soils become more erosive, 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.

q. Use sodding for permanent stabilization

Sodding permanently stabilizes an area with a thick vegetative cover. Sodding provides immediate stabilization of an area 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.

r. 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 nondegradable 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 for soil filling and retention.

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).
- 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 feet per second and shear stresses of up to 8 lb/ft^2. 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 \$5.25/yd^2 to \$15.75/yd^2 (USEPA, 1999; adjusted to 2001 dollars using BLS, 2001). Factors influencing the cost of TRMs include

- The type of TRM material required.
- Site conditions, such as the underlying soils, the steepness of the slope, and other grading requirements.
- 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 \$9.20/yd^2 (adjusted to 2001 dollars using BLS, 2001). This cost was substantially less than the \$20/yd^2 estimate for the rock riprap alternative.

s. Use chemical stabilization

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 not only used for erosion control but is also employed in municipal water treatment, paper manufacturing, food and animal feed processing, cosmetics, friction reduction, mineral and coal processing, and textile production.

PAM is available in powder form or as aqueous concentrate, blocks and cubes, or 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; updated to 2001 dollars with BLS, 2001) 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 increased 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, the effects of PAM application 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. AMD has been shown to be both a neurotoxin and a carcinogen in laboratory experiments. 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, overapplication, or other accidents.

Minton and Benedict (1999) examined the use of polymers to clarify construction site runoff that had been detained on-site. The study was undertaken because traditional management practices did not reduce turbidity and sediments to the level desired by the city of Redmond, Washington, or to the level required to meet receiving water standards of the state of Washington, especially since several streams within the city limits had salmon fisheries.

Minton and Benedict 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 5.1). 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).

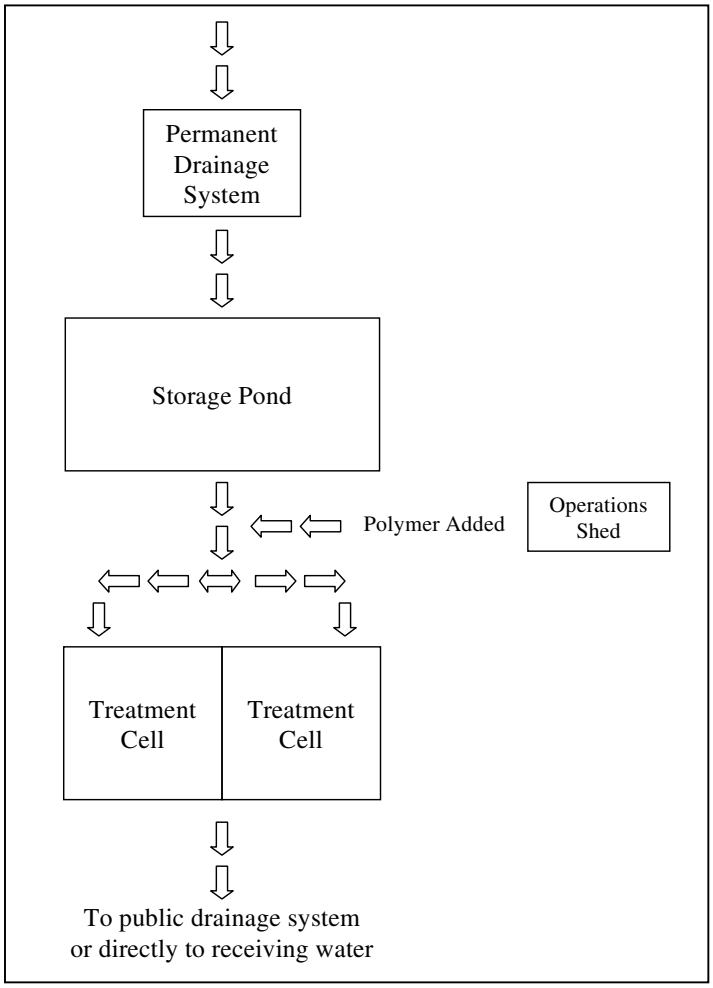

Figure 5.1: Schematic of the basic polymer treatment system (Minton and Benedict, 1999).

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. The duration of settling depended on the need to clear the treatment cell for further treatment. 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 5.4 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.

Table 5.4: Summary of operating performance data for six test sites (Minton and Benedict, 1999)[a].

	Polymer Dosage		Influent Turbidity		Effluent Turbidity		pH Control	
Site	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.

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.

t. Use wildflower cover

Because of the hardy drought-resistant nature of wildflowers, they may be more beneficial as an erosion control practice than turf grass. Though not as dense as turfgrass, wildflower thatches and associated grasses are expected to be as effective in erosion control and contaminant absorption. An additional benefit of wildflower thatches is that they provide 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 stand requires several years to become established, but maintenance requirements are minimal once established.

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 5.5 shows cost and effectiveness information for several sediment control practices.

a. 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 will be able 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.

Table 5.5: 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: \$0.73/ft^3 Range: \$0.24–\$1.58/ft^3 storage For more than 50,000 ft^3 of storage space: Average: \$0.36/ft^3 Range: \$0.12–\$0.48/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: \$0.73/ft^3 storage Range: \$0.24–\$2.42/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	\$3.50–\$9.10/linear ft	SWRPC, 1991; USEPA, 1992
Inlet protection	NA	NA	\$60–\$120/inlet	USEPA, 1993
Stabilized construction entrance	NA	NA	Without wash rack: Average: \$2,400/entrance Range: \$1,200–\$4,800/entrance With wash rack: Average: \$3,600/entrance Range: \$1,200–\$6,000/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: \$485/acre Range: \$250–\$1,200/acre Established from sod: Average: \$13,000/acre Range: \$5,500–\$58,000/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 Consumer Pricing Index (BLS, 2001). NA: Not available

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 (h:v).
- Safety fencing, perforated riser, dewatering (optional, seldom required).

Sediment basins can be classified as either temporary or permanent structures, depending on the length of service of the structure. 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. 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.

b. 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. Also, because it lowers to the bottom of the basin, 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 design storm event (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 5.6 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 5.6: 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.

c. 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 disturbed 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].)

d. 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 contributing length 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.

These conditions can be avoided with proper siting, installation, and maintenance. Silt fences typically have a useful life of approximately 6 to 12 months.

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.

e. 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.

f. 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.

g. Install vegetated filter strips

Vegetated filter strips are low-gradient vegetated areas that 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.

h. Use vegetated buffers

Like filter strips, vegetated buffers provide a physical separation between a construction site and a waterbody. The difference between a filter strip and a vegetated buffer area is that a filter strip is an engineered device, whereas a buffer is a naturally occurring filter system. Vegetated buffers remove nutrients and other pollutants from runoff, trap sediments, and shade the waterbody 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 so as to minimize the impact of construction activities on existing vegetation. Trees should be clearly marked at the dripline 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).

4. Develop and Implement Programs to Control Chemicals and Other Construction Materials

a. 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 material 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 washwater 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 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.

b. 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

- 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.
- Training program for designated on-site personnel.

A periodic spill "fire drill" should be conducted to help train personnel on proper responses to spill events and to keep response actions fresh in the minds of personnel.

c. 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.
- 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 spill 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 present. 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.

Information Resources

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 *www.epa.gov/npdes/pubs/owm0307.pdf* or it can be ordered from the National Service Center for Environmental Publications (NSCEP) at *www.epa.gov/ncepihom/index.htm* or by calling 513-489-8190 (Publication # EPA 833-R-92-001).

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 *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 erosion and sediment control and runoff control BMPs 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 *www.dlr.enr.state.nc.us/eropubs.html*.

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Management Measure 9
Pollution Prevention

A. 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 hazardous 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.
- Trash accumulation.

B. Management Measure Description and Selection

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. Some of the major sources include improper disposal of household hazardous wastes, lawn and garden activities, turf grass management, operation and maintenance of diesel and gasoline vehicles, illicit discharges to urban runoff conveyances, commercial activities, and pet wastes. 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. These practices are nonstructural in nature and reduce the amount of pollutants generated, thereby reducing the burden of treatment to maintain water quality. Costs of source control practices are typically associated with programmatic expenses such as signage, outreach materials, workshops, and development and enforcement of ordinances. Source reduction practices can reduce the quantity of runoff and the concentration of pollutants entering runoff treatment facilities, resulting in an overall cost savings from smaller sizes and less maintenance.

a. Household hazardous wastes

Household hazardous wastes can be defined as wastes that display any of the following characteristics: flammable, combustible, toxic, explosive/reactive, or corrosive. Household hazardous wastes can pose long-term threats to human health, wildlife, vegetation, and other environmental resources. Unlike industrial hazardous wastes, not all household hazardous wastes are regulated by federal, state, and local laws. In fact, the federal Resource Conservation and Recovery Act, which regulates other forms of hazardous waste, has a special exemption for household hazardous wastes (Kopel, 1998). The Federal Insecticide, Fungicide, and Rodenticide Act regulates the use and disposal of pesticides, herbicides, and fungicides through labeling.

Studies indicate that Americans generate 1.6 million tons of household hazardous wastes each year (Earth's 911, 2000). The following is a list of common household hazardous wastes that contribute to nonpoint source pollution (MPCA, 2002):

Automotive
- Auto batteries
- Brake fluid
- Carburetor cleaner
- Degreasers
- Fuels
- Oil filters
- Used antifreeze
- Used motor oil

Household items
- Aerosol products
- Button batteries
- Batteries (rechargeable)
- Drain cleaners
- Fluorescent lights
- Mothballs
- Nail polish/remover
- Oven cleaner
- Polish w/solvents
- Spot removers
- Thermometers (Hg)

Lawn & garden
- Bug spray
- Charcoal lighter fluid
- Fertilizer (w/weed killer)
- Insect killer
- Pool chemicals
- Rodent bait
- Weed killer

Home improvement
- Concrete cleaner
- Driveway sealer
- Furniture stripper
- Glue (w/solvents)
- Latex paint
- Oil-based paint
- Paint remover
- Paint thinner
- Roofing tar
- Stain/varnish
- Wood preservatives

The four main avenues for household hazardous wastes to become problem pollutants are through leaks and spills, improper use, improper storage, and improper disposal.

(1) *Leaks and spills*. Leaks from improperly maintained automobiles and lawn equipment or faulty chemical containers can accumulate on roads, driveways, and lawns and be carried by runoff to receiving waterbodies.

(2) *Improper use*. Overapplication of fertilizers and pesticides 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*. Earth's 911 (2000) estimates that the average home may accumulate as much as 100 pounds of household hazardous wastes in the garage, basement, and storage closets. Improper storage of chemicals can lead to spills that can contaminate runoff and ground water or can 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 waterbodies. Additionally, when chemicals are poured down drains connected to a wastewater treatment plant or septic system, the chemicals 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.

(5) *Outdoor car washing*. This activity can result in high loads of nutrients, metals, and hydrocarbons 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).

b. Failing septic systems

Approximately one in four American households rely on septic systems 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 7 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 last 3 years. (Schueler and Swann, 2000b).

c. Lawn and garden activities

It has been estimated that up to 30 million acres of turf and lawn exist in the United States, which, if classified as a crop, would rank as the fifth largest crop in the country (Roberts and Roberts, 1989). A lush, green front lawn is highly desirable to homeowners. Maintaining this image often requires help from fertilizers, pesticides, and heavy watering. In terms of fertilizer inputs, nutrients typically are applied to lawns at about the same application rates as those used for row crops. Contrary to popular belief, beautifully landscaped yards are achievable without massive quantities of chemicals and water.

The chemical lawn care industry generates $1.5 billion of business each year (Environmental Defense Fund, 2000). The products they apply to lawns—fertilizers, pesticides, and herbicides—can pollute runoff if they are applied improperly to the ground. Fertilizers contain nitrogen and phosphorus, which become pollutants when runoff carries excess fertilizers into lakes and streams. Excessive nutrients stimulate algae growth that may 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. Jenkins (1994) estimated that a 1-acre lawn generates nearly 6 tons of grass clippings per year and that yard wastes fill up approximately 10 to 50 percent of the nation's landfills. Alternative practices can be used to reduce the quantity of yard wastes generated by lawns and to reuse or dispose of yard wastes to prolong the capacity of landfills.

d. 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.

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 methods for appropriately disposing 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.

e. Pet wastes

When pet waste is not properly disposed of, it can wash into nearby waterbodies or can 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 waterbody, 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. Pet waste can be controlled through enforcement of ordinances (e.g., warnings and citations, public education, signage, and providing disposal containers).

f. 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, which results in expensive repairs. Finally, municipalities must incur the cost of cleanup efforts to restore water quality.

2. Management Measure Selection

This management measure was selected to identify ways that 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 affecting whether education and outreach activities and administrative mechanisms such as certification and training requirements are practical or effective solutions.

C. Management Practices

1. Household Hazardous Wastes

The key to preventing household hazardous wastes from entering receiving waters is to educate the public about the hazards of everyday materials. The practices discussed below are intended to inform the public on proper procedures for handling and disposing of household hazardous wastes to prevent pollution resulting from carelessness or ignorance and to instill a sense of responsibility for their actions and choices as consumers.

a. Promote the use of alternative products

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. Table 6.1 lists several less-toxic alternatives to typical household chemicals.

Table 6.1: Less-toxic alternatives to household chemicals (Tacoma-Pierce County, Washington, Health Department, no date).

Purpose	Less-toxic alternative
Air freshener	Simmer cinnamon and cloves
Aluminum spot remover	2 tablespoons cream of tartar + 1 quart hot water
Ants	Red chili powder at point of entry
Bleach	Borax
Brass polish	Worcestershire sauce
Car battery corrosion	Baking soda + water
Chrome polish	Apple cider vinegar Baby oil to polish
Cleaners: general household	Baking soda
Coffee cup stain remover	Moist salt
Coffee pot stain	Vinegar
Copper cleaner	Lemon juice + salt
Decal remover	Soak in white vinegar
Dish detergent: grease cutter	1/2 cup baking soda + usual amount of liquid detergent
Drain cleaner	Plunger followed by 1/2 cup baking soda + 1/2 cup of vinegar + 2 quarts boiling water
Fertilizer	Compost and vermicompost
Fiberglass stain remover	Baking soda paste
Fleas on pets	Gradually add brewers yeast to pet's diet

Table 6.1 (continued).

Purpose	Less-toxic alternative
Flies	Well watered pot of basil
Furniture polish	1 tablespoon lemon oil in 1 pint of mineral oil
Garbage disposal deodorizers	Used lemons
Grease fire	Douse with baking soda
Grease removal	Borax on damp cloth
Handcleaner: paint/grease	Baby oil
Ink spot remover	Cold water + 1 tablespoon cream of tartar + 1 tablespoon lemon juice
Insects on plants	Soapy water on leaves, then rinse
Laundry detergent	Basic soap
Linoleum floor cleaner	1 cup white vinegar + 2 gallons water
Mildew remover	Equal parts of vinegar and salt
Mosquito repellent	Burn citronella candles or citronella oil
Moth repellent	Cedar chips enclosed in cotton sachets
Nematode repellent	Plant marigolds
Oil stain remover	White chalk rubbed into stain before laundering
Oven cleaner	2 tablespoons liquid soap + 2 teaspoons borax + warm water
Paint; oil based/stain/spray	Water-based, non-aerosol paints
Paint brush softener	Hot vinegar
Perspiration spot remover	Baking soda
Pet odor remover	Cider vinegar
Porcelain stain removal	Baking soda
Refrigerator deodorizer	Open box baking soda
Roach repellent	Chopped bay leaves and cucumber skins
Rug/carpet cleaner	Club soda
Rust removal (clothing)	Lemon juice + salt + sunlight
Rusty bolt/nut removal	Carbonated beverage
Scorch mark removal	Grated onion
Scouring powder	Baking soda
Shaving cream	Brush and shaving soap
Shoe polish	Banana peel
Silver polish	1 quart warm water + 1 tablespoon baking soda + piece of aluminum foil + 1 tablespoon salt in glass dish; soak silver, rinse, and dry
Slug and snail repellent	Onion and marigold plants
Spot remover	Club soda, lemon juice, or salt
Stainless steel polish	Mineral oil
Toilet bowl cleaner	Paste of borax + lemon juice
Tub and tile cleaner	1/4 cup baking soda + 1/2 cup white vinegar + warm water
Upholstery spot removal	Club soda
Water mark removal	Toothpaste
Water softener	1/4 cup vinegar
Wine stain removal	Salt
Window cleaner	2 tablespoons vinegar in 1 quart warm water
Wood polish	3 parts olive oil + 1 part white vinegar; almond or olive oil (interior unvarnished wood only)

b. Educate the public on proper storage and disposal of hazardous materials

Watershed managers can produce outreach materials that describe methods that homeowners 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 potentially hazardous materials 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 the proper storage and disposal procedures. Pesticides, herbicides, and fungicides are addressed below in Section g.

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 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 hazardous wastes, especially used oil and batteries, can reduce the amount of hazardous 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.

c. Conduct storm drain stenciling

Storm drain stenciling involves labeling storm drain inlets with painted messages that warn citizens of the environmental hazards of dumping materials into storm drains. Stenciling projects are typically conducted by volunteer groups in cooperation with local authorities. The stenciled 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 waterbody the inlet drains to or name the particular river, lake, or bay. Commonly stenciled 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 stencils in both English and Spanish or use a graphic without text.

d. 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 Chapter 1) to treat and/or

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 *www.epa.gov/owow/watershed/outreach/documents/getnstep.pdf* or by calling Books on Demand at 1-800-521-3042.

reuse wash water. 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 waterbodies 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 as much wash water as possible 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 if it enters receiving waters.

2. Lawn, Garden, and Landscape Activities

Lawns are a significant feature of urban landscapes. Estimates of turf and lawn coverage in the United States are as high as 30 million acres, which, if lawns were classified as a crop, would rank as the fifth largest in the country after corn, soybeans, wheat, and hay (Swann and Schueler, 2000). This large area of managed landscape has the potential to contribute to urban runoff pollution due to overfertilization, overwatering, overapplication 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 homeowners 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 homeowners, lawn care businesses, landscapers, and municipal crews. Materials should highlight the following steps to help homeowners 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.

a. 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 and places where grass does not grow well, such as frost pockets, exposed areas, dense shade, steep slopes, and wet, boggy areas. Replacement vegetation that is best suited to the local conditions should be chosen to replace turf.

b. Soil building

Lawn owners should analyze their soil every 1 to 3 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 soil 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 by the local cooperative extension service. Soil tests reveal whether fertilizer or lime is needed, helping to avoid overfertilization and loss of nutrients. Soil compaction can be determined by inserting a screwdriver into the soil. If the screwdriver easily penetrates the soil, then aeration is not needed. 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 should be added. The final test is to count earthworms. The density of earthworms is an indicator of soil texture, and a test that reveals fewer than 10 worms per square foot signifies that the soil may require aeration.

NRCS's Backyard Conservation

USDA's Natural Resources Conservation Service (2000) web site sponsors a Backyard Conservation web site (*www.nhq.nrcs.usda.gov/CCS/Backyard.html*) 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 to be used in suburban landscapes.

c. Grass selection

Grass seed is available in a wide range of cultivated varieties, so homeowners 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 that have 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, zoysiagrass, 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 is best adapted to the site conditions.

d. Mowing and thatch management

Many property owners strive to maintain a lawn that resembles a golf course. However, mowing a lawn to such a short height increases its susceptibility to drought, sun damage, and weed encroachment; prevents the development of deep roots; inhibits lateral stem growth; and can encourage the overdevelopment of thatch (a straw-like layer between the grass and soil that signifies unhealthy growth conditions and can result from shallow watering, overfertilization, and close mowing). 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. 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 automated dethatcher and/or sprinkled with compost and aerated.

To prevent insects and weed problems, property owners should mow high, mow frequently, and keep mower blades sharp. Lawns should not be cut shorter than 2 ½ to 3 ½ 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 1 ½ inches (Audubon Society, 2000).

e. 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 the excess yard waste. Additional nutrients can be supplied with compost or commercially available fertilizers that are of an organic or encapsulated nitrogen type, but they should be applied at or below the rates prescribed on the packaging. Use of 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. Organic products offer the additional benefits of increasing soil condition and promoting the growth of desirable soil organisms.

Case Study: Late-Season Fertilization Effects on Turfgrass Growth and Nitrate Leaching and Runoff Losses

A significant portion of the managed landscape in Connecticut and other states on the east coast is covered with turfgrass. Fertilizer is routinely applied to manage turfgrass vigor and quality. Late-season or "fall" fertilization of cool-season turfgrass is a common practice throughout most of the northern United States, which is typically beneficial for turf quality. An appropriate cut-off date for the last fertilization during late-season fertilization has not yet been identified for most regions. Considering the fact that climatic conditions during the fall vary by regions, it is reasonable to vary the last date of fertilizer application of turf accordingly. However, fertilizer recommendations for many northern regions typically recommend a November application or are vague in providing a date for the last application. Applying fertilizers past the date when cool-season turfgrasses become dormant increases the potential of nitrate losses from runoff and leaching.

A two-year study by the University of Connecticut, which is still underway, is seeking to determine an appropriate cut-off date for fall fertilization of turf in southern New England that maintains acceptable turf quality while minimizing nitrate runoff and leaching losses. Applying fertilizers appropriately can help reduce nutrient enrichment of surface water and ground water. The study established a typical home lawn mixture of Kentucky bluegrass, perennial ryegrass, and creeping red fescue (from sod) on plots. The plots were managed with standard lawn care practices and soil monolith lysimeters were placed in each plot to collect percolating soil water from the turf. Runoff plots were also constructed adjacent to and downslope of the lysimeters. The turf is fertilized using a typical schedule of three applications: 1) once in the spring; 2) once in the early summer; and 3) once in the late season. A total nitrogen rate of 3 pounds of nitrogen per 1,000 cubic feet will be split equally across each application.

Timing of fertilizer application is an important consideration. Fertilizer should not be applied when rain is expected. Not only will the rainfall decrease the effectiveness of the fertilizer application, but it will also increase the risk of surface and ground water contamination. Fertilizer should be applied in the season most appropriate for each grass type to ensure that nutrients are fully utilized. Cool season grasses should be fertilized in the fall, whereas warm season grasses should be fertilized frequently and in small doses during the summer. Applying fertilizer at the wrong time might promote the growth of weed species or may increase the plants' water needs. 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 *www.reeusda.gov* or from *farmboys.com/resources/ext_serv/ext_serv.htm*.

f. 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. If patches of weeds are present, they can be covered for a few days with a black plastic sheet, a technique called solarization. Solarization kills the weeds while leaving the grass intact. If weeds blanket a large enough area, the patch can be covered with clear plastic for several weeks, effectively "cooking" the weeds and their seeds. The bare area left behind after weeding should be reseeded to prevent weeds from growing back. As a last resort, homeowners can use chemical herbicides to spot-treat weeds. 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 *www.reeusda.gov* or at *farmboys.com/resources/ext_serv/ext_serv.htm*.

g. Pest management

Integrated Pest Management (IPM) is an effective and environmentally sensitive approach to pest management 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 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 pest 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 to control pests. Municipalities can encourage homeowners 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

Case Study: Target 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.

installed to keep rodents out, and netting can be used to keep birds and insects away from leaves and fruit. Property owners 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, property owners 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, including the following:

(1) Visible insects can be removed by hand (with gloves or tweezers) and placed in soapy water or vegetable oil. Alternatively, insects can be sprayed off the plant with water or in some cases vacuumed off of larger plants.

(2) Store-bought traps, such as species-specific, pheromone-based traps or colored sticky cards, can be used.

(3) Sprinkling the ground surface with abrasive diatomaceous earth can prevent infestations by soft-bodied insects and slugs. Slugs also can be trapped in small cups filled with beer that are set in the ground so the slugs can get in easily.

(4) In cases where microscopic parasites, such as bacteria and fungi, are causing damage to plants, the affected plant material can be removed and disposed of. (Pruning equipment should be disinfected with bleach to prevent spreading the disease organism.)

(5) Small mammals and birds can be excluded using fences, netting, tree trunk guards, and, as a last resort, trapping. (In some areas trapping is illegal. Property owners should check local codes if this type of action is desired.)

(6) Property owners can promote beneficial organisms, such as bats, birds, green lacewings, ladybugs, praying mantis, ground beetles, parasitic nematodes, trichogramma wasps, seedhead weevils, and spiders, that prey on detrimental pest species. These desirable organisms can be introduced directly or can be attracted to the area by providing food and/or habitat.

When these lower-impact practices are not enough to remove the pest species, homeowners can use chemical controls. Chemical controls are highly effective but may result in damage to or death of desirable species such as bees. Strong chemical pesticides can contaminate receiving waters, especially when they are applied over large areas or just before a storm. Several less-toxic pesticide alternatives are available to prevent infestations or to halt current infestations, including spraying plants with a solution of dishwashing detergent and water. Garlic and baking soda also 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.

The University of Maryland developed a test for bluegrass, ryegrass, and fine fescue lawns to determine whether pesticide application was necessary. The premise of the test is that each insect has a population level below which spraying does more harm than good. To conduct the test, three sides of a square foot of sod, one inch deep, should be cut back with a flat blade shovel. If fewer than 6 to 10 grubs, 6 to 8 billbugs, 4 to 6 sod webworms, or 15 to 20 chinch bugs are found, the sod should be replaced, the lawn watered thoroughly, and no pesticides need to be applied (Audubon Society, 2000). If more insects are found, then pesticides might be warranted.

If chemical pesticides are used, municipalities should try to select the least toxic, water soluble, and volatile pesticides possible. All selected pesticides should be screened for their potential to harm water resources. Organophosphate pesticides, such as diazinon and chlorpyrifos, are popular because they target a broad range of pests and they are less expensive than newer, less toxic pesticides. Organophosphates rank among the worst killers of wildlife, however, and they often pose the greatest health risk. Synthetic pyrethroids are more selective and typically much less toxic than organophosphates, yet they can harm beneficial insects. When possible, pesticides that pose less risk to human health and the environment should be chosen (Audubon Society, 2000). A list of popular pesticides, along with their uses, their toxicity to humans and wildlife, EPA's toxicity rating, and alternatives to the listed chemicals is available from *The Audubon Guide to Home Pesticides* at *magazine.audubon.org/pdf/pesti_chart.pdf*.

Where necessary, restrictions should be placed on the timing, amount, and areas of application for each pesticide. Before applying any pesticide, the label directions should be read and followed. Pesticides should be applied correctly 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 targeted away from 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 should be consulted about the proper use of pesticides. State-specific information regarding cooperative extension services is available from CSREES at *www.reeusda.gov* or at *farmboys.com/resources/ext_serv/ext_serv.htm*.

Pest management methods can also be altered legislatively. In response to the negative effects of many pesticides, some parts of the country are planning to restrict or prohibit the use of certain hazardous pesticides (Johnson, 1999). 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 hazardous 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 (RWQCP'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 RWQCP and other local wastewater treatment plants have urged restrictions on the three types of chemicals. The state Department of Pesticide Regulation adopted regulations in December of 1995 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.

Case Study: Arcata Pesticide Use Ordinance

Recently the City of Arcata, in Northern California, created an ordinance that officially eliminated the use of pesticides on all properties owned or managed by the city (CATs, 2000). When city residents became aware of the dangers of pesticides, they demanded change. By 1986, the city council was composed of an anti-pesticide majority and had received so much feedback about the city's pesticide use that it created a citizen's task force to search for nontoxic alternatives. The task force compared the costs of pesticide application and manual vegetation removal and found that increased labor costs were balanced by decreased costs of purchasing, applying, reporting, and storing of the pesticides. The city then conducted small-scale tests to determine the most efficient and cost-effective solutions. Upon receiving the task force recommendations in May of 1986, the City Council consequently declared a moratorium on the use of all pesticides on city properties. Workers gradually became accustomed to the moratorium and now find the use of alternatives routine. Years later, the city decided to establish an ordinance that established successful nontoxic practices as permanent city policy. In February 2000, the City Council unanimously approved the ordinance. Arcata hopes that this ordinance will be a model for other cities with similar health and safety concerns.

h. 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 during dry weather 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. 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. Determining and controlling the rate, amount, and timing of irrigation 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.

3. Commercial Activities

a. 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.

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:

(1) Instituting building and plumbing codes to prevent connections of potentially hazardous pollutant sources to storm drains.

(2) 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.

(3) 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.

(4) Surveying individual buildings to discover where connections to the storm drain exist.

(5) Inspecting sewer lines with television equipment to visually identify all physical connections.

(6) Comparing the results of field tests and video inspections with the known connections on the map. Areas with suspected connections should be further investigated.

(7) Instituting mandatory inspections for new development, redevelopment, and remodeling projects.

(8) Removing and testing sediment from catch basins or equivalent structures.

(9) 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.

   (a) *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.

   (b) *Visual inspection*. Remotely guiding television cameras through sewer lines is another way to identify physical connections.

   (c) *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 for some people.)

(d) *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 events 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.

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 (*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 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 target 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 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. For additional information, contact the Nonpoint Source Control Program Information Line at 800-794-2482.

b. 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.

c. 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 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.

d. Devise spill prevention, control, and cleanup 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 cleanup 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.

e. 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 nonhazardous wastes, and identifying recycling options to reduce the amount of wastes that require disposal. EPA's Office of Pollution Prevention and Toxics web site (*www.epa.gov/p2/assist/index.htm*) offers technical information and assistance about environmental audits for both businesses and state regulatory agencies (USEPA, 2001a).

f. Practice safe equipment washing and maintenance

It is important when washing and maintaining equipment to adhere to certain pollution prevention measures. When cleaning industrial equipment, in most cases the resulting flow must be discharged as process wastewater to the sanitary sewer and is not allowed in storm drains. When cleaning greasy equipment or trucks, a special cleaning area should be designated and equipment installed to capture, pretreat, 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 is 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, when performing maintenance on a vehicle, it should be done in an indoor garage, not in an outdoor parking area.

g. Use care when performing construction, repairs, or remodeling

When repairing, remodeling, or constructing buildings there are several key pollution prevention 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 buckets and barrels of materials should be stored away from contact with runoff.

During painting cleanup, 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 consider water-based spray paints 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.

4. 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, where the waste can decompose slowly. When buried, the waste should be at least 5 inches below the ground surface and away from waterbodies 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 announcements. Many communities have “pooper scooper” ordinances that govern pet waste cleanup. 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 also 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.

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 cleanup 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.

5. Trash

When developing control strategies for trash, the source of the trash should be considered to most effectively implement a control structure designed to target the most prevalent types of trash. 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 and can be utilized at the lowest cost. 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 waterbody but should reduce the quantity of trash entering waterbodies.

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 cleanup campaigns. Community education, such as informing citizens about options for recycling and waste disposal and educating them about the consequences of littering, can instill a sense of responsibility in citizens to maintain a clean environment. 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 the purchase of products with less disposable packaging and encouraging manufacturers to reduce the amount of packaging they use. Finally, cleanup campaigns are an effective way to reduce trash. Municipal projects such as street sweeping, receptacle servicing, and cleanup crews along roadsides can also be effective in preventing trash from accumulating and entering waterways.

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 of physical filtering structures are trash racks, mesh nets, bar screens, and trash booms. Continuous deflection separation targets inputs of trash from storm flows during and after heavy precipitation events and involves physical separation of solids and floatables from water in runoff detention structures by increasing the settling time of trash and particles.

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 $905,000, not including maintenance. A large-scale continuous deflection separation device for urban runoff can cost as much as $3 million (capital cost only).

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).

Sweeping technology can have a profound effect on sweeping results. Previously, sweepers were unable to pickup very fine sediments that can be highly contaminated. Today, street sweeping has proven to be an effective management practice for reducing pollutant loads to waterways. High-efficiency pavement sweepers are thought to be very efficient 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 washoff 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 washoff was reduced by 49 to 85 percent. Other tested sweepers reduced annual TSS washoff in major arterials by up to 24 percent (Minton et al., 1998).

High-efficiency sweepers were also compared to the efficiency of wet vaults (Sutherland et al., 1998). Simulated results indicate that high-efficiency sweepers removed 40 to 75 percent of annual TSS, while water vaults removed 75 to 91 percent. All removal efficiency ranges depended on sweeping frequency.

The projected water quality benefits of high-efficiency street sweeping are based on modeling. Because the technology has not been field verified and there is currently no end-of-the-pipe water quality data to verify the modeling results, high-efficiency sweeping is not widely used at this time (Minton et al., 1998).

6. 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 any 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.

Schueler and Swann (2000a) recommend the following techniques to effectively market a watershed message:

(1) Present a simple, direct watershed message, repeat it frequently, use multiple types of media, and emphasize the connection between the message and a local waterbody.

(2) Develop an increased awareness of the connection between yards, streets, storms, and streams.

(3) Pool resources with other local or regional organizations to expand the budget for the campaign.

(4) Use cable network and public television channels for commercials and targeted TV programs to more effectively reach target audiences.

(5) Focus the campaign on one or more target audiences. In general, men between the ages of 35 and 55 with relatively high income and education levels are most likely to engage in polluting activities. However, a survey of watershed demographics and problem pollutants should be conducted to better identify target populations.

(6) Keep the message simple and humorous and develop durable, attractive, nontechnical outreach materials.

(7) Educate and partner with private sector companies such as septic tank cleaners, commercial car washes, and oil change franchises.

a. 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 their 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 stencils in both English and Spanish (University of Texas at Austin, 1997).

b. Use classroom education to deliver nonpoint source messages

Providing nonpoint source education to children through schools exposes 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 learning activities about water science, history, geography, and drama. The Albuquerque-based Ciudad Soil and Water Conservation District use their "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 role 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.

Case Study: Delaware Department of Natural Resources and Environmental Control's Whole Basin Management Strategy

The Delaware Department of Natural Resources and Environmental Control's (DNREC) Whole Basin Management strategy focuses on protecting Delaware's environment by managing it by drainage basin. The strategy uses the state's four major drainage basins (the Piedmont, Chesapeake Bay, Delaware Bay and Estuary, and Inland Bays/Atlantic Ocean Basins) as the chief management units. Whole Basin Management involves a phased approach to assessing the health of the targeted basin and developing an implementation plan to address its environmental problems. The Inland Bays Environmental Profile offers residents a list of ways to contribute to improving the Inland Bays/Atlantic Ocean Basin. Among the recommended activities are several pollution prevention-related activities. Examples of activities recommended in the profile include (DNREC, no date):

Reducing Household Hazardous Waste

- Use non-phosphate laundry detergents or purchase nontoxic cleaning products.
- Read and follow directions on labels carefully.
- Use latex paint instead of oil-based paint and stains and finishes derived from natural sources if possible.
- Use fabric softener sheets rather than liquids (they have a lower metals count), or add one cup vinegar or a quarter cup of baking soda to the final rinse.
- Know how to identify (labeled "danger," "warning," or "caution") and safely dispose of hazardous products.

Maintaining a Healthy Lawn and Garden

- Perform soil tests every 3-4 weeks to determine the amount of nutrients necessary for a healthy lawn. Contact your local soil conservation district for more information and test kits.
- Lawns should be 2-4 inches high. Cutting too short or too frequently weakens grass and cultivates weeds.
- Leave grass clippings on the lawn to serve as a natural fertilizer or compost them.
- Use pesticides sparingly and read and follow directions carefully. Try to use natural alternatives. Never use pesticides if rain is forecast to avoid runoff into a local stream or storm drain.
- Do not overwater lawns or gardens to prevent chemicals from leaching into ground water.

Recycle paper, plastic, cans, glass, cardboard, motor oil, oil filters, and batteries

Build a Compost Pile

- Select a flat, well-drained spot that gets full sun. Try to build the pile in the middle of the garden.
- Construct a compost bin out of lumber, bricks, concrete blocks, or wire. Make sure the bin has air openings.
- Feed the pile, mixing coarse and fine materials in 6- to 8-inch layers. The bottom layer should contain twigs, chopped cornstalks, or other coarse material. Next add a layer high in nitrogen such as grass clippings or manure. Top with soil and repeat the process. Sprinkle the pile with water.
- Mix the layers well and shape so the center is lower than the sides to help water flow into the pile. Turn the pile once a month and remoisten the material as it is turned.

Keep Septic Systems Functioning Properly

- Keep all toxic and hazardous materials out of septic systems and minimize the solids and liquid loads.
- Avoid dumping grease and fats down kitchen drains. Collect grease in a container beside the sink.
- Have a septic tank pumped by a certified contractor every 3 years.

Follow Bay-Friendly Boating Practices

- Avoid discharging sewage directly into the water, and do not litter.
- Clean fish at designated areas and dispose of waste in proper containers.
- Avoid over-fueling, and perform boat maintenance out of the water if possible.

Additional pollution prevention activities are available from the Inland Bays Environmental Profile, which is available on DNREC's web site at *www.dnrec.state.de.us*.

Information Resources

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 at all levels. 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 *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 fact sheet 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 *www.cityofseattle.net/util/proipm/default.htm* 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 *www.afcee.brooks.af.mil/pro_act/fact/jun00a.asp*. PRO-ACT may be contacted by phone at 800-233-4356 or by e-mail at pro-act@hqafcee.brooks.af.mil.

The National IPM Network (NIPMN, no date) is an evolving and cooperating group of universities, government agencies, and other organizations for providing up-to-date, accurate pest management information to growers, extension members, consultants, regulatory personnel, and the public. NIPMN's web site can be accessed at *plantprotection.org/nipmn/index.htm*.

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 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 *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 homeowners 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 *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 *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 *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 natural resource protection, 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 *nemo.uconn.edu*.

Organic Gardening magazine and web site (*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; listservers; and links to agencies, associations, and non-governmental organizations. The H_2infO web site can be accessed at *www.riversides.org/newwin/win.html*. 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 website 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 *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 *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 *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 turfgrass 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 *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 *www.epa.gov/owow/watershed/outreach/documents/getnstep.pdf* or by calling Books on Demand (800-521-3042).

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Management Measure 10
Existing Development

A. 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 to runoff patterns).
- Devise a schedule for implementing appropriate controls.
- Limit destruction of natural conveyance systems.
- Where appropriate, preserve, enhance, or establish buffers along surface waterbodies and their tributaries.
- Promote redevelopment by assessing previously contaminated soils.

B. Management Measure Description and Selection

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.
- Limit the volume of surface water runoff to minimize sediment loading from erosion of streambanks and other natural conveyance systems.
- Preserve, enhance, or establish buffers that provide water quality benefits along waterbodies 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,

siltation, increases in 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. These factors include 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 might 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 waterbodies and their tributaries, where water quality and the biological integrity of the waterbody are dependent on the presence of an adequate buffer or riparian area. Buffers might 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 waterbody.

Where existing development precludes the use of effective nonstructural controls, structural practices might be the only suitable option to decrease the nonpoint source pollution loads generated from developed areas. 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—identifying priority pollutants and selecting the most appropriate retrofits that will result in the greatest improvement to water quality—might 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 area 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, bio-filters, or water quality inlets with oil/grit separators might be appropriate for retrofits because they do not limit use of the land.

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 developed communities. Watershed management programs allow these communities to select and implement the practices that best address local needs. Identifying priority local and/or regional pollutant reduction opportunities and setting schedules for implementing appropriate controls were selected as logical starting points in the process of establishing an institutional framework to address nonpoint source pollutant reduction.

The third and fourth components of this management measure were selected to preserve, enhance, and establish areas within existing development that provide positive water quality benefits such as natural streams, ponds, and wetlands and aquatic buffers. These natural systems provide efficient runoff conveyance, as well as wildlife and aesthetic benefits. The fifth component was selected to encourage redevelopment of underused or contaminated sites in urban areas to improve soil, surface water, and ground water quality at those sites and to preserve undeveloped green spaces that could provide a water quality benefit. Also, In January of 2002, the Small Business Liability Relief and Brownfields Revitalization Act was signed into law (USEPA, 2002b). This act greatly expands the brownfields program and specifies the following changes to the program:

- Provides legislative authority for the brownfields program including grants for assessment and cleanup.
- 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 cleanup grants.
- Includes a new provision for direct cleanup grants of up to $200,000 per site.
- Streamlines current requirements for the brownfields cleanup revolving loan fund and makes funding available to nonprofit organizations.
- Applies the Davis Bacon Act on the same terms as the authority for the current program.
- 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 *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.
- Extraordinarily high costs associated with implementing retention ponds and exfiltration systems in developed areas.

C. Management Practices

1. Identify, Prioritize, and Schedule Retrofit Opportunities

In the watershed assessment phase of the urban runoff management cycle, watershed managers should identify waterbodies that have been degraded by urban runoff and require restoration. One method to halt further degradation and initiate waterbody 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 retrofitting project should be planned in the context of a comprehensive watershed plan, and managers should have a clear set of objectives for each retrofit project to ensure that the project results in measurable improvements in hydrologic, habitat, and/or water quality indicators.

a. 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 and areas with poor habitat and water quality that need to be improved. Topographic 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 facility.
- 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 areas, golf courses, wide floodplains, highway rights-of-way, and parking lot edges.

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 management practice implementation. At this point, a conceptual sketch for the management practice for each site should be drawn and preliminary cost estimates made.

b. 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, a retrofit program might be targeted to preserve streams or reaches known to have high-quality habitat or exceptional water quality. The goal of another program might be to restore poor habitat and degraded water quality. The program might target particular land uses thought to contribute the majority of pollutants to receiving waters. Retrofit facilities can also be installed to treat runoff that drains the largest area of the subwatershed, 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.

c. 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, rainbarrels, rooftop greening, and planting urban trees in buffers in urban areas (see Management Measure 5 for a more detailed discussion of these practices). All of these practices can be designed on a small scale to accommodate space constraints that may be present on already-developed sites. They will aid in retaining runoff on-site and reducing the total volume of runoff reaching receiving waters. 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 (*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 (*www.fs.fed.us*) produces many good references about how trees can be used to reduce runoff volume and improve runoff quality

Case Study: 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).

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 in-stream practices in channels.
- Constructing on-site measures at the edge of large parking areas.
- Constructing new management practices in highway rights-of-way.

a. 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. The retrofit process often includes the following:

- Analyzing existing hydraulic characteristics and the flood control design specifications of the facility.
- Determining whether there is available storage for water quality treatment.
- If water quality storage is available, usually excavating the pond bottom to create permanent pool storage (for pond and wetland systems).
- If extended detention is needed, raising the embankment or modifying the outlet structure to obtain additional storage.
- To increase particulate settlement, increasing the flow path from inflow point to discharge point by using baffles or earthen berms or by regrading the pond's contours.

b. 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 could be installed to create a small, permanent micropool excavated to provide water storage, water quality, and habitat

Case Study: 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 *www.epa.gov/ednnrmrl/news/main.htm*.

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.

Because roadways are not originally constructed as runoff management embankments, however, 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.

c. 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 enters a receiving water.

d. 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 in-stream practice is implemented.

e. 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 like bioretention areas, porous pavement, sand filters, and underground vaults are good candidates. Two examples of successful use of bioretention areas can be found at *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 *www.epa.gov/owow/nps/pavements.pdf* (USEPA, 2000b).

f. 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.

g. 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 after storm events 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.

h. Install inlet and grate inserts

A wide variety of inserts are also commercially available that trap oil and grease from parking lots, maintenance yards, and streets. These can be used with or without trash capture in storm drain inlets and grates. Inspection and maintenance 1 to 4 times per year (depending on pollutant concentrations in runoff) is usually recommended.

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. These modifications are manifested in increases in imperviousness, runoff, peak flows during storm events, erosion, and pollutant transport, which results in greater downstream impacts. These modifications resulted from the prevalence of traditional runoff management techniques that involved rapidly transporting runoff off-site by means of curbs and pipes.

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 storm events. 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 *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 *www.usda.gov/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.

a. Disconnect impervious areas

Roof downspouts can be disconnected from streets and culverts and runoff diverted over vegetation or into rain barrels for reuse (see Management Measure 5 for more information on rain barrels). 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 www.*epa.gov/owow/nps/ roofcover.pdf*.

b. Encourage overland sheet flow

Concentrated flow of runoff during storm events 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. 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.

c. 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.

d. 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.

e. 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.

Case Study: 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 *www.anacostia.net*.

f. 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.

Case Study: 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.

g. 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.

4. Restore Natural Streams

Restoration design for streams degraded by prior urbanization should consider preexisting conditions and their effects on restoration objectives. 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 *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 *www.noltemedia.com/nm/urbanstream/index2.html*.

a. Partially restore the predevelopment hydrologic regime

The primary objective of storm water management is to reduce the frequency of bankfull flows 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). A common design storm for extended detention is the 1-year, 24-hour storm event. Storm water retrofit ponds are often critical in the restoration of small and mid-sized streams, but they might be impractical in larger streams and rivers.

b. Reduce urban pollutant pulses

A second need in urban stream restoration is to reduce concentrations of nutrients, bacteria, and toxics in the stream, as well as trapping excess sediment loads. Generally, three tools can be applied to reduce pollutant inputs to an urban stream: storm water ponds or wetlands (see Management Measure 5), watershed pollution prevention programs (see Management Measure 9), and the elimination of illicit discharges or improper connections to the storm sewer network (see Management Measure 9).

c. Stabilize channel morphology

Over time, urban stream channels enlarge their dimensions 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 cover to improve fish habitat. Depending on the stream order, the impervious cover in the watershed, and 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.

Case Study: 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 high concentration events, including hurricanes. This change 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.

Case Study: 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.

d. Restore in-stream habitat structure

Most urban streams have poor in-stream habitat structure, often typified by indistinct and shallow low-flow channels within a much larger and unstable storm channel. The goal is to restore in-stream 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.

Case Study: 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).

e. Reestablish riparian cover

Riparian cover is an essential component of the urban stream ecosystem. It stabilizes banks, provides large woody debris and detritus, and shades the stream, reducing water temperatures. Therefore, this tool involves reestablishing the riparian cover plant community along the stream network. This can entail active reforestation of native species, removal of exotic species, or changes in mowing operations to allow gradual succession. It is often essential that the riparian corridor be protected by an urban stream buffer (see Management Measure 3).

f. 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 apply tools to 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.

g. Allow for recolonization of the stream community

It might 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.

h. 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 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 in-stream 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 of the project to determine whether the project is worthwhile.

A source of information about daylighting is *Daylighting: New Life for Buried Streams*. In addition to summary findings, recommendations, and conclusions, the report also provides information about completed and proposed daylighting projects (Pinkham, 2000).

Case Study: 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 started the project initially to provide environmental education to high school and college students on stream ecology and restoration, but Bukosky continued to gather data and design 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.

5. Preserve, Enhance, or Establish Buffers

Stream buffers might 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. Also, if the buffer is not protected from disturbance or excessive traffic, it can deteriorate over time. Buffers offer several environmental benefits, including improving soil and water quality, stabilizing stream banks, decreasing flood severity, replenishing ground water supply, and improving 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.
- 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.

6. Revitalize Urban Areas

a. Encourage infill development

Infill development is a tool planners use to encourage siting of new development in unused lands in existing urban areas. Infill development usually works in tandem with community redevelopment initiatives to foster revitalization of existing neighborhoods. 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 might 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.

Case Study: Examples of Infill Development

Wilson et al. (1998), in their book entitled *Green Development: Integrating Ecology and Real Estate*, described several infill development projects in California that are designed to revitalize the neighborhood, encourage the use of public transportation, and capitalize on proximity to complementary land uses. For example, the San Francisco Main Library was built on an infill site in San Francisco's Civic Center district that previously had been a parking lot with a small municipal building. The library contributes to the character of the neighborhood. It is located adjacent to a Bay Area Regional Transit station, is easily accessible by foot or bus, and has bike racks to encourage staff and patrons to use forms of transportation other than private automobiles.

Another infill project, in Pasadena, California, is the Holly Street Village Apartments, which combine "mixed-use, mixed-income housing, historic preservation, and attractive site planning and architecture." The complex is located between Pasadena's Civic Center and its revitalized historic commercial district. The apartment complex itself consists of 358 units of new housing, 16 loft apartments adapted from the historic former police headquarters building, and ground-floor retail units. A light rail station is soon to be built near the complex. This project's success has attracted further residential development projects in the area.

Both of these projects, and infill projects in general, take advantage of existing infrastructure and increase tax revenues without substantially increasing municipal expenses. Although development density increases with infill development, quality of life will not be compromised if the new development is properly planned to complement the existing neighborhood.

b. Assess previously 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. These dormant, sometimes contaminated sites contribute to water quality degradation by contaminating runoff and ground water and by contributing to imperviousness in the watershed. These underused urban areas can be assessed for contamination, remediated, and redeveloped in an environmentally friendly manner to improve surface and ground water quality. An additional benefit is improvement of the socioeconomic climate of the neighborhood. Redevelopment plans can include features such as disconnected impervious areas, infiltration areas, biofiltration systems, and on-site runoff storage to ensure that runoff leaving the site more closely mimics predevelopment water quality and quantity conditions.

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 cleanup 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 cleanup and redevelopment to improve the community's surface 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 *www.epa.gov/brownfields/sblrbra.htm* for more information). More information about EPA's Brownfields Initiative is available at *www.epa.gov/brownfields*.

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 cooperation 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 *www.usda.gov/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 *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). They offer 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 *www.iwla.org/sos*.

The Natural Resources Conservation Service National Conservation Buffer Initiative web site (*www.nhq.nrcs.usda.gov/CCS/Buffers.html*) 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 *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 *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 post-implementation monitoring, restoration project descriptions, and links to other restoration resources. The site is located at *www.epa.gov/owow/wetlands/restore*.

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Management Measure 11
Operation and Maintenance

A. Management Measure

Develop a program for regular inspection and prompt repair or replacement of urban runoff management practices.

- Establish a program to conduct inspections and perform maintenance on runoff management practices.
- Maintain transportation and storm drain infrastructure to reduce loads at their source.
- Inspect, maintain, and repair runoff treatment controls to maintain design treatment capacity.
- Inspect, maintain, and restore aquatic buffers.

B. Management Measure Description and Selection

1. Description

Regular inspection and monitoring are essential to maintain performance objectives of storm water management facilities. Measuring the performance of each facility after large storms provides a baseline against which to compare future performance. Maintenance checklists facilitate inspections by promoting thoroughness and consistency among inspectors, in addition to providing a historical record of maintenance and reducing the potential for future liability. This record of inspections and maintenance is also useful in justifying funding by documenting problems that require attention.

Several general maintenance activities should be conducted for runoff management practices: vegetation management, sediment removal, and protection against erosion. First, where appropriate, facilities should be maintained for optimal vegetation. Too little vegetation, or the wrong type of vegetation, can promote high runoff velocity and erosion, as well as poor infiltration and pollutant removal capacity. Too much vegetation might result in decay and release of nutrients. Additionally, vegetation that is too dense can impede the flow of water and result in near-imperviousness.

Second, runoff management practices are subject to clogging from sediments. Both coarse and fine particles can reduce the effectiveness of the facility. The particles can cause sealing of soil pore spaces, which prevents infiltration and results in standing water. Inlets or outlets can become blocked with sediment over time, causing overflow of runoff into areas not designed to

receive this type of flow. Also, when sediments build up in ponds, the retention capacity of the ponds is decreased and high peak flows downstream can result.

Finally, erosion from contributing drainage areas exacerbates sedimentation problems. Stabilizing areas surrounding the site by using vegetation or other erosion control methods can greatly reduce the frequency of required maintenance, thereby reducing maintenance costs. The following section discusses specific operation and maintenance (O&M) requirements for several types of runoff management practices.

When maintenance considerations are incorporated into management practice designs, subsequent maintenance costs and repairs are often lower. The removal of sediment, for example, can be less expensive if sediment traps are designed for easy cleaning and provide adequate access for the intended equipment. Safe and convenient access to outlet structures for repairs or to remove blockages can also reduce maintenance costs and prevent nuisance flooding. Proper construction techniques, particularly for infiltration management practices, can also reduce the frequency of maintenance or repairs.

2. Management Measure Selection

Improper O&M can result in increased discharge of pollutants to downstream waters, increased risk of flooding, and increased channel instability downstream. Life and property might be at a greater risk when runoff systems are poorly maintained. Therefore, standards should be devised for maintenance of runoff controls and an inspection schedule should be created to determine what maintenance or improvements are needed. Inspection frequency depends on the local climate and precipitation and the type of runoff management system.

Effective programs need to identify the governmental or other functional department(s) responsible for the maintenance program. Because maintenance issues are critical to successful program implementation, they should be planned for at the outset of the runoff management program and maintenance activities should be conducted continuously throughout program implementation.

Implementing the practices described under this management measure will facilitate the development of an effective O&M program for continued effectiveness and longevity of runoff management practices.

C. Management Practices

1. Establishing an Operation and Maintenance Program

The expense of maintaining most structural 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. The following section outlines several practices that will facilitate development of a runoff control O&M program.

a. 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 are completed.

EPA (2000) has provided model ordinance language on its web site (*www.epa.gov/nps/ordinance*) that includes consideration of maintenance of runoff control management practices. Examples from across the country are provided, including ordinance language, an example maintenance agreement, an easement and right-of-way agreement, an inspection checklist, and a performance bond.

It is important for O&M ordinances to identify a specific entity responsible for long-term maintenance and to require regular inspection visits. The ordinance also should address 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 language regarding maintenance of postconstruction controls because of the short-term nature of the erosion and sediment control practices.

b. 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 for easy access for maintenance equipment (mowers and vactor trucks). Also, many practices have been designed with inadequate pretreatment (without a sediment basin at the inlet). Finally, inlet and outlet structures tend to clog easily. Adequate size and storage volume based on expected sediment loads from the contributing drainage area is required in the design of inlets and pretreatment structures.

c. 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, or local government agency. In many cases local governments assume the responsibility of maintaining privately owned facilities because private entities have proven to be lax in fulfilling their maintenance responsibilities; if the facilities fail, then the burden of downstream restoration will ultimately fall under the local government's responsibility anyway. Public financing for maintenance of both public and private facilities can come from general tax revenues, storm water utility fees, inspection or permit fees, or dedicated contributions. 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 (1997) *Operation, Maintenance, and Management of Stormwater Management Systems*.

It is important that the funding source for maintenance of runoff control facilities is 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 performing regular maintenance. They reason that citizens and government officials will be more willing to allocate funds to projects that they know will provide tangible

benefits to the community. WMI also recommends that funding programs for maintenance activities

- 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.
- Be consistent with applicable state laws and regulations.

d. Plan regular inspections

Inspections are essential to successful operation of the facility. They require necessary equipment, proper attitudes, appropriate training, and suitable inspection procedures. An inspection schedule and checklist should be developed and adhered to.

e. Schedule maintenance, cleaning, and debris removal to avoid sediment accumulation

Sediment and debris can contain hazardous contaminants and can clog filtration and infiltration practices, which will reduce their effectiveness over time. Maintenance programs should include measures for cleaning catch basins and drainage channels in addition to major structural controls. Establishment of an effective O&M program should include creating maintenance logs and identifying specific maintenance triggers for each class of control (e.g., removing sediment from forebays every year and retention ponds every 5 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.

f. Make provisions for monitoring of treatment criteria

Regular monitoring of the influent to and effluent from structural management practices will support program goals by facilitating the development of a database from which future decisions can be made about the performance of selected practices for various applications. Also, these data will make it easier to quantify the performance of the practice and determine its response to regular maintenance.

g. Implement training certification programs and 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 fund staff dedicated to these activities. 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.

2. Source Control Operation and Maintenance

a. 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 street sweeping program requires that it be conducted on a regular basis. Sweeper operators require training, and equipment needs to be maintained regularly to ensure that sweepers are functioning as designed. Finally, parking restrictions can be implemented to guarantee adequate cleaning despite on-street parking. Table 8.1 shows O&M costs associated with street sweeping. Also see Management Measure 9: Pollution Prevention for more information about street sweeping in the context of trash removal.

Table 8.1: 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 removes deposited materials from storm drain pipes to maintain the design 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 costs for supplying flush water, collecting sediment, and treating sediment-laden water if the storm drains are being flushed to a receiving waterbody.

(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 be targeted to areas with the greatest pollutant loading and to areas near sensitive waterbodies. A maintenance log should be maintained to track progress. If there are many catch basins in a community, mechanical cleaners (vactors, vacuums, or bucket loaders) might be required; otherwise, hand cleaning will suffice. Proper recordkeeping, 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 salting; 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, which will help contain pollutants from traffic as well as from maintenance activities. (Also see Management Measure 7: Bridges and Highways.)

b. Trash in channels and creeks

Cleanup 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 might also discourage potential transgressors. Costs for these practices are associated with the purchase of signs and equipment, personnel to conduct inspections and cleanup, and landfill space to dispose of recovered items. Cost savings also can be achieved through community or volunteer cleanup programs.

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 the performance of such devices. Regular inspections should be performed along with routine maintenance. Nonroutine maintenance may be required to repair structures, control erosion, and remove unwanted vegetation. Table 8.2 and the following practices describe maintenance costs, activities, and schedules for several categories of urban runoff treatment practices.

a. Ponds and wetlands

Extended dry detention ponds are submerged only during storms and are dry between storm events. They 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 might 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. In general, sediments should be cleared every 10 to 20 years. Sediment removal involves draining the pond (leaving some water to maintain the fish population) and removing the sediments for drying. Pond water should be disposed of in an approved manner; it should be tested for pollutants and released to the receiving water, if allowed, or pumped and hauled to a disposal facility. While 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 and nuisance 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 might be a problem in some areas, and introducing natural predators such as mosquito fish (*Gambusia*) can control them effectively. Consultation with a wetland scientist is recommended to ensure that the constructed wetland functions as intended.

Table 8.2: 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 storm events (>2" rainfall) – Harvest 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 8.2 (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) – Harvest 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) – Harvest 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 8.2 (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
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

Table 8.2 (continued).

Category	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Filtration practices (continued)	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.
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 swale bottom and removal of thatching – Discing or aeration of swale bottom	Annual or as needed
				– Scraping swale bottom, and removal of sediment to restore original cross section and infiltration rate – Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle

b. 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 what the possible causes are. 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 once the facility has been drained to restore it to its original capacity. If the standing water results from 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. The filter fabric in infiltration devices adjacent to roads and parking lots in cold climates that are sanded in the winter should be replaced before spring because sediment loads are high during the winter months.

Promotion of a vegetative cover will help to maintain percolation rates, slow runoff velocity, and minimize ground water pollution. Nonvegetated basins require tilling or disking and leveling after sediment removal to maintain aeration and permeability. Vegetated filters that are adjacent to infiltration trenches should be cleared of sediments periodically to prevent sediment loading to the trench.

Regular monitoring of infiltration rates after storm events will indicate when maintenance is required to maintain the system's treatment design capacity.

c. 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 sediment depth to determine if the deposited sediments are getting 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 5 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 during filter maintenance identify accumulation to more than ¾ of capacity. Filtration chambers for these systems might 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. All materials removed from the systems should be tested to determine if contamination is present and 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 (between 2 and 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 replacements are 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 at least monthly. 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.

Table 8.3 lists maintenance equipment needed for the tasks described previously, along with purchase and rental costs.

Table 8.3: Typical O&M equipment and material costs (All costs are in 1997 dollars).

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

Table 8.3 (continued).

Equipment	Purchase	Rent (per day)
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	
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	

Source: WMI, 1997.

Information Resources

Operation, Maintenance, and Management of Stormwater Management Systems (WMI, 1997) presents a comprehensive review of the technical, educational, and institutional elements needed to ensure that storm water management systems are designed, built, maintained, and operated properly during and after their construction. The book includes fact sheets that summarize the operation, maintenance, and management needs and obligations, as well as construction recommendations, for 13 common storm water treatment BMPs. Other chapters review planning and design considerations, programmatic and regulatory aspects, considerations for facility owners, construction inspection, inspection and maintenance after construction, costs and financing, and disposal of storm water sediments. Forms for inspecting BMPs during construction and to determine maintenance needs afterwards are included in the book and in a separate supplement and are available at *www.epa.gov/owow/nps/wmi/inspform.pdf*.

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 *www.scdhec.net/eqc/ocrm/pubs/ponds.pdf*. 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 also 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 their web site (*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.

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Management Measure 12
Evaluate Program Effectiveness

A. Management Measure

Develop and implement a program to evaluate and improve the effectiveness of the urban runoff management program.

B. Management Measure Description and Selection

1. Description

The purposes of this management measure are to

- Determine if the runoff management program framework is protecting and/or improving water quality. This is determined 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.

- Reassess the watershed, as described in Management Measure 2, to determine whether water quality has improved or declined. Based on this assessment, each management measure should be reevaluated to determine if additional practices should be implemented or if improvements should be made to existing practices.

2. Management Measure Selection

This management measure was selected to periodically assess the effectiveness of urban runoff management programs and to identify areas where program improvement is possible. Programs that are periodically reviewed and evaluated are perceived as being more effective and will be more likely to receive the public and political support necessary to achieve success. This management measure and its practices present the basic elements of a successful program evaluation.

C. Management Practices

1. Assess the Runoff Management Program Framework

It is important for watershed managers to objectively assess the runoff management program framework to determine if the goals of 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. 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 having been installed. 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. Measures 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.

a. 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 their state certification as one measure of program success. In addition to monitoring water chemistry, sediments, and the biological community, Florida measures program success with the number of local government storm water utilities implemented as well as successful education and public involvement activities.

Watershed managers can use a combination of measures to assess the program framework based on program 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 and operation and maintenance of management practices as indicators of the success of a program framework. See Section 2 for a discussion of management practice tracking.

b. Quantitative measures

Another way for watershed managers to gauge the effectiveness of the runoff management program framework is to quantitatively determine if water quality has improved. Some quantitative measures include

- Chemical monitoring of practices.
- Chemical monitoring of receiving waters.
- Biological monitoring of receiving waters (bioassessments with habitat assessment).
- Stream flow monitoring.
- Sediment monitoring (deposition, chemistry).
- Measuring the volume of material removed by street sweeping and catch basin cleaning.

See Section 3 for a more thorough discussion of the different types of monitoring that can be used to gauge changes in water quality after management practice implementation.

c. Quality assurance/quality control

An integral part of the design phase of any monitoring project is quality assurance and 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 integrates 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 contains statements about the expectations and requirements of those for whom the data are being collected (i.e., the decision maker) and provides details on project-specific data collection and data management procedures that are designed to ensure that these requirements are met. 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).

2. Track Management Practice Implementation

Implementation monitoring can be used to determine the extent to which management measures and management practices are implemented in accordance with relevant standards and specifications. In general, implementation monitoring is used to determine whether the goals, objectives, and standards detailed in implementation plans are being met through management practice implementation.

Evaluating management practice implementation involves establishing a program that tracks either the implementation or the operation and maintenance of all management practices of certain types. 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 authorities might 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 *www.epa.gov/owow/nps/pubs*. Below are several tools that can be used to track management practice implementation.

a. Track permits

States 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, the mechanisms 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, and site-specific activities. A permitting system places on the applicant the burden of obtaining and supplying all necessary data and information needed to get the permit. Issuance of these permits encourages construction and operation of management practices in compliance with local laws and regulations.

b. Use operation and maintenance records

In many instances the extent of proper operation and maintenance of a management practice is as important as the proper design and installation of the management practice. Operation and maintenance for management practices is discussed in Management Measure 11 and in a manual published by the Watershed Management Institute (1997b) entitled *Operation, Maintenance, and Management of Stormwater Management Systems*. 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, the tasks of tracking operation and maintenance and ascertaining the effectiveness of the practice is much easier.

c. Use geographic information systems

Geographic information systems (GISs) are useful tools for inventorying management practice implementation. A GIS can be extremely useful for management practice tracking since it can be used to keep track of and detect trends in management practice implementation, land treatment, changes in land use, and virtually any data related to management practices and water quality. An advantage of using a GIS for management practice tracking is the ability 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 data analysis tools, can be used to design sampling protocols for tracking studies, and can help watershed managers analyze management program effectiveness by integrating land treatment and water quality information.

d. Develop surveys

Surveys for property managers and developers can be used to collect background information about management practice implementation, such as the following:

- Type, number, and size of management practices installed.
- Management practice location/watershed.
- Land use (i.e., residential, commercial, industrial).
- Percent impervious area.
- Inspection schedule.
- Operation and maintenance practices.
- Dates of management practice installation.
- Design specifications.
- Type of waterbody 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 gleaned from these surveys to identify locations for new management practices and to more closely examine practices that are operating upstream of areas known to be degraded to determine if they are operating as designed or if they require redesign or maintenance.

e. Consider expert evaluations

Expert evaluations might be needed to augment or verify information provided in surveys. Experts are especially useful in determining the following:

- Design sufficiency.
- Installation sufficiency.
- Adequacy of operation and maintenance.
- Confirmation of information from self-evaluations.

Each of these tools listed above 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.

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, or purpose, 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 would be to identify project constraints such as financial, staffing, and temporal issues. Clear and detailed information should be obtained on the time frame within which management decisions need to be made, the amounts and types of data that must be collected, the level of effort required to collect the necessary data, and the equipment and personnel needed to conduct the monitoring. From this information it can be determined whether available personnel and budget are sufficient to implement or expand the monitoring program.

As with monitoring program design, the level of monitoring that will be conducted is largely determined when goals and objectives are set for a monitoring program, although there is some flexibility for achieving most monitoring objectives. Watershed managers should determine the appropriate temporal and geographic scales 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 5 years or longer might be necessary.

Watershed managers also need to determine the size of the watershed, because factors such as drainage patterns, stream order, stream permanence, climate, number of landowners in the area, homogeneity of land uses, watershed geology, and geomorphology have an influence on stream characteristics, water quality, and therefore the complexity of the monitoring program design. 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 determine that the expectations of the monitoring program are realistic. Ward et al. (1990) identify the following key steps to ensure that policymakers and other stakeholders know the type 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 that 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.

Since there are numerous variables to choose from but monitoring budgets are limited, some method to prioritize variable selection is often necessary. Table 9.1 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.

Designing and implementing a monitoring program is an interdisciplinary and interagency activity. 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 a few agencies acting as project coordinator(s) should seek to obtain an agreement from each involved party with respect to their role(s) and responsibilities in the performance of the project. These agreements can be formalized as commitments and specified in the quality assurance project plan.

Table 9.1: 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, macroinvertebrates, 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.

Such coordinated cooperation permits each involved party to offer the results of its ongoing activities to the monitoring effort and lessens the burden on the proposed budget. 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.

a. 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 monitoring 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 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 that a baseline, or starting point, be established. Any changes in the measured parameter are then detected in reference to the baseline. Baseline monitoring is generally thought of as determining a condition prior to pollutant entry or prior to a change in waterbody condition, whether beneficial or detrimental. Controlling for influencing factors such as climate is necessary 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.

Trend monitoring involves long-term monitoring 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 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?"

b. 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 at 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 5 years), while others might take longer. Evaluation of management practice systems is typically conducted over a long term (more than 5 years) because management practice implementation can take years to affect water quality. 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.

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 are present. 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:

- 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. 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 ambient water quality monitoring data 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). 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 5 years).

Information Resources

Restoring Life in Running Waters: Better Biological Monitoring (Karr, 1998) describes how and why biological monitoring and multimetric 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 *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 *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 *www.epa.gov/owow/nps/urban.pdf*, or it can be ordered through EPA's National Service Center for Environmental Publications at *www.epa.gov/ncepihom/index.htm*.

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 *www.epa.gov/owow/nps/stormwater.html*.

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