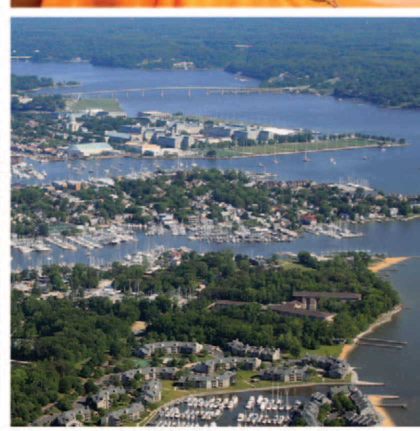
Guidance for Federal Land Management in the Chesapeake Bay Watershed











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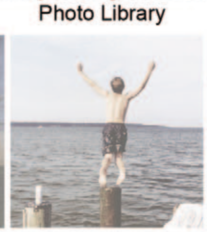

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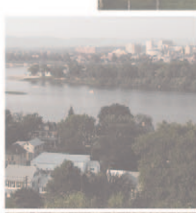

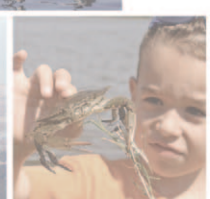

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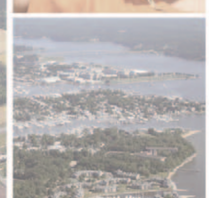

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Guidance for Federal Land Management in the Chesapeake Bay Watershed

EPA 841-R-10-002

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Contents

Chapter 1. Introduction

1 Background

On May 12, 2009, President Barack Obama signed Executive Order 13508, which recognizes the Chesapeake Bay as a national treasure and calls on the federal government to lead a renewed effort to restore and protect the nation's largest estuary and its watershed. In the Executive Order, the President states that despite significant efforts by federal, state, and local governments and other interested parties, water pollution in the Chesapeake Bay prevents the attainment of existing state water quality standards and the *fishable and swimmable* goals of the Clean Water Act. The President further notes that at the current level and scope of pollution control within the Chesapeake Bay's watershed, restoration of the Chesapeake Bay is not expected for many years. Nutrients (forms of both nitrogen and phosphorus) and sediment delivered from the Chesapeake Bay watershed are the pollutants largely responsible for the continued degradation and restoration complexities of the Chesapeake Bay.

The Executive Order expresses the great challenge facing our renewed efforts to restore the health of the Chesapeake Bay,

> Restoration of the health of the Chesapeake Bay will require a renewed commitment to controlling pollution from all sources as well as protecting and restoring habitat and living resources, conserving lands, and improving management of natural resources, all of which contribute to improved water quality and ecosystem health.

To meet that challenge, the Executive Order lays out a series of steps. One of the first key steps requires the federal agencies to define the "*next generation* of tools and actions to restore water quality in the Chesapeake Bay and describe the changes to be made to regulations, programs, and policies to implement these actions." The Executive Order assigns the lead responsibility to the U.S. Environmental Protection Agency (EPA), and the federal government published the final report on November 24, 2009. The report is at http://executiveorder.chesapeakebay.net (President Barack Obama 2009).

Another key step in the Executive Order is for EPA to publish this guidance document. Section 502 of the Executive Order states,

> The Administrator of the EPA shall, within 1 year of the date of this order and after consulting with the Committee and providing for public review and comment, publish guidance for Federal land management in the Chesapeake Bay watershed describing proven, cost-effective tools and practices that reduce water pollution, including practices that are available for use by Federal agencies.

2 Purpose of This Document

This document provides information and data on land management practices for federal agencies with land, facilities, or installation management responsibilities affecting 10 or more acres within the watershed of the Chesapeake Bay to contribute toward the restoration of the Chesapeake Bay and its watershed. The ultimate goal of the Executive Order—to restore the health of the Chesapeake Bay—is very high. Yet, as the Executive Order states, the Chesapeake Bay is, "one of the largest and most biologically productive estuaries in the world." It is certainly deserving of the ambitious effort laid out in the Executive Order.

However, we cannot underestimate the challenge. In particular, abating nonpoint source[1] pollution, which is the focus of this document, presents a huge challenge to the recovery of the Bay. Unless we adequately address the vast majority of nonpoint source pollution, the Chesapeake Bay will not be restored. Consider the following:

- Almost half of all the nitrogen and phosphorus pollution delivered to the Chesapeake Bay derive from agricultural sources, from both livestock production and row crop land.
- In addition to contributing 31 percent of phosphorus loads and 11 percent of nitrogen loads to the Bay, urban runoff and stormwater sources compose the only significant pollutant source category that is increasing in the Bay watershed.
- River basins with the highest percentage of agricultural lands yield the highest overall amount of sediment each year, while basins with the highest percentage of forest cover yield the lowest amount of sediment.

[1] This document uses the term *nonpoint source* broadly, as EPA has in the past, to refer to sources that are treated as nonpoint sources in EPA's implementation of section 319 of the Clean Water Act. Some of those sources may legally be made subject to regulation as point sources under section 402(p) of the Clean Water Act. EPA has designated several categories of those stormwater sources for regulation, such as small municipal separate storm sewer systems, and may designate others for regulation in the future.

- On a per-acre basis, construction sites can contribute the most sediment of all land uses—as much as 10 to 20 times that of agricultural lands.
- A large percentage of riparian buffers in the Chesapeake Bay have been lost or degraded. While the Chesapeake Bay Commission set a goal in 2004 to achieve buffer along 70 percent of riparian lands, the percentage currently stands at 60 percent.

For those and other reasons, it is critically important that we achieve, at a minimum, the nonpoint source implementation measures set forth in this document for the various land management categories. The implementation measures are designed to promote the use of the best, cost-effective and reasonable practices available to achieve the Executive Order's broad and ambitious goals for the Chesapeake Bay. In turn, the practices and actions described and recommended in this document are those that are indicated by the current, state-of-the-art scientific and technical literature to be the most effective and cost-effective in achieving the Chesapeake Bay goals. Thus, the information presented in this document will enable practitioners to design and implement on-the-ground solutions that collectively will move the entire watershed toward achieving the goals.

Note: This document provides guidance regarding practices that may be used to reduce nonpoint source pollution in the Chesapeake Bay and other waterbodies. At times, 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, other federal agencies, or any other entity and might not apply to a particular situation according to the circumstances. EPA, other federal agencies and any other user of this document retain the discretion to adopt approaches to control nonpoint source pollution that differ from this guidance where appropriate. EPA may change this guidance in the future.

3 Scope

As required by Section 502 of the Executive Order, this document (1) provides guidance for federal land management in the Chesapeake Bay and (2) describes proven, cost-effective tools and practices that reduce water pollution, including practices that are available for use by federal agencies. Federal agencies in the Chesapeake Bay watershed will find this guidance useful in managing their lands, ranging from the development and redevelopment of federal facilities to managing agricultural, forested, riparian, and other land areas the federal government owns or manages.

At the same time, the great majority of land in the Chesapeake Bay watershed is nonfederal land that private landowners, states, and local governments manage. Indeed, the vast majority of actions to restore the Chesapeake Bay will need to take place on nonfederal lands, and nonfederal actors will be implementing them. From the perspective of land management and water quality restoration/protection, the same set of "proven cost-effective tools and practices that reduce water pollution" are appropriate for both federal and nonfederal land managers to restore and protect the Chesapeake Bay.

Therefore, states and others (e.g., states, local governments, conservation districts, watershed groups, developers, farmers and other citizens in the Chesapeake Bay watershed) may choose to use this guidance document to the extent that they find it relevant and useful to their needs. The document presents practices and actions that are not unique to federal lands and thus will often be applicable to lands that are managed by nonfederal land managers. Thus, while this document has been written specifically to address the needs of federal land managers, other parties may also find it to provide a useful guide to implementing the most effective and cost-effective practices available to restore and protect the Chesapeake Bay.

In addition, many of the nutrient and sediment sources in the Chesapeake Bay watershed are similar to sources in other watersheds around the country. Many of the practices needed to protect and restore the Bay are the same as or very similar to those used in other large-scale, multistate watersheds in the country. Indeed, while great efforts have been made in preparing this document to assure the consideration of all relevant data on the Chesapeake Bay watershed, data from outside the Bay watershed have also been used when deemed relevant and applicable to the Bay. For that reason, much of the information provided in this document is relevant to other areas of the United States. Therefore, practitioners outside the watershed may wish consider this guidance document as they develop and implement their own watershed plans and strategies to address nutrient and sediment pollution from nonpoint sources.

This document provides information pertaining to all the major categories and subcategories of nonpoint source pollution that are relevant to the Chesapeake Bay. Those categories include agriculture, urban and suburban development, hydromodification, decentralized wastewater treatment, forestry, and riparian streamside areas.

Each chapter describes the problem presented by the relevant nonpoint source category or subcategory of activity and its relevance to the Chesapeake Bay's recovery. Each chapter states the key goals that readers should strive to achieve to attain the ambitious overall goals for the Chesapeake Bay set forth in the Executive Order. The goals are accompanied by information and data on the cost-effective tools and practices that practitioners can employ to help achieve the goals. It also provides available effectiveness data and cost data.

4 Relationship to Previous Documents

EPA has produced a considerable amount of technical information regarding the effectiveness and costs of various measures and practices to address nonpoint source pollution in the past. In 1993, as required by section 6217 of the Coastal Zone Act Amendments of 1990, EPA published the *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA 1993), which contains chapters on agriculture, forestry, urban runoff, marinas and recreational boating, hydromodification, and wetlands and riparian areas (see http://www.epa.gov/owow/nps/MMGI/). Section 6217 defines *management measures* as, "economically achievable measures for the control of the addition of pollutants...which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives." The 1993 guidance includes a set of management measures in each chapter and then provides information on available practices, their effectiveness, and their costs.

The National Management Measures volumes expand a chapter from the 1993 coastal guidance into an entire book series that contains national management measures patterned after the coastal guidance, complete with updated data (see http://www.epa.gov/owow/nps/pubs.html). All the practices and actions in the National Management Measures books are based on those established in the 1993 publication, but the newer publications provide updated information and addresses to some extent select newly emerging issues and practices. The six *National Management Measures* books are

- *National Management Measures for the Control of Nonpoint Pollution from Agriculture* (USEPA 2003)
- *National Management Measures to Control Nonpoint Sources of Pollution from Forestry* (USEPA 2005b)
- *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution* (USEPA 2005c)
- *National Management Measures to Control Nonpoint Source Pollution from Urban Areas* (USEPA 2005d)
- *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems* (USEPA 2005a)
- *National Management Measures to Control Nonpoint Source Pollution from Hydromodification* (USEPA 2007)

This guidance document builds on those two earlier efforts but also differs in significant ways. It focuses to a considerable extent on newer, more effective approaches to controlling some of the most significant aspects of nonpoint pollution in the Chesapeake Bay watershed. Most importantly, it responds to the imperative of implementing in the Chesapeake Bay watershed those "next generation tools and actions" that reflect, in the words of the Executive Order, "a renewed commitment to controlling pollution from all sources as well as protecting and restoring habitat and living resources, conserving lands, and improving management of natural resources, all of which contribute to improved water quality and ecosystem health."

5 Some Topics Receive New or Special Emphasis

The key areas in which this document focuses on next-generation tools and actions that go beyond the previous nonpoint source guidance documents are the following:

1. Nutrient Management. This document focuses specifically on significantly expanding on practices and actions that control the delivery of nutrients and sediment from agriculture by employing a whole-farm nutrient management planning approach from source control and avoidance, in-field control, and edge-of-field trapping and treatment. The practices and actions presented here build from the most recent, state-of-the-art literature in nutrient management planning and provide information on achieving reduced nutrient losses from both livestock production on animal feeding operations and row crop agricultural lands.

2. Control of Urban Runoff and Stormwater. In this document, EPA recognizes and emphasizes that hydrology is the principal driver of water quality impairments in developed and developing areas. From that understanding, EPA establishes in this document a primary focus on the goal of maintaining and restoring predevelopment hydrology to the maximum extent technically feasible (METF). The guidance presents background information, data, examples, and resources that demonstrate how practitioners can achieve that goal by implementing low impact development (LID) and other green infrastructure techniques that infiltrate, evapotranspire, and use rainwater on-site.

3. Turf Management. At 3.8 million acres, the total cultivated area for turf makes it the number one crop grown in the Chesapeake Bay watershed. A significant portion of the turf is grown in a manner that includes high inputs of fertilizers. Thus, turf management practices can at present contribute a substantial amount of nutrient to the Chesapeake Bay. Therefore, this document includes implementation measures that can help reduce nutrient runoff from turf.

4. Decentralized Wastewater Treatment Systems. This document presents an increased emphasis on reducing nitrogen from decentralized systems, because of both the need to reduce nutrient delivery to the Chesapeake Bay and the rapidly advancing state of the art. In addition, this document uses the term *decentralized systems* rather than *onsite systems*, reflecting the technical, feasibility, and management advantages of cluster treatment systems that treat effluent from multiple lots at nearby off-site locations.

6 Some Topics are Addressed by Reference to Existing Documents

Some nonpoint source practices remain important, but EPA has already adequately addressed them in previous management measures documents and in other published literature. In those cases, this document does not repetitively include details on those practices. (The six *National Management Measures* books total approximately 1,500 pages.) Instead, this document briefly acknowledges the issue or subject and then refers the reader to the appropriate existing documents.

7 References

President Barack Obama. 2009. *Executive Order 13508: Chesapeake Bay Protection and Restoration.* The White House, Office of the Press Secretary, Washington, DC. <http://executiveorder.chesapeakebay.net>. Accessed January 28, 2010.

USEPA (U.S. Environmental Protection Agency). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* EPA 840-B-92-002. U.S. Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2003. *National Management Measures to Control Nonpoint Pollution from Agriculture*. EPA 841-F-05-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2005a. *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems*. EPA 832-B-05-001. Office of Wastewater Management. Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2005b. *National Management Measures to Control Nonpoint Sources of Pollution from Forestry*. EPA 841-B-05-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2005c. *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution*. EPA 841-B-05-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2005d. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. EPA 841-B-05-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2007. *National Management Measures to Control Nonpoint Source Pollution from Hydromodification*. EPA 841-B-07-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Chapter 2. Agriculture

Contents

1 Purpose and Overview

1.1 Need for an Agricultural Chapter

1.1.1 Purpose

Approximately 87,000 farm operations and 8.5 million acres of cropland, or nearly a quarter of the watershed, in the Chesapeake Bay watershed provide food and fiber, as well as significant natural areas and aesthetic and environmental benefits. Farms in the Chesapeake Bay watershed are very diverse. They vary greatly in size and produce a wide variety of products. Today, according to the U.S. Department of Agriculture (USDA), more than 50 commodities are produced in this region. The area's primary crops include corn, soybeans, wheat, hay, pasture, vegetables, and fruits. The eastern part of the region is also home to a rapidly expanding nursery and greenhouse industry.

On federal lands in the Chesapeake Bay watershed, approximately 30,396 acres are managed for agricultural production. Specifically

- National Park Service: 14,669 acres
- USDA: 7,000 acres[1]
- Department of Defense: 5,588 acres
- Fish and Wildlife Service: 1,259 acres

The purpose of this document is to present an overview of the practices and information resources available for federal land managers and others to achieve water quality goals in the most cost-effective and potentially successful manner, with the overall objective of improving water quality, habitat, and the environmental and economic resources of the Chesapeake Bay and its tributaries.

This chapter provides a host of practices and actions that can be employed to reduce the loadings of nitrogen (N), phosphorus (P), and sediment from agricultural activities to local waters and the Chesapeake Bay. This chapter focuses on nutrient management on cropland and the prevention of soil erosion from cropland, and on nutrient management in the production

[1] USDA manages a number of large facilities in the Chesapeake Bay watershed. The Beltsville Agricultural Research Center in Maryland is a leader in agricultural research and, at approximately 7,000 acres, serves as a laboratory for state-of-the-art conservation practices. The National Arboretum in Washington, DC, managed by USDA's Agricultural Research Service, sits on more than 440 acres and is intensively managed for horticultural purposes. USDA manages additional smaller sites around the watershed and provides technical assistance for agricultural practices on small acreages of federal lands managed by other agencies.

area of animal feeding operations (AFOs). It is important to note that planning and implementing successful conservation or control measures depends on site-specific considerations and information. Consequently, the practices and actions presented here are a general guide to inform development of a more detailed plan or approach tailored to a specific facility, activity, or location.

This chapter does not address the management of agricultural lands to protect and restore water quality by reducing impacts from pesticides and from irrigation; for information on those subjects, see the chapters devoted to those activities in the *National Management Measures for the Control of Nonpoint Pollution from Agriculture* (USEPA 2003). This chapter does not thoroughly cover losses of N to air, but it does provide some information on volatilization controls. Finally, while recognizing the need to create new markets and alternative manure uses, this chapter does not cover the emerging technologies and financial mechanisms that are being developed to address those needs.

1.1.2 Intended Audience

The primary audience for this document is land managers in federal agencies who are responsible for meeting water quality goals and implementing water quality programs on agricultural land. In addition, state and local agencies may use this guidance in developing Watershed Implementation Plans to meet water quality goals. Others who can benefit from the information in this document include conservation districts; the agricultural services community; farm owners, operators, and managers; local public officials responsible for land use and water quality decision making; environmental and community organizations; and the business community.

1.1.3 Water Quality Significance of Agricultural Runoff in the Chesapeake Bay Watershed

Agriculture is the single largest source of nutrients and sediments to the Chesapeake Bay, and according to the Chesapeake Bay model, it is responsible for approximately 43 percent of the N, approximately 45 percent of the P, and approximately 60 percent of the sediment loads. Much of that load is delivered from Pennsylvania (Susquehanna River), Virginia (Shenandoah and Potomac rivers), and the Delmarva Peninsula of Maryland, Delaware, and Virginia. Chemical fertilizer accounts for 17 percent of the N and 19 percent of the P load, and manure accounts for 19 percent of the N and 26 percent of the P load. Seven percent of the total nitrogen (TN) load comes from air deposition from livestock and soil emissions from agriculture.

Implementing agricultural management practices might not provide nutrient load reductions to the Chesapeake Bay as quickly as implementing actions by other sectors; however, reductions in agricultural loads are the most cost-effective means to restore the Bay over time. Excess N from cropland is transported to the Bay via groundwater with a lag time of years or decades, depending on the location in the watershed. Additionally, reductions in P loads from agricultural lands might not be seen immediately after implementing P-control practices because of current P saturation in cropland soils in areas with high animal densities. Protecting the Bay and its watershed is costly and will require a variety of cost-share and economic support measures as the next generation of tools and practices are expanded.

Historical Context of Agricultural Land in the Chesapeake Bay Watershed

Since European settlement, agriculture has played an important role in sustaining the people of the Chesapeake Bay watershed. In the 1650s, the land was first broadly cleared for timber and agriculture. The land was able to support the growing population and in the 1700s, as agriculture expanded, the first signs of environmental degradation were noted. By the 1750s, 20 to 30 percent of the forested areas were stripped for settlement, and the shipping ports began to fill with eroded sediment. By the 1800s, plows were used widely in agriculture, beginning the widespread use of tillage, preventing reforestation and encouraging soil erosion. In the first half of the 1800s, the Chesapeake and Delaware canal project encouraged even broader expansion of agriculture. Half of the forests were cleared for agriculture and settlement, wetlands were drained, and the first imported fertilizers (bird guano) were introduced from the Caribbean and from nitrate (NO_3) deposits on the northern Chilean coast.

Agriculture in the Chesapeake Bay Watershed Today

Immediately following World War II, chemical fertilizer use became widespread, and as suburban expansion began in the 1950s, wetlands continued to be drained and filled. In the 1980s, nutrient management efforts began to take hold in agriculture, and in the 1990s, Chesapeake Bay tributary strategies were put in place, setting goals for reductions of nutrient and sediment loadings to the Bay. Today, for assessment purposes, the Bay and its tidal tributaries are broken into 92 segments. The states have identified those segments as being impaired because they do not meet water quality standards, and a total maximum daily load (TMDL) will be prepared for each of the segments, collectively adding up to the Chesapeake TMDL. A TMDL is a calculation of the maximum amount of a pollutant that the Bay can receive and still safely meet water quality standards.

Approximately 25 percent of the land in the Chesapeake Bay watershed is used for agriculture. Some practices used to maximize crop yields can cause deterioration in the quality of the Bay and its watershed. Improperly applied fertilizers and pesticides can flow off the land and deliver excess N, P, and chemicals to the Bay. The nutrients and bacteria in animal manure, which is used for fertilizer, can seep into groundwater and run into waterways if managed improperly on site at an AFO or off-site on cropland or elsewhere. Poor tilling and irrigation practices can promote erosion and can lead to additional sediment loads being delivered to waterbodies. The outflow of the tile or the edge of drain creates a high potential for loss of streamside vegetation and sediment scouring (see Chapters 5 and 7). Those practices can be improved, enhanced, or modified as appropriate to reduce pollutant loads from agriculture throughout the Chesapeake Bay watershed. Also, an imbalance of nutrients in the Chesapeake Bay watershed must be addressed through agriculture.

1.1.4 Managing Agricultural Runoff to Reduce Nutrient and Sediment Loss

Recommended Water Pollution Control Strategy: Implement Next Generation of Tools and Actions

To reach the Bay goals, the Chesapeake Bay Executive Order calls for implementation of the *next generation* of tools and actions (Chesapeake Bay Program Office 2010). While nutrient management planning (NMP) has been a part of farm operations since the 1980s because of state program requirements, this document presents a description of the next generation of NMP based on state-of-the-art science and understanding of the farm landscape today. The NMPs will provide a strong link between production, nutrient management on the land, and water quality. The NMPs described in this document will enable producers to achieve their expected yields and reduce waste of the valuable, finite resources of nutrients and sediments, while reducing the losses of the nutrients and sediments to surface water that eventually enters the Chesapeake Bay.

Although agriculture is a key part of the solution to the Chesapeake Bay restoration given the magnitude of loads and the relative cost-effectiveness of practices, we must overcome significant barriers to reach broad-scale implementation in agriculture. While the draft Executive Order section 203 Federal Strategy notes that restoration of the Chesapeake Bay or its watershed is not expected for many years, restoration will require a renewed commitment and therefore actions taken throughout the agricultural landscape will need to become more strategic, coordinated, and goal-oriented to meet the Bay goals (Federal Leadership Committee 2009).

The most significant improvement in agricultural production needed to restore the Chesapeake Bay is to change how excess manure nutrients are handled. Therefore, the major focus of this chapter is on nutrient management, accompanied by practices and actions for AFO production areas as well as sediment and erosion control on cropland. The practices, taken together, can greatly reduce the introduction of nutrients to the Chesapeake Bay.

The most effective practices to reduce pollution inputs of nutrients to the Chesapeake Bay focus around controlling the rate, timing, method and form of nutrient application. This guidance presents the implementation measures component of NMPs that would maximize reductions by agriculture. The current practices in the Chesapeake Bay watershed being reported by states should be expanded. The Chesapeake Bay Program Office has compiled a great deal of information on the effectiveness of those practices, http://www.chesapeakebay.net/marylandbmp.aspx?menuitem=34449.

Achieving Multiple Benefits

The benefits and services provided by well-managed agriculture in the Chesapeake Bay watershed are numerous and include sustained crop yields; restored waterbodies for drinking water, recreational, and other beneficial uses; habitat benefits; a functioning ecosystem; reduced vulnerability to invasive species; and a continued healthy and productive agricultural economy in the Chesapeake Bay watershed. When effective land cover from agriculture occurs year-round, those systems can store carbon and minimize soil erosion that fills local waters and the Bay. A healthy agricultural network in the Bay watershed will provide for key connections across the landscape for animals and birds, as well as reduce the watershed's vulnerability to flooding and the effects of climate change.

Readers of this chapter should also see Chapters 4 and 5 regarding Forestry and Riparian Buffers. While this chapter focuses on source control and treatment options for cropland and animal production areas in agriculture, it is essential that a holistic restoration of the Chesapeake Bay watershed also achieve the benefits that can be reaped when all these systems are operating together to serve the watershed.

1.2 Overview of the Agriculture Chapter

This chapter provides recommendations in the form of implementation measures for the suite of practices that can be implemented on agricultural lands. While these recommendations are made from state-of-the-art literature, the chapter expands on the *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003).

Information on the effectiveness of practices included in this chapter is largely taken from literature published after 2000 to build on the earlier literature that was used in developing the *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003). For some practices, however, the literature search went back further in time. This includes, for example, drainage water management, a practice not addressed to a significant extent in EPA's 2003 guidance. The bulk of literature used in this chapter comes from professional journal publications (e.g., *Journal of Environmental Quality*), but information is also derived from government documents and resources (e.g., USDA conservation practice standards), books, Cooperative Extension publications, proceedings from professional meetings, and online publications by professional groups and industry. Most literature was found through keyword searches of sources such as the National Agricultural Library Catalog and specific professional journals. Literature specific to the Chesapeake Bay watershed states was given top priority, but relevant literature from across the United States and from other countries was included to provide as complete coverage as possible on each of the topics addressed in this chapter.

Practice cost data taken from the literature and other sources were converted to 2010 dollars using the conversion factors provided by the U.S. Inflation Calculator (2010). Exceptions are that cost data provided for fiscal year 2010 by states were not changed, and aggregate cost data expressed over a range of years were not converted to 2010 dollars. Unless specified, the year of publication was used as the initial year for conversion of dollars.

1.2.1 Management Practices and Management Practice Systems

To best plan and implement practices that will benefit water quality, producers should have in place a conservation plan. A conservation plan based on an evaluation of the soil, water, air, plant, and animal resources should present the practices, tools, and actions that will be used on the agricultural land to benefit water quality. This plan outlines the management practices to be implemented and maintained.

Management practices are implemented on agricultural lands for a variety of purposes, including protecting water resources, human health, terrestrial or aquatic wildlife habitat, and land from degradation by wind, salt, and toxic levels of metals. The primary focus of this guidance is on agricultural management practices that reduce the delivery of pollutants into water resources by reducing pollutant generation or by remediating or intercepting pollutants before they enter water resources. This guidance generally refers to the term management practice, and this encompasses all agricultural practices, including structural, cultural, and traditional management practices.

The Natural Resources Conservation Service (NRCS) maintains a continuously updated *National Handbook of Conservation Practices* (USDA-NRCS 2010d), which details nationally accepted management practices. Those practices are on the USDA-NRCS Web site at http://www.nrcs.usda.gov/technical/Standards/nhcp.html. Each state adopts and tailors those standards to meet state and local conditions and criteria, and the state-adopted standards could be more restrictive than the national criteria referenced in this guidance. In addition to the NRCS standards, many states use locally determined management practices that are not reflected in the NRCS handbook. Note that while a wide variety of practices are available, all require regular inspection and maintenance to ensure continued performance at expected levels. Readers interested in obtaining information on management practices used in their area should contact their local Soil and Water Conservation District or local USDA office. Two very helpful handbooks are *60 Ways Farmers Can Protect Surface Water* (Hirschi et al. 1997), and *50 Ways Farmers Can Protect their Ground Water* (Hirschi et al. 1993).

Management practices are used to control a pollutant type from specific land uses. For example, conservation tillage is used to control erosion from irrigated or non-irrigated cropland. Management practices can also provide secondary benefits by controlling other pollutants, depending on how the pollutants are generated or transported. For example, practices that reduce erosion and sediment delivery often reduce P losses because P is strongly adsorbed to silt and clay particles. Thus, conservation tillage reduces erosion and reduces transport of particulate P.

In some cases, a management practice can provide environmental benefits beyond those linked to water quality. For example, riparian buffers, which reduce P and sediment delivery to waterbodies, can also serve as habitat for many species of birds and plants where the design and width provide for this use.

Sometimes, however, management practices used to control one pollutant might inadvertently increase the generation, transport, or delivery of another pollutant; management practices should be implemented through a systems approach to ensure balance. Conservation tillage, because it creates increased soil porosity (i.e., large pore spaces), can increase water transport through the soil. Without crop growth and the associated root system that would take up available N, increased water transport through the soil can also lead to increased N leaching particularly where fertilizer N is applied not as part of the management plan that accounts for the timing and amount of crop N needs. Tile drains, used to reduce surface runoff and increase soil drainage, can also have the undesirable effect of concentrating and delivering N directly to streams (Hirschi et al. 1997). To reduce the N pollution caused by tile drains, other management practices, such as nutrient management for source reduction, cover crops and biofilters that treat the outflow of the tile drains, might be needed. On the other hand, practices that reduce runoff might contribute to reduced in-stream flows, which have the potential to adversely affect habitat. Therefore, management practices should be chosen only in the context of a holistic evaluation of both the benefits and potential adverse effects of the suite of practices, or management system, to be implemented at a site.

Some management practice systems include both repetitive treatment by the same practice at different places in a field as well as diversification of practices to enhance all the benefits of each. An example of such a system is an animal waste management system in which some components are included to help others function. For example, diversions and subsurface drains might be necessary to convey runoff and wastes to a waste treatment lagoon for treatment. While the diversions and subsurface drains might not provide any measurable pollution control of their own, they are essential to the overall performance of the animal waste management system. Other components, such as lagoons and waste utilization plans, are added to provide repetitive treatment.

Note on Practice Effectiveness: The effectiveness of any management practice is a function of a variety of factors including the characteristics of the baseline condition (e.g., influent water quality, soil nutrient levels, and current management practices), slope, soil type, climate, crops, and weather conditions during the study. Further, the monitoring and assessment approach used in a study imparts significant limitations to interpreting the findings. For example, inflow-outflow studies can be used to assess pollutant removal but only if the outflow and inflow measurements pertain to the same parcel of water. Load and concentration reductions have different meanings and utility, and it is particularly important to have full understanding of the comparison or benchmark against which the reduction is measured. This chapter's summary of literature findings on the effectiveness of agricultural management practices and systems must be interpreted carefully, and EPA strongly recommends that the reader review full reports before applying the findings to any specific situation, because the information presented represents general examples applicable to the site and situation studied and the effects of conservation tools and approaches applied depends on a number of variables site specific to the farm operation.

This chapter is divided into three sections regarding specific control options. Three types of practices are necessary in agricultural production to control nutrients and sediments; through these types of practices, the path of nutrients and sediment can be controlled. These three types avoid, control, and trap pollutants (ACT), and practices that suit each should be implemented in agricultural production.

- Section 2: Nutrient and sediment source control and avoidance from cropland and animal production areas
- Section 3: Cropland in-field controls
- Section 4: Cropland edge-of-field trapping and treatment

This guidance separately discusses source control and avoidance practices for the two critical topics of cropland agriculture and animal agriculture. However, the link between ensuring adequate storage and developing appropriate land application practices is one of the most critical considerations in successfully developing and implementing a site-specific nutrient management plan for manure, litter and process wastewater on animal agriculture operations that rely on cropland agriculture. Therefore, while the specific management practices are separately discussed in this guidance, it should be understood that those two aspects of agriculture are intricately linked and must be implemented through a systems approach to ensure a reduction in nutrient delivery to the Bay watershed.

Controlling the sources of nutrients and sediment entering the Chesapeake Bay through a variety of approaches at the field or production area, farm, and watershed scale will minimize the pollutants available throughout the agricultural operation. Source control and avoidance pertains to a crop's ability to use the nutrients available throughout the growing season, cropping cycles, feed management, manure management, and chemical fertilizer management. Source control approaches for cropland carefully evaluate the proper rate, timing, method, and form of nutrient application.

The cropland in-field controls focus on nutrient and sediment controls throughout the field itself. In-field practices will impede the transport or delivery (or both) of pollutants, either by reducing water transported, and thus the amount of the pollutant transported, or by transforming the pollutant into less harmful forms into the soil or atmosphere.

Wetlands, drainage water management, and buffers and setbacks are examples of important edge-of-field or end-of-pipe measures to prevent nutrient loads to the Chesapeake Bay.

This chapter presents a set of implementation measures that are organized by the pathway in which nutrient and sediment controls can be implemented. While the implementation measures are discussed independently from one other, they are intended to be implemented together as a comprehensive management system. The implementation measures are organized into the three components of source control and avoidance, in-field control, and edge-of-field trapping and treatment. The specific set of practices to be chosen by an agricultural producer to achieve pollutant reductions will necessarily be tailored as appropriate on the basis of a variety of factors related to the landscape, agricultural operation, and other similar factors; the practices chosen should link controls at the source, in the field, and at the edge of the field.

1.2.2 Implementation Measures for Agriculture in the Chesapeake Bay Watershed to Control Nonpoint Source Nutrient and Sediment Pollution

Source Control and Avoidance

Cropland Agriculture

Implementation Measures:

A-1. Base P application on P saturation in soils as follows:

- If the soil P saturation percentage is above 20 percent, do not apply manure or commercial fertilizer that contains P to cropland, grazing or pasture land.
- When soil P saturation percentage allows for application (i.e., is below 20 percent saturation), apply up to an N-based rate.
- Also, implement a soil P monitoring plan to ensure that soil-P levels are staying steady over time.
- If soil P saturation percentage is increasing, adjust manure applications to P-based rate and use commercial N fertilizer to make up the difference; if levels exceed 20 percent P saturation, no longer apply P.

A-2. Maximize N fertilizer use efficiency to maximize the net benefit from the lowest-needed amount of manure, biosolids, or commercial N fertilizer entering the cropland system. Whenever N fertilizer is applied where manure has already been applied, reduce N fertilizer rates according to the N credit of the manure that was applied. That N credit will vary depending on the amount, timing, type, and method of manure that was applied.

A-3. Replace high nutrient loading crops in high-risk areas for water quality effects with sound alternatives.

A-4. (1) Retire highly erodible lands (HELs) from cropland and replace the crop with perennial native vegetation, or (2) develop and implement a soil conservation plan to reduce sheet and rill erosion to the Soil Loss Tolerance Level (T) as well as a nutrient management plan.

A-5. When using commercial fertilizer, give credit for manure nutrients. When commercial fertilizer is used, provide for the proper storage, calibration, and operation of chemical fertilizer nutrient application equipment.

Animal Agriculture

Implementation Measures:

A-6. Formulate animal feeds to reduce nutrient concentration in manure, improve the manure N:P ratio in relation to crop needs, and/or eliminate toxic substances such as arsenic in manure used as fertilizer. Align the N:P ratio of the manure to be equal to (or greater than) the N:P ratio of the crop need.

A-7. Safely and strategically apply (with properly calibrated equipment), store, and transport manure.

- Liquid manure storage systems including tanks, ponds, and lagoons (e.g., NRCS Practice Code 313 Waste Storage Facility) should be designed and operated to safely store the entire quantity and contents of animal manure and wastewater generated, contaminated runoff from the facility, and the direct precipitation from events in the geographic area, including chronic rain.
- Dry manure (i.e., stackable, greater than or equal to 20 percent dry matter), such as that produced in poultry and certain cattle operations, should be stored in production buildings, storage facilities, or otherwise covered to prevent precipitation from coming into direct contact with the manure and to prevent the occurrence of contaminated runoff. When necessary, temporary field storage of dry manure (e.g., poultry litter) may be possible under protective guidelines (e.g., NRCS Practice Code 633 Waste Utilization).
- For manure and litter storage, the AFO should maintain sufficient storage capacity for minimum critical storage period consistent with planned utilization rates or utilization practices and schedule.

A-8. Exclude livestock from streams and streambanks and provide alternative watering facilities and stream crossings to reduce nutrient inputs, streambank erosion, and sediment inputs and to improve animal health.

A-9. Process/treat through physical, chemical, and biological processes facility wastewater and animal wastes to reduce as much as practicable the volume of manure and loss of nutrients.

Cropland In-Field Control

Implementation Measures:

A-10. Manage nutrient applications to cropland to minimize nutrients available for runoff. In doing so

- Apply manure and chemical fertilizer during the growing season only
- Do not apply any manure or fertilizer to saturated, snow-covered, or frozen ground
- Inject or otherwise incorporate manure or organic fertilizer to minimize the available dissolved P and volatilized N
- Apply nutrients to HELs only as directed by the nutrient management plan, while at the same time implementing all aspects of the soil conservation plan

A-11. Use soil amendments such as alum, gypsum, or water treatment residuals (WTR) to increase P adsorption capacity of soils, reduce desorption of water-soluble P, and decrease P concentration in runoff.

A-12. Use conservation tillage or continuous no-till on cropland to reduce soil erosion and sediment loads except on those lands that have no erosion or sediment loss.

A-13. Use the most suitable cover crops to scavenge excess nutrients and prevent erosion at the site on acres that have received any manure or chemical fertilizer application. Cover crops should be used during a non-growing season (including winters) or when there is bare soil in a field.

A-14. Minimize nutrient and soil loss from pasture land by maintaining uniform livestock distribution, keeping livestock away from riparian areas, and managing stocking rates and vegetation to prevent pollutant losses through erosion and runoff.

A-15. Where drainage is added to an agricultural field, design the system to minimize the discharge of N.

Cropland Edge-of-Field Trapping and Treatment

Implementation Measures:

A-16. Establish manure and chemical fertilizer application buffers or minimum setbacks from in-field ditches, intermittent streams, tributaries, surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters.

A-17. Treat buffer or riparian soils with alum, WTR, gypsum, or other materials to adsorb P before field runoff enters receiving waters.

A-18. Restore wetlands and riparian areas from adverse effects. Maintain nonpoint source abatement function while protecting other existing functions of the wetlands and riparian areas such as vegetative composition and cover, hydrology of surface water and groundwater, geochemistry of the substrate, and species composition.

A-19. For both new and existing surface (ditch) and subsurface (pipe) drainage systems, use controlled drainage, ditch management, and bioreactors as necessary to minimize off-farm transport of nutrients.

A-20. Manage runoff from livestock production areas under grazing and pasture to minimize off-farm transport of nutrients and sediment.

2 Implementation Measures and Practices for Source Control and Avoidance

2.1 Cropland Agriculture

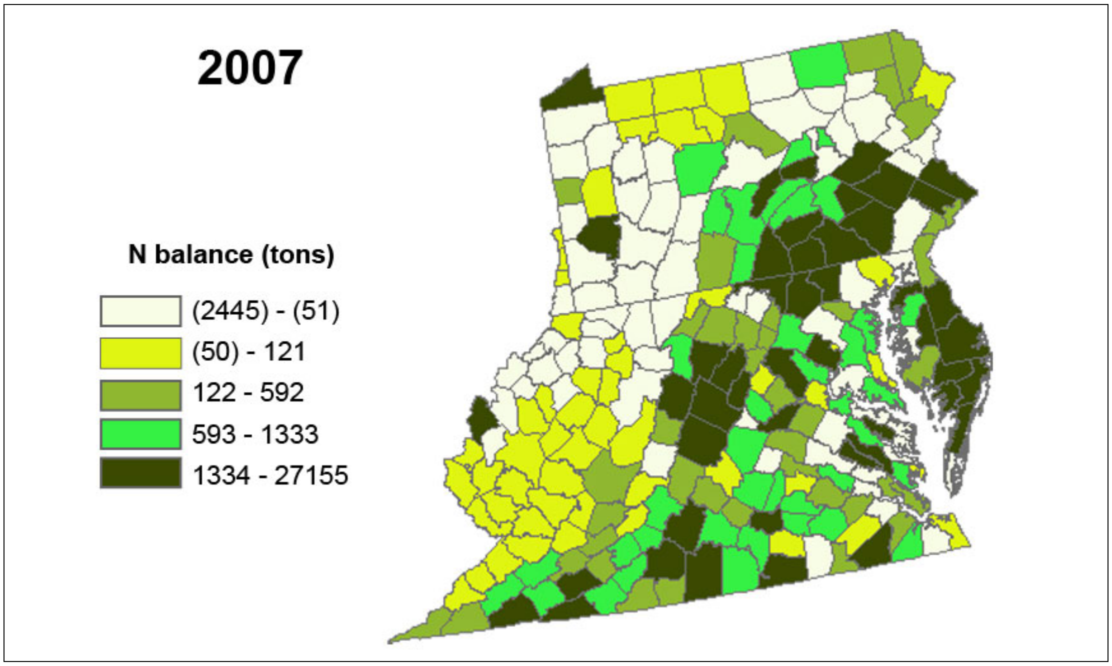
2.1.1 Nutrient Imbalance in the Chesapeake Bay Watershed

In the Chesapeake Bay watershed, the overall delivery of agriculture-based nutrients to the Bay needs to decrease significantly to protect the quality of the Chesapeake Bay. Unfortunately, a significant nutrient imbalance exists in the Bay watershed. More P is produced and imported into the watershed than is needed to fertilize crops, resulting in the imbalance and excess N and P available for delivery to the Bay through surface and ground waters. Nationwide, 1997 USDA estimates show that most U.S. counties (78 percent) need to move manure P from at least some animal operations to avoid P accumulation. Also, 1997 USDA estimates show that poultry operations account for two-thirds of N on farms and half of the excess P because generally, poultry litter has a high P-content, and poultry operations have less land than other operations for application. Dairy and hog operations also contribute to excess on-farm P. While manure as fertilizer does provide benefits to the soil in the form of amendments and carbon, the controlled use of manure is imperative to protecting water quality in the Bay watershed.

The Mid-Atlantic Water Program (MAWP), a consortium of land grant universities in the Chesapeake Bay watershed, developed nutrient budgets and balances by county and state for 2007 (MAWP 2007). Nutrient budgets are, “a summary of the major nutrient inputs and outputs to the cropland in a geographic region.” Nutrient balances are defined as “the difference between nutrient inputs and outputs.” When the nutrient balance is close to zero, nutrients applied from manure and commercial fertilizer are closely matched to crop use. When the nutrient balance is positive, nutrient inputs exceed outputs and excess nutrients are available that can reach the Bay. When the nutrient balance is negative, nutrient outputs exceed inputs.

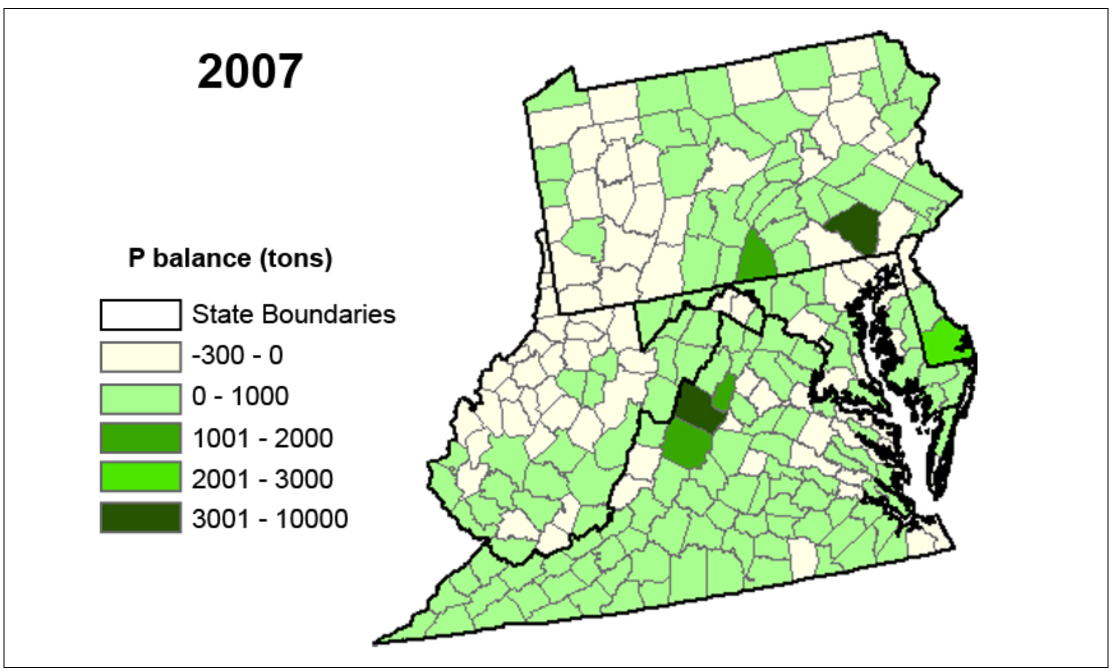
The MAWP also developed maps, in which nutrient input equals the amount of manure and fertilizer nutrient available for application, and nutrient output is determined by the amount of nutrient taken up by the crop, measured in the plant biomass harvested. The maps do not account for the level of nutrients that are already in the soil before application of additional nutrient inputs and also do not account for the N and P chemical fertilizers that are applied to crops annually; however, in places where there is a zero balance and it might seem that nutrients are being appropriately managed, high soil nutrients are available in those areas that could lead to nutrient loss to the Bay because P-saturation is not part of the consideration. The analysis identifies three such *hotspots* in the Chesapeake Bay watershed: the Shenandoah

River Valley in Virginia, the Eastern Shore of Maryland, and Lancaster County and surrounding areas in Pennsylvania (Figures 2-1 and 2-2).



Source: MAWP 2007, Note: The darkest color indicates counties with the highest N balances.

Figure 2-1. The map shows the N balance for cropland in mid-Atlantic counties in 2007.



Source: MAWP 2007, Note: The darkest color indicates counties with the highest P balances.

Figure 2-2. The map shows the P balance for cropland in mid-Atlantic counties in 2007.

Realistic production goals should guide nutrient rate reductions in agriculture and are critical for reducing N and P export from agricultural lands and moving toward a nutrient-balanced Chesapeake Bay watershed. The current model for nutrient use maximizes plant uptake by saturating nutrients through application, especially for N; this should be adjusted to account for non-optimum weather patterns. Because optimum weather conditions occur on average once every 5 to 7 years, an excess of N and P is in the fields in most years (those with non-optimum weather).

The following section details practices and actions that can minimize excess nutrients from entering the agricultural production system and achieve a nutrient balance.

2.1.2 Nutrient Management

The management tools and practices in widespread use in the Chesapeake Bay watershed for both organic (manure, sludge, and such) and inorganic (commercial fertilizer) nutrient application are insufficient to prevent over-application and the resulting nutrient loading to the Chesapeake Bay. However, NMP in line with those implementation measures, if broadly applied in the watershed, will significantly reduce nutrients available as runoff into local waters and the Chesapeake Bay. Controlling the rate of nutrient application is the first defense to limiting the amount of nutrients that might be able to leave the land throughout the production process.

The goals of NMP are to apply nutrients at rates necessary to achieve realistic crop yields, improve the timing of nutrient application, employ appropriate tools to determine application rate, method and form (manure or inorganic), and to reduce the risks of nutrients moving from the land and production area to local waters. When manure is the source of fertilizer, both the nutrient value and the rate of availability of the nutrients should be determined. With commercial fertilizer, that information is on the label. Where legume crops (e.g., soybeans) are planted, the N contribution of the crop should be determined and credited to the following crop.

NMP is implemented to increase the efficiency with which crops use applied nutrients, thereby reducing the amount available to be transported to both surface and ground waters. Controlling nutrient inputs (source) by practicing effective nutrient management is imperative, and reducing the nutrient inputs to the agricultural system will effectively minimize nutrient losses from cropland occurring at the edge-of-field by runoff and by leaching from the root zone. Once N, P, or other nutrients are applied to the soil, their movement is largely controlled by the movement of soil and water and must therefore be managed through other control systems such as erosion control and water management. That is usually achieved by developing a nutrient budget for the crop, applying nutrients at the proper time with proper methods, applying only the types and amounts of nutrients necessary to produce a crop, and considering the environmental hazards of the site. In cases where manure is used as a nutrient source, manure storage will be needed to provide capability to apply manure at optimal times. Even with proper nutrient management, rain can cause nutrients to move into waterways if the rain is heavy, frequent, or comes soon after nutrient applications. Therefore, nutrient management needs to be supplemented with in-field and edge-of-field controls.

In many instances, NMP results in using lower application rates of commercial fertilizer because of the availability of manure nutrients and, therefore, a reduction in production costs. However, the agriculture system in the watershed has a general imbalance of nutrients due to excess manure generated annually by the combination of all AFOs in the watershed. Thus, for any cropland where there has not been a balanced use of nutrients in the past, NMP should incorporate the options for source control presented in this section—the reduction of nutrients for input into the agricultural production system—to reduce the possibility of excess nutrients being applied out of need to reduce capacity of manure.

Nutrient management planning should consider all aspects of the rate, timing, method, and form of nutrients, consistently using the host of data available through effective use of nutrient use tools. Nutrient management plans typically focus on N and P, the nutrients of greatest concern for water quality, and it is important to consider all sources of those nutrients as input to the agricultural system. The major sources of nutrients include the following:

- Commercial fertilizers
- Manures, sludges, and other organic materials
- Crop residues and legumes in rotation
- Irrigation water
- Atmospheric deposition of N
- Soil reserves

Good and strategic NMP can significantly reduce costs. For example, when manure is used, the total cost of a nutrient management system are those costs associated with manure nutrient application, plus the disposal of alternative use cost for manure that cannot be applied within a reasonable local transport area, less the savings incurred by reduced commercial fertilizer. Maximizing the nutrient use efficiency (NUE), the measure of how much crop is produced per unit of nutrient supplied, should always be a part of NMP. A greater NUE of a crop leaves less N and P available for transport to waterbodies. NUE consists of two main components:

- Crop removal efficiency or the removal of nutrient in a harvested crop as a percent of nutrient applied to the crop (Mosier et al. 2004)
- The increase in residual nutrients available to the crop from the soil (Ladha et al. 2005)

Because N and P behave very differently, basic understanding of how N and P are cycled in the soil-crop system is an important foundation for effective nutrient management. The *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003) is an excellent source describing the technical details of each of the nutrient sources and cycles in agriculture. Figures 2-3 and 2-4 depict the N and P cycles, respectively.

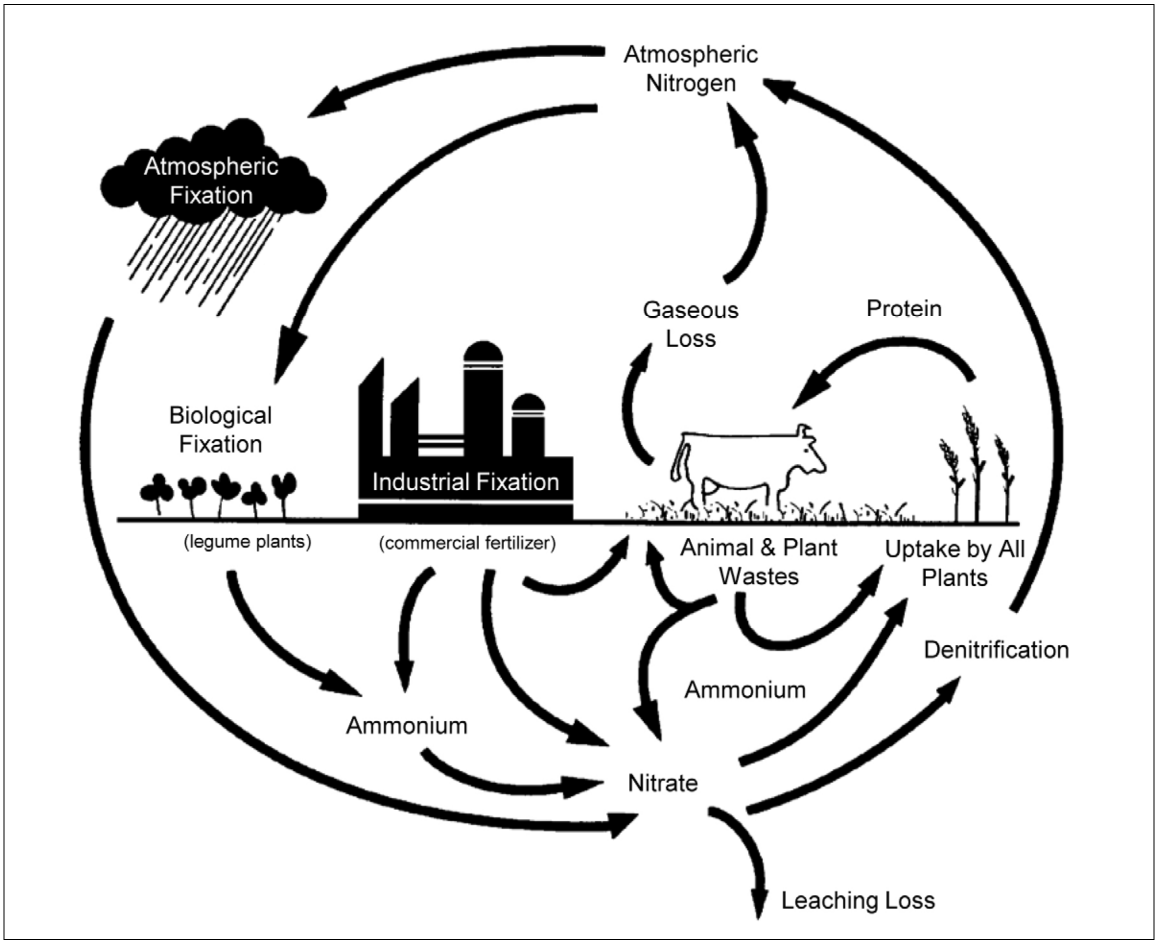


Figure 2-3. The N cycle.

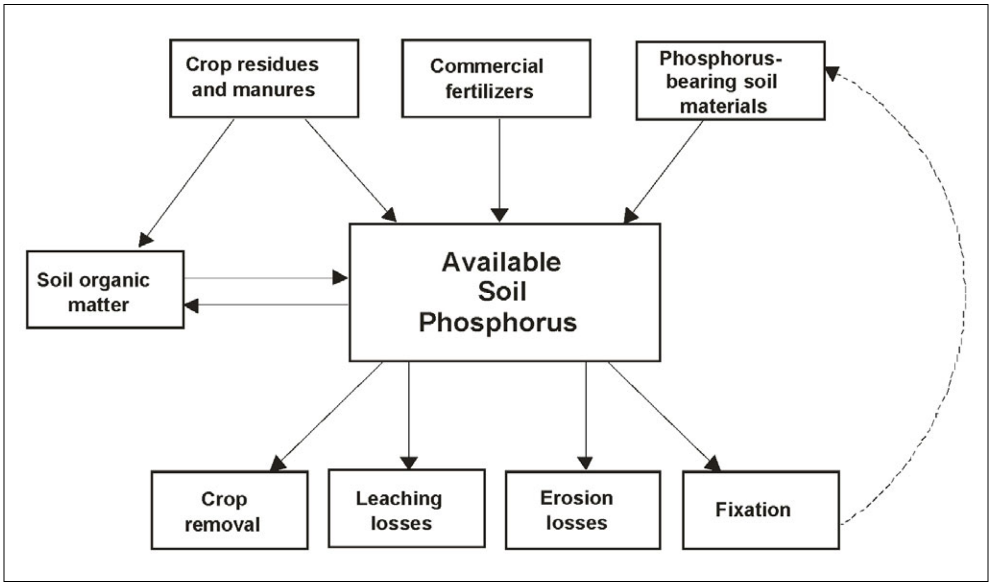


Figure 2-4. The P cycle.

N is continually cycled among plants, soil organisms, soil organic matter, water, and the atmosphere in a complex series of biochemical transformations. Some N forms are highly mobile, while others are not. At any time, most of the N in the soil is held in soil organic matter (decayed plant and animal tissue) and the soil humus. *Regeneration* processes slowly transform the N in soil organic matter by microbial decomposition to ammonium ions (NH_4+), releasing them into the soil where they can be strongly adsorbed and kept relatively immobile. Plants can use the ammonium, however, and it can be moved with sediment or suspended matter. *Nitrification* by soil microorganisms transforms ammonium ions (either mineralized from soil organic matter or added in fertilizer) to nitrite (NO_2-) and then quickly to nitrate (NO_3-), which is easily taken up by plant roots. NO_3, the form of N most often associated with water quality problems, is soluble and mobile in water. *Plant uptake* includes processes by which ammonium and NO_3 ions are converted to organic-N, through uptake by plants or microorganisms, and by binding with the soil. *Denitrification* converts NO_3 into nitrite (NO_2) and then to nitrous oxide (N_2O) and gaseous N through microbial action in an anaerobic environment. *Volatilization* is the loss of ammonia gas (NH_3) to the atmosphere.

An N atom can pass through the cycle many times in the same field. The processes in the N cycle can occur simultaneously and are controlled by soil organisms, temperature, and availability of oxygen and carbon in the soil. The balance among the processes determines how much N is available for plant growth and how much will be lost to groundwater, surface water, or the atmosphere.

P lacks an atmospheric connection (although it can be transported via airborne soil particles) and is much less subject to biological transformation, rendering the P cycle considerably simpler. Most of the P in soil occurs as a mixture of mineral and organic materials, and P exists largely in a single valence state, unlike N. A large amount of P (50–75 percent) is held in soil organic matter, which is slowly broken down by soil microorganisms. Some of the organic P is released into soil solution as phosphate that is immediately available to plants. The phosphate released by decomposition or added in fertilizers is strongly adsorbed to soil particles and is rapidly converted into forms that are unavailable to plants. The equilibrium level of dissolved P in the soil solution is controlled by the chemical environment of the soil (e.g., pH, oxidation-reduction, iron and aluminum concentration) and by the P content of the soil. Plant-available P is measured by varying methods, and this guidance references P measurements made with the following extractable solutions: Mehlich 1, Mehlich 3, Bray 1, and modified Morgan.

Throughout the Chesapeake Bay watershed, those cycling processes are constantly occurring throughout agricultural lands. To effectively plan, design, and implement controls, it is imperative to understand these basic nutrient cycles.

Practice Costs

An analysis of the more than $3.5 billion spent toward nutrient controls in the Chesapeake Bay watershed between 1985 and 1996 found that nutrient management (e.g., USDA-NRCS Conservation Practice Code 590) was the least costly practice for nutrient control (Butt and Brown 2000). The estimated average unit cost in fiscal year (FY) 2010 for development and record keeping for a comprehensive nutrient management plan in Virginia is $1,190 (USDA-NRCS 2010).

Phosphorus

Implementation Measure A-1:

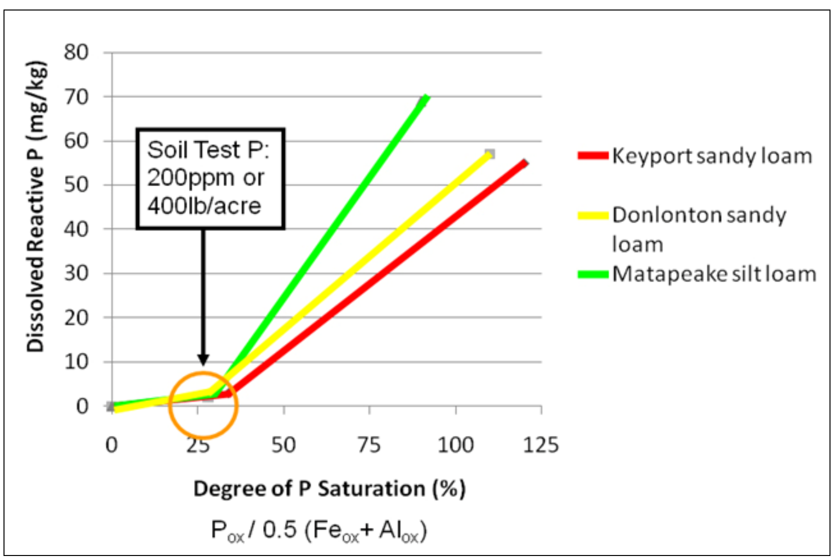
Base P application on P saturation in soils as follows:

- If the soil P saturation percentage is above 20 percent, do not apply manure or commercial fertilizer that contains P to cropland, grazing or pasture land.
- When soil P saturation percentage allows for application (i.e., is below 20 percent saturation), apply up to an N-based rate.
- Also, implement a soil P monitoring plan to ensure that soil-P levels are staying steady over time.
- If soil P saturation percentage is increasing, adjust manure applications to P-based rate and use commercial N fertilizer to make up the difference; if levels exceed 20 percent P saturation, no longer apply P.

In the Chesapeake Bay watershed, where animal manure is a dominant and available source of fertilizer, an overabundance of P exists, as described in Section 2.1.1.

Because P attaches to soil particles, P levels can build up in the soil, and the P saturation (P-sat) percentage increases. (P-sat is a tool that can estimate the degree to which P sorbing sites are saturated with P.) Thus, P fertilizer application is dependent on the existing soil P-sat percentage. When P is attached to the soil, it poses a risk to water quality if soil erosion is not controlled appropriately, because it will move off-site with the soil. For an environmental risk to exist from P transport to surface waters, P must be in a form that can be released to water. The P-sat percentage does not measure directly the risk for P loss in runoff; the P-sat percentage indicates the amount of P that is desorbed and moved into solution *when the soil comes into contact with water* (Kovzelove et al. 2010). This is only one mechanism by which P will be released from a soil mineral. While P will cease to sorb to mineral surfaces if binding sites are saturated, P can also be released if the sorbing complexes solubilize. Various environmental conditions control the solubility of such complexes. For example, iron, when oxidized, forms strong insoluble complexes with P, but if iron becomes reduced, the complex will solubilize and release P. When P bound to soil sediments via iron complexes are eroded to surface waters, the iron will become reduced and release P. While this is one pathway for P to move into the water solution if there are no more places for P to bind to on the mineral, there are other pathways for loss as well.

Butler and Coale (2005) describe how the amount of P released from soil when in contact with water increases exponentially once the P-sat percentage is between 20–30 percent (Figure 2-5).



Source: adapted from Butler and Coale 2005

Figure 2-5. The chart shows the relationship between P-saturation and dissolved P release to water.

EPA recommends that P fertilizer not be applied to soils that are above 20 percent where P desorption and loss as runoff can occur. In addition, it is important for the nutrient management plan to address the slope and movement patterns for water as runoff in a field by implementing cropland in-field controls (as described below in Section 3 of this chapter), because P-sat percentage does not dictate the probability of P in runoff to move to a ditch or local waterbody.

Tools can be used to plan for the applicable rate, timing, form, and method of P fertilizer application. Understanding P-sat percentages in soils throughout the field is necessary to ensure that the farmer is not applying P that is above the level needed for the crop and dually affecting water quality. When testing for soil P, depth of measurement below the surface is an important consideration, to account for buildup on the surface when manure is applied (but not incorporated); a host of soil P of testing options are available, including Mehlich 1, Mehlich 3, Bray 1, and modified Morgan, all of which must be fully understood because they are not immediately exchangeable. P-sat percentage calculations can be implemented with the assistance of USDA-NRCS staff, extension agents, Technical Service Providers (TSPs), or other private industry consultants and researchers.

Beck et al. (2004) have calculated for three major physiographic regions of Virginia the degree of P-sat as a function of Mehlich 1 extractable P for soils. That calculation provides a useful model that can be adopted throughout the Chesapeake Bay watershed. Future research should include calculation of the degree of P-sat in major soil types, starting in the areas of the Bay watershed where there is a significant P imbalance (Figure 2-2).

Nitrogen

Implementation Measure A-2:

Maximize N fertilizer use efficiency to maximize the net benefit from the lowest-needed amount of manure, biosolids, or commercial N fertilizer entering the cropland system. Whenever N fertilizer is applied where manure has already been applied, reduce N fertilizer rates according to the N credit of the manure that was applied. That N credit will vary depending on the amount, timing, type, and method of manure that was applied.

The NUE should be maximized to the extent practicable, and the expected NUE based on the tests described here should be incorporated into the NMP. A host of tools can assist nutrient management planners in developing the N application rate on the basis of in-field variability. By using tools to increase crop NUE, N loss is minimized through reductions in leaching, surface flow, ammonia volatilization, nitrification and denitrification, and soil erosion by calibrating the N input to the yield potential and crop needs. NUE is maximized to reduce N loss when the crop-removal efficiency (the efficiency of the crop to take in all N made available to it) works in tandem with the increase in residual nutrients available from the soil during the time the crop is growing.

Use of N use efficiency tools reduces over-applied N from leaving the production field and entering local waterways. Good N use efficiency is critical because higher use efficiency reduces the level of excess N available to create potential environmental problems, especially after the fall crop harvest during groundwater recharge events.

Improving the N application rate of a nutrient management plan for any cropland should use NUE tools as a guide through a series of steps to determine the rate, realistic production goals, and precision/decision agriculture systems and tools to efficiently apply N through improved materials, timing, placement, and use. A variety of in-field tests can be used to adjust inputs to meet the optimum yield of the plant in a manner in which N loss to the environment is minimized.

Maryland and Delaware have determined a suite of tools that make up a decision agriculture program, and other states in the Chesapeake Bay watershed are actively considering similar approaches; a broad range of effective tools can be used where applicable. The tools have varying degrees of technical needs and can all be implemented with the assistance of NRCS, extension agents, TSPs, or other private industry consultants and researchers. Many of the tools can be implemented at a scale broader than the field level, so it can be financially beneficial if neighboring smaller farms collaborate in implementation. Those include the following decision agriculture tools (additional tools and references are in Appendix 2):

- **Stalk nitrate tests** for field corn production is one of the most accurate methods to estimate N application rate for subsequent years when used over time to make better and more confident N management decisions. The test is done at the end-of-season and provides field specific data to know if the N available for crop uptake was deficient, marginal, optimal, or in excess for the plant to produce the optimum yield. The results of the test can be used to improve the NUE practice, and the NUE effectiveness is enhanced when the results are shared among localized area farmers with comparable cropland production conditions (Blackmer and Mallarino 1996).
- **Crop testing** is a broader approach for a wider diversity of crops than the stalk NO_3 test. Crop testing is used generally to detect the relative plant available N by sight with a leaf color chart or chlorophyll meter, measuring plant available soil N with the Pre-Sidedress Nitrate Test (PSNT) or employing real time chlorophyll measurement for variable rate application in the field.

- **Fertilizer prescription rate maps** can be a very useful NUE tool; they are developed using strategic soil testing (e.g., PSNT) and global positioning system (GPS) crop yield monitoring data. Soil tests are conducted throughout a field and GPS crop yield data maps are joined, to chart the field variability of N availability, to determine realistic crop production levels, and to help determine the subsequent season's appropriate nutrient prescriptive application rates.
- To maintain existing soil fertility levels, **crop nutrient removal** can be used to measure the difference between the application rate and the plant uptake rate. Simple charts can be devised to employ this tool, or software programs are available to ease the calculations.
- **Aerial imagery and strip trials** are effective individual tools, but when coupled at the end of a season, can provide an effective means to understand the spatial variability of a field remotely. This can also help identify field areas where there are signs of planter or applicator skips, diseased or pest-damaged areas, weed infestations and other non-uniform areas, which can decrease the amount of plant available N required to meet crop needs. While strip trials are conducted throughout the season, aerial imagery is generally done during the growth phase of the crop (as opposed to when the crop is mature).
- **Nutrient source integration** is used generally with organic fertilizer (manure), as a part of developing a manure management plan. This tool provides multiple benefits and is used to determine subsequent season's manure needs and can simplify manure application records.
- A tool being developed for the future is **environmental risk assessment**. It considers the location of the field and its potential to impair local or far-field areas using known transport factors.

2.1.3 Alternative Crops

Implementation Measure A-3:

Replace high nutrient loading crops in high-risk areas for water quality effects with sound alternatives.

High-risk areas exist in places where there is intense animal agriculture because of the resulting imbalance in nutrients (see Section 2.1.1). High nutrient loading crops, such as corn and soybean, should be replaced with alternatives in environmentally sensitive areas such as those in close proximity to local waters or in areas where there is a recorded nutrient imbalance for N or P. High-risk areas include such agricultural lands as sandy soils, which allow for easy N transport. When shifting high-nutrient loading crops out of the sensitive areas, the viability and market for the replacement crops will play an important role in deciding on which crops to grow.

Local agricultural contacts such as extension agents, conservation district staff, and TSPs can provide the best assistance in choosing alternative crops while meeting production goals. In Maryland, the document *Alternative Agriculture in Maryland: A Guide to Evaluate Farm-Based Enterprises* (Musser et al. 1999) provides a workbook with 78 separate decision worksheets. The USDA National Agricultural Library document *Alternative Crops & Enterprises for Small Farm Diversification* (Gold and Thompson 2009) provides a broad range of information on alternative crops.

2.1.4 Land Retirement

Implementation Measure A-4:

(1) Retire highly erodible lands (HELs) from cropland and replace the crop with perennial native vegetation, or (2) Develop and implement a soil conservation plan to reduce sheet and rill erosion to the Soil Loss Tolerance Level (T) as well as a nutrient management plan.

Highly erodible land (HEL) is defined by the Sodbuster, Conservation Reserve, and Conservation Compliance parts of the Food Security Act of 1985 and the Food, Agriculture, Conservation, and Trade Act of 1990 (USDA-NRCS 2010b). A soil map unit with an erodibility index (EI) of 8 or greater is HEL. The EI for a soil map unit is determined by dividing the potential erodibility for the soil map unit by the soil loss tolerance (T) (USDA-NRCS 2010c) T is an integer value from 1 through 5 tons/acre/year. T of 1 ton/acre/year is for shallow or otherwise fragile soils, and 5 tons/acre/year is for deep soils that are least subject to damage by erosion. The classes of T are 1, 2, 3, 4, and 5. A field is considered HEL if either one-third or more of the field has an EI value of 8 or greater or if the HEL in the field totals 50 acres or more (USDA-NRCS 2010a).

Sheet and Rill Equation

$$\frac{R \times K \times LS = EI}{T}$$

where

T = soil loss tolerance, or the maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely (tons/acre/year)

R = rainfall/runoff factor, quantifying the effect of raindrop impact and the amount and rate of runoff associated with the rain, based on long term rainfall record

K = soil erodibility factor based on the combined effects of soil properties influencing erosion rates

LS = slope length factor, a combination of slope gradient and continuous extent

The methodology used in implementing the Farm Bill Conservation Reserve Program has encouraged the retirement of HELs from cropland and replacing the crop with perennial vegetation.

When the lands are retired through the federal program, a suite of environmental benefit indicators are considered:

- Water quality benefits from reduced erosion, runoff, and leaching
- Wildlife habitat benefits resulting from covers on contract acreage
- On-farm benefits from reduced erosion
- Benefits that will likely endure
- Air quality benefits from reduced wind erosion
- Cost

Those indicators can be used to assess environmentally sensitive areas as well as USDA-identified HELs to determine where they are in the Chesapeake Bay watershed. Nutrients should not be applied to HELs, even if the lands are in continuous cropland production.

For HELs adjacent to stream channels, employ the recommendations from Chapters 5 and 7 (Riparian and Hydromodification) as the perennial vegetation. For information on federal programs that can assist landowners through the process of land retirement, see Chapter 5. Emerging and alternative markets can be used in conjunction with this recommendation to make this viable for the producer.

When the retirement of HEL will significantly affect the sustainability of the farm and after all native vegetation markets are considered, a conservation plan to reduce sheet and rill erosion to T as well as a nutrient management plan should be implemented.

2.1.5 Commercial Fertilizer Use

Implementation Measure A-5:

When using commercial fertilizer, give credit for manure nutrients. When commercial fertilizer is used, provide for the proper storage, calibration, and operation of chemical fertilizer nutrient application equipment.

Commercial fertilizers represent the largest single source of N and P applied to most cropland in the United States. In the Chesapeake Bay watershed, commercial fertilizers are used when manure is not readily available or undesirable, and are an important source of inorganic nutrient. Commercial fertilizers can be a tool used to abate the nutrient imbalance in the Chesapeake Bay watershed; where soils have a high range of P-sat percentage, but are below 20 percent, commercial N fertilizer can be applied so that manure can be applied at the P rate.

Major commercial fertilizer N sources include anhydrous ammonia, urea, ammonium nitrate (NH_4NO_3), and ammonium sulfate [$(NH_4)_2SO_4$]. Major commercial P fertilizer sources include monoammonium phosphate, diammonium phosphate, triple superphosphate, ammonium phosphate sulfate, and liquids. Descriptions of common commercial fertilizer materials are given in Table 2-1.

Also, where soils have a high range of P-sat below 20 percent, apply commercial N fertilizer to apply manure at the P rate.

Commercial fertilizers offer the advantage of allowing exact formulation and delivery of nutrient quantities specifically tailored to the site, crop, and time of application in concentrated, readily available forms. The use of any particular material or blend is governed by the characteristics of the formulation (such as volatilization potential and availability rate), suitability for the particular crop, crop needs, existing soil test levels, economics, application timing and equipment, and handling preferences of the producer.

Table 2-1. Common commercial fertilizer minerals

Common name chemical formula	Analysis (%)		
	N	P_2O_5	K_2O
N materials			
Ammonium nitrate NH_4NO_3	34%	0%	0%
Ammonium sulfate $(NH_4)_2SO_4$	21%	0%	0%
Ammonium nitrate-urea NH_4NO_3+$(NH_2)_2CO$	32%	0%	0%
Anhydrous ammonia NH_3	82%	0%	0%
Aqua ammonia NH_4OH	20%	0%	0%
Urea $(NH_2)_2CO$	46%	0%	0%
Phosphate materials			
Superphosphate $Ca(H_2PO_4)_2$	0%	20%–46%	0%
Ammoniated superphosphate $Ca(NH_4H_2PO_4)_2$	5%	40%	0%
Monoammonium phosphate NH_4H2PO_4	13%	52%	0%
Diammonium phosphate $(NH_4)_2HPO_4$	18%	46%	0%
Urea-ammonium phosphate $(NH_2)_2CO$+$(NH_4)_2HPO_4$	28%	28%	0%
Potassium materials			
Muriate of potash KCl	0%	0%	60%
Monopotassium phosphate KH_2PO_4	0%	50%	40%
Potassium hydroxide KOH	0%	0%	70%
Potassium nitrate KNO_3	13%	0%	45%
Potassium sulfate K_2SO_4	0%	0%	50%

Note: Adapted from Pennsylvania State University (1997) and Cornell Cooperative Extension (1997)

However, because of the nutrient imbalance from the amount of livestock manure produced in the Chesapeake Bay watershed, EPA recommends that use of commercial fertilizer be minimized by applying it only to the extent that manure nutrients are not available to be used. EPA also recommends that provisions be in place for storing fertilizer, as well as regularly calibrating and properly operating commercial fertilizer application equipment. That recommendation encourages considering manure as the first-choice source of nutrients. While there could be an upfront equipment cost, the benefits previously mentioned that manure can bring to the soil should be considered. Moreover, such an approach will help reduce the imbalance of nutrients that exists in significant portions of the Chesapeake Bay watershed that has resulted from the existing excess supply of manure in the watershed.

2.2 Animal Agriculture

In the Chesapeake Bay watershed, because of the intensity of animal agriculture and manure generation, it is imperative to control all nutrient sources in the livestock production area. All AFOs should provide the capacity to properly store for the minimum critical storage period (dictated by the size of the storage facility) (1) all manure generated, (2) all contaminated runoff generated, and (3) for open liquid manure storage structures, the direct precipitation from events in the geographic area, including chronic rain. Proper storage of dry manure, such as that produced at poultry operations, means covered storage, e.g., in production buildings or storage sheds. All AFO personnel should also ensure no runoff of pollutants is occurring from the production area or discharged through conveyances to local waters, including any precipitation-related water that comes into contact with the animals, animal by-products, litter, or feed. Proximity to waterbodies, floodplains, HELs, and other environmentally sensitive areas is a critical consideration in siting manure storage systems.

Strategies for source control associated with animal agriculture focus on containing and treating feed, manure, and facility wastewater and preventing their movement to surface waters. Four general principles can help control sources of nutrients and other pollutants from animal agriculture: animal feed management, manure storage and transport, treatment or processing of wastes, and management of grazing livestock. NRCS Practice Standards exist for those four general principles and are referenced throughout this section.

2.2.1 Animal Feed Management

Important feeding strategies for livestock production focus on adjustment of feed additives, formulations, phase feeding (matching feed to growth stage), or feeding methods to reduce the nutrient content, change the form of nutrient excreted in manure, and feed as close to animal requirements as possible (NRCS Practice Code 592). Decreasing the P and N content of manure through diet modification is a powerful, effective approach to reducing the nutrient balance and nutrient losses from livestock farms (Knowlton et al. 2004; Maguire et al. 2007; Swink et al. 2009). Reduction of P and N overfeeding, use of feed additives to enhance dietary P and N utilization, and development of grains in which a high proportion of the P is available (high-available P, or HAP, grains) have all been shown to decrease P and N excretion without impairing animal performance (Maguire et al. 2005). Phytase, a feed additive generally used in poultry or swine feed, is an enzyme that breaks down the form of phosphorus (phytate) that is found in grains so that the phosphorus can be digested and used by the animal. The phytase enzyme is regularly produced and is present naturally in ruminants (e.g., dairy and beef cattle).

The ratio of N to P in manure applied to the land is a critical issue. Manures used as fertilizers on fields commonly contain N:P ratios of approximately 3:1, whereas most major crops require

N:P ratios of approximately 8:1. Application of manure to meet N requirements consequently tends to apply excess P. Two major factors contributing to the low N:P ratio in manure are the loss of N through ammonia volatilization and the presence of excess P in the diets of farm animals. In addition to reducing the P content of manure through feed management, the combination of reducing N volatilization losses and immobilization of P through manure or litter amendment can significantly increase the final N:P ratio of land applied manure (Lefcourt and Meisinger 2001).

Finally, some feed additives that pass through the animal and reside in the manure can be problematic in the environment. For example, most of the arsenic used as an antibiotic in commercial broiler production remains in the litter. As a result, higher levels of arsenic tend to be found in soils that receive poultry litter compared to areas where litter is not applied. Reducing or eliminating arsenic in poultry feed can reduce this problem.

Implementation Measure A-6:

Formulate animal feeds to reduce nutrient concentration in manure, improve the manure N:P ratio in relation to crop needs, or eliminate toxic substances such as arsenic in manure used as fertilizer. Align the N:P ratio of the manure to be equal to (or greater than) the N:P ratio of the crop need.

Practice Effectiveness

Several studies have shown that reducing the nutrients in feed has a significant effect on the manure nutrient content.

Arriaga et al. (2009) estimated that dietary manipulation in Spain could decrease dairy herd N excretion by 11 percent per hectare, whereas P would be decreased by 17 percent. On two New York dairy farms, Cerosaletti et al. (2004) reported that fecal P concentrations decreased 33 percent following dietary adjustments; milk production was not adversely affected. In a modeling study of the same New York farms, precision feed management reduced the P imbalance on each farm and reduced the soluble P lost to the environment by 18 percent (Ghebremichael et al. 2007). Ebeling et al. (2002) applied dairy manure from two dietary P levels to corn land in Wisconsin and reported that at equivalent manure rates, dissolved P concentration in runoff from the high P diet manure was 10 times higher (2.84 versus 0.30 mg/L) than the low P diet manure, and four times higher (1.18 versus 0.30 mg/L) when applied at equivalent P rates.

In a review, Graham et al. (2003) reported that including xylanase or phytase in poultry feeds can reduce manure volume by up to 14 percent and N and P outputs by up to 13 percent and 70 percent, respectively. A review by Powers and Angel (2008) reported that for each one percent reduction in dietary crude protein, estimated NH_3 losses are decreased by 10 percent, creating the potential for a 20–40 percent reduction in NH_3 emissions from poultry houses. For P, under commercial conditions, broiler litter P was decreased by 30 percent when diet P was decreased by 10 percent. In North Carolina, Leytem et al. (2008) reported that inclusion of phytase in poultry diets at the expense of inorganic P or reductions in dietary available P decreased litter total phosphorus (TP) by 28 to 43 percent. Litter water-soluble P decreased by up to 73 percent with an increasing dietary Ca/available P ratio, irrespective of phytase addition. Nahm (2009) found that phytase addition to simple gastric animal diets in South Korea can decrease the litter water-soluble P concentration by 30–35 percent. In Arkansas, Smith et al. (2004) showed that phytase and HAP corn diets reduced litter-dissolved P content in broiler litter by 10 and 35 percent, respectively, compared with the normal diet (789 mg P/kg). P concentrations in runoff water were highest from plots receiving poultry litter from the normal diet, whereas plots receiving poultry litter from phytase and HAP corn diets had reduced P concentrations.

In Canada, Emiola et al. (2009) showed that complete removal of inorganic P from growing pig diets coupled with phytase supplementation improves digestibility and retention of P and N, thus reducing manure P excretion without any negative effect on pig performance. In another Canadian study, Grandhi (2001) reported that replacing inorganic P with phytase and lowering the dietary protein level while supplementing amino acids in swine diets can decrease the excretion of P up to 44 percent and N up to 28 percent in manure with no adverse effect on performance of pigs. In a Danish study, replacing inorganic phosphates with phytase in pig feed reduced the concentration of P in slurry by 35 percent (Sommer et al. 2008). In Europe, Aarnink and Verstegen (2007) found that a combination of lowering crude protein intake and increasing fermentable carbohydrates, and other modifications to feeding strategies could reduce ammonia emission from growing-finishing pigs by 70 percent.

Despite ample research evidence that phytase addition, use of HAP feeds, and other approaches can significantly reduce N and P content in manure, marketing and adoption of such feeds has been slow. Recent survey data in Delaware suggest that poultry producers with high soil P levels are willing to adopt HAP corn, despite increased costs and yield loss (Bernard and Pesek 2007). It is possible that the lack of economic return for sales of HAP seed has inhibited production and marketing of modified seed by suppliers. There is an apparent need for additional work in this area to determine how to effectively get this promising technology into wider production and use.

Dao (1999) reported that treatment of cattle manure with alum and other amendments can increase the effective N:P ratio in manure, bringing it into a range suitable for using manure as a balanced source of nutrients for crop production. Alum addition to stockpiled and composted cattle manure reduced water-extractable P (WEP) in the manure by 85–93 percent. Worley and Das (2000) reported that separation of solids from flushed swine manure and subsequent amendment with alum removed 75 percent of P and only small amounts of N from the manure. As a result, the N:P ratio of the effluent entering the lagoon improved from 3.6 without separation to 8 with separation and to 16.7 with separation and alum amendment.

Table 2-2. Summary of reported practice effects resulting from changes in animal feeding strategies

Location	Study type	Practice	Practice effects	Source
Spain	Farms	Dairy feed formulation	11% reduction in N excretion; 17% reduction in P excretion	Arriaga et al. 2009
New York	Farm	Dairy dietary management	33% reduction in manure P concentration	Cerosaletti et al. 2004
New York	Model	Dairy precision feeding	18% reduction in soluble P lost from farm	Ghebremichael et al. 2007
Wisconsin	Field	Dairy dietary management	75% reduction in dissolved P in runoff from land applied manure[a]	Ebeling et al. 2002
Many	Review	Phytase in poultry feed	14% reduction in manure volume; 13% reduction in litter N, 70% reduction in litter P	Graham et al. 2003
Many	Review	Poultry feed formulation	10% reduction in NH3 losses per 1% decrease in dietary crude protein; 30% reduction in litter P with 10% reduction in dietary P	Powers and Angel 2008
North Carolina	Animal trials	Phytase in poultry feed	28%–43% decrease in litter TP; Up to 73% reduction in litter water-soluble P[b]	Leytem et al. 2008
S Korea	Review	Phytase in poultry feed	30%–35% reduction in litter water-soluble P	Nahm 2009
Arkansas	Farm/ Plot	Phytase and high available P corn in poultry feed	10% reduction in litter dissolved P with phytase; 35% reduction with high available P corn[c]	Smith et al. 2004
Canada	Animal trials	Swine diet	Removal of inorganic P from diet plus phytase supplementation improved digestibility and retention of P and N, reduced manure P excretion without negative effects on growth	Emiola et al. 2009
Canada	Animal trials	Swine diet	44% reduction in P excretion, 28% reduction in N excretion from replacing inorganic P with phytase and lowering dietary protein	Grandhi 2001
Denmark	Farm	Phytase in swine diet	35% reduction in P in slurry	Sommer et al. 2008
Europe	Review	Swine feeding strategies[d]	70% reduction in ammonia emissions from growing-finishing operations	Aarnink and Verstegen 2007

Notes:
a. High-P diet manure and low-P diet manure applied at equivalent P rates
b. With increasing Ca/available P in feed, irrespective of phytase
c. Study also reported that P concentrations in plot runoff were reduced where litter from modified diets was applied
d. Feeding changes included lowering crude protein intake, increasing fermentable carbohydrates, and addition of acidifying salts

Practice Costs

In an experiment in India, Khose et al. (2003) reported that the cost of broiler production per kg live weight was lowest in the group fed the diet with a 50 percent reduction in feed dicalcium phosphate supplemented with phytase. Osei et al. (2008) used an integrated economic and environmental modeling system to evaluate effects of N- and P-based manure application rates in Texas. Results of the study indicate that edge-of-field TP losses can be reduced by about 0.8 kg/ha/year or 14 percent when manure applications are calibrated to supply all the recommended crop P requirements from manure TP sources only versus manure applications at the recommended crop N agronomic rate. Corresponding economic effects are projected to average $4,852 (2010 dollars) annual cost increase per farm.

2.2.2 Manure Storage and Transport

Implementation Measure A-7:

Safely and strategically apply (with properly calibrated equipment), store, and transport manure.

- Liquid manure storage systems including tanks, ponds, and lagoons (e.g., NRCS Practice Code 313 Waste Storage Facility) should be designed and operated to safely store the entire quantity and contents of animal manure and wastewater generated, contaminated runoff from the facility, and the direct precipitation from events in the geographic area, including chronic rain.
- Dry manure (i.e., stackable, greater than or equal to 20 percent dry matter), such as that produced in poultry and certain cattle operations, should be stored in production buildings, storage facilities, or otherwise covered to prevent precipitation from coming into direct contact with the manure and to prevent the occurrence of contaminated runoff. When necessary, temporary field storage of dry manure (e.g., poultry litter) may be possible under protective guidelines (e.g., NRCS Practice Code 633 Waste Utilization).
- For manure and litter storage, the AFO should maintain sufficient storage capacity for minimum critical storage period consistent with planned utilization rates or utilization practices and schedule.

The manure and other wastes generated by livestock production should be contained and management should prevent runoff losses from the facility. Key measures and some component practices (including some as USDA-NRCS National Practice Codes) include the following:

- Ensure that the farm has sufficient storage for all manure.
  - **Waste storage facility (NRCS Practice Code 313)**: A waste impoundment made by constructing an embankment, excavating a pit or dugout, or by fabricating a structure.
  - **Waste treatment lagoon (NRCS Practice Code 359)**: An impoundment made by excavation or earth fill for biological treatment of animal or other agricultural wastes.
- Ensure that manure and litter are stockpiled safely.
  - **Waste Utilization (NRCS Practice Code 633[2])**: Using agricultural wastes, such as manure and wastewater, or other organic residues (including temporary field storage).
- Minimize the need for temporary storage by scheduling clean-outs as close to utilization as possible.
- Locate storage on level ground not subject to flooding and away from surface waters and wells.
- Stack manure on an impermeable pad or in areas with adequate separation from the groundwater table.
- Rotate temporary storage areas to avoid buildup of salts and nutrients in a single location.
- Cover stockpiles when practical. Although data on the benefits of covering poultry litter is mixed (Poultry Litter Experts Science Forum 2008), there is evidence that dry broiler litter should be covered to protect litter quality and to prevent extensive nutrient runoff (Mitchell et al. 2007). Most Extension recommendations call for covering field stockpiles of poultry litter and other solid manure (e.g., Carter and Poore 1998, Arkansas Cooperative Extension Service 2006, Ogejo 2009).
- Minimize stockpile footprint and provide grass filter strip to protect downslope areas.
  - Set total (whole-house) clean-out schedules that ensure no poultry litter stockpiling during times of the year with the greatest environmental losses (e.g., winter).

[2] NRCS Practice Code 633 is being revised at the national level. If the practice cannot be isolated as a unique technology different from the technology delivered by NRCS Code 590, it may be abandoned or redefined. Interested parties should be advised that the 590 is under revision and that 633 practice will be redefined or abandoned.

  - Divert clean water away from waste storage areas.
  - **Diversion (NRCS Practice Code 362)**: A channel constructed across the slope with a supporting ridge on the lower side.
  - **Roof runoff management (NRCS Practice Code 558)**: A facility for controlling and disposing of runoff water from roofs.
- Ensure that any recipient of manure generated has planned effectively to meet, at a minimum, the same performance goals as those of the sourced manure.
  - Areas receiving manure should be managed in accordance with meeting the goals for erosion and sediment control, irrigation, and grazing management applicable, including practices such as crop and grazing management practices to minimize movement of applied nutrient and organic materials, and buffers or other practices to trap, store, and *process* materials that might move during precipitation events.
  - **Waste utilization (NRCS Practice Code 633)**: Using agricultural wastes or other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources.

Measures for manure storage protect the wastes from precipitation and runoff and provide opportunities for further treatment (see Section 2.2.4) or for subsequent manure management according to a nutrient management plan (see Section 2.1.1). Thus, little recent literature exists quantifying the effectiveness of waste storage alone. General pollutant reductions associated with containment structures were reported (TP 60 percent, TN 65 percent, sediment 70 percent, and fecal coliform 90 percent) in *National Management Measures to Control Nonpoint Pollution from Agriculture* (USEPA 2003) based on information published by Pennsylvania State University (PSU 1992). Mitchell et al. (2007) reported high nutrient losses in runoff from uncovered poultry litter. Habersack (2002) studied runoff from uncovered and covered poultry manure stockpiles and concluded that even protecting litter piles with the common 95 percent plastic coverage technique was unsuccessful in reducing environmental pollution. It was recommended that poultry litter be stored in a litter shed that prevents all contact from precipitation and runoff. Reductions of fecal coliform bacteria numbers of two to three orders of magnitude have been reported with manure storage for 2 to 6 months (Patni et al. 1985; Moore et al. 1988).

Practice Costs

Concrete pits for storing wet animal waste can cost from $42.50/yd^3 for pits larger than 1,000 yd^3 to $159/yd^3 for pits smaller than 370 yd^3, with typical total costs ranging from $42,800 for smaller pits to over $200,000 for larger pits (USDA-NRCS 2010). The cost of earthen ponds ranges from $9.92/yd^3 for ponds larger than 1,000 yd^3 to $13.65/yd^3 for smaller ponds. A typical small, earthen pond costs about $12,500, while a larger pond could cost just under $17,000. Earthen floor storage for dry waste costs from $41.50 to $55.90/yd^3, with typical small (less than or equal to 1,000 yd^3) structures costing just over $37,000 and larger structures costing nearly $50,000. Storage of dry wastes costs more with concrete floors ($70.90 to $106/yd^3); structures with a capacity of less than or equal to 500 yd^3 typically cost around $50,000, whereas larger structures cost nearly $70,000. Loose housing for dry waste storage costs about $207/yd^3, and typical structures holding 1,150/yd^3 cost about $240,000. Waste field storage consisting of fabric and gravel with a tarp costs $1.62/ft^2 while a concrete slab and tarp goes for $3.67/ft^2 in Virginia, with typical total costs of $11,310 and $14,665, respectively (USDA-NRCS 2010).

Waste treatment lagoons with earthen bottoms cost about $13/yd^3, and lagoons typically cost about $21,440 (USDA-NRCS 2010). Pond sealing or lining with flexible membrane ($1.38/ft^2), soil dispersant ($1.52/ft^2), or bentonite clay ($1.52/ft^2) are improvement options in Virginia for which total costs are typically in the range of $6,700 to $7,500. Sealing with compacted clay costs about $6.91 or $16.63/yd^3 of earth moved for on-site and off-site clay sources, respectively. Typical total costs for compacted clay liners are about $2,300 for on-site clay and $5,500 for off-site clay.

Earthen diversions cost about $2.70 per linear foot. Roof runoff structure costs range from $1.84/gallon for underground cisterns with hookup, to $4.54/ft for downspouts and drain lines, to $6.00/ft for 6-inch gutters. Dry poultry spreading generally costs about $33.90/ac, whereas spreading of liquid dairy waste costs about $12.50/ac. Waste utilization via lagoons and irrigation systems cost about $377/ac, with typical systems running about $66,000.

2.2.3 Livestock Exclusion from Streams

Implementation Measure A-8:

Exclude livestock from streams and streambanks to reduce nutrient inputs, streambank erosion, and sediment inputs and to improve animal health.

Grazing livestock should be excluded from streams and riparian areas to reduce direct nutrient and pathogen inputs, prevent streambank damage and resulting sediment inputs, and improve animal health (NRCS Practice Code 472). Fencing is the most reliable way to protect streams and riparian areas from the effects of livestock, and can be woven wire or electric (NRCS Practice Code 382). Cost-share programs might require permanent fencing, rather than temporary or movable fence. Management intensive or rotational grazing could, however, involve using movable fences to create temporary paddocks to direct livestock away from a water course. If complete fencing is not possible, the most sensitive streambank areas should be fenced, while providing an alternate watering source (NRCS Practice Code 614) for access to drinking water for grazing animals. Some trials have documented success in keeping livestock out of streams without continuous fencing by providing drinking water and/or shade away from the stream to encourage livestock to congregate away from riparian areas.

Practice Effectiveness

Livestock exclusion fencing

Line et al. (2000) documented 33, 78, 76, and 82 percent reductions in weekly nitrate + nitrite, total Kjeldahl nitrogen (TKN), TP, and sediment loads, respectively, resulting from fencing dairy cows from a 10- to 16-m wide riparian corridor along a small North Carolina stream. In the same system, Line (2003) showed that fecal coliform and enterococci levels decreased 65.9 percent and 57.0 percent, respectively, after livestock exclusion.

In Vermont streams draining dairy pastures, Meals (2002) reported 20–50 percent reductions in nutrient and suspended solids loads and 40–60 percent reductions in fecal bacteria counts following livestock exclusion and riparian restoration with bioengineering techniques.

James et al. (2007) estimated 32 percent reduction of in-stream deposition of fecal P by grazing dairy cattle in New York following livestock exclusion under the CREP.

In central Pennsylvania, Carline and Walsh (2007) reported that following riparian treatments, consisting of fencing, 3- to 4-m buffer strips, stream bank stabilization, and rock-lined stream crossings, stream bank vegetation increased from 50 percent or less to 100 percent in formerly grazed riparian buffers, suspended sediments during base flow and storm flow decreased 47–87 percent, and macroinvertebrate densities increased in two treated streams.

However, Agouridis et al. (2005) reported that incorporation of an alternate water source or fenced riparian area along a central Kentucky stream did not significantly alter stream cross-sectional area where the measures were applied. The authors suggested that riparian recovery within the exclosures from pretreatment grazing practices might require decades, or greater intervention (i.e., stream restoration), before a substantial reduction in streambank erosion is noted.

Table 2-3. Summary of reported practice effects resulting from livestock exclusion

Location	Study type	Practice	Practice effects	Source
North Carolina	Small watershed	Fencing dairy cattle	Load reductions: 33% NO_2+NO_3-N, 78% TKN, 76% TP, and 82% sediment	Line et al. 2000
North Carolina	Small watershed	Fencing dairy cattle	Reductions: 66% fecal coliform, 57% enterococci	Line 2003
Vermont	Small watersheds	Fencing dairy cattle; riparian restoration	Load reductions: 20–50% TP, TKN, TSS Reductions: 40–60% fecal coliform, fecal strep., and *E. coli*	Meals 2002
New York	Stream	Fencing dairy cattle[a]	32% reduction in deposition of fecal P in stream	James et al. 2007
Pennsyl-vania	Small watersheds	Fencing, buffer strips, stream bank stabilization, rock-lined stream crossings	Streambank vegetation increase from ≤ 50%–100%; 47–87% reduction in SS concentrations; increase in macroinvertebrate densities	Carline and Walsh 2007
Georgia	Stream	Off-stream water supply	63% decrease time cattle spent in riparian zones	Franklin et al. 2009
North Carolina	Stream	Off-stream water supply	No significant changes in physical water quality parameters or bacteria counts	Line 2003

Note:
a. Livestock exclusion under Conservation Reserve Enhancement Program (CREP)

Alternative water supply

In Georgia, Franklin et al. (2009) found that when the temperature and humidity index ranged between 62 and 72, providing cattle with water troughs outside of riparian zones tended to decrease time cattle spent in riparian zones by 63 percent. The study suggests that water troughs placed away from unfenced streams can improve water quality by reducing the amount of time cattle spend in riparian zones.

However, Line (2003) reported that levels of most measured physical parameters and bacteria were not significantly different following the installation of alternate water supply in a North Carolina pasture.

Practice Costs

Fence costs range from $0.49/ft for 1-strand, stainless steel electric poly wire used as temporary fencing, to $8.77/ft for 4-foot chain-link fence with one strand of barbed wire (USDA-NRCS 2010). Most fencing falls within the range of about $2/ft to $3/ft, with typical total costs of about $3,000 to $4,000. Watering facilities cost about $812 each for converted heavy truck tires to as much as $1,700 for 4-hole, freeze-proof troughs including gravel and a concrete pad. Portable shade structures for livestock cost $4.85/ft^2 for a typical total cost of $1,940. Graded stream crossings made of gravel and fabric cost under $2.50/ft^2, while stream crossings with concrete access or culverts cost about $4.10/ft^2 and $4.90/ft^2, respectively (USDA-NRCS 2010). Typical total costs for graded stream crossings range from $1,700 to $2,900 for gravel and fabric, to $4,300 with concrete access, to just over $5,100 for culverts.

2.2.4 Wastewater and Animal Wastes

Implementation Measure A-9:

Process/treat through physical, chemical, and biological processes facility wastewater and animal wastes to reduce as much as practicable the volume of manure and loss of nutrients.

Manure and wastewater stored on farms has a significant pollution potential even after wastes are collected and stored appropriately. Researchers have recommended a variety of practices to manage the effects of animal wastes, focusing on treating waste to change its physical, chemical, or biological properties; remove potential pollutants; or improve handling characteristics (Bicudo and Goyal 2003; Ritter et al. 2003; Martinez et al. 2009).

Such practices include the following:

- **Waste treatment and processing**—treating manure or farm wastewater to separate liquids and solids, immobilize pollutants, or remove nutrients from the waste stream
- **Digestion**—processing animal wastes to capture biogas for use as fuel, reducing bulk of remaining residuals for further management. The digestion process removes only carbon, hydrogen, and water from the animal waste; the residuals from digestion contain all the N, P, and trace minerals and about half of the carbon of the original manure.
- **Composting**—composting of animal wastes, possibly combined with other green wastes, to reduce bulk, stabilize nutrient forms, and facilitate export and land application of animal wastes. High temperatures during composting kill manure microorganisms, largely eliminating the risk of contaminating crops with pathogens where composted manure is land-applied. Composting reduces the mass and volume of manure significantly, while P content remains essentially unchanged. Substantial N losses can occur, however, through volatilization of ammonia N created by decomposition of organic N and by conversion of organic N to NO_3 followed by leaching.
- **Constructed Wetland treatment**—to remove nutrients by plant uptake and promotion of denitrification

- **Other biological treatments—**treatment systems using microorganisms, algae, or other plants to break down wastes and absorb nutrients
- **Air quality management—**practices to reduce or capture airborne pollutants like ammonia or fine particulates from animal housing

Practice Effectiveness

Waste treatment and processing—manure and wastewater amendment

Amending poultry litter with alum [$Al_3(SO_4)_2$-$14H_2O$] is a method of economically reducing ammonia volatilization in the poultry house and soluble P in runoff waters (e.g., Amendments for Treatment of Agricultural Waste, NRCS Practice Code 591). In South Korea, Do et al. (2005) reported that application of aluminum chloride ($AlCl_3$-$6H_2O$) to litter lowered atmospheric ammonia concentrations at 42 days by 97.2 percent, whereas ferrous sulfate ($FeSO_4$-$7H_2O$) lowered it by 91 percent. Ammonia concentrations were reduced by 86, 79, 76, and 69 percent by alum, alum + $CaCO_3$, aluminum chloride + $CaCO_3$, and potassium permanganate ($KMnO_4$), respectively, when compared with a control at 42 days. The addition of 6.25 percent zeolite or 2.5 percent alum to dairy slurry in Maryland reduced ammonia emissions by nearly 50 and 60 percent, respectively. Alum treatment retained ammonia by reducing the slurry pH to 5 or less. In contrast, zeolite, (a cation exchange medium) adsorbed ammonium and reduced dissolved ammonia gas (Lefcourt and Meisinger 2001).

In Arkansas, Moore et al. (1999 and 2000) reported that reductions in litter pH in alum-treated broiler litter reduced NH_3 volatilization by 97 percent, which led to reductions in atmospheric NH_3 in the alum-treated houses. Broilers grown on alum-treated litter were significantly heavier than controls (1.73 kg versus 1.66 kg). Soluble reactive P (SRP) concentrations in runoff from pastures fertilized with alum-treated litter were 75 percent lower than those from normal litter. Also in Arkansas, Smith et al. (2001) found that alum and aluminum chloride amendment to swine manure reduced SRP concentrations in runoff by 84 percent that were not statistically different from SRP concentrations in runoff from unfertilized control plots. Smith et al. (2004) reported that the addition of alum to various poultry litters reduced P runoff by 52 to 69 percent from pastures where the litter was applied; the greatest reduction occurred when alum was used in conjunction with dietary modification with HAP corn and phytase.

In Pennsylvania, Dou et al. (2003) reported reductions of soluble P in dairy, swine, and broiler manures of 80 to 99 percent at treatment rates of 100 to 250 g alum/kg manure dry matter. Fluidized bed combustion fly ash reduced readily soluble P by 50 to 60 percent at a rate of 400 g/kg for all three manures. Flue gas desulfurization by-product reduced soluble P by nearly 80 percent when added to swine manure and broiler litter at 150 and 250 g/kg.

Table 2-4. Summary of reported practice effects resulting from waste amendment

Location	Study type	Practice	Practice effects	Source
Korea	Poultry house	Poultry litter amendments	Atmospheric ammonia concentration reductions: 97% (Aluminum chloride), 91% (Ferrous sulfate), 86% (alum), 79% (alum+$CaCO_3$), 76% (aluminum chloride+$CaCO_3$), 69% ($KMnO_4$)	Do et al. 2005
Maryland	Dairy farm	Dairy slurry amendments	50% ammonia emissions reduction (zeolite), 60% ammonia emissions reduction (alum)	Lefcourt and Meisinger 2001
Arkansas	Poultry houses	Alum amendment	97% ammonia volatilization; 75% reduction in soluble P in runoff from pastures receiving treated litter	Moore et al. 1999 and 2000
Arkansas	Field	Alum and aluminum chloride treated poultry litter	52%–69% reduction in P concentration in runoff from pastures where treated litter applied[a]	Smith et al. 2004
Arkansas	Plots	Alum and aluminum chloride treated swine manure	84% reduction in soluble P concentration in runoff from plots receiving treated manure; P concentration not significantly different from un-manured control plots	Smith et al. 2001
Pennsyl-vania	Laboratory	Dairy, swine, broiler manure amendments	Manure soluble P reductions: 80-99% (alum), 50%–60% (fly ash), 80% (flue gas desulfurization byproduct	Dou et al. 2003
Unknown	Laboratory	Dairy wastewater amendment	93%–99% reduction in ortho-P with alum treatment; ortho-P reduced to < 1 mg P/L by alum and PAM combined	Jones and Brown 2000
Unknown	Laboratory	Dairy manure amendment	Liquid from separated manure amended with alum and polymer had 82% less TP, 36% less TS, and 71% lower COD than untreated manure	Oh et al. 2005
Ohio	Laboratory	Dairy manure amendment	Amending dairy manure with WTR reduced $CaCl_2$-extractable P > 75%	Dayton and Basta 2005
Vermont	Laboratory	Dairy manure amendment	Amending dairy manure with alum-based WTR reduced manure soluble P up to 79%, TP up to 50%	Meals et al. 2007
Idaho	Field	Cattle, swine manure amendment	Amending manure with PAM, alum, and CaO treatments reduced fecal bacteria 90–>99% in runoff from application sites compared to untreated manure control	Entry and Sojka 2000
Taiwan	Laboratory	Swine wastewater amendment	Amending swine wastewater with alum, ferric chloride, calcium hydroxide, and polyaluminum chloride reduced COD by 54%	Cheng 2001

Note:

a. Greatest P reductions when alum used in conjunction with dietary modification

In laboratory studies, alum reduced ortho-P in dairy wastewater 93–99 percent at rates less than three g alum/L. Ortho-P was reduced to one mg P/L or less by a combination of alum and polyacrylamide (PAM) treatment (Jones and Brown 2000).

Oh et al. (2005) reported that alum and polymer addition improved the efficacy of mechanical separation of dairy manure. When compared to the control, waste amended with alum and polymer had 82 percent less TP in the press liquor, which indicates that P was partitioned into the press cake. The combined alum/polymer treatment also resulted in a 36 percent reduction in total solids (TS) and a 71 percent reduction in chemical oxygen demand (COD) in the press liquor when compared to the control.

Codling et al. (2000) recommended substituting Al-rich drinking WTR for alum for reducing water-soluble P in poultry litter. In Ohio, Dayton and Basta (2005) reported that blending WTR to manure at 250 g/kg reduced $CaCl_2$–extractable P by greater than 75 percent. In a Vermont study, Meals et al. (2007) found that additions of alum-based WTR to liquid dairy manure could reduce manure soluble P concentrations up to 79 percent and TP concentrations by up to 50 percent.

In Idaho, Entry and Sojka (2000) reported that treatment of cattle and swine manure with combinations of PAM, aluminum sulfate ($Al(SO4)_3$), and calcium oxide (CaO) treatments reduced fecal bacteria counts by 10- to 1,000-fold in water flowing downstream of treated manure application sites, compared to the untreated manure control.

In Taiwan, Cheng (2001) was able to reduce COD levels in swine wastewater by 54 percent to 190 mg/L using coagulants such as aluminum chloride, ferric chloride, calcium hydroxide, and polyaluminum chloride.

Waste treatment and processing—waste separation

Note that waste separation does not treat wastes in the sense of removing or inactivating pollutants; rather, the process of separation produces a separate liquid and solid waste stream that could facilitate handling, transport, and further use of waste components.

An inclined stationary screen separator removed 61 percent of the TS, 63 percent of the volatile solids, 49 percent of the TKN, 52 percent of the organic-N, and 53 percent of the TP from South Carolina dairy manure in a flush system; the complete manure treatment system consisting of the screen separator, separator, a two–chambered settling basin, and a lagoon removed 93 percent of the TS, 96 percent of the VS, 74 percent of the TKN, 91 percent of the organic-N, and 86 percent of the TP (Chastain et al. 2001).

In Wisconsin, Converse and Karthikeyan (2004) reported that long-term settling of flushed dairy manure will remove 75 to 80 percent of TP from raw flushed manure or separator effluent and concentrate it in the bottom 25 percent of the volume. Cantrell et al. (2008) reported that geotextile filtration of liquid dairy manure in South Carolina reduced volume to less than one percent of total influent volume, concentrated the solids and nutrients in the dewatered material 16 to 21 times greater than the influent, and retained 38 percent of TS, 26 percent of TKN, and 45 percent of TP. In South Carolina, Garcia et al. (2009) used the natural flocculant chitosan to improve the performance of screen separation efficiencies for flushed dairy manure to greater than 95 percent for total suspended sediment (TSS), greater than 73 percent for TKN, and greater than 54 percent for TP.

Table 2-5. Summary of reported practice effects resulting from waste separation

State	Study type	Practice	Practice effects	Source
South Carolina	Farm	Inclined stationary screen separator	For flush-system dairy manure, separator removed 61% of TS, 63% of the volatile solids, 49% of the TKN, 52% of the organic–N, and 53% of the TP	Chastain et al. 2001
South Carolina	Farm	Separator + settling basin + lagoon	For flush-system dairy manure, full system removed 93% of TS, 96% of the volatile solids, 74% of the TKN, 91% of the organic–N, and 86% of the TP	Chastain et al. 2001
Wisconsin	Laboratory	Long-term settling	75%–80% of TP removed from raw flushed dairy manure, concentrated in 25% of original volume	Converse and Karthikeyan 2004
South Carolina	Farm	Geotextile separation	For liquid dairy manure, reduced volume to < 1% of influent volume and retained 38% of TS, 26% of TN, and 45% of TP	Cantrell et al. 2008
South Carolina	Farm	Flocculation + separation	Use of natural flocculant chitosan improved performance of screen separation efficiencies for flushed dairy manure to > 95% for TSS, > 73% for TKN, and > 54% for TP	Garcia et al. 2009
North Carolina	Farm	PAM + screening	For swine waste, addition of PAM before screening increased separation efficiencies to 95% TSS and VSS, 92% organic P, 85% organic N, 69% COD, and 59% BOD_5;	Vanotti et al. 2002
North Carolina	Farm	Flocculation + filtration	System removed 97% of TSS and VSS, 85% of BOD, 83% of COD, 61% TKN, and 72% of TP from flushed swine manure	Vanotti et al. 2005

Although screening alone was not effective for separating swine waste in a North Carolina study, Vanotti et al. (2002) found that adding PAM before screening increased separation efficiencies to 95 percent TSS and volatile suspended solids (VSS), 92 percent organic P, 85 percent organic N, 69 percent COD, and 59 percent BOD_5; the N:P ratio was improved from 4.79 to 12.11, resulting in a more balanced effluent for fertilizing crops. In a subsequent study, Vanotti et al. (2005) reported that a combined flocculation and filtration treatment system removed 97 percent of TSS and VSS, 85 percent of BOD, 83 percent of COD, 61 percent TKN, and 72 percent of TP from flushed swine manure.

Waste treatment and processing—lagoon treatment

Waste treatment processes typically leave a residual material after producing a cleaner effluent; thus, the reductions cited in the literature generally refer to the treated effluent compared to the original waste. In all cases, the residual should be managed properly to prevent pollution impacts.

Aerobic lagoon treatment of swine waste in Nova Scotia accomplished removals of 59–71 percent TSS, 59–73 percent VSS, 42–60 percent TKN, and 42–51 percent NH_4-N (Trias et al. 2004). In France, combined aerobic/anoxic treatment of swine manure wastewater achieved 86 percent reduction in TSS, 90 percent reduction in TN and COD (Prado et al. 2009); 50 percent of soluble P was biologically removed by an intermittent aerobic/anoxic sequence.

In Korea, Ra et al. (1998) reported that a two-stage sequencing batch reactor system achieved removal efficiencies of 98 percent total organic carbon (TOC), 100 percent NH_4-N, 98 percent TKN, 97 percent ortho-P, 98 percent TP, 97 percent suspended solids (SS) and 97 percent VSS.

Vanotti and Szogi (2008) tested a new swine waste treatment system combining liquid-solids separation with biological N and P removal in North Carolina and reported removal of 73–98 percent TSS, 40–76 percent of TS, 77–100 percent of BOD_5, 85–98 percent of TKN and NH_4-N, 38–95 percent of TP, and 37–99 percent of Zn and Cu. A second-generation version of the system removed 98 percent TSS, 97 percent NH_4-N, 95 percent TP, 99 percent Zn and Cu, 99.9 percent odors, and 99.99 percent pathogens (Vanotti et al. 2009).

Table 2-6. Summary of reported practice effects resulting from lagoon treatment

Location	Study type	Practice	Practice effects	Source
Nova Scotia	Farm	Aerobic lagoon	For swine waste, removals of 59%–71% TSS, 59%–73% VSS, 42%–60% TKN, and 42%–51% NH_4-N	Trias et al. 2004
France	Farm	Aerobic/anoxic lagoons	For swine manure wastewater, achieved 86% TSS reduction, 90% TN and COD reduction; 50% of soluble P was biologically removed by an intermittent aerobic/anoxic sequence.	Prado et al. 2009
Korea	Farm	Two-stage sequencing batch reactor	Removal efficiencies of 98% TOC, 100% NH_4-N, 98% TKN, 97% ortho-P, 98% TP, 97% suspended solids, and 97% volatile suspended solids from swine waste	Ra et al. 1998
North Carolina	Farm	Solids separation + biological N and P removal	For swine waste treatment, removal of 73-98% TSS, 40%–76% of TS, 77%–100% of BOD_5, 85-98% of TKN and NH_4-N, 38%–95% of TP, and 37%–99% of Zn and Cu.	Vanotti and Szogi 2008
North Carolina	Farm	Solids separation + biological N and P removal (2nd generation)	For swine waste treatment, removal of 98% TSS, 97% NH_4-N, 95% TP, 99% Zn and Cu, 99.9% odors, and 99.99% pathogens	Vanotti and Szogi 2009

Waste treatment and processing—other treatment

Masse et al. (2007) reviewed the most recent literature on membrane filtration for manure concentration and treatment and found studies of ultrafiltration of manure that reported up to 100 percent removal of coliform and SS, 87 percent P reduction, but no effect on soluble COD from ultrafiltration (0.01 μm) and lower efficiency from microfiltration (0.2 μm), e.g., 75 percent SS removal.

In Ireland, Healy et al. (2004) tested recirculating sand filters for treatment of dairy wastewater and reported TN reduction of 27 to 41 percent; TN reduction increased to 83 percent when sand filter effluent was recirculated through an anoxic zone. A subsequent study (Healy et al. 2007) reported consistent COD and TSS removals of greater than 99 percent, and an 86 percent reduction in TN.

Lee and Song (2006) reported average removal of 81 percent COD, 92 percent SS, 68 percent TN, and 95 percent TP using ozone to treat livestock wastewater through a dissolved air flotation system in Korea. Separation, collection, and treatment of swine waste with an ammonia recovery process using a metal ion treated resin bed achieved greater than 90 percent reduction in ammonia content in North Carolina (Loeffler and van Kempen 2003). Removal of up to 90 percent of P from swine waste treated by chemical precipitation with struvite and hydroxyapatite was reported in South Korea (Choi et al. 2008).

Table 2-7. Summary of reported practice effects resulting from other wastewater treatment

Location	Study type	Practice	Practice effects	Source
Numerous	Review	Membrane filtration	Ultrafiltration (0.01 μm) of manure: up to 100% removal of coliform and SS, 87% P reduction, no effect on soluble COD; lower efficiency from microfiltration (0.2μm: 75% SS removal.	Masse et al. 2007
Ireland	Farm	Recirculating sand filter	For dairy wastewater, reported TN reduction of 27 to 41%; TN reduction increased to 83% when sand filter effluent was recirculated through an anoxic zone	Healy et al. 2004
Ireland	Farm	Recirculating sand filter	For dairy wastewater, COD and TSS removals of > 99%, and an 86% reduction in TN	Healy et al. 2007
Korea	Farm	Ozone dissolved air flotation system	Average removals of 81% COD, 92% SS, 68% TN, and 95% TP removal from livestock wastewater	Lee and Song 2006
North Carolina	Farm	Separation + ammonia recovery[a]	Achieved > 90% reduction in ammonia content in swine waste	Loeffler and van Kempen 2003
Korea	Farm	Chemical precipitation[b]	Up to 90% removal of P from swine waste	Choi et al. 2008

Notes:
a. Ammonia recovery using a metal ion treated resin bed
b. Struvite and hydroxyapatite

Digestion

Anaerobic digestion of manure can offer substantial benefits, both economic and intangible, to animal feeding operators and surrounding communities, such as renewable energy generation; reduction in bulk and improvement of handling characteristics; production of stable, liquid fertilizer and high-quality solid soil amendment; reduction in odors; reduction of greenhouse gasses (GHGs); and reduction in ground and surface water contaminants (Demirer and Chen 2005; Cantrell et al. 2008; Garrison and Richard 2005). There is ample literature concerning digester performance and yield, but not all studies report performance relevant to water quality concerns. It should be noted that digestion does not generally remove nutrients from the original waste material, and the residuals from digestion require further management.

Costa et al. (2007) evaluated the efficiency of the anaerobic digestion in reducing the organic load of swine waste. Results showed an average reduction of COD of 58 percent.

In Turkey, Gungor-Demirci and Demirer (2004) investigated the potential biogas generation from anaerobic digestion of broiler and cattle manure. The efficiency of total COD removal was 32–43 percent and 40–50 percent for initial COD concentrations of 12,000 and 53,500 mg/L, respectively. The biogas yields observed for initial COD concentrations of 12,000 and 53,500 mg/L were 180–270 and 223–368 mL gas/g COD added, respectively.

A thermochemical conversion process applied to the treatment of swine manure for oil production in Illinois achieved a 75 percent reduction in COD (He et al. 2000). Lansing et al. (2008a) reported 84 percent reduction in COD and a 78 percent increase in dissolved NH_4-N concentration in a study of seven low-cost digesters in Costa Rica. In a companion study of very small farms, Lansing et al. (2008b) reported reductions in COD of 86 percent for dairy digester and 92 percent for a swine digester.

Thermophilic aerobic digestion reduced volatile solids by 28–54 percent in Ireland, while producing Class A biosolids suitable for land application (Layden et al. 2007). Anaerobic digestion of poultry feces in Nigeria achieved greater than 99 percent reductions in *E. coli* bacteria counts compared to an undigested, but equal-aged control (Yongabi et al. 2009).

In China, adding undigested swine wastewater to digested wastewater in a sequencing batch reactor process significantly improved COD removal to greater than 80 percent and NH_4-N removal up to 99 percent (Deng et al. 2005). The effluent COD concentration was in the range of 250 mg/L to 350 mg/L and effluent NH_4-N concentration was less than 10 m/L. A pilot-scale sequencing batch reactor built to treat swine waste in Australia achieved NH_4-N and odor reductions of greater than 99 percent as well as 79 percent removal of COD and a 49 percent reduction of PO_4-P on a mass balance basis because of struvite formation within the reactor (Edgerton et al. 2000).

In China, enhancement of a traditional sequencing batch reactor for swine waste with two-step feeding and low-intensity aeration at laboratory scale yielded reductions of 94 percent TN, 99 percent TP, and 99.9 percent BOD_5, possibly reflecting the activity of denitrifying P-accumulating organisms (Lue et al. 2008; Lu et al. 2009).

Table 2-8. Summary of reported practice effects resulting from manure digestion

Location	Study type	Practice	Practice effects	Source
Unknown	Farm	Anaerobic digestion	Average reduction of COD of 58%.	Costa et al. 2007
Turkey	Pilot	Anaerobic digestion	For digestion of broiler and cattle manure, COD removal was 32%–43% and 40%–50% for initial COD concentrations of 12,000 and 53,500 mg/L, respectively. The biogas yields observed for initial COD concentrations of 12,000 and 53,500 mg/L were 180-270 and 223-368 mL gas/g COD added, respectively	Gungor-Demirci and Demirer 2004
Illinois	Pilot	Thermochemical conversion	75% reduction in COD of swine manure	He et al. 2000
Costa Rica	Farms	Anaerobic digestion	84% reduction of COD; 78% increase in NH_4-N	Lansing et al. 2008a
Costa Rica	Farms	Anaerobic digestion	86% reductions of COD for dairy digester 92% reductions of COD for a swine digester	Lansing et al. 2008b
Ireland	Farm	Thermophilic aerobic digestion	28%–54% reduction in volatile solids[a]	Layden et al. 2007
Nigeria	Farm	Anaerobic digestion	> 99% reductions in *E. coli*[b]	Yongabi et al. 2009
China	Farm	Sequencing batch reactor	Adding additional undigested swine wastewater to digested wastewater in a sequencing batch reactor process significantly improved with COD removal to > 80% and NH_4-N removal up to 99%	Deng et al. 2005
Australia	Pilot	Sequencing batch reactor	For swine waste, > 99% NH_4-N and odor reductions, 79% removal of COD, and a 49% reduction of PO_4-P on a mass balance basis[c]	Edgerton et al. 2000
China	Laboratory	Enhanced sequencing batch reactor[d]	Reductions of 94% TN, 99% TP, and 99.9% BOD_5, possibly from growth of denitrifying P-accumulating organisms	Lue et al. 2008; Lu et al. 2009

Notes:

a. Produced Class A biosolids suitable for direct land application
b. Compared to an undigested, but equal-aged control
c. Due to struvite formation within the reactor
d. Addition of two-step feeding and low-intensity aeration to traditional SBR

Composting

Composting of animal manure can reduce bulk, kill microorganisms, improve handling, and provide a value-added product (Brodie et al. 2000). While significant quantities of N can be lost through volatilization in the composting process (consider air quality issues), composting has no net effect on the TP content of the material.

In Texas, Bekele et al. (2006) documented a 19–23 percent decrease in soluble P in streams draining areas where significant quantities of manure had been composted and removed from the watershed. While composting did not change the P content of the end product, composting facilitated transport and marketing of the final product.

Gibbs et al. (2002) measured nutrient losses from aerobic composting of cattle manure in the UK. Total mass loss ranged from 23 percent for an unturned static composting to 67 percent of the initial mass for the indoor composting turned three times. N losses from the manure heaps ranged from 8 to 68 percent of the initial total manure N content. Gaseous N losses, primarily as NH_3, accounted for between 7 and 67 percent of the initial manure N content.

Table 2-9. Summary of reported practice effects resulting from manure composting

Location	Study type	Practice	Practice effects	Source
Texas	Watershed	Composting + export	19%–23% decrease in soluble P in streams draining areas where significant quantities of manure had been composted and removed from the watershed	Bekele et al. 2006
U.K.	Farm	Aerobic composting	23% mass loss for an unturned static composting; 67% mass loss for the indoor composting turned 3 times Compost piles lost 8%–68% of initial TN; gaseous N losses, primarily as NH_3, accounted for 7%–67% of the initial manure N	Gibbs et al. 2002
Canada	Farm	Aerobic composting	Exposure to temperatures > 55 °C for 15 d inactivated *Giardia* cysts and *Cryptosporidium* oocysts in beef feedlot manure	Larney and Hao 2007
Georgia	Farm	Co-composting	Co-composting of chicken hatchery waste and poultry litter was effective in eliminating 99.99% of *E. coli* bacteria	Das et al. 2002

In beef feedlot manure composting in Alberta, Canada, Larney and Hao (2007) reported that exposure of manure to temperatures above 55 °C for a period of 15 days appears to be an effective method of inactivating both *Giardia* cysts and *Cryptosporidium* oocysts in feedlot manure. The authors report mean carbon and N concentrations in eight feedlot manure composts: total carbon 228 g/kg, TN 16.0 g/kg, soluble carbon11.3 g/kg, soluble N 1.6 g/kg.

Das et al. (2002) reported that co-composting of chicken hatchery waste and poultry litter was effective in eliminating 99.99 percent of *E. coli* bacteria in Georgia. Koenig et al. (2005) reported that alum and process controls such as moisture content, carbon source and particle size have the potential to reduce NH_3 loss from poultry manure composted inside high-rise layer structures.

Constructed wetland treatment

N in wastewater from dairy and swine operations has been successfully treated in constructed wetlands (Hunt and Poach 2001). Plants are an integral part of wetlands. Cattails and bulrushes are commonly used in constructed wetlands for nutrient uptake, surface area, and oxygen transport to sediment. Improved oxidation and nitrification can also be obtained by using the open water of marsh-pond-marsh designed wetlands. High levels of N removal by denitrification have been reported from constructed wetlands, especially when the wastewater is partially nitrified (Hunt et al. 2009). Manure solids must be removed before wetland treatment is essential for the wetland to function long term.

A constructed wetland to treat incoming barnyard runoff in Ireland retained greater than 60 percent of the P load delivered to the wetland (Dunne et al. 2004). A subsequent study (Dunne et al. 2005) reported that P retention by the wetland varied with season (5–84 percent) with lowest retention occurring in winter.

In a review of 12 constructed wetlands treating livestock wastewater on the south coast of Ireland, Harrington and McInnes (2009) reported that over an 8-year period, mean reduction of total and soluble P exceeded 95 percent and the mean removal of ammonium-N exceeded 98 percent.

Mustafa et al. (2009) reported removal efficiencies of 98 percent BOD, 95 percent COD, 94 percent SS, 99 percent ammonia N, 74 percent NO_3-N, and 92 percent soluble P in dairy wastewater treatment through a constructed wetland system in Ireland.

Lee et al. (2004) reported that average reduction efficiencies in subsurface flow constructed wetlands in Taiwan were SS 96–99 percent, COD 77–84 percent, TP 47–59 percent, and TN 10–24 percent. While physical mechanisms were dominant in removing pollutants, the contributions of microbial mechanisms increased with the duration of wetland use, achieving 48 percent of COD removed and 16 percent of TN removed in the last phase. Water hyacinth made only a minimal contribution to the removal of nutrients.

In Kansas, Mankin and Ikenberry (2004) evaluated a constructed wetland without vegetation as a sequencing batch reactor. Using 3-week batch periods without plants, overall mass removal averaged 54 percent for COD, 58 percent for TSS, 90 percent for TN, 72 percent for NH_4, -54 percent for NO_3, 38 percent for TP, and -8 percent for PO_4.

Prantner et al. (2001) reported that a U.K. wetland system treating liquid swine manure after soil infiltration removed 94 percent of the NH_3-N and NH_4-N, 95 percent of the NO_3-N, and 84 percent of the TP.

Table 2-10. Summary of reported practice effects resulting from wetland treatment

Location	Study type	Practice	Practice effects	Source
Ireland	Farm	Constructed wetland	Retained > 60% of the P load delivered in barnyard runoff; P retention by the wetland varied with season (5%–84%) with lowest retention occurring in winter	Dunne et al. 2004, 2005
Ireland	Review	Constructed wetland	8-year mean reduction of total and soluble P > 95% and the mean removal of ammonium-N > 98%.	Harrington and McInnes 2009
Ireland	Farm	Constructed wetland	Removal efficiencies of 98% BOD, 95% COD, 94% SS, 99% ammonia N, 74% NO_3-N, and 92% soluble P in dairy wastewater treatment	Mustafa et al. 2009
Taiwan	Review	Constructed wetlands (subsurface flow)	Average reduction efficiencies in subsurface flow constructed wetlands in Taiwan were SS 96-99%, COD 77–84%, TP 47–59%, and TN 10–24%[a]	Lee et al. 2004
Kansas	Wetland	Constructed wetland without vegetation	Mass removal averaged 54% COD, 58% TSS, 90% TN, 72% NH_4, -54% NO_3, 38% TP, and -8% PO_4	Mankin and Ikenberry 2004
U.K.	Farm	Constructed wetland	Treating liquid swine manure after soil infiltration removed 94% of NH_3-N and NH_4-N, 95% of NO_3-N, and 84% of TP.	Prantner et al. 2001
Maryland	Farm	Constructed wetland	Treating dairy wastewater TN reduced 98%, ammonia 56%, TP 96%, ortho-P 84%, SS 96%, and BOD 97%; NO_3/ NO_2 increased 82%	Schaafsma et al. 2000
Nova Scotia	Farm	Constructed wetland	Load reductions from 62%–99% for BOD, TSS, TP, and NH_3-N treating agricultural wastewater	Smith et al. 2006
Nova Scotia	Farm	Constructed wetland	Load reductions of 54% TP and 53% soluble P treating milkhouse wash water and liquid manure	Wood et al. 2008
Vermont	Farm	Subsurface flow constructed wetland with slag filter	Removed 75% of P mass from dairy barnyard runoff and milk parlor waste	Weber et al. 2007

Note:

a. Physical mechanisms were dominant in removing pollutants; the contributions of microbial mechanisms increased with the duration of wetland use. Water hyacinth made only a minimal contribution to the removal of nutrients.

Flow of dairy wastewater through the wetland system in Maryland resulted in significant reductions in concentrations of all analytes except NO_3/NO_2 (Schaafsma et al. 2000). Relative to initial concentrations, TN was reduced 98 percent, ammonia 56 percent, TP 96 percent, ortho-P 84 percent, SS 96 percent, and BOD 97 percent. NO_3/NO_2 increased by 82 percent, although mean concentrations were much lower than concentrations of ammonia or TN.

In Nova Scotia, Smith et al. (2006) reported load reductions from 62 to 99 percent for BOD, TSS, TP, and NH_3-N in wetlands treating agricultural wastewater. Also in Nova Scotia, Wood et al. (2008) reported mass reductions of 54 percent for TP and 53 percent soluble P over 4 years in a surface flow constructed wetland milkhouse wash water and liquid manure. In Vermont, a subsurface flow constructed wetland with a slag filter removed 75 percent of P mass from dairy barnyard runoff and milk parlor waste (Weber et al. 2007).

Other biological treatment

A multiple-pond system (APS) treating dairy milking parlor effluent in New Zealand produced effluent with 50–60 percent less BOD, TSS, TKN and ammonia-N than equivalently sized two-pond systems with medians of 43, 87, 61, and 39 mg/L, respectively. TP was reduced by 70 percent to 19 mg/L. *E. coli* were reduced in the APS by two orders of magnitude to 918 MPN/100 mL (Bolan et al. 2009).

In Morocco, El Hafiane et al. (2003) reported average removals of 70 percent for N and 40 percent for P in a high-rate algal pond treating wastewater. Water hyacinth ponds were reported to achieve approximately 50 percent removal of applied organic loads (COD, BOD, TN, and TP) from swine waste in Brazil (Costa et al. 2000).

In Scotland, an algal-based bioreactor achieved sustained nutrient removal efficiencies (up to 99 percent and 86 percent for NH_4-N and PO_4-P, respectively) from swine wastewater while total COD was removed up to 75 percent (Gonzalez et al. 2008). Lu et al. (2008) augmented a wetland treating duck waste in China with water hyacinth and reported removal of 64 percent of COD, 22 percent TN, and 23 percent TP loads. The hyacinth was harvested and recycled as duck feed.

Anaerobically digested dairy manure effluent was treated with algal turf scrubber raceways in Maryland (Mulbry et al. 2008). Removal rates of 70 to 90 percent of input N and P were achieved at loading rates below one g TN, 0.15 g TP $/m^2/d$; N and P removal rates decreased to 50–80 percent at higher loading rates.

Table 2-11. Summary of reported practice effects resulting from other biological treatment

Location	Study type	Practice	Practice effects	Source
New Zealand	Farm	Multiple pond system	Treating dairy milking parlor effluent produced effluent with 50%–60% less BOD, TSS, TKN and ammonia-N than equivalently sized two-pond systems. TP was reduced by 70% to 19 mg/L. *E. coli* reduced by two orders of magnitude.	Bolan et al. 2009
Morocco	Farm	High-rate algal pond	averaged removals of 70% N and 40% P	El Hafiane et al. 2003
Brazil	Farm	Water hyacinth ponds	About 50% removal of applied organic loads (COD, BOD, TN, TP) from swine waste	Costa et al. 2000
Scotland	Farm	Algal bio-reactor	Removed 99% NH_4-N, 86% of PO_4-P, and 75% of COD mass from swine wastewater	Gonzalez et al. 2008
China	Farm	Water hyacinth wetland	Removed 64% COD, 22% TN, and 23% TP loads from duck waste[a]	Lu et al. 2008
Maryland	Farm	Algal turf scrubber	Treating anaerobically digested dairy manure effluent, removal rates of 70-90% of input N and P were achieved at loading rates below 1 g TN, 0.15 g TP /m^2/d; N and P removal rates decreased to 50–80% at higher loading rates.	Mulbry et al. 2008
Hawaii	Farm	Entrapped mixed microbial cells process	Removed 84% of COD and 98% of TP from dilute swine wastewater	Yang et al. 2003

Note:

a. Water hyacinth was harvested and recycled as duck feed.

An entrapped mixed microbial cells process was used to investigate the simultaneous removal of carbon and N from dilute swine wastewater in Hawaii (Yang et al. 2003). COD removal efficiencies were 84 percent and TP removal efficiencies of 98 percent were achieved.

Air quality

Ammonia, dust, and odors associated with animal agriculture—especially on large facilities—can be important local air pollutants. For example, Melse and Timmerman (2009) reported that N emissions in exhaust air from pig houses in the Netherlands can represent as much as 25 percent of the TN excretion by the animals. Airborne ammonia can also become a significant water pollutant when deposited in local waterbodies. Indoor air quality can affect animal health as well, especially at large poultry and hog facilities. Animal production facilities can be important producers of greenhouse gases (van der Meer 2008).

Ullman et al. (2004) reviewed abatement technologies available to reduce atmospheric emissions from animal production facilities and summarized the following:

- Scrubbers have been shown to reduce odors by 60–85 percent and to reduce ammonia by 15–45 percent.
- Filter systems can reduce airborne dust from broiler operations by up to 50 percent.
- Biofilters can exhibit 90 percent or better reductions of odor-causing chemicals such as hydrogen sulfide, methanethiol, dimethyl sulfide, and dimethyl disulfide.
- Ionization systems can reduce dust concentrations 68–92 percent.
- Indoor ozone systems can decrease total dust concentrations by 60 percent and ammonia levels by 58 percent compared to similar buildings without ozone treatment.

The authors added that poultry litter amendments such as sodium bisulfate and alum can reduce odor and ammonia emissions and natural windbreaks can provide an entrapment mechanism for odorous compounds that require minimal maintenance. Windbreaks placed downwind of exhaust fans and litter storage areas can provide an economical management practice for broiler producers when used in conjunction with other air-cleaning practices.

In Kentucky, Singh et al. (2009) reported that adding a commercially available urease inhibitor to poultry litter resulted in a significant reduction in equilibrium ammonia concentration over time by disrupting the enzymatic degradation of uric acid.

Melse and Timmerman (2009) reported average ammonia removal efficiencies of 70–96 percent for farm-scale operated acid scrubbers on swine facilities in the Netherlands. Reported average removal efficiency for odor was only 31 percent and showed a large variation. Multi-pollutant scrubbers removed an average of 66 percent of ammonia, 42 percent of odor, 50 percent of PM_{10}, and 57 percent of $PM_{2.5}$.

Adrizal et al. (2008) evaluated the potential of trees planted around Pennsylvania commercial poultry farms to trap ammonia and dust or particulate matter. Results indicated that poplar, hybrid willow, and Streamco willow are appropriate species to absorb poultry house aerial NH_3-N, whereas spruce and hybrid willow are effective traps for dust and its associated odors.

Koenig et al. (2005) reported that alum and process controls such as moisture content, carbon source and particle size have the potential to reduce ammonia loss from poultry manure composted inside high-rise layer structures. Although both low moisture and temperature reduced NH_3 capture, managing temperature and moisture to achieve low NH_3 would adversely affect microbial activity and other desired benefits of composting.

In a Texas laboratory study, Shi et al. (2001) evaluated amendments for reducing ammonia emissions from open-lot beef cattle feedlots and found that cumulative ammonia emissions after 21 days compared to the untreated control were 2–8 percent for alum, 22–29 percent for $CaCl_2$, 32–40 percent for humate, 34–36 percent for a urease-inhibitor NBPT, and 68–74 percent for a commercial product.

In North Carolina, Szogi and Vanotti (2007) demonstrated that solid-liquid separation technologies can substantially reduce ammonia emissions from anaerobic swine lagoons. Ammonia emissions from a lagoon with solid-liquid separation had 73 percent lower ammonia emissions compared to an anaerobic lagoon.

Table 2-12. Summary of reported practice effects for air quality issues

Location	Study type	Practice	Practice effects	Source
Numerous	Review	Various	Scrubbers can reduce odors by 60%–85% and reduce ammonia by 15%–45% Filter systems can reduce airborne dust from broiler operations by up to 50% Biofilters can exhibit 90% or better reductions of odor-causing chemicals Ionization systems can reduce dust concentrations 68%–92% Indoor ozone systems can decrease total dust concentrations by 60% and ammonia levels by 58% compared to similar buildings without ozone treatment	Ullman et al. 2004
Netherlands	Farm	Acid scrubbers	Average 70%–96% ammonia removal, 31% odor removal on swine facilities; multi-pollutant scrubbers removed 66% of ammonia, 42% odor, 50% PM_{10} removal, and 57% $PM_{2.5}$	Melse and Timmerman 2009
Pennsylvania	Farm	Tree windbreaks	Poplar, hybrid willow, and *Streamco* willow absorb poultry house aerial NH_3-N; whereas spruce and hybrid willow are effective traps for dust and odors.	Adrizal et al. 2008
Texas	Laboratory	Beef feedlot amendments	21-day cumulative ammonia emissions compared to untreated control were: 2%–8% for alum, 22%–29% for $CaCl_2$, 32%–40% for humate, 34%–36% for a urease-inhibitor NBPT, and 68%–74% for a commercial product.	Shi et al. 2001
North Carolina	Farm	Liquid-solid separation	Ammonia emissions from a lagoon with solid-liquid separation had 73% lower ammonia emissions compared to an anaerobic lagoon.	Szogi and Vanotti 2007
North Carolina	Farm	Aerobic lagoon	Reduced GHG emissions 96.9%, from 4,972 t to 153 t of carbon dioxide equivalents (CO_2-eq)/yr	Vanotti et al. 2008

Replacing swine waste lagoon technology with cleaner aerobic technology in North Carolina reduced GHG emissions 96.9 percent—from 4,972 metric tons (MT) to 153 MT of carbon dioxide equivalents (CO_2-eq)/yr (Vanotti et al. 2008).

Practice Costs

Systematic cost data for most practices are rarely given in the scientific literature; better cost data might be available on a state or county basis from producers, groups, or agencies funding or managing implementation. Among reported cost data, there is a lack of consistency in unit costs (e.g., $/cow, $/kg P removed, or $/L of waste treated) that sometimes makes comparison among practices difficult. Cost figures are reported in dollars for the year given by the authors.

In laboratory studies, Jones and Brown (2000) estimated chemical cost (2010 dollars) for combinations of alum and PAM of $74–$200/kg ortho-P removed from dairy wastewater. For supplementary precipitation of soluble P in the treatment of dairy manure by mechanical separation, Oh et al. (2005) estimated costs for alum and polymer addition of about $3.21 per 1,000 L (2010 dollars) of treated manure slurry.

Moore et al. (2000) found that alum applications to poultry litter was cost-effective, with a benefit/cost ratio of 1.96 partly from heavier birds, better feed conversion, and lower energy use to vent ammonia from the houses.

In a cost analysis of anaerobic digestion and methane production, Garrison and Richard (2005) noted that the economic feasibility of the energy conversion technology varies widely with scale, with significant advantages for larger facilities. Farrow-to-finish and finishing swine operations needed more than 20,000 head and 5,000 head, respectively, to be economically feasible. Dairy operations in the midwestern United States hold considerably more economic promise, with feasible herd counts in the 150- to 350-head range for electricity prices of $0.13/kWh (2010 dollars). Results indicate that increased energy prices and financial assistance will be needed to encourage significant numbers of facilities to recover energy from manure.

In Virginia, covered lagoon anaerobic digesters run from about $112/head for swine to about $318/head for dairy, with plug-flow digesters for dairy costing just under $700/head (USDA-NRCS 2010). Typical total costs are about $112,000 for covered lagoons for swine, $240,000 for covered lagoons for dairy, and just over $512,000 for plug-flow anaerobic digesters for dairy.

Brodie et al. (2000) studied technologies to manufacture compost from poultry litter and reported that screened compost was produced at an operational cost of $37 (2010 dollars) while unscreened compost could be produced for about $25 per ton of compost. A production scheme where poultry litter is a static pile composted on farms for later transport to regional processing centers appeared feasible.

Kemper and Goodwin (2009) reported that in composting poultry litter and eggshell waste into a marketable soil amendment, compost could be produced at an average cost of $17.73 to $20.38/ton (2010 dollars) for small-scale and large-scale systems, respectively. The cost for disposing of eggshell waste in landfills was $25.36/ton (2010 dollars).

Static pile/windrow composting facilities with a concrete floor that are used for vegetative materials cost about $55/yd^3, with typical facilities costing about $18,100 (USDA-NRCS 2010). Animal mortality composting facilities cost about $330/yd^3 for either poultry or swine. Typical dead-poultry composting facilities cost about $12,000, whereas typical dead-swine composting facilities cost much more—about $35,000. A static pile/windrow composter with a concrete floor for animal mortality is a lower cost option that runs about $107/yd^3, with typical total costs of under $9,500. Larger (1,500-lb capacity) dead-animal incinerators cost about $10.60 per pound of capacity, while smaller incinerators (400-lb capacity) cost $23.44 per pound of capacity, with typical costs of about $16,000 and $9,500 each for larger and smaller incinerators, respectively. Gasification units are a higher-end option for dead animals, ranging from just over $58 to nearly $150 per pound of capacity, with units typically costing $40,000 to $70,000 depending on size. Even more expensive are forced aeration composters. They can cost from about $900 to $1,300/yd^3 depending on capacity and whether a grinder is included, with typical facility costs ranging from about $130,000 each to just over $250,000 each.

In a study of using filamentous green algae grown in outdoor raceways to treat dairy manure effluent, Mulbry et al. (2008) projected annual operational costs of $788 per cow (2010 dollars). For comparison, the operational costs of $11.12 per kg N removed are well below the costs cited for upgrading existing water treatment plants.

Vegetative environmental buffers (strategically planted trees and shrubs) around poultry houses cost $4.05/ft in the form of containerized plants, with typical costs reaching $4,055 in Virginia (USDA-NRCS 2010). Windbreaks or shelterbelts consisting of pines, hardwoods, and mixed shrubs cost $82.50, $909, and $1,453 per acre, respectively, with respective typical total costs of $41.25, $456, and $726.

Shi et al. (2001) calculated the costs of six amendments for reducing ammonia emissions from open-lot beef cattle feedlots, ranging from $0.15 to $6.81 (2010 dollars) per application per head. Only one treatment had a benefit/cost ratio greater than 1.0. Results suggest that amendments can reduce ammonia emissions from open feedlots, but the costs might be prohibitive.

Vanotti et al. (2008) analyzed GHG emission reductions from implementing aerobic technology on swine farms in North Carolina and estimated emission reductions of 4,776.6 MT CO_2-eq per year or 1.10 MT CO_2-eq/head per year. The dollar value from implementation was $19,312/year (2010 dollars) using current Chicago Climate Exchange trading values of $4.04/t CO_2 (2010 dollars). That translates into a direct economic benefit to the producer of $1.77 (2010 dollars) per finished pig. The authors suggest that GHG emission reductions and credits can help compensate for the higher installation cost of cleaner aerobic technologies and facilitate producer adoption of environmentally superior technologies to replace current anaerobic lagoons.

In studies of poultry litter amendments to reduce odor and ammonia volatilization, Ullman et al. (2004) found that sodium bisulfate and alum treatments ranged in price from $253 to $530 per ton (2010 dollars), resulting in a cost of $13 to $18 for 92.9 m^2 (1,000 ft^2) at recommended application rates. Another cost benefit analysis showed that ammonia reduction by ventilation during cold periods would cost $4,400 per flock (19,000 birds weighing four lb each).

Unit and typical total costs for various amendments to treat agricultural waste are the following (USDA-NRCS 2010):

- Ferric sulfate or alum for broiler house litter: $0.199/$ft^2$, $3,750 total
- Ferric sulfate or alum for turkey or rooster house litter: $0.159/$ft^2$, $3,000 total
- Liquid alum treatment for very dry broiler house litter: $0.268/$ft^2$, $5,060 total
- Liquid alum treatment for turkey or rooster house litter: $0.214/$ft^2$, $4,050 total
- Sodium bisulfate treatment for broiler house litter: $0.205/$ft^2$, $3,880 total
- Sodium bisulfate treatment for turkey or rooster house litter: $0.164/$ft^2$, $3,100 total

3 Implementation Measures and Practices for Cropland In-Field Control

The best approach to minimize nutrient transport to local waters depends on whether the nutrient is in the dissolved phase or is attached to soil particles. For dissolved nutrients, effective management includes source reduction and reduction of water runoff or leaching. Erosion and sediment transport controls are necessary to reduce transport of nutrients attached to soil particles. Practices that focus on controlling the transport of smaller soil particle sizes (e.g., clays and silts) are most effective because they are the soil fractions that transport the greatest share of adsorbed nutrients.

3.1 Field Nutrient Management

Strategies for in-field control on cropland focus on managing the form, application method, and timing of waste and nutrient applications and on controlling soil conditions to reduce the potential for runoff of nutrients. Pasture management strategies address managing animal stocking rates and timing as well as maintaining vigorous vegetation to provide for soil stability and nutrient recycling.

Implementation Measure A-10:

Manage nutrient applications to cropland to minimize nutrients available for runoff. In doing so

- Apply manure and chemical fertilizer during the growing season only
- Do not apply any manure or fertilizer to saturated, snow-covered, or frozen ground
- Inject or otherwise incorporate manure or organic fertilizer to minimize the available dissolved P and volatilized N
- Apply nutrients to HELs only as directed by the nutrient management plan, while at the same time implementing all aspects of the soil conservation plan

In many crop areas, nutrient imports into the watershed from feed and fertilizers exceed nutrient exports in crops and livestock produced; that imbalance often exists at both the individual field and the watershed level (Beegle 2000). In such circumstances, nutrients can accumulate in soils from over-application of fertilizer or animal waste relative to crop need. Excessive soil nutrient levels have been linked to high P losses in runoff and leaching losses of N, especially in areas of animal-based agriculture.

Nutrient management is an important tool to match nutrient inputs more closely to crop needs. The USDA-NRCS Nutrient Management Practice (NRCS Practice Code 590) generally defines nutrient management as, “managing the amount, source, placement, form and timing of the application of nutrients and soil amendments.” The Nutrient Management Practice can be applied for a number of purposes:

- To budget and supply nutrients for plant production
- To properly use manure and organic byproducts or biosolids as a plant nutrient source
- To minimize agricultural nonpoint source pollution of surface and ground water resources
- To protect air quality by reducing N emissions and the formation of atmospheric particulates
- To maintain or improve the physical, chemical, and biological condition of soil

This section presents information concerning several management practices to manage nutrients on cropland to reduce nutrient losses:

- **Manure and fertilizer form and rate**—selecting the form (N and P amounts in solid, semi-solid, or liquid manure) and rate of nutrients applied to cropland to reduce runoff or leaching losses
- **Nutrient application methods and timing**—selecting the method and timing of manure or fertilizer application to cropland to support crop growth and reduce runoff or leaching losses
- **Nutrient management planning**—preparing and implementing a comprehensive plan to manage nutrients from all sources to provide for crop growth while minimizing runoff and leaching losses of nutrients
- **Soil and manure amendment**—treating soils or manure to reduce the availability or mobility of nutrients

Using the products and methods described in this section should be considered carefully relative to existing practices because timing and placement of fertilizers play an important role in maximizing NUE. For example, if a producer replaces side dressing with use of a urease inhibitor, the timing and fertilizer placement must be a factor in the decision to switch. Also, emerging technologies will allow producers who use no-till on their cropland to inject manure so that no-till is continuous. That type of technology is welcome and should continue to be developed and widely implemented.

Reference documents are available that provide guidance on selection of practices with consideration for fertilizer source as well as timing, placement, and rate of application. Some examples are listed below (all Web sites were accessed April 24, 2010). Other regional- or state-specific guidance should be available from NRCS Field Offices and Land Grant Universities in each state.

- EPA's National Management Measures for the Control of Nonpoint Pollution from Agriculture
- NRCS Agricultural Waste Management Field Handbook
- eXtension Resource Areas including Animal Manure Management and several industry-specific resource areas (http://www.extension.org/main/communities)
- Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming (Snyder 2008)
- Best Management for Fertilizers on Northeastern Dairy Farms (Bruulsema and Ketterings 2008)
- Optimizing Nitrogen Fertilizer Decisions (Nielsen 2001)
- Cornell University's Whole Farm Nutrient Management Tutorials (http://instruct1.cit.cornell.edu/Courses/css412/index.htm)
- Penn State Cooperative Extension Nutrient Management Planning Tools and Resources (http://panutrientmgmt.cas.psu.edu/main_planning_tools.htm)
- Penn State Agronomy Guide, Section 2 Soil Fertility Management, (http://agguide.agronomy.psu.edu/cm/sec2/sec2toc.cfm)
- Delaware Nutrient Management Program Publications and Resources (http://dda.delaware.gov/nutrients/NM_Pubs_resources.shtml)
- University of Maryland Agricultural Nutrient Management Program (http://anmp.umd.edu/)
- West Virginia University Extension Service Nutrient/Waste Management Web page (http://www.wvu.edu/~agexten/wastmang/index.html)

EPA encourages producers to consult with crop advisors, nutrient management planners, NRCS Field Offices and Cooperative Extension Services for assistance in evaluating the relative costs and benefits of a particular practice or system.

Practice Effectiveness

Manure and fertilizer form and rate

Chien et al. (2009) reviewed recent developments of fertilizer production and use that improve nutrient efficiency and minimize environmental impact. Improving N use efficiency includes using the following:

- Controlled-release coated urea products
- Nitrification inhibitors (NI) to reduce NO_3 leaching and denitrification
- Urease inhibitors to reduce ammonia hydrolysis from urea, with subsequent volatilization
- Ammonium sulfate to enhance N efficiency of urea by reducing ammonia volatilization from urea

As indicated above, field conditions and relative benefits must be carefully considered when evaluating use of these products to improve N use efficiency. Nielsen (2006) reports that, even when compared to urease inhibitors or nitrification inhibitors, using a more traditional sidedress application strategy remains one of the easiest and least expensive ways to maximize N use efficiency because other application methods need to be carefully matched to the N fertilizer source to minimize the risk of N loss before plant uptake.

Little research is available that directly compares the effectiveness of ammonium sulfate versus urease inhibitors in reducing ammonia volatilization from urea. A widely used and intensively researched urease inhibitor has been shown to reduce ammonia volatilization by an average of 60 percent compared to urea alone (Cantarella et al. 2005). Other studies (Fleisher and Hagin 1981, Kumar and Aggarwal 1998, and Goos and Cruz 1999) found that application of ammonium sulfate 2 to 4 weeks in advance of urea reduced ammonia volatilization by approximately 50 percent.

Practicality and cost are also important considerations. Goos and Cruz (1999) suggest that application of ammonium sulfate in advance of urea could be limited in practical application because it is not always possible to replicate the fertilizer applications in the same field location. Other studies (Lara-Cabezas et al. 1992, 1997; Oenema and Velthof 1993; Vitti et al. 2002) suggest that substituting ammonium sulfate for part of the urea mixture at application could be effective in reducing ammonia volatilization, but as Chien et al. (2009) point out, this use must be weighed in terms of its relative cost including an increase in the transportation cost for ammonium sulfate compared to urea because ammonium sulfate contains less N.

Chien et al. (2009) report that slow-release urea-aldehyde polymer fertilizers are generally more efficient than soluble N sources when the gradual supply of N is an advantage to crops. Under certain conditions, however, using slow-release urea-aldehyde polymer products might provide no production advantage. For example, Cahill et al. (2007) reported that grain yield and N use efficiency with urea NH_4NO_3 solution was statistically similar to or better than with urea formaldehyde polymer. Shaviv (2005) reports that the high cost of slow-release polymers limits their use in agriculture, but the potential for increased use is high where the products have been shown to increase nutrient recovery, sustain high yields, and reduce nutrient losses and associated environmental impacts based on reduced application levels and the ability to match release characteristics with plant demand. Bundick et al. (2009) describe advantages for the use of controlled-release fertilizers including reduced leaching, denitrification or volatilization losses, and more uniform crop growth because of reduced risk of seedling burn or salt damage. Disadvantages include cost, ineffectiveness when a quick release is needed (e.g., when side dressing corn at the 6-leaf stage).

Using urea supergranules for deep placement has been shown to improve N use efficiency used in small-scale rice production where plants are fertilized by hand. If problems related to labor cost and difficulty in deep placement of urea supergranules in upland soils can be solved, Chien et al. (2009) expect that deep placement of urea supergranules should also perform well as an N source for upland food crops.

Using nonconventional P fertilizers includes phosphate rock (PR) for direct application, a mixture of PR and water-soluble P sources, and nonconventional acidulated P fertilizers containing water-insoluble P compounds (Chien et al. 2009). PR has been studied for agronomic use for more than 50 years and can be agronomically beneficial depending on the solubility of PR, soil properties, management practices, climate, and crop species. For example, it is most effective where the PR is highly reactive and when used in acidic soils or tropical climates. Several decision support systems (PRDSS) have been developed to help integrate such factors to evaluate the effectiveness of PR for direct application under specific conditions. Where use of PR is not as feasible as water-soluble P sources, PR can be mixed with water-soluble P sources to economically achieve the same results as use of the water-soluble P source or PR alone because the water-soluble P source has a starter effect that allows for better initial root development, resulting in more effective PR utilization. Recent research has focused on eutrophication reduction when PR is used to replace water-soluble P sources as well as the use of PR in organic farming. Several studies have been conducted under controlled conditions to determine the relative effectiveness of nonconventional acidulated fertilizers made from lower quality PR ore compared to those with a higher proportion of water-soluble P. The review stresses that additional field studies are needed to adequately evaluate the agronomic use of PR under a variety of conditions.

Chien et al. (2009) indicate that using fluid P fertilizers can improve the efficiency of conventional P fertilizers, although additional research is needed. Recent research in Australia indicates that fluid P fertilizers were more effective than the commercial granular P fertilizers using the same P compound in increasing crop yield in calcareous and alkaline soils (Holloway et al. 2001) and that total and labile P from fluid sources diffused further into the soil than when granular sources are used (Hettiarachchi et al. 2006; Lombi et al. 2004). However, a number of earlier studies also showed no difference in P use efficiency between liquid and granular forms.

Slow-release fertilizer (SRF) and controlled-release fertilizer (CRF) materials can improve nutrient uptake efficiency and reduce the leaching potential of nutrients (Morgan et al. 2009). Those considerations are particularly important for crops grown on sandy soils with relatively low nutrient- and water-holding capacities.

In New Zealand, Sojka (2009) compared the efficacy of matrix-based fertilizers (MBFs) formulated to reduce NO_3, ammonium, and TP leaching with conventional SRFs, and an unfertilized control. SRF leachate contained higher amounts of NO_3, ammonium, and TP than leachate from all other fertilizers. There were no consistent differences in the amount of NO_3, ammonium, and TP in the MBF leachates compared to the control leachate.

Penn et al. (2004) tested the effects of phytase enzyme and HAP corn supplemented diets on runoff P concentrations from Virginia pasture soils receiving surface applications of turkey manure. The alternative diets caused a decrease in manure total and water-soluble P compared with the standard diet. Runoff dissolved P concentrations were significantly higher from HAP manure-amended soils, while dissolved P losses from other manure treatments were not significantly different from each other.

In a laboratory study, Loria and Sawyer (2005) compared the effect of raw and digested liquid swine manure application on soil test P and inorganic N. Raw and digested manure produced the same NH_4-N disappearance, NO_3-N formation, net inorganic N, and an increase in soil test P. Routine soil test P methods estimated similar P recovery with both manure sources.

In Iowa, Loria et al. (2007) found no difference between raw swine manure and manure digested for biogas as a source of N for plant use in the year of application or in the residual year; equivalence to fertilizer N was the same with both raw and digested swine manure.

In Georgia, Risse and Gilley (2000) reported that runoff was reduced from one to 68 percent, and soil loss decreased from 13 to 77 percent for locations on which manure was added annually. Measured runoff and soil loss values were found to be strongly influenced by manure application rates. Regression equations were developed relating reductions in runoff and soil loss to manure application rates.

In Colorado, Shoji et al. (1999) conducted field trials on CRFs and an NI to show their potential to increase NUE. TN fertilizer losses averaged 15 and 10 percent in the NI and urea treatments, respectively. On the other hand, those from the CRF treatment averaged only 1.9 percent, indicating that CRF showed the highest potential to increase N use efficiency.

King and Torbert (2007) designed an Ohio plot study to compare temporal losses of NO_3-N and NH_4-N from three SRFs (sulfur-coated urea, composted dairy manure, and poultry litter) and one fast-release fertilizer (NH_4NO_3) applied to Bermuda grass turf. Cumulative NO_3-N loss from plots receiving application of the manufactured (NH_4NO_3 and sulfur-coated urea) products was significantly greater than the measured losses from plots receiving application of composted dairy manure and poultry litter. The cumulative NO_3-N recovered in the runoff expressed as a proportion of applied N was 0.37 for NH_4NO_3, 0.25 for sulfur-coated urea, 0.10 for composted dairy manure, and 0.07 for poultry litter.

Table 2-13. Summary of reported practice effects resulting from management of manure and fertilizer form and rate

Location	Study type	Practice	Practice effects	Source
New Zealand	Plot	Fertilizer formulation	Leachate from conventional SRFs contained higher amounts of NO_3, ammonium, and TP than leachate from all other fertilizers	Sojka 2009
Brazil	Field	Urease inhibitor	The percentage of reduction in volatilization due to NBPT application ranged from 15% to 78% depending on the weather conditions during the days following application of N. Addition of NBPT to urea helped to control ammonia losses, but the inhibitor was less effective when rain sufficient to incorporate urea into the soil occurred only 10 to 15 days or later after fertilizer application.	Cantarella et al. 2005
North Carolina	Field	Slow-release urea formaldehyde polymer	In all cases aqueous urea ammonium nitrate (UAN) outperformed or was statistically similar to urea formaldehyde polymer (UFP). UFP would be economically viable only if priced similar to UAN. UFP released N on a time scale similar to UAN (1 to 2 weeks). Similarity of the two N sources might have been because the release rate of UFP might not be optimal for the crops or varieties at the chosen application timings.	Cahill et al. 2007
Australia	Field	Fluid P fertilizer	70 of 103 wheat experiments showed positive yield increases compared to granular P sources when fluids were applied over calcareous soils. The positive increase rate with fluids was much greater when micronutrients were applied in solution with P and N.	Holloway et al. 2001

Table 2-13. Summary of reported practice effects resulting from management of manure and fertilizer form and rate *(continued)*

Location	Study type	Practice	Practice effects	Source
Australia	Laboratory	Fluid P fertilizer	When P is supplied in granular form, P diffusion and isotopic lability in calcareous soils are reduced compared with equivalent liquid fertilizer formulations, probably due to precipitation reactions induced by osmotically induced flow of soil moisture into the fertilizer granule.	Hettiarachchi et al. 2006; Lombi et al. 2004
Virginia	Field	Poultry litter from phytase and HAP feeding	Alternative diets decreased manure total and water-soluble P compared with the standard diet. Runoff dissolved P concentrations were significantly higher from HAP manure-amended soils than from phytase manure applications, while dissolved P losses from other manure treatments were not significantly different from each other.	Penn et al. 2004
Iowa	Plot	Slow release fertilizers	Raw and digested manure produced the same NH_4-N disappearance, NO_3-N formation, net inorganic N, and an increase in soil test P. Routine soil test P methods estimated similar P recovery with both manure sources.	Loria and Sawyer 2005
Iowa	Plot	Raw vs. digested swine manure	No difference between raw swine manure and manure digested for biogas as a source of N for plant use in the year of application or in the residual year; equivalence to fertilizer N was the same with both raw and digested swine manure.	Loria et al. 2007
Georgia	Fields	Manure application rates	Runoff was reduced from 1%–68%, and soil loss decreased from 13%–77% where manure was added annually. Measured runoff and soil loss values were found to be strongly influenced by manure application rates; regression equations were developed relating reductions in runoff and soil loss to manure application rates.	Risse and Gilley 2000
Colorado	Field trials	CRF, NIs	TN fertilizer losses averaged 15% and 10% in the NI and urea treatments, respectively. N losses from the controlled release fertilizer treatment averaged only 1.9%	Shoji et al. 1999
Ohio	Plot	SRFs	Cumulative NO_3-N loss from plots receiving application of manufactured (NH_4NO_3 and sulfur-coated urea) products was significantly greater than the measured losses from plots receiving application of composted dairy manure and poultry litter. The cumulative NO_3-N recovered in the runoff expressed as a proportion of applied N was 0.37 for NH_4NO_3, 0.25 for sulfur-coated urea, 0.10 for composted dairy manure, and 0.07 for poultry litter.	King and Torbert 2007

Nutrient application methods and timing

In soil column and field studies in New York, Geohring et al. (2001) reported that high P concentrations observed in tile drain effluent soon after dairy manure application can be attributed to macropore transport processes. Plowing-in manure apparently disturbs these macropores and promotes matrix flow, resulting in greatly reduced P concentrations in the drainage effluent.

In New York, Lewis and Makarewicz (2009) reported significant decreases in winter concentrations of TP, soluble P, TKN, and NO_3-N but not TSS following cessation of winter dairy manure application to cropland.

Chen and Samson (2002) investigated the effects of fertilizer source and manure application timing, rate, and method on soil nutrient concentrations, corn grain yields, and groundwater NO_3 concentrations in Ontario, Canada. In general, higher NO_3-N concentrations were observed in those plots where N sources had been applied shortly before soil sampling. Trends of residual NO_3-N concentrations varied among experiments, and results were inconclusive. Two-fold higher P concentrations were observed in the manured plots than in the inorganically fertilized plots as a result of higher P_2O_5 inputs from swine manure.

In Kansas plots, Reiman et al. (2009) tested the effect of manure placement depth on corn and soybean yield and N retention in soil. The net effect of placement on TN was that deep manure injection treatments had 31–59 more kg N/ha than the shallow injection treatment 12 to 30 months after application. Higher corn yield in the deep-injected treatment was attributed to increased N use efficiency. Higher inorganic N amounts in the deep injection treatment were attributed to reduced N losses through ammonia volatilization, leaching, or denitrification.

Ali et al. (2007) tested simplified surface irrigation of dairy farm effluents in Quebec, Canada, and reported that seepage losses represented less than one percent of the total volume of effluents (nutrients and bacteria) applied; nutrients and bacteria applied were lost in subsurface drainage, implying a treatment efficiency of greater than 99 percent compared to conventional land spreading.

On-farm trials were conducted near Ottawa, Ontario, to determine the effect of preplant and sidedress fertilizer N application on corn yield, N uptake and N_2O gas emission (Ma 2007). Data showed that for each kg N applied, 70–77 kg ha^{-1} of yield was produced for sidedress compared to 46–66 kg of yield for preplant N application. When the same amount of fertilizer was applied, significantly greater yield (7.6–10.6 percent) was produced with sidedress than preplant N application. Ebelhar et al. (2009) tested nine different N sources in part to determine the N use efficiencies for new fertilizer technologies and evaluate their effects on crop yields. In general, for wet sites, the sidedress injection of N provided the highest corn yields and best N use efficiencies (with a polymer coated urea product second). Note that the sidedress treatment at dry locations appear to be a detriment, likely because dry conditions prevented N from reaching the corn roots when needed.

Harmel et al. (2004) conducted a paired watershed study to evaluate the impact of variable rate N fertilizer application on surface water quality. Few water quality differences were observed during the first year, but overall median NO_3 + NO_2-N concentrations were significantly lower for the variable rate field receiving sidedress N applications in the second year.

In an Ontario, Canada, plot study, Coelho et al. (2006) determined the effects of rate and method of sidedress application of liquid swine manure on N recovery by corn using in-row injection or topdressing to sidedress manure. Coelho et al. (2006) measured grain N uptake and NO_3-N in drainage water, stalks, and topsoil postharvest. Apparent recovery of manure TN was greater with injection (59 percent) than topdress (41 percent) and transport of N to groundwater and surface water was minimized when side dressed at or below rates for optimal yield. When injected N exceeded crop demand, NO_3-N increased to more than 10 mg/kg in topsoil, 20 mg/L in drainage water, and to excessive (3.6 g/kg) levels in stalks.

Drainage NO_3-N concentration and load increased linearly by 0.69 mg NO_3-N/L and 4.6 kg NO_3-N/ha, respectively, for each 10 kg N/ha applied over the minimum of 275 kg N/ha in trials of swine waste application to corn in Spain (Dauden et al. 2004). An increase in irrigation efficiency did not induce a significant increase of leachate concentration, and the amount of NO_3 leached decreased about 65 percent. Application of low manure doses before sowing complemented with side dressing N application and good irrigation management were found to be key factors to reduce NO_3 contamination of water courses.

Hebbar et al. (2004) compared fertigation with various fertilizer sources, rates, and application methods with drip- and flood-irrigated controls in a red sandy loam soil in India. They found that fertigation with 100 percent water-soluble fertilizer (WSF), subsurface drip fertigation, N-potassium fertigation, and half soil–half fertigation increased the hybrid tomato yield significantly over the controls. Significant yield reduction was recorded with 75 percent rate fertigation and normal fertilizer fertigation compared to WSF fertigation. WSF fertigation resulted in a significantly higher number of fruits per plant and fertilizer use efficiency compared to drip- and furrow-irrigated controls. Fertigation also resulted in less leaching of NO_3-N and K to deeper soil layers. Subsurface drip fertigation resulted in higher assimilable P in deeper soil layers. Root growth and NPK uptake was increased by WSF fertigation. Tan et al. (2003) studied the effects of drip irrigation and fertigation on yield, quality, and water and NUE of tomatoes. They found no significant difference in marketable tomato yields between broadcast fertilizer and fertigation for both subsurface and surface drip irrigation on a loamy sand soil.

Various micro-irrigation systems were used to evaluate the impact of fertigation and soil type on the potential for NO_3 leaching to groundwater (Gärdenäs et al. 2005). Seasonal leaching was found to be highest for coarse-textured soils. Modeling also showed that fertigation at the beginning of the irrigation cycle tends to increase seasonal NO_3 leaching, whereas fertigation at the end of the irrigation cycle reduced the potential for NO_3 leaching. Long fertigation times resulted in uniform NO_3 distributions in the wetted regions for three of the four irrigation systems. Surface-applied irrigation on finer-textured soils enhanced lateral spreading of water and nitrates with subsequent infiltration downwards and horizontal spreading of soil NO_3 near the soil surface. Leaching potential increased with the difference between the extent of the wetted soil volume and rooting zone.

Soil injection of swine manure on soybeans in Illinois compared with surface application resulted in runoff concentration decreases of 93, 82, and 94 percent, and load decreases of 99, 94, and 99 percent for dissolved P, TP and algal-available P, respectively (Daverede et al. 2004). Incorporating inorganic P fertilizer also reduced P concentration in runoff significantly. Runoff P concentration and load from incorporated amendments did not differ from the control.

Allen and Mallarino (2008) assessed total runoff P, bioavailable P, and dissolved P concentrations and loads in surface runoff after liquid swine manure application with or without incorporation into soil and different timing of rainfall in Illinois. For events 24 hours after application, P concentrations were two to five times higher for unincorporated manure than for incorporated manure; P loads were 3.8 to 7.7, and 3.6 times higher. A 10- to 16-day rainfall delay resulted in P concentrations that were about three times lower than for 24-hour events across all unincorporated P rates.

Andraski et al. (2003) investigated the effects of manure history and tillage on P levels in runoff from continuous corn in Wisconsin. Soil P levels increased with the frequency of manure applications and P stratification was greater near the surface in no-till than in chisel plow. In chisel plow, soil test P level was linearly related to dissolved P and bioavailable P loads in runoff. In no-till, P loads were reduced by an average of 57 percent for dissolved P, 70 percent for bioavailable P, and 91 percent for TP compared with chisel plow.

In an Iowa plot study, Bakhsh et al. (2009) determined the effects of swine manure application to corn and soybeans on NO_3-N concentrations in subsurface drainage water and corn-soybean yields. Average flow-weighted NO_3-N concentrations and leaching losses increased by greater than 50 percent when manure was applied to both corn and soybean compared to manure application to corn only, while yield differences were less than 4 percent. Those results suggest that fall manure application to both corn and soybean is likely to increase NO_3-N leaching to shallow groundwater without resulting in significant yield benefits.

Kleinman et al. (2009) evaluated losses of P in subsurface and surface flow as a function of dairy manure application to no-till soils in Pennsylvania. Incorporation of manure by tillage lowered P loss in leachate relative to broadcast application because of the destruction of preferential flow pathways. In contrast, rainfall simulations on runoff plots showed that TP losses in surface runoff differed significantly by soil but not by application method. Results confirm the near-term benefits of incorporating manure by tillage to protect groundwater quality but suggest that for surface water quality, avoiding soils prone to runoff is more important.

Warren et al. (2008) compared surface broadcast litter application and subsurface litter banding on grassland in Alabama. Subsurface band applications resulted in forage yields equivalent to those achieved by conventional broadcast litter applications and did not significantly alter the Mehlich 3 extractable P content of soils collected at a depth of 0 to 15 cm.

In Arkansas, Pote et al. (2003) determined the effects of poultry litter incorporation into Bermuda grass and mixed forage plots on quantity and quality of runoff water. Nutrient concentrations and mass losses in runoff from incorporated litter were 80–95 percent less than in runoff from surface-applied litter. Litter-incorporated soils had greater rain infiltration rates, water-holding capacities, and sediment retention than soils receiving surface-applied litter. In a subsequent study, Pote et al. (2009) confirmed that fully mechanized litter subsurface banding increased forage yield while decreasing nutrient N and P loss in runoff by at least 90 percent compared to surface-broadcast litter.

Sistani et al. (2009) evaluated the effect of broiler litter application method and the runoff timing on nutrient and *E. coli* losses from Alabama perennial grassland. TP, inorganic N, and *E. coli* concentrations in runoff from broadcast litter application were all significantly greater than from subsurface litter banding. TP losses from broadcast litter applications averaged 6.8 times greater than those from subsurface litter applications. Average NO_3-N and TSS losses from subsurface banding were reduced by 64 percent and 68 percent, respectively, compared to the broadcast method.

In soil columns, Guo et al. (2009) evaluated nutrient release dynamics of Delmarva poultry litter under local weather conditions. Release of most nutrients occurred principally in the first 100 days, but for P, release would last for years. The nutrient supply capacity of surface-applied Delmarva poultry litter was predicted at 10.9 kg N/Mg (kilograms per megagram) and 6.5 kg P/Mg. The results suggest that Delmarva poultry litter should be applied to conservation tillage systems at 6.6 Mg/ha, which would furnish 25 kg P/ha and 63 kg N/ha to seasonal crops. In repeated annual applications, the rate should be reduced to 5.2 Mg/ha, with supplemental N fertilization to meet crop N requirements.

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing

Location	Study type	Practice	Practice effects	Source
New York	Soil column, field	Manure incorporation	Plowing-in manure apparently disturbs macropores and promotes matrix flow, resulting in greatly reduced P concentrations in tile drainage effluent.	Geohring et al. 2001
New York	Field	Cessation of winter manure spreading	Significant decreases in winter concentrations of TP, soluble P, TKN, and NO_3-N but not TSS following cessation of winter dairy manure application to cropland.	Lewis and Makarewicz 2009
Ontario	Plots	Nutrient source and timing	Higher NO_3-N concentrations observed in plots where N sources applied shortly before soil sampling. Trends of residual NO_3-N concentrations varied among experiments, and results were inconclusive. Two-fold higher P concentrations were observed in the manured plots than in the inorganically fertilized plots as a result of higher P_2O_5 inputs from swine manure.	Chen and Samson 2002
Ontario	Field	Sidedress N application	For each kg N applied, 70–77 kg ha-1 of yield was produced for sidedress compared to 46-66 kg of yield for preplant N application. When the same amount of fertilizer was applied, significantly greater yield (7.6%–10.6%) was produced with sidedress than preplant N application.	Ma 2007
Illinois	Field	Sidedress N application	Of nine different N sources tested, the sidedress injection of N provided the highest corn yields (164 bu/a) and best N use efficiencies (0.96 lb N/bu) at locations receiving > 12 inches rainfall over the 15 week period after fertilizer application.	Ebelhar et al. 2009
Kansas	Plots	Manure placement depth	Deep manure injection treatments had 31–59 more kg N/ha than the shallow injection treatment 12–30 months after application. Higher corn yield in the deep injected treatment attributed to increased N use efficiency. Higher inorganic N amounts in deep injection treatment attributed to reduced N losses through ammonia volatilization, leaching, or denitrification	Reiman et al. 2009
Quebec, Canada	Fields	Irrigation of dairy effluent	Seepage losses represented < 1% of the total volume of effluents, nutrients and bacteria applied implying a treatment efficiency of > 99% compared to conventional land spreading.	Ali et al. 2007

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing *(continued)*

Location	Study type	Practice	Practice effects	Source
Ontario, Canada	Plot	Liquid manure injection	Apparent recovery of manure TN was greater with injection (59%) than topdress (41%) and transport of N to ground- and surface waters was minimized when side dressed at or below rates for optimal yield. When injected N exceeded crop demand, NO_3-N increased to over 10 mg/kg in topsoil, 20 mg/L in drainage water, and to excessive (3.6 g/kg) levels in stalks	Coelho et al. 2006
Spain	Plot	Waste irrigation	Drainage NO_3-N concentration and load increased linearly by 0.69 mg NO_3-N/L and 4.6 kg NO_3-N/ha, respectively, for each 10 kg N/ha applied over the minimum of 275 kg N/ha. An increase in irrigation efficiency did not induce a significant increase of leachate concentration and the amount of NO_3 leached decreased about 65%.	Dauden et al.2004
India	Field	Fertigation	Water-soluble fertilizer (WSF) fertigation recorded significantly higher total dry matter (181.9 g) and leaf area index (3.69) over the drip irrigation control. Fertigation with 100% WSF increased the fruit yield by 24.8% over the furrow-irrigated control and by 9.2% over drip irrigation. WSF fertigation resulted in significantly fertilizer-use efficiency (226.48 kg yield/kg NPK) compared to drip- and furrow-irrigated controls. Fertigation resulted in less leaching of NO_3-N and K to deeper layer of soil and subsurface drip fertigation caused higher assimilable P in deeper layers. Root growth and NPK uptake was increased by WSF fertigation.	Hebbar et al. 2004
California	Modeling	Fertigation	An adapted version of the computer simulation model, Hydrus-2D was used to evaluate NO_3 leaching potential under various combinations of micro-irrigation systems, fertigation scenarios, and soil types typical of California conditions. The study concluded that fertigation at the beginning of the irrigation cycle tends to increase seasonal NO_3 leaching.	Gärdenäs et al. 2005
Illinois	Plots	Manure injection	Soil injection of manure on soybeans compared with surface application resulted in runoff P concentration decreases of 82%–99%.	Daverede et al. 2004
Iowa	Plot	Manure incorporation	For events 24 hours after application, P concentrations were 2 to 5 times higher for unincorporated manure than for incorporated manure; P loads were 3.8 to 7.7, and 3.6 times higher.	Bakhsh et al. 2009

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing *(continued)*

Location	Study type	Practice	Practice effects	Source
Wisconsin	Field	Manure history, tillage	Soil P levels increased with the frequency of manure applications. In no-till, P loads were reduced by an average of 57% for dissolved P, 70% for bioavailable P, and 91% for TP compared with chisel plow	Andraski et al. 2003
Iowa	Plot	Manure application timing	NO_3-N concentrations and leaching losses increased by > 50% when manure applied to both corn and soybean compared to manure application to corn only, while yield differences were less than 4%. Fall manure application to both corn and soybean is likely to increase NO_3-N leaching to shallow groundwater without resulting in significant yield benefits.	Bakhsh et al. 2009
Pennsyl-vania	Plots	Manure incorporation by tillage	Incorporating manure by tillage lowered P loss in leachate relative to broadcast application from the destruction of preferential flow pathways; TP losses in surface runoff differed significantly by soil but not by application method	Pote et al. 2009
Alabama	Field	Subsurface banding of poultry litter	Subsurface band applications resulted in forage yields equivalent to conventional broadcast litter applications and did not significantly alter the Mehlich 3 extractable nutrient content of soils.	Warren et al. 2008
Arkansas	Plots	Litter application rate	Nutrient concentrations and mass losses in runoff from incorporated litter were 80%–95% less than in runoff from surface-applied litter. Litter-incorporated soils had greater infiltration rates, water-holding capacities, and sediment retention than soils receiving surface-applied litter	Guo et al. (2009
Alabama	Plots	Subsurface banding of poultry litter	TP, inorganic N, and *E. coli* concentrations in runoff from broadcast litter application exceeded those from subsurface litter banding. TP losses from broadcast litter applications averaged 6.8 times greater than those from subsurface litter applications. Average NO_3-N and TSS losses from subsurface banding were reduced by 64% and 68%, respectively, compared to the broadcast method.	Kaiser et al. 2009
Delmarva Peninsula	Plot	Soil aeration	Soil aeration reduced runoff volume by 27% in the first runoff event but the effect disappeared after 1 month; aeration did not affect the mass losses of DRP, TKN, or NH4-N from plots fertilized with either inorganic fertilizer or poultry litter	Guo et al. 2006

Table 2-14. Summary of reported practice effects resulting from management of nutrient application methods and timing *(continued)*

Location	Study type	Practice	Practice effects	Source
Iowa	Field	Soil aeration, broiler litter	Unincorporated manure consistently increased concentrations of all runoff P fractions in five sites; on average manure increased dissolved P, bioavailable P, and TP 32, 23, and 12 times, respectively, over the control. Tillage to incorporate manure reduced dissolved P, bioavailable P, and TP by 88, 89, and 77% on average	Kaiser et al. 2009
Georgia	Plot	Soil aeration	Soil aeration reduced runoff volume by 27% in the first runoff event but the effect disappeared after one month; aeration did not affect the mass losses of DRP, TKN, or NH4-N from plots fertilized with either inorganic fertilizer or poultry litter	Butler et al. 2006
Georgia	Field	Soil aeration	On well-drained soils, grassland aeration reduced surface runoff volume and mass losses of DRP in runoff by 35%. However, on poorly drained soils, grassland aeration increased runoff volume and mass losses of dissolved and TP	Franklin et al. 2007
Georgia	Plots	Soil aeration	Core aeration reduced TP export by 55%, dissolved P by 61%, and bioavailable P by 54% plots with applied broiler litter. Core and no-till disk aeration also showed potential for reducing P export from applied dairy slurry.	Butler et al. 2008a
British Columbia, Canada	Field	Soil aeration	For mechanically aerating grassland before liquid manure application, annual runoff amounts were reduced by 47%–81%, suspended and volatile solid loads by 48%–69% and 42%–83%, respectively, TKN loads by 56%–81%, and TP loads by 25%–75%. Loads of the soluble nutrient NH_4-N, DRP, and K were reduced by 41%–83%.	van Vliet et al. 2006

Kaiser et al. (2009) assessed P loss immediately after poultry manure application to soybean residue with and without tillage at eight Iowa fields. Unincorporated manure consistently increased concentrations of all runoff P fractions in five sites. On average, non-incorporated manure increased dissolved P, bioavailable P, and TP 32, 23, and 12 times, respectively, over the control. Tillage to incorporate manure reduced dissolved P, bioavailable P, and TP by 88, 89, and 77 percent on average, respectively.

In a Georgia plot study, Franklin et al. (2006) reported that soil aeration reduced runoff volume by 27 percent in the first runoff event, but the effect disappeared after one month; aeration did not affect the mass losses of dissolved reactive P (DRP), TKN, or NH_4-N from plots fertilized with either inorganic fertilizer or poultry litter.

Franklin et al. (2007) evaluated the effects of slit aeration on runoff volume and P losses from fescue fertilized with broiler litter in Georgia. In the field with mostly well-drained soils, grassland aeration reduced surface runoff volume and mass losses of DRP in runoff by 35 percent. However, on poorly drained soils, grassland aeration increased runoff volume and mass losses of dissolved and TP.

Butler et al. (2008a) evaluated the effects of three aeration treatments on export of TSS and P from grassland plots receiving broiler litter and dairy slurry in Georgia. Core aeration reduced export of TP by 55 percent, dissolved P by 61 percent, and bioavailable P 54 percent on plots with applied broiler litter as compared with the control. Core and no-till disk aeration also showed potential for reducing P export from applied dairy slurry.

In British Columbia, Canada, van Vliet et al. (2006) studied the effect of mechanically aerating grassland before liquid manure application on surface runoff and transport of nutrients and solids. Annual runoff amounts were reduced by 47–81 percent, suspended and volatile solid loads by 48–69 percent and 42–83 percent, respectively, TKN loads by 56–81 percent, and TP loads by 25–75 percent. Loads of the soluble nutrient NH_4-N, DRP, and K were reduced by 41–83 percent.

Soil and manure amendment

Implementation Measure A-11:

Use soil amendments such as alum, gypsum, or water treatment residuals (WTR) to increase P adsorption capacity of soils, reduce desorption of water-soluble P, and decrease P concentration in runoff.

Because runoff losses of P are strongly influenced by the quantity and form of P in the soil (Sharpley 1995; Pote et al. 1996), reducing P runoff from cropland can be accomplished by influencing soil test P levels through soil amendments that change the availability of P and through NMP.

In Arkansas plots, Haustein et al. (2000) surface application of treatment residuals and HiClay® Alumina to soil plots high in P decreased Mehlich 3 soil test P levels and the two highest rates of WTR decreased runoff P levels below those of the control plots.

From a Texas field experiment, Brauer et al. (2005) reported that annual additions of gypsum at 5.0 Mg/ha significantly reduced soil-dissolved P, although soil amendment did not affect Bray 1 P values. Elliott et al. (2002) conducted laboratory and greenhouse studies of the ability of WTR to alter P solubility and leaching in a Texas soil amended with biosolids and triple superphosphate. Without residual amendment, 21 percent of soluble P and 11 percent of biosolids TP leached over 4 months. With co-applied residuals, soluble P losses were reduced to less than 1–3.5 percent of applied P. Amendment with residuals retarded downward P flux such that leachate P was not statistically different than for control (soil only) columns.

In North Carolina, Novak and Watts (2004) conducted laboratory experiments to determine if WTR mixed into soils could significantly increase their P sorption capacities. Mixing residuals into soils increased their P-max values several-fold (between 1.7 to 8.5 mg P/g) relative to soils with no WTR addition. The authors suggested that WTR incorporation into sandy soils has the potential to be a new chemical-based best management practice (BMP) for reducing off-site P transport.

In Oklahoma, Peters and Basta (1996) reported that alum-based WTR applied at 30–100 g/kg soil reduced Mehlich 3 extractable P in soils from 553 mg/kg to 250 mg/kg (55 percent) in one soil and from 296 mg/kg to 110 mg/kg (63 percent) in another soil. Reductions of soluble P followed similar trends. Treatments did not result in excessive soil pH or increase in soil salinity, soil extractable Al, or heavy metals.

In a Maryland study, Codling et al. (2000) reported that addition of poultry litter amended with alum-based WTR led to significant reductions in water soluble P concentrations in several soils. The authors reported reductions in water-soluble P of 72–99 percent in soils amended with 10–50 g/ha treated poultry litter after 2 to 4 weeks. Reductions of 27–89 percent in Bray 1 P were reported in the same soils.

Cornwell et al. (2000) reported a 34 percent reduction in available soil P after application of alum WTR at a rate of 25.7 dry t/ha to Pennsylvania agricultural soils with soil P levels six times higher than optimum level for soybean production.

Novak and Watts (2005) evaluated the ability of alum-based WTR to reduce soil P concentrations in three P-enriched North Carolina Coastal Plain soils. Incorporating residuals into the soils caused a near linear and significant reduction in soil P concentrations. In two soils, 6 percent WTR application caused a soil Mehlich 3 P concentration decrease to below the soil P threshold.

Adding WTR to Oklahoma soil plots treated with poultry litter reduced runoff P by 14–85 percent (Dayton et al. 2003). Reductions in runoff P were strongly correlated with P-max and Al-ox.

Performance of treatment residuals as a P sorbent to reduce runoff P from manured land can be estimated from their P-max or Al-ox content.

In a Connecticut laboratory study, Hyde and Morris (2000) reported that WTR significantly reduced Mehlich 3 P concentrations when added to soils. Adding residuals to soils reduced soil P concentrations by 23–64 percent, depending on how the residuals were dewatered.

Adler and Sibrell (2003) tested the use of flocculants (flocs) resulting from neutralizing acid mine drainage (AMD) (as a possible low-cost amendment to reduce the loss of soluble P from agricultural fields and animal wastewater) in West Virginia. About 70 percent of WEP was sequestered by the floc when applied to agricultural soils at a rate of 20 g floc/kg soil, whereas plant-available P decreased by 30 percent. Under anaerobic conditions simulating manure storage basins, all AMD flocs reduced soluble P by greater than 95 percent.

At two Michigan field sites with a history of heavy manure applications, amendment with WTR reduced water-soluble P concentration by greater than or equal to 60 percent as compared to the control plots, and the residuals-immobilized P remained stable 7.5 years after residuals application (Agyin-Birikorang et al. 2007).

Staats et al. (2004) investigated the efficacy of alum-amended poultry litter in reducing P release from three Delaware Coastal Plain soils. Long-term desorption (25 days) of the incubated material resulted in about 13 percent reductions in cumulative P desorbed when comparing soil treated with unamended poultry litter. In addition, the P release from the soil treated with alum-amended litter was not significantly different from the control (soil alone).

Zvomuya et al. (2006) tested the P-binding ability of various amendment materials in a laboratory soil incubation experiment. Lysimeter breakthrough tests using tertiary-treated potato-processing wastewater showed that alum application reduced leachate TP and SRP concentrations by 27 percent and 25 percent, respectively.

Stout et al. (1999) reported that a 10 g/kg application of a gypsum byproduct to Pennsylvania soils reduced the concentration of water-soluble P by 50 percent. Projection of these results over an agricultural watershed indicated that treating only four percent of the watershed could reduce the loss of water-soluble P by 30 percent. In an Indiana lab study, Favaretto et al. (2006) showed that gypsum addition to soils significantly decreased the mass loss in runoff of dissolved reactive P, TP, soluble NH_4-N, and total N by 85, 60, 80, and 59 percent, respectively. The concentration of these constituents was also significantly decreased by 83, 52, 79, and 50 percent, respectively. Murphy et al. (2010) reported that gypsum addition decreased reactive P solubility by 14–56 percent and organic P solubility by 10–53 percent in five Irish soils.

Table 2-15. Summary of reported practice effects resulting from soil and manure amendment

Location	Study type	Practice	Practice effects	Source
Arkansas	Plot	Soil amendments	Surface application of treatment residuals and HiClay® Alumina to high P soils decreased soil test P levels; the highest rates of WTR decreased runoff P levels below those of the control plots.	Haustein et al. 2000
Texas	Field	Gypsum amendment	Annual additions of gypsum at 5.0 Mg/ha significantly reduced soil dissolved P, although soil amendment did not affect Bray1 P values.	Brauer et al. 2005
Oklahoma	Field	WTR	Alum-based WTRs applied at 30–100 g/kg soil reduced Mehlich 3 extractable P in soils from 55% to 63%.	Peters and Basta 1996
Maryland	Field	WTR	Addition of poultry litter amended with alum-based WTRs led to 72%–99% reductions in water-soluble P and 27%–89% reductions in Bray 1 P of in soils amended with 10–50 g/ha treated poultry litter after 2 to 4 weeks.	Codling et al. 2000
Pennsyl-vania	Field	WTR	34% reduction in available soil P after application of alum WTRs at a rate of 25.7 dry t/ha to soils with soil P levels six times higher than optimum level for soybean production.	Cornwell et al. 2000
Texas	Laboratory, greenhouse	WTR	Without residual amendment, 21% of soluble P and 11% of biosolids TP leached over 4 months; with co-applied residuals, soluble P losses were reduced to < 1%–3.5% of applied P. Amendment with residuals retarded downward P flux such that leachate P was not statistically different than for control (soil only) columns.	Elliott et al. 2002
North Carolina	Laboratory	WTR	Mixing residuals into soils increased their P-max values several-fold (between 1.7 to 8.5 mg P/g) relative to soils with no WTR addition.	Novak and Watts 2004
North Carolina	Laboratory	WTR	Incorporation of residuals into soils caused a near linear and significant reduction in soil P concentrations. In two soils, 6% WTR application caused a soil Mehlich 3 P concentration decrease to below the soil P threshold.	Novak and Watts 2005
Oklahoma	Plots	WTR	Addition of WTR to OK soil plots treated with poultry litter reduced runoff P by from 14%–85% Reductions in runoff P were strongly correlated with P-max and Al-ox. Performance of treatment residuals as a P sorbent to reduce runoff P from manured land can be estimated from their P-max or Al-ox content.	Dayton et al. 2003

Table 2-15. Summary of reported practice effects resulting from soil and manure amendment *(continued)*

Location	Study type	Practice	Practice effects	Source
Connect-icut	Laboratory	WTR	Adding residuals to soils reduced soil P concentrations by 23%–64%, depending on how the residuals were dewatered.	Hyde and Morris 2000
Pennsyl-vania, Oklahoma, Colorado	Field	WTR	WTRs reduced Mehlich 3 soil test P to less than 200 mg/kg at a 10% loading rate after 1 wk of incubation time. Reductions of soluble P ($CaCl_2$ extraction) were greater than reductions in Mehlich 3 P.	DeWolfe 2006
West Virginia	Laboratory	Neutralized AMD flocs	About 70% of WEP was sequestered by the floc when applied to agricultural soils at a rate of 20 g floc/kg soil; plant-available P decreased by 30%. Under anaerobic conditions simulating manure storage basins, AMD flocs reduced soluble P by > 95%.	Adler and Sibrell 2003
Michigan	Field	WTR	Amendment reduced water-soluble P concentration by $\geq$ 60% vs. control plots, and the residuals-immobilized P remained stable for 7.5 yr.	Agyin-Birikorang et al. 2007
Delaware	Laboratory	Alum amendment	About 13% reductions in cumulative P desorbed vs. soil treated with unamended poultry litter. P release from soil treated with alum-amended litter was not significantly different from the control (soil alone).	Staats et al. (2004)
Various	Laboratory	Alum soil amendment	Lysimeter breakthrough tests showed that alum application reduced leachate TP and SRP concentrations by 27% and 25%, respectively	Zvomuya et al. 2006
Pennsyl-vania	Laboratory	Gypsum amendment	10 g/kg application of a gypsum byproduct to Pennsylvania soils reduced the concentration of water-soluble P by 50%.	Stout et al. 1999
Indiana	Laboratory	Gypsum amendment	Gypsum addition to soils significantly decreased the mass loss in runoff of dissolved reactive P (85%), TP (60%), soluble NH_4-N (80%), and total N (59%).	Favaretto et al. 2006
Ireland	Laboratory	Gypsum amendment	Gypsum addition decreased reactive P solubility by 14%–56% and organic P solubility by 10%–53%.	Murphy et al. 2010

Nutrient management planning

In a Virginia field study, Maguire et al. (2008) investigated how changing poultry litter application rates from an N to a P basis affected crop yields and soil properties in high P soils over a 7-year period. After 7 years, Mehlich 1 P and water-soluble P were greatest in soils under the N-based treatments, smallest in the no-P treatment, and intermediate in the P-based treatments; there were no significant differences between inorganic fertilizer and poultry litter nutrient sources. The results show that soil test P can be decreased in high-P soils over a few years by changing from an N-based to a P-based nutrient management plan or by stopping P applications without negatively affecting yields.

In Quebec, Canada, Giroux and Royer (2007) measured the effect of three P fertilizer rates on crop yields and evolution of the soil test values, saturation and P solubility. Soil test P values decreased by 11–33 percent over 8 years, even at P application rates above crop removal rates. Annual rates of P-sat decrease were 1.087, 0.891 and 0.750 percent/year respectively for the 0, 30, and 60 kg P_2O_5/ha fertilizer rates. The P-sat value of 13.1 percent of the Quebec regulation was achieved after 10 years for the 0 kg P_2O_5/ha rate.

Table 2-16. Summary of reported practice effects resulting from nutrient application planning

Location	Study type	Practice	Practice effects	Source
Virginia	Field	P-based nutrient management	After 7 years, Mehlich 1 P and water soluble P were greatest in soils under the N-based treatments, smallest in the no P treatment, and intermediate in the P-based treatments. Soil test P can be decreased in high-P soils by changing from an N-based to a P-based nutrient management plan or stopping P applications without negatively affecting yields.	Maguire et al. 2008
Quebec, Canada	Field	P fertilizer rates	Soil test P values decreased by 11%–33% over 8 years, even at P application rates above crop removal. Annual rates of P-sat decrease were 1.087, 0.891 and 0.750%/yr, respectively, for the 0, 30, and 60 kg P_2O_5/ha fertilizer rates. The P-sat value of 13.1% of the Quebec regulation is achieved after 10 years for the 0 kg P_2O_5/ha rate	Giroux and Royer 2007
Texas	Field	Turfgrass sod export	46%–77% of the applied manure P removed in a single turfgrass sod harvest. Total dissolved P concentrations in the runoff were directly related to P concentrations in the soil. 3.8% of the applied P from composted dairy manure was lost in the surface runoff.	Choi et al. 2003
Texas	Plot	Zero P fertilizer	Using only commercial N on soils with high extractable P levels decreased P loadings in edge-of-field runoff by ≥ 40%.	McFarland and Hauck 2004
Texas	Model	P-based manure management	Edge-of-field TP losses can be reduced by about 0.8 kg/ha/year or 14% when manure applications are calibrated to supply all the recommended crop P requirements from manure TP sources only, vs manure applications at N agronomic rate.	Osei et al. 2008

In Texas, Choi et al. (2003) reported that 46–77 percent of the applied manure P was removed in a single turfgrass sod harvest. Total dissolved P concentrations in the runoff were directly related to P concentrations in the soil. A total of 3.8 percent of the applied P from composted dairy manure was lost in the surface runoff.

From Texas plot studies, McFarland and Hauck (2004) reported that using only commercial N on soils with high extractable P levels decreased P loadings in edge-of-field runoff by greater than or equal to 40 percent. However, no notable changes in extractable soil P concentrations were observed after 5 years of monitoring because of drought conditions limiting forage uptake and removal.

In a Texas study using an integrated economic and environmental modeling system across multiple ecoregions, Osei et al. (2008) suggested that edge-of-field TP losses can be reduced by about 0.8 kg/ha/year or 14 percent when manure applications are calibrated to supply all the recommended crop P requirements from manure TP sources only, when compared to manure applications at the recommended crop N agronomic rate.

3.2 Sediment and Erosion Control

Sediment loss is the result of erosion. It is the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by wind, water, gravity, or ice. The types of erosion associated with agriculture that produce sediment are (1) sheet and rill erosion, (2) ephemeral and classic gully erosion, (3) wind erosion, and (4) streambank erosion. Soil erosion can be characterized as the transport of particles that are detached by rainfall, flowing water, or wind. Eroded soil is either redeposited on the same field or transported from the field in runoff or by wind.

The strategies for controlling erosion and sedimentation involve reducing soil detachment, reducing sediment transport, and trapping sediment before it reaches water. The first objective for both water and wind erosion is to keep soil on the field, and the easiest and often most effective strategy to accomplish that is to reduce soil detachment. Detachment occurs when water splashes onto the soil surface and dislodges soil particles or when wind reaches sufficient velocity to dislodge soil particles on the surface.

Crop residues (e.g., straw) or living vegetative cover (e.g., cover crops, grasses) on the soil surface protect against detachment by intercepting and/or dissipating the energy of falling raindrops. A layer of plant material also creates a thick layer of still air next to the soil to buffer against wind erosion. In some areas, crops that maintain a greater surface coverage could be substituted for existing crops to control erosion.

Implementing tillage practices such as continuous no-till or other forms of conservation tillage also preserves or increases organic matter and soil structure, resulting in improved water infiltration and surface stability. In addition, creating a rough soil surface through practices such as surface roughening will break the force of raindrops and trap water, reducing runoff velocity and erosive forces.

Sediment transport can be reduced in several ways, including using crop residues or conservation buffers. Vegetation slows runoff, increases infiltration and traps sediment. Reductions in slope length and steepness reduce runoff velocity, thereby reducing sediment carrying capacity as well. Practices are also typically needed to trap sediment leaving the field before it reaches a wetland or riparian area. Deposition of sediment is achieved by practices that slow water velocity or increase infiltration.

Properly functioning natural wetlands and riparian areas can significantly reduce nonpoint source pollution by intercepting surface runoff and subsurface flow and by settling, filtering, or storing sediment and associated pollutants. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent waterbodies. Loss of these systems allows a more direct contribution of nonpoint source pollutants to receiving waters. Degraded wetlands and riparian areas can even become pollutant sources. Thus, natural wetlands and riparian areas should be protected and should not be used as designated erosion control practices. Their nonpoint source control functions are most effective as part of an integrated land management system focusing on nutrient, sediment, and erosion control practices applied to upland areas.

Additional descriptions of erosion and sediment control practices are in previous guidance (USEPA 2003). Also, NRCS provides a host of Practice Codes that can be used to implement sediment and erosion controls.

Implementation Measure A-12:

Use conservation tillage or continuous no-till on cropland to reduce soil erosion and sediment loads except on those lands that have no erosion or sediment loss.

Conservation tillage includes a variety of tillage systems that leave varying amounts of residue on a field. Continuous no-till leaves all residue after harvest on the field, protecting the soil. In general, conservation tillage is any tillage system that maintains 30 percent or more of the soil surface with crop residue after planting (USDA-NRCS 2010e). The amount of residue needed to achieve erosion and sediment reduction goals, however, is dependent on numerous factors; the

Revised Universal Soil Loss Equation (RUSLE) is a tool that can help determine the amount left on the field.

Water erosion rates are affected by rainfall energy, soil properties, slope, slope length, vegetative and residue cover, and land management practices. Rainfall impacts provide the energy that causes initial detachment of soil particles. Soil properties like particle size distribution, texture, and composition influence the susceptibility of soil particles to be moved by flowing water. Vegetative cover and residue can protect the soil surface from rainfall impact or the force of moving water. Those factors are used in the RUSLE, an empirical formula widely used to predict soil loss in sheet and rill erosion from agricultural fields, primarily crop land and pasture, and construction sites (USDA-ARS 2005):

Revised Universal Soil Loss Equation (RUSLE)

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

where

A = estimated average annual soil loss (tons/acre/year)

R = rainfall/runoff factor, quantifying the effect of raindrop impact and the amount and rate of runoff associated with the rain, based on long-term rainfall record

K = soil erodibility factor based on the combined effects of soil properties influencing erosion rates

LS = slope length factor, a combination of slope gradient and continuous extent

C = cover and management factor, incorporating influences of crop sequence, residue management, and tillage

P = practice factor, incorporating influences of conservation practices such as contouring or terraces

Practice Effectiveness

Past reviews of the effectiveness of sediment control measures have concluded that reduced tillage systems reduce TP losses by 45 percent, TN losses by 55 percent, and sediment losses by 75 percent (USEPA 2003).

Harmel et al. (2006, 2008) have compiled measured annual N and P load data representing field scale transport from agricultural land uses. The 2006 compilation includes results from 40 scientifically peer-reviewed studies but draws heavily from the 1980s. The more recent data (2008 update) include 15 additional studies. In all, the database contains 1,677 watershed years of data for various agricultural land uses and practices. Most data are from the Southeast and upper Midwest, with only one study from the Chesapeake Bay Drainage area. Table 2-17, below, provides a summary of median N and P export coeffcients from Harmel et al. (2006) from which N and P reductions could be estimated. The current version is at http://www.ars.usda.gov/spa/manage-nutrient.

Table 2-17. Median N and P export coefficients

Table 4. Median annual dissolved, particulate, and TN and P export coefficient values (kg/ha) for selected treatments

Treatment*	TN (kg/ha)	Dissolved N (kg/ha)	Particulate N (kg/ha)	TP (kg/ha)	Dissolved P (kg/ha)	Particulate P (kg/ha)
Tillage						
Conventional	7.88a	2.41a	7.04a	1.05a	0.19b	0.64a
Conservation	7.70a	2.30ac	3.40c	1.18ac	0.65ac	1.00a
No-Till	1.32b	4.20c	1.80bc	0.63c	1.00c	0.80a
Pasture/Range	0.97b	0.32b	0.62b	0.22b	0.15b	0.00b
Conservation Practice						
None	2.19a	1.60a	1.70a	0.41a	0.26ab	0.64ab
One Practice	6.73b	1.33a	14.80a	0.61ab	0.14a	0.37a
2+ Practices	8.72b	2.61b	3.30a	1.22b	0.50b	0.75b
Soil Texture						
Clay	4.93a	4.47a	2.00a	0.92a	0.50a	0.55a
Loam	4.05a	1.64b	5.78b	0.41b	0.18b	0.93a
Sand	2.74a	1.70ab	–**	1.50ab	0.07ab	–**

Source: Harmel et al. 2006

* For each nutrient form within a treatment, medians followed by a different letter are significantly different (a – 0.05).

** No particulate N or P data were available for sandy soils.

In another literature review, Merriman et al. (2009) developed a compilation of BMP effectiveness results. Table 2-18 presents a listing of individual results for conservation tillage practices along with percent reductions for TP, TN, and sediment. Additional data on reductions for particulate P, dissolved P, NO_3-N, and ammonium are also available.

Soil loss and ortho-P transport were measured from a conventional and two conservation tillage treatments (zero and ridge tillage) from January 1988 to September 1990 in southwestern Ontario (Gaynor and Findlay 1995). Compared to conventional tillage, conservation tillage reduced average soil loss by 49 percent (899 kg/ha) and increased ortho-P concentrations in runoff 2.2 times (0.25 mg/L).

Table 2-18. TP, TN, and sediment reductions for various conservation tillage practices

Reference (as cited by Merriman et al. 2009)	State	BMP name	Study scale	3-8	C		TN %	Total sediment %
Zhu et al. 1989	Missouri	No-till	Field plot	3	D			92%
Zhu et al. 1989	Georgia	No-till	Field plot	3	D			90%
Zhu et al. 1989	Georgia	No-till	Field plot	3	D			92%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			72.3%
Dabney et al. 1979	Georgia	No-till	Field plot	3	B			86%
Dabney et al. 1979	Georgia	No-till	Field plot	3	C			86%
Dabney et al. 1993	Mississippi	No-till	Field	3-8	B			95.49%
Yoo et al. 1988	Alabama	No-till	Field plot	3-8	B	5%	7.6%	20.8%
Mutchler et al. 1985	Mississippi	No-till	Field plot	3-8	C			47%
Meyer et al. 1999	Mississippi	No-till	Field plot	3-8	C	84%	90%	99%
McGregor and Greer 1982	Virginia	No-till	Field plot	8	C			95.49%
Yoo et al. 1986	Alabama	No-till	Field plot	8	B		-2.76%	54.44%
Meyer et al. 1999	Virginia	No-till	Field plot	8	C			85.11%
Meyer et al. 1999	Louisiana	No-till	Field plot	3-8	C			90.84%
Hairston et al. 1984	Virginia	No-till	Field plot	3-8	D			16.28%
McGregor et al. 1975	Virginia	No-till	Field plot	8	B			85.71%
McGregor et al. 1975	Mississippi	No-till	Field plot	3-8	C			85.71%
Mutchler and Greer 1984	Mississippi	No-till	Field plot	3-8	C			94.08%
Hairston et al. 1984	Mississippi	No-till	Field plot	3-8	C			92.7%
Langdale et al. 1979	Georgia	No-till	Field plot	3-8	B			86%
Truman et al. 1979	Georgia	No-till	Field plot	3-8	C			86%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			56.76%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			50%
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			66.67%

Table 2-18. TP, TN, and sediment reductions for various conservation tillage practices *(continued)*

Reference (as cited by Merriman et al. 2009)	State	BMP name	Study scale	3-8	C		TN %	Total sediment %
Dabney et al. 1993	Mississippi	No-till	Field plot	3-8	C			83.33%
Yoo et al. 1988	Alabama	No-till	Field plot	3-8	B	22.5%	23.8%	52.3%
Schreiber and Cullum 1998	Mississippi	No-till	Large watershed	3-8	C	76.52%	67.68%	
Meyer et al. 1999	Mississippi	No-till	Field plot	3-8	C			88.47%
Mostaghimi, Dillaha, Shanholtz 1988	Virginia	No-till	Field plot	8-15	C	97%		98%
Mostaghimi et al. 1992	Virginia	No-till	Field plot	8-15	C	65.52%	90.55%	69.47%
Mostaghimi et al. 1991	Virginia	No-till	Field plot	8-15	C		90.55%	94.75%
Feagley et al. 1992	Louisiana	No-till	Field plot	N/A	D			74.25%
Daniels and Gilliam 1996	Virginia	No-till with subsurface injection	Field plot	3-8	B	91%		92%
Mostaghimi et al. 1991	Virginia	No-till with subsurface injection	Field plot	8-15	C		95.42%	
McGregor and Greer 1982	Mississippi	Reduced Tillage	Field plot	3-8	C			91.84%
McGregor and Greer 1982	Mississippi	Reduced Tillage	Field plot	3-8	B			91.84%
Hairston et al. 1984	Mississippi	Reduced Tillage	Field plot	3-8	D			13.85%
Mutchler and Greer 1984	Mississippi	Reduced Tillage	Field plot	3-8	C			58.78%
Truman et al. 2003	Alabama	Cover crop (general)	Field plot	N/A	B			46%

Source: Merriman et al. 2009

Using a rain simulator on plots, Avalos et al. (2007) found that corn straw residue decreased N losses from 88.82 to 16.65 kg/ha (81 percent reduction) and decreased TP losses from 7.87 to 1.72 kg/ha (78 percent reduction). In another plot study using rainfall simulation, it was found that under no-till conditions, plots with corn residue and grass hedges averaged 52 percent less runoff and 53 percent less soil loss than similar plots without grass hedges (Gilley et al. 2000). Under tilled conditions, the plots with corn residue and grass hedges averaged 22 percent less runoff and 57 percent less soil loss than comparable plots without grass hedges. The plots with corn residue removed but with grass hedges present averaged 41 percent less runoff and 63 percent less soil loss than similar plots without grass hedges.

One alternative to reduce compaction and restricted infiltration under long periods of no-till is rotational tillage (Smith et al. 2007). In the first year of converting from long-term, no-till to rotational tillage on small plots that had been in a no-till corn-soybean rotation for 15 years, runoff volumes and nutrient concentrations for NH_4-N, NO_3-N, and dissolved P were greater from the no-till field. Before fertilization, no-till resulted in 83 g/ha greater NH_4-N and 32.4 g/ha greater dissolved P losses than rotational tillage. After fertilization, no-till was observed to lose 5.3 kg/ha more NH_4-N, 1.3 kg/ha more NO_3-N, and 2.4 kg/ha more dissolved P than rotational tillage.

Conventional tillage, conservation tillage with cover crop, and no-till with cover crop were compared in a small grain-corn rotation in Austria in a field study from 1994 to 1999 (Klik et al. 2001). The field plots ranged from 3–4 m in width and 15-m long, and slope ranged from 6 to 16 percent. Runoff was not statistically different among the practices, but nutrient losses from April to October were 13.7 kg/ha for conventional tillage, 9.1 kg/ha (34 percent decrease) for conservation tillage, and 7.7 kg/ha (44 percent decrease) for no-till. P losses were 6.5, 3.1 (52 percent decrease), and 2.0 kg/ha (69 percent decrease), respectively. In a 9-year field study in Finland, Puustinen et al. (2005) found that traditional cultivation treatments produced the highest TSS concentrations (1.38 and 1. 18 mg/L, respectively), whereas values between 0.44 and 0.53 mg/L were measured for three treatments with reduced (or no) tillage. Particle-bound P concentrations closely followed those of TSS, but DRP showed contrasting behavior.

Finnish researchers (Turtola et al. 2007) found that the frequency of tillage, rather than the depth of tillage, has a greater effect on erosion on clayey soils. Shallow autumn tillage produced erosion as high as moldboard plowing (407–1,700 kg/ha-yr), but 48 percent and 12 percent lower erosion levels were measured from plots left untilled in autumn, covered by grass or barley residues, respectively. In a companion study, Uusitalo et al. (2007) found that stubble treatment yielded higher DRP losses (104–259 g/ha-yr) than autumn plowing (77–96 g/ha-yr), and equally high particulate P (PP) losses (mean 660, 235–1,300 g/ha-yr). Shallow autumn tillage produced 28 percent higher DRP losses (mean 120, 107–136 g/ha-yr) than plowing (83–117 g/ha-yr) and 11 percent higher PP losses (mean 1,090, 686–1,336 g/ha-yr) than plowing (783–1253 g/ha-yr).

Practice Costs

In an analysis of various combinations of practices to control sediment loss in a 12-ha subwatershed of the Mississippi Delta Management System Evaluation Area using the Annualized Agricultural Nonpoint Source pollutant loading model (AnnAGNPS 2.1), it was found that the most cost-effective practices were management of volunteer winter weeds as cover crops and various types of edge-of-field, grade-control pipes (Yuan et al. 2002; Dabney et al. 2001). The average marginal cost using practices for sediment yield reduction was about $10/MT (2010 dollars) for conventional and reduced tillage. The cost was higher, about $13/MT for no-till because the practice of no-till alone reduced sediment yield by half, and further marginal reductions were more expensive.

Using the Water Erosion Prediction Project, or WEPP, model calibrated to a 6.4-ha site within Four Mile Creek watershed in eastern Iowa, Zhou et al. (2009) compared the cost of lost soil for chisel plow, disk tillage, and no-tillage. The value of lost soil resulting from soil erosion ranged between $11 and $139/ha-yr (2010 dollars) for the simulated scenarios in the study when a soil value of $6.19/t was considered. When factoring in the value of soil, no-tillage was the most efficient practice with the highest net benefit of $95.86/ha-yr.

Both national and selected state costs for a number of common erosion control practices are presented in Table 2-19. The variability in costs for practices can be accounted for primarily through differences in site-specific applications and costs, differences in the reporting units used, and differences in the interpretation of reporting units. For example, grassed waterways in Virginia cost $3,237/ac and terraces cost $0.59/ft with typical total costs of $2,972 and $295, respectively (USDA-NRCS 2010).

Table 2-19. Representative costs of selected erosion control practices

Practice	Unit	Range of capital costs[a]	References
Diversions	ft	$2.63–$7.36	Sanders et al. 1991 Smolen and Humenik 1989
Terraces	ft a.s.[b]	$4.43–$19.75 $32.24–$89.15	Smolen and Humenik 1989 Russell and Christiansen 1984
Waterways	ft ac a.e.[c]	$7.85–$11.84 $151–$5,684 $1,669–$2,902	Sanders et al. 1991 Barbarika 1987; NCAES 1982; Smolen and Humenik 1989 Russell and Christiansen 1984
Permanent Vegetative Cover	ac	$92–$360	Barbarika 1987; Russell and Christiansen 1984; Sanders et al. 1991; Smolen and Humenik 1989
Conservation Tillage	ac	$12.68–$84.58	NCAES 1982; Russell and Christiansen 1984; Smolen and Humenik 1989

Notes:

a. Reported costs inflated to 1998 dollars by the ratio of indices of prices paid by farmers for all production items, 1991 = 100. 1998 dollars then converted to 2010 dollars.
b. acre served
c. acre established
[Note: 1991 dollars from CZARA were adjusted by +15%, based on ratio of 1998 Prices Paid by Farmers/1991 Prices Paid by Farmers, according to USDA National Agricultural Statistics Service, http://www.allcountries.org/uscensus/1114_indexes_of_prices_received_and_paid.html, 28 September 1998]. 1998 dollars then converted to 2010 dollars.

The cost estimates for control of erosion and sediment transport from agricultural lands in Table 2-20 are based on experiences in the Chesapeake Bay Program.

Table 2-20. Annualized cost estimates and life spans for selected management practices from Chesapeake Bay installations[a]

Practice	Practice life span	Median annual costs[b] (Years) (EAC[c]) ($/acre/yr)
Nutrient Management	3	4.00
Strip-cropping	5	19.32
Terraces	10	140.75
Diversions	10	86.74
Sediment Retention Water Control Structures	10	148.56
Grassed Filter Strips	5	12.17
Cover Crops	1	16.65
Permanent Vegetative Cover on Critical Areas	5	117.72
Conservation Tillage[d]	1	28.87
Reforestation of Crop and Pastured	10	77.69
Grassed Waterways[e]	10	1.67/LF/yr
Animal Waste System[f]	10	6.26/ton/yr

Source: Camacho 1991

Notes:

a. Median costs (1990 dollars) obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking database and Chesapeake Bay Agreement Jurisdictions' unit data cost. Costs per acre are for acres benefited by the practice. 1990 dollars converted to 2010 dollars.
b. Annualized BMP total cost including O&M, planning, and technical assistance costs.
c. EAC = equivalent annual cost: annualized total; costs for the life span. Interest rate = 10%.
d. Government incentive costs.
e. Annualized unit cost per linear foot of constructed waterway.
f. Units for animal waste are given as $/ton of manure treated.

Practice Savings

It is important to note that for some practices, such as conservation tillage, the net costs often approach zero and in some cases can be negative because of the savings in labor and energy. In fact, it is reported that cotton growers can lower their cost per acre by $88/ha (2010 dollars) because of lower fixed costs associated with conservation tillage (Zeneca 1994).

3.3 Cover Crops

Implementation Measure A-13:

Use the most suitable cover crops to scavenge excess nutrients and prevent erosion at the site on acres that have received any manure or chemical fertilizer application. Cover crops should be used during a non-growing season (including winters) or when there is bare soil in a field.

A cover crop is any crop grown to provide soil cover, primarily to prevent soil erosion by wind and water (Sullivan 2003) (NRCS Practice Code 340). Cover crops can be annual, biennial, or perennial plants grown in a pure or mixed stand during all or part of the year to provide ground cover, fix N (legumes), suppress weeds, reduce insect pests and diseases, and reduce nutrient leaching following a main crop. The Midwest Cover Crop Council Web site (www.mccc.msu.edu/CCinfo/cropbycrop.html) provides information on a variety of options for planting cover crops, and describes the various plant species available. Cover crops come in several forms, depending on the situation and objectives.

A *winter cover crop* is planted in late summer or fall to provide soil cover during the winter; a legume is often planted to generate N for the subsequent crop (Sullivan 2003). Legumes, however, are not recommended for reducing NO_3 leaching. In general, a winter cover crop is planted shortly before or soon after the main crop is harvested and remains on the field through the winter. It is then killed or removed before or soon after planting of the subsequent season's main crop.

A *summer green manure* is a warm-season cover crop used to fill a niche in crop rotations, to improve the conditions of poor soils, or to prepare land for a perennial crop (Sullivan 2003). Legumes such as cowpeas, soybeans, annual sweet clover, sesbania, guar, crotalaria, or velvet beans are often grown to add N and organic matter, while non-legumes such as sorghum-sudangrass, millet, forage sorghum, or buckwheat are grown for biomass, to smother weeds, and to improve soil tilth.

A *living mulch* is a cover crop that is interplanted with an annual or perennial cash crop to suppress weeds, reduce soil erosion, enhance soil fertility, and improve water infiltration (Sullivan 2003). Producers should plant a species that is suppressed during the intensive growth period of the main crop and is taking in excess available nutrients and is growing as the main crop matures or after it is harvested. Living mulches can be incorporated into bare earthen rows during a cropping season for corn, vegetables and many other crops grown in the Chesapeake Bay. For example, New York vegetable growers can interseed ryegrass or clover into a standing vegetable crop or plant barley windbreaks in muck-grown onions (Stivers et al. 1998).

A *catch crop* is a cover crop established after harvesting the main crop and is used primarily to reduce nutrient leaching from the soil profile but can also be used to fill a niche within a crop rotation (Sullivan 2003). When applying cover crops for the purpose of capturing and recycling excess nutrients in the soil profile, NRCS Practice Code 340 specifies that they should be established and actively growing before the expected period(s) of nutrient leaching and that cover crop species will be selected for their ability to take up large amounts of nutrients from the rooting profile of the soil. Deep-rooted crops, such as winter annual grasses (rye, wheat, and barley) can absorb excess nutrients from the soil and then release them through decomposition for the subsequent crop, in effect capturing nitrates that could otherwise leach through the root zone to groundwater (Poole 2004). Greater amounts of N can be taken up by cover crops when a drought-stricken summer crop has failed to use most of the fertilizer applied or on soils that mineralize large amounts of N in the fall because of previous manure applications (Weil et al. 2009).

According to the Sustainable Agriculture Network, an excellent resource for information on cover crops, the best cover crops to use for NO_3 conservation are non-legumes (e.g., rye, sorghum-sudan) that form deep, extensive root systems quickly after cash crops are harvested (SAN 2007). Cereal rye is the best choice for catching nutrients after a summer crop over much of the United States. Rye has cold tolerance that allows it to continue to grow in late fall and develop roots to a depth of 3 feet or more; rye can also grow through mild winter months. Weil et al. (2009) report that because of their exceptionally deep root system, rapid growth, and heavy N feeding, forage radish cover crops can take up most of the soluble N left in the soil profile after summer crops have ceased their uptake. The forage radish takes up N from both the topsoil and from deep soil layers, typically taking up 112 to 168 kg/ha of N if planted while soils are warm. Brassica cover crops (e.g., forage radish, oilseed radish, and rape) are new to the mid-Atlantic region, however, and one of their limitations is the need for early planting. Farmers in the region have successfully planted Brassica cover crops after harvest of corn silage, small grains, and sweet corn, but their application in the widespread corn grain–soybean rotations might require a more risky broadcast seeding into standing crop canopies.

In summary, the top N scavengers include the following (SAN 2007):

1. Excellent N scavengers
    a. Rye
    b. Sorghum-sudan
    c. Radish

2. Very good N scavengers
   d. Annual ryegrass
   e. Barley
   f. Oats
   g. Wheat
   h. Rapeseed
   i. Berseem clover
3. Good N scavengers
   j. Mustards
   k. Crimson clover
   l. Red clover
   m. Woollypod vetch

If the objective is to best synchronize the use of a cover crop to cycle nutrients, factors such as the carbon:nitrogen ratio (C:N) should be considered to determine the kill date to match the release of nutrients with uptake by a following cash crop. Killing or plowing down the cover crop when the crop is still relatively young is important for N availability because decomposition will be slower when the plant is in boot stage or later (Bosworth 2006). If the C:N ratio is over 30:1, N will generally be immobilized during the early stages of the decomposition process (SAN 2007). The C:N ratio of small grain residues is generally lower in young plant tissue, but if the cover crop is killed too early, this lower C:N ratio results in rapid decomposition of a smaller amount of residue, reducing ground coverage. The wide C:N ratio of small grain residues, therefore, must be taken into account for best nutrient management.

In their study of Brassica cover crops Dean and Weil (2009) recommend that the choice of cover crop should take into consideration both the timing of N release in relation to the N demands of the subsequent crop and the impact of soil texture on the susceptibility of NO_3-N to leaching in fall and spring. The forage radish, a cover crop that freeze-kills in the mid-Atlantic region, releases N from plant tissues early in spring. Although this early N availability can provide an agronomic advantage for the summer crop, significant amounts of NO_3-N can be lost to leaching if a main crop is not planted early enough to recapture this N. Early planting of a subsequent summer crop is especially important to minimize spring leaching losses in coarse-textured, well- to excessively drained soils. Rape, which continues to capture soil NO_3-N until terminated in spring, could be a more appropriate choice of cover crop on coarse-textured soils when the summer crop will not be planted until late spring.

Practice Effectiveness

Staver and Brinsfield (1998) investigated the effects of cereal grain winter cover crops on NO_3 leaching rates, profile NO_3 storage, and NO_3 concentrations in shallow groundwater in two Chesapeake Bay field-scale watersheds planted continuously in corn from 1984 through 1996. Rye winter cover crops planted after corn harvest consistently reduced NO_3-N concentrations in root zone leachate to less than 1 mg/L during most of the groundwater recharge period and reduced annual nitrate leaching losses by approximately 80 percent relative to winter-fallow treatments. Shallow groundwater NO_3-N concentrations under long-term continuous corn production decreased from the 10 to 20 mg/L range to less than 5 mg/L after 7 years of cover crop use.

In a Maryland study comparing N uptake ability and potential to reduce N leaching, three Brassica cover crops (forage radish, oilseed radish, and rape) and rye all decreased soil mineral N losses compared with winter weed control plots by storage of N in plant tissues throughout the fall and early winter (Dean and Weil 2009). Averaged across three site-years, forage radish and rape shoots had greater dry matter production and captured more N in fall than rye shoots. Compared with a weedy fallow control, rape and rye caused similar decreases in soil NO_3-N in fall and spring throughout the sampled profile. During the spring on coarse-textured soil, pore water NO_3-N concentrations in freeze-killed radish plots were greater than in control and overwintering rape and rye plots. On fine-textured soil, all cover crops provided a similar decrease in pore water NO_3-N concentration compared with the control. The authors conclude that on coarse-textured soils, freeze-killed Brassica cover crops should be followed by an early planted spring main crop but that additional research is needed to determine the optimal agronomic management of the new cover crops in various types of cropping systems in the region.

A 2-year study comparing sediment, N, and P runoff losses for cotton managed with winter fallow and conventional tillage versus cotton managed with a winter wheat cover crop and strip-tillage, found that the cover crop/strip-till treatment reduced sediment loss for all sampling dates, especially in 2000 when sediment losses were less than half of those with conventional tillage. Sediment loss was also reduced with cover crop/strip-till during the early growing season, before crop canopy closure, and vegetative field borders further reduced runoff of sediment and sediment-attached P (Hoyt 2005).

Hairy vetch, a legume, was shown to not be effective in reducing NO_3 losses on tomato lands in a study conducted on a Norfolk sandy loam in central Georgia (Sainju 1999). Although hairy vetch increased tomato N uptake and recovery, it was not effective in reducing NO_3-N content and movement compared with N fertilizer.

In a field study to determine the potential of a Bermuda grass/ryegrass combination to reduce the level of Mehlich 3 P that had accumulated in a Savannah soil from broiler litter application over 30 years, coupled with antecedent litter rates of 0, 4.48, 8.96, 17.9, and 35.8 Mg/ha, Read et al. (2009) found that annual dry matter (DM) yield and P uptake generally increased as litter rate increased up to 17.9 Mg/ha. Analysis of Mehlich 3 P in surface soil (0–15 cm depth) at four sampling dates over 19 months showed reductions of 25, 27, 22, 26, and 29 percent at the five antecedent litter rates, respectively. Ryegrass-Bermuda grass significantly increased DM yield and P uptake but did not increase reductions in Mehlich 3 P, as compared to Bermuda grass winter fallow, and both forage systems removed about 49 kg/ha P and reduced Mehlich 3 P by about 26 mg/kg annually via five harvests per year.

Sharma and Sahi (2005) examined the phytoremediation potential of Gulf and Marshall ryegrass grown in a greenhouse under varying conditions of soil P concentration, pH, and temperature, finding that an increase in plant biomass was proportional to the increasing concentrations of P up to a level of 10 g of P/kg of soil. Significant effects of both soil pH and temperature on plant uptake of P were measured, and the researchers concluded that Gulf and Marshall ryegrass can accumulate high P under optimal conditions and thus reduce soil P concentrations in successive cropping.

A 3-year field experiment was conducted on sandy loam soils in southwestern Michigan to investigate the combined effects of N fertilization rates and rye cover crops on NO_3 leaching in inbred maize fields (Rasse et al. 2000). Annual NO_3 leaching losses to groundwater in lysimeters fertilized at 202 kg N/ha averaged 88 kg NO_3-N/ha, but rye interseeded with inbred maize fertilized at 202 kg N/ha sequestered from 46 to 56 kg/ha of excess fertilizer N. Well-established rye cover crops reduced NO_3 leaching by as much as 65 kg N/ha when sediment losses were less than half of those with conventional tillage. Sediment loss was also reduced with cover crop/strip-till during the early growing season, before crop canopy closure, and corn yield. Although fall (but not spring) cover crop DM was 26 percent lower with manure than without manure, no difference was detected for N (9.4 kg/ha) or P (1.4 kg/ha) uptake. Shoot DM and N, P, and K uptake increased 29, 41, 31, and 25 percent, respectively, from the cover crop manure 112 kg N/ha treatment to the cover crop manure 224 kg N/ha treatment, with no increase above the cover crop manure 224 kg N/ha treatment. Cover crop N, P, and K uptake were all higher in cover crop manure versus no manure (60.1 versus 35.6 kg N/ha, 9.2 versus 6.6 kg P/ha and 41.3 versus 30.0 kg K/ha, respectively), while corn yield was unaffected by cover crop and responded positively to manure application (11,022 with manure versus 9,845 kg/ha without manure).

A comparison of a rye winter cover crop and strips of gamagrass (3.05-m wide) placed above subsurface tiles under a no-till corn and soybean management system on drained fields in Iowa showed that rye winter cover crops have the potential to reduce the NO_3 concentrations and loads delivered to surface waters by subsurface drainage systems (Kaspar et al. 2007). Averaged over 4 years, the rye cover crop treatment reduced flow-weighted NO_3-N concentrations by 59 percent and loads by 61 percent, with no significant reduction in cumulative drainage. The gamagrass strips did not significantly reduce cumulative drainage, the average annual flow-weighted NO_3 concentrations, or cumulative NO_3 loads averaged over the 4-year period.

A winter rye cover crop following corn in Minnesota did not affect subsequent soybean yield but reduced subsurface tile drainage discharge, flow-weighted mean NO_3 concentration, and NO_3-N loss relative to winter fallow, with the magnitude of the effect varying considerably with annual precipitation (Strock et al. 2004). Over 3 years, subsurface tile-drainage discharge was reduced 11 percent and NO_3-N loss was reduced 13 percent for a corn-soybean cropping system with a rye cover crop following corn versus no rye cover crop.

An incubation experiment designed to assess the effect of freeze-thaw-cycle duration and frequency on the release of P from catch crop biomass (ryegrass), illustrated the trade-offs of establishing catch crops in frigid climates, which can enhance P uptake by biomass and reduce erosion potential but increase dissolved P runoff (Bechmann et al. 2005). Before freezing and thawing, TP in runoff from catch-cropped soils was lower than from manured and bare soils because of lower erosion. Repeated freezing and thawing significantly increased WEP from catch crop biomass and resulted in significantly elevated concentrations of dissolved P in runoff (9.7 mg/L) compared with manured (0.18 mg/L) and bare soils (0.14 mg/L). Catch crop WEP was strongly correlated with the number of freeze-thaw cycles. Freezing and thawing did not change the WEP of soils mixed with manures, nor were differences observed in subsurface losses of P between catch-cropped and bare soils before or after manure application.

A 2-year field lysimeter study was established in Uppsala, Sweden, to evaluate the effect of a perennial ryegrass cover crop interseeded in barley on NO_3-N leaching and availability of N to the main crop (Bergström and Jokela 2001). Barley yields and total fertilizer N uptake in year one (1992) were unaffected by cover crop. Study results clearly show that a ryegrass cover crop, interseeded in spring barley for one season, substantially reduced NO_3-N leaching. In that case, leaching was reduced by two-thirds in the first year and by more than 50 percent over a 2-year period. The cover crop reduced NO_3-N concentration in the leachate to levels (about 3 mg/L) well below the U.S. and European drinking water standards, compared with approximately 15 mg/L without a cover crop. Barley yield was not significantly affected by the presence of the interseeded ryegrass cover crop during the first year, although it was reduced somewhat during the residual year.

In a 2-year lysimeter study in Switzerland, three non-winter hardy catch crops (sunflower, yellow mustard, and phacelia) were compared with fallow at low (4 g N/m^2/yr) and high (29 g N/m^2/yr)

N input levels in a spring wheat-catch crop succession (Herrera and Liedgens 2009). Catch crops reduced N leaching by 31–36 percent and by 16–24 percent versus fallow at the low-N and high-N input levels, respectively, but the capacity of the catch crop for recycling N in situ and to increase grain yield and N uptake of the successive spring wheat varied among catch crop species and depended on the level of N input. Although the catch crops reduced N leaching for the entire crop succession, it was mostly from reductions during the periods when water percolation and NO_3 concentration in the soil solution were high (i.e., winter and autumn). A significant amount of the N saved from leaching during autumn and winter was lost during the spring wheat season.

Brandi-Dohrn et al. (1997) used a randomized complete-block split plot design with three N application rates (0 to 280 kg N/ha/yr) to compare winter NO_3-N leaching losses under winter-fallow and a winter cereal rye cover crop following the harvest of sweet corn or broccoli. At the recommended N rate for the summer crops, NO_3 leaching losses were 48 kg N/ha under sweet corn-winter-fallow for winter 1992-1993, 55 kg N/ha under broccoli-winter-fallow for winter 1993–1994, and 103 kg N/ha under sweet corn-winter-fallow for winter 1994–1995, which were reduced to 32, 21, and 69 kg N/ha, respectively, under winter cereal rye. For the first two winters, most of the variation (61 percent) in NO_3 leaching was explained by N rate (29 percent), cereal rye N uptake (17 percent), and volume of leachate (15 percent). Seasonal, flow-weighted concentrations at the recommended N rate were 13.4 mg N/L under sweet corn-winter-fallow (1992–1993), 21.9 mg N/L under broccoli-winter-fallow, and 17.8 mg N/L under sweet corn-winter-fallow (1994–1995), which were reduced by 39, 58, and 22 percent, respectively, under winter cereal rye.

In Denmark, a 24-year-old permanent field trial on coarse sand with spring-sown crops (wheat) was used in a NO_3 leaching study to determine both the effect of long-term cover crop use compared with the introduction of perennial ryegrass as a cover crop on plots with a history of no previous cover crop use as well as the effect of discontinuing long-term use of ryegrass as a cover crop compared with no previous cover crop use (Hansen et al. 2000). From the 4-year average for two N rates (60 and 120 kg/N ha/yr), it was found that leaching was 14 kg/N ha/yr or 29 percent higher in plots with long-term previous cover crop use than in plots without. The effect of previous long-term use of ryegrass as a cover crop lasted at least 4 years, and the authors concluded that if the higher N mineralization from long-term use of a cover crop is not taken into consideration by adjusting the cropping system, the reduction in NO_3 leaching caused by the cover crop might not be as significant in the long term.

Van Vliet et al. (2002) compared different fall-manure application strategies on runoff and contaminant transport from silage corn land in the Lower Fraser Valley of British Columbia. They had three treatments: a control that did not receive manure in the fall, manure broadcast in the fall on corn stubble, and manure broadcast in the fall on corn stubble with an established relay crop. Runoff, solids, and nutrients loads from natural precipitation were measured on replicated experimental plots (0.0125 ha) from 1996 to 1998. Fall-applied manure on 3–5 percent sloping silage corn without a relay crop yielded high suspended solids export of between 7 and 14 Mg/ha/yr and high nutrient transport with mean annual TKN, P, and K losses of 98, 21, and 63 kg/ha respectively. Compared with no relay crop, intercropping silage corn with a relay crop of Italian ryegrass reduced the mean annual runoff and suspended solid load by 53 and 74 percent, respectively, TKN load by 56 percent, P load by 42 percent, K load by 31 percent, and Cu load by 57 percent. Even though total nutrient loads were lower with the relay crop treatment, all fall manure treatments including the relay crop resulted in nutrient loads above local guidelines for the first three runoff events immediately following application.

Practice Costs

The Chesapeake Bay Commission (2004) evaluated 34 nutrient and sediment-reduction practices representing a wide range of specific actions associated with wastewater treatment plants, agriculture, urban stormwater, land preservation, forestry, and air pollution. The analysis resulted in identifying six measures that could achieve a substantial portion of the N, P, and sediment-reduction goals set for the period 2002–2010 in the Chesapeake 2000 agreement. One of those practices is enhanced adoption of late cover crops and use of early cover crops to absorb excess nutrients in the soil. The report estimates that implementing fall cover crops at the maximum extent feasible (0.83 million hectares) in the watershed could achieve annual N reductions of 6,893 Mg of N at $9.54/kg (2010 dollars), 99.8 Mg of P, and 49.9 Mg of sediment at no additional cost. Maximum feasible implementation of early cover crops could provide annual reductions of 3,673 Mg of N at $5.90/kg and 99.8 Mg of P and 049.9 Mg of sediment at no additional cost.

Factors affecting the economics of cover crop use consist of the following (SAN 2007):

- The cash crop grown
- The cover crop selected
- Time and method of establishment
- Method of termination
- The cash value applied to the environment, soil productivity, and soil protection benefits derived from the cover crop
- The cost of N fertilizer and the fertilizer value of the cover crop
- The cost of fuel

The economic picture is most affected by seed costs, energy costs and N fertility dynamics in cover crop systems (SAN 2007). Cover crop seed costs vary considerably from year to year and from region to region, but historically, legume cover crops cost about twice as much to establish as small grain covers. The increased cost of the legume cover crop seed can be offset by the value of N that legumes can replace. Depending on the system in place on a farm, legume cover crops can replace 50 to 112 kg N/ha. On the other hand, a rye cover crop terminated at a late stage of growth might require an additional 22–34 kg N/ha because of N immobilization by the wide C:N ratio rye residue. Thus, the difference in cost between a rye cover crop and a legume cover crop would be offset by the value of 73 to 140 kg N/ha. At a price of $0.21/kg N (2010 dollars), it would be worth $75/ha to $145/ha.

The highest cost for annual cover crops is for the seed, with hairy vetch and crimson clover typically ranging from $1.30 to $3.90/kg (2010 dollars) (Sullivan 2003). With a 22.4-kg/ha seeding rate, seed costs range from $30 to $86/ha. With a 28-kg/ha seeding rate at $2.22/kg and a $7.69 no-till drilling cost, it would cost $82/ha to plant this cover crop.

Saleh et al. (2005) used the modified SWAT (SWAT-M) and FEM (Farm-level Economic Model) models to evaluate the environmental and economic impacts of various BMP scenarios often adopted by local farmers to reduce sediment and nutrient loadings (in particular NO_3-N). Measured values of water quality indicators from the Walnut Creek watershed in central Iowa were used to verify the capability of SWAT-M to predict the impact of late-spring NO_3 test (LSNT) and rye cover crop management on NO_3-N reduction at the subbasin level. The results obtained from SWAT-M simulation results, similar to field measurement data, indicated a 25 percent reduction in NO_3-N under the LSNT scenario. FEM results indicated a corresponding increased annual cost of $6.69/ha (2010 dollars) across all farms in the watershed. Simulating other scenarios, including winter cover cropping and a combination of LSNT and cover cropping at different adoption rates within WCW, resulted in a progressive reduction in sediment and nutrient losses as adoption rates increased. Using the rye cover crop added about $28/ha to $39/ha to the annual cost of the average farm, indicating that some cost-share support might be necessary to encourage farmers to use winter cover crops.

In an application of the Annualized Agricultural Nonpoint Source pollutant loading model (AnnAGNPS 2.1) to a 12-ha Mississippi Delta Management System Evaluation Area (MDMSEA) subwatershed, cover crops, filter strips, grade control pipes, and impoundments were modeled in combination with three tillage systems: conventional tillage, reduced tillage, and no-till (Yuan et al. 2002). Costs of management practices were estimated using 2001 state average prices for Mississippi, and amortized fixed costs—using a 25-year planning horizon and interest rates of both 5 percent and 10 percent—were combined with direct annual costs into total annual cost estimates. AnnAGNPS predicted that no-till alone, reduced tillage with winter cover and an edge-of-field pipe, or conventional tillage with a small permanent impoundment (covering less than 3 percent of the watershed) would all reduce sediment yield by at least 50 percent. The most cost-effective BMPs were managing volunteer winter weeds as cover crops and various types of edge-of-field grade-control pipes. The average marginal cost using BMPs for sediment yield reduction was about $9.84/MT ($8.98/t) (2010 dollars) for conventional and reduced tillage. The cost was higher, about $13.16/MT ($11.93/t), for no-till because the practice of no-till alone reduced sediment yield by half, and further marginal reductions were more expensive.

An assessment of options to address NO_3 problems in the Neuse River Basin of North Carolina concluded that cover crops can reduce N loading to shallow groundwater by 5 to 15 percent (Wossink 2001). Conservation tillage, including cover crops, is identified as one of the three best options for N reduction in the Piedmont region, and the cost of a wheat cover crop is estimated at $230/ha with $0 in net receipts, for a net revenue of -$230/ha.

Franzluebbers (2005) summarizes research on some of the key components that could produce viable integrated crop-livestock production systems in the Southeast: sod-based crop rotation, cover cropping, intercropping, and conservation tillage. Despite its agronomic benefits, adopting cover cropping appears to be limited because of cost without immediate economic benefit, but the author suggests that grazing of cover crops could provide such an immediate economic benefit to producers. On the basis of the research reviewed, barriers to adopting integrated crop–livestock systems include lack of experience or time to manage both the crops and livestock. Franzluebbers reviewed several studies regarding economic returns from grazing livestock and found the following:

- Livestock increased labor required on an average North Dakota farm by about 50 percent, but only about 30 percent of the additional time competed directly during critical crop management. Net economic return attributed to livestock increased whole farm income by about 20 percent.

- Ten steers and heifers were grazed on a 4-ha area of rye or ryegrass cover crop at the Sunbelt Agricultural Exposition near Moultrie, Georgia. The equivalent of $346 ±$69/ha (2010 dollars) greater gross income was generated in the value of animal gain (assuming $1.95/kg animal gain).

- A 3-year experiment was conducted at Headland, Alabama, to compare the effect of oat and ryegrass winter cover crops under cattle grazing on cotton and peanut production managed under different tillage systems. Net return from winter grazing of cover crops (5 head/ha for 80 d) was $206 to $223/ha/yr.

- Using an economic model comparing a conventional system (53 ha cotton, 27 ha peanut) with a sod-based rotation system (20 ha cotton, 20 ha peanut, 40 ha bahiagrass) on a typical small farm in Florida, net profit was expected to be $17,483/year on a conventional farm and $49,967/year on a sod-based farm with cattle grazing the second year bahiagrass.

3.4 Pasture Land Management

Implementation Measure A-14:

Minimize nutrient and soil loss from pasture land by maintaining uniform livestock distribution, keeping livestock away from riparian areas, and managing stocking rates and vegetation to prevent pollutant losses through erosion and runoff.

Livestock can obtain their nutrients through feed supplied to them in a confined livestock facility, through forage, or through a combination of forage and feed supplements. Forage systems can be pasture-based or rangeland-based.

There are important differences between rangeland and pasture. *Rangeland* refers to those lands on which the native or introduced vegetation (climax or natural potential plant community) is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing. Rangeland includes natural grassland, savannas, many wetlands, some deserts, tundra, and certain forb and shrub communities. *Pastures* are those improved lands that have been seeded, irrigated, and fertilized and are primarily used for producing adapted, domesticated forage plants for livestock. Other grazing lands include grazable forests, native pastures, and crop lands producing forage.

The major differences between rangeland and pasture are the kind of vegetation and level of management that each land area receives. In most cases, range supports native vegetation that is extensively managed through the control of livestock rather than by agronomy practices, such as fertilization, mowing, or irrigation. Rangeland also includes areas that have been seeded with introduced species (e.g., clover or crested wheatgrass) but are managed with the same methods as native range. For both rangeland and pasture, the key to good grazing practice is vegetative management, i.e., timing of grazing should be managed to ensure adequate vegetative regrowth and soil stability.

Pastures are represented by those lands that have been seeded, usually with introduced species (e.g., legumes or tall fescue) or in some cases with native plants (e.g., switchgrass or needle grass), and that are intensively managed using agronomy practices and control of livestock. Permanent pastures are typically based on perennial, warm-season (e.g., Bermuda grass) or cool-season (e.g., tall fescue) grasses and legumes (e.g., warm-season alfalfa, cool-season red clover), while temporary pastures are generally plowed and seeded each year with annual legumes (e.g., warm-season lespedezas, cool-season crimson clover) and grasses such as warm-season pearl millet and cool-season rye (Johnson et al. 1997). Plants for pastures should be selected on the basis of climate, soil type, soil condition, drainage, livestock type and expected forage intake rates, and the type of pasture management to be used. Management of pH and soil fertility is essential to both establishing and maintaining pastures (Johnson et al. 1997). In some climates (e.g., Georgia), overseeding of summer perennials with winter annuals is done to provide adequate forage for the period from mid-winter to the following summer.

Pollutant runoff from pasture land can be controlled by managing animal stocking rates and maintaining vigorous vegetation to provide for soil stability and nutrient recycling. Osmond et al. (2007) recommend using those practices that encourage more uniform livestock distribution over the pasture; riparian areas should not be used as shade paddocks, holding areas, or feeding areas; and access to riparian areas should be limited and should not occur when soils are wet or boggy and when acceptable forage is available on non-riparian sites within the same grazing unit. Good pasture management maintains stocking rates and vegetation to prevent pollutant losses through erosion and runoff, and silvopasture techniques integrate trees into pastures to improve nutrient uptake and vegetation stability. Forestry practices and methodologies that can be incorporated into silvopasture are described in Chapter 4.

Practice Effectiveness

Pasture management

In a Georgia plot study, Butler et al. (2008b) compared runoff and sediment and nutrient export from poorly drained and well-drained riparian soils where heavy or light grazing pressure by cattle was simulated. Runoff volume was generally greater from heavily grazed areas than from lightly grazed areas. Light-use plots were effective at minimizing export of TSS on both soils (less than 30 kg/ha). Mean TP export was fourfold greater from heavy-use plots than from light-use plots on both soils. While export of NO_3-N was unaffected by grazing pressure and soil drainage, mean NH_4-N and TN export from poorly drained heavy-use plots was greater than fivefold that from well-drained light-use plots. Results indicate that livestock heavy-use areas in the riparian zone can export substantial TSS and nutrients, especially on poorly drained soils. However, when full ground cover is maintained on well-drained soils, TSS and nutrient losses can be limited.

Sistani et al. (2008) investigated the effect of pasture management and broiler litter application rate on nutrient runoff from Bermuda grass pasture plots in Kentucky. Runoff was 29 percent greater from grazed than hayed pastures regardless of the litter application rate. There was greater inorganic N in the runoff from grazed paddocks when litter rate was based on N rather than P. The mean TP loss per runoff event for all treatments ranged from 7 to 45 g/ha, and the grazed treatment with litter applied on an N basis had the greatest TP loss. The SRP was greater for treatments with litter applied on an N basis regardless of pasture management. Litter can be applied on an N basis if the pasture is hayed and the soil P is low. In contrast, litter rates should be applied on a P-basis if the pasture is grazed.

Cattle did not cause substantial damage to the soil when they were put on fields to graze cover crops in Georgia (Franzluebbers and Stuedemann 2008). The grazing had little effect on soil bulk density or the stability of macroaggregates in. There was a slight tendency for water infiltration rate to be lower with grazing of cover crops (5.6 mm/min) than when ungrazed (6.9 mm/min).

In New Zealand, McDowell and Houlbrooke (2009) assessed restricted grazing and applying alum for their potential to decrease contaminant loss from winter grazing of forage crops. Volumes of surface runoff and loss of P and sediment showed significant differences between the control treatments (i.e., no mitigation) with cattle crop (88 mm surface runoff) greater than sheep crop (67 mm) and greater than sheep pasture (33 mm). Restricted winter grazing and alum application after grazing significantly decreased P losses in surface runoff under cattle (from 1.4 to 0.9 kg P/ha, 36 percent) and sheep (from 1.0 to 0.7 kg/P/ha, 30 percent). In cattle-grazed plots, restricted grazing also decreased suspended sediments by 60 percent.

Owens and Shipitalo (2009) evaluated two systems of over-wintering cattle in Ohio. Vegetative cover in the continuous wintering area frequently decreased to less than 50 percent by late winter/early spring while it remained at or near 100 percent in the rotational system. Annual runoff from the rotational wintering system was 69 percent lower than from the continuous wintering system; sediment loss was also reduced by 91 percent under the rotational system compared to continuous wintering. Surface runoff losses of N from the continuous system were double those from the rotational system during the dormant season. Some of the differences could be attributed to higher cattle occupancy rate in the continuous wintering system.

In North Carolina, Butler et al. (2007) reported that mean NO_{3-} export was greatest from bare ground and was reduced by 31 percent at 45 percent cover. Mean TN export was greatest from bare ground and was reduced by at least 85 percent at cover levels from 45 to 95 percent. Whereas site did not affect N export, results indicate that cover and time of rainfall following manure deposition are important determinants of the effect of riparian grazing.

In a review of experimental data from the Northeast United States, Stout et al. (2000) assessed the relationships between stocking rate and NO_3-N leaching losses beneath an intensively grazed pasture. A relatively low cumulative seasonal stocking rate of about 200 mature Holstein per hectare could result in a 10 mg/L NO_3-N concentration in the leachate beneath a fertilized, intensively grazed pasture. That means that while management intensive grazing can improve farm profitability and help control erosion, it can have a significant negative effect on water quality beneath pastures.

Lyons et al. (2000) compared bank erosion, fish habitat characteristics, trout abundance, and a fish-based index of biotic integrity (IBI) among stations with riparian continuous grazing, intensive rotational grazing, grassy buffers, or woody buffers along 23 trout stream reaches in Wisconsin. After statistically factoring out watershed effects, stations with intensive rotational grazing or grassy buffers had the least bank erosion and fine substrate in the channel. Continuous grazing stations had significantly more erosion and, with woody buffers, more fine substrate. Station riparian land use had no significant effect on width/depth ratio, cover, percent pools, habitat quality index, trout abundance, or IBI score.

From Minnesota, Magner et al. (2008) reported that low IBI scores were associated with streams draining continuously grazed pasture, while higher IBI scores occurred on ungrazed sites. Ungrazed sites were associated with reduced soil compaction and higher bank stability, whereas continuously grazed sites showed increased soil compaction and lower bank stability. Short-duration grazing sites were intermediate.

Table 2-21. Summary of reported practice effects resulting from pasture management

Location	Study type	Practice	Practice effects	Source
Georgia	Plots	Stocking rate	Runoff volume was greater from heavy use than from light use. Light-use plots were effective at minimizing export of TSS. Mean TP export was fourfold greater from heavy-use plots than from light-use plots. While export of NO_3-N was unaffected by grazing pressure and soil drainage, mean NH_4-N and TN export from poorly drained heavy-use plots was greater than fivefold that from well-drained light-use plots.	Butler et al. 2008b
Kentucky	Plots	Pasture management, litter application rate	Runoff was 29% greater from grazed than hayed pastures regardless of litter application rate. There was greater inorganic N in the runoff from grazed paddocks when litter rate was based on N rather than P. The mean TP loss per runoff event for all treatments ranged from 7 to 45 g/ha and the grazed treatment with litter applied on N basis had the greatest TP loss.	Sistani et al. 2008
Georgia	Field	Grazing cover crops	Grazing of cover crops had little effect on soil bulk density; stability of macroaggregates in water was unaffected by grazing of cover crops.	Franzluebbers & Studemann 2008
New Zealand	Field	Restricted grazing, alum	Restricted winter grazing and alum application after grazing significantly decreased P losses in surface runoff under cattle (from 1.4 to 0.9 kg P/ha, 36%) and sheep (from 1.0 to 0.7 kg/P/ha, 30%). In cattle grazed plots, restricted grazing also decreased suspended sediments by 60%.	McDowell and Houlbrooke 2009

Table 2-21. Summary of reported practice effects resulting from pasture management *(continued)*

Location	Study type	Practice	Practice effects	Source
Ohio	Field	Cattle wintering systems	Annual runoff from the rotational wintering system was 69% lower than from the continuous wintering system; sediment loss was also reduced by 91% under the rotational system vs. continuous wintering. Surface runoff losses of N from the continuous system were double those from the rotational system during the dormant season.[a]	Owens and Shipitalo 2009
North Carolina	Plots	Vegetative cover	Mean NO_3-N export from bare ground plots was greatest from bare ground and was reduced by 31% at 45% cover. Mean TN export was greatest from bare ground and was reduced by at least 85% at cover levels from 45%–95%.	Butler et al. 2007
Northeast U.S.	Review	Intensive grazing	A relatively low cumulative seasonal stocking rate of about 200 mature Holstein/ha could result in a 10 mg/L NO_3-N concentration in the leachate beneath a fertilized, intensively grazed pasture.	Stout et al. 2000
Wisconsin	Field	Rotational grazing	Stations with intensive rotational grazing or grassy buffers had the least bank erosion and fine substrate in the channel. Continuous grazing stations had significantly more erosion and more fine substrate. Station riparian land use had no significant effect on width/depth ratio, cover, percent pools, habitat quality index, trout abundance, or IBI score.	Lyons et al. 2000
Minnesota	Field	Short-duration grazing	Low IBI scores associated with streams draining continuously grazed pasture; higher IBM scores occurred on ungrazed sites. Ungrazed sites associated with reduced soil compaction and higher bank stability; continuously grazed sites showed increased soil compaction and lower bank stability. Short-duration grazing sites were intermediate.	Magner et al. 2008

Note:
a. Some of the differences could be attributed to higher cattle occupancy rate in the continuous wintering system

Silvopasture

In Missouri, Garrett et al. (2004) reported that many cool-season forages benefit from 40 percent to 60 percent shade, and grazing trials in such conditions have proven to be successful. Also in Missouri, Kallenbach et al. (2006) reported that cumulative forage production in annual ryegrass/cereal rye planted into a 6- to 7-year-old forested stand was reduced by approximately 20 percent compared to the same forages planted in open pasture. However, beef heifer average daily gain and gain/ha were equal for both treatments, suggesting that a silvopasture system likely would not sacrifice livestock production in the system. In Florida, Bambo et al. (2009) documented 56 percent reduction in NO_3 concentrations under silvopasture compared to conventional open pasture.

Blazier et al. (2008) evaluated soil nutrient dynamics, loblolly pine nutrient composition, and loblolly pine growth of an annually fertilized silvopasture on a well-drained soil in Louisiana in response to fertilizer type, litter application rate, and subterranean clover. Litter stimulated loblolly pine growth, and neither litter treatment produced soil test P concentrations above runoff potential threshold ranges. However, both litter treatments led to accumulation of P in upper soil horizons relative to inorganic fertilizer and unfertilized control treatments. Subterranean clover kept more P sequestered in the upper soil horizon and conferred some growth benefits to loblolly pine. The authors concluded that although the silvopasture systems had a high capacity for nutrient use and retention, litter should be applied less frequently than in their study to reduce environmental risks.

In Florida, Michel et al. (2007) reported that water-soluble P concentrations in the upper soil layer ranged from 4 to 11 mg/kg for the silvopasture sites and 10 to 23 mg/kg in the treeless pasture sites, with higher P concentrations in the treeless pasture at each location. TP storage capacity in the upper 1-m depth ranged from 342 to 657 kg/ha in the silvopasture sites and –60 to 926 kg/ha in the treeless pasture sites (a negative value indicates that the soil is a P source). The results suggest that P builds up within the soil profile (P-sat increases) and therefore the chances for loss of P from soil to waterbodies were less from silvopastures than from treeless pastures.

Nair et al. (2007) monitored soil N and P concentrations under a treeless pasture, a pasture under 20-year-old trees, and a pasture of native vegetation under pine trees in Florida. P concentrations were higher in treeless pasture (mean: 9.11 mg/kg in the surface) compared to silvopastures (mean: 2.51 mg/kg), and ammonium-N and NO_3-N concentrations were higher in the surface horizon of treeless pasture. The more extensive rooting zones of the combined stand of tree + forage might have caused higher nutrient uptake from silvopastures than treeless system. Further, compared to treeless system, soils under silvopasture showed higher P storage capacity.

Table 2-22. Summary of reported practice effects resulting from silvopasture

State	Study type	Practice	Practice effects	Source
Missouri	Field	Forage planted in forest stand	Cool-season forages benefit from 40% to 60% shade and grazing trials in such conditions have proven to be successful	Garrett et al. 2004
Missouri	Field	Forage planted in forest stand	Cumulative forage production in annual ryegrass/cereal rye planted into a 6-7 year-old forested stand was reduced by about 20% vs. the same forages planted in open pasture. However, beef heifer average daily gain and gain/ha were equal for both treatments.	Kallenbach et al. 2006
Florida	Field	Silvopasture	56% reduction in NO_3 concentrations under silvopasture compared to conventional open pasture	Bambo et al. 2009
Louisiana	Field	Silvopasture fertilized with poultry litter	Litter stimulated tree growth, and did not produce soil test P concentrations above runoff potential threshold ranges. However, litter treatments led to accumulation of P in upper soil horizons vs. inorganic fertilizer and unfertilized control treatments. Subterranean clover kept more P sequestered in the upper soil horizon and conferred some growth benefits to loblolly pine.	Blazier et al. 2008
Florida	Field	Silvopasture	Water-soluble P concentrations in the upper soil layer on treeless sites (10 to 23 mg/kg) exceeded those on silvopasture sites (4 to 11 mg/kg) at each location. TP storage capacity in the upper 1-m depth was 342 to 657 kg/ha in the silvopasture sites and -60 to 926 kg/ha in the treeless pasture sites (a negative value indicates that the soil is a P source).	Michel et al. 2007
Florida	Field	Silvopasture	Surface soil P concentrations were higher in treeless pasture (mean: 9.11 mg/kg) compared to silvopastures (mean: 2.51 mg/kg), and ammonium-N and NO_3-N concentrations were higher in the surface horizon of treeless pasture. The more extensive rooting zones of the combined stand of tree + forage might have caused higher nutrient uptake from silvopastures than treeless system. Further, compared to treeless system, soils under silvopasture showed higher P storage capacity.	Nair et al. 2007

Practice Costs

Giasson et al. (2003) examined the cost-effectiveness and the risk of P loss associated with various combinations of manure management options for a typical mid-sized dairy farm in New York using mathematical programming techniques and utility functions to select optimum management practices. Compared with current practices, the recommended combination of practices resulted in an approximate 45 percent reduction in the mean area-weighted P index (64.2 versus 36.1) for a cost (2008 dollars) increase of less than 2 percent ($173,086 versus $175,740) (2010 dollars).

Prescribed grazing plan development costs about $7.50/ac in Virginia, with typical total costs of about $900 (USDA-NRCS 2010). Implementing the plan runs about $70/ac with total costs typically in the neighborhood of $8,300. Forage harvest management costs are about $28/ac for record keeping and forage tissue testing ($421 typical total cost), and about $17/ac for record keeping and monitoring only ($260 typical total cost). Grass establishment for pasture and hay land costs are approximately $260/ac for native warm season grass and $330/ac for cool season grass, with typical total costs of about $2,600 for warm-season grass and $3,300 for cool-season grass. Renovating pasture and hay land with legumes costs nearly $30/ac for broadcast and $40/ac for drilling; typical total costs in Virginia are just under $300 for broadcast and $400 for drilling.

3.5 Drainage System Design

Reduction of nutrient loads from agricultural drainage water has elements of source control (e.g., nutrient management, crop rotations), in-field control (e.g., the drainage system), and edge-of-field control (e.g., controlled drainage, bioreactors). Basic subsurface drainage system design consists of field or lateral drains to collect drainage from the fields, collectors or mains to collect the water from the lateral drains, and a ditch or other conveyance to convey the collected water away from the field. The size, depth, and spacing of the drains are key determinants of the drainage rate or drainage intensity.

Implementation Measure A-15:

Where drainage is added to an agricultural field, design the system to minimize the discharge of N.

Practice Effectiveness

Several studies performed under different conditions document significant reductions in both discharge volume and NO_3 loads for shallower and more widely spaced drains compared to deeper and more closely spaced drains (Table 2-23). However, other studies show no significant effect or increases in NO_3 loads.

Table 2-23. Measured effects of changes in drain depth and spacing

State	Soils and crops	Study type	Practice			Reference practice			Reduction vs. reference practice			Source
			Depth (m)	Spacing (m)	Drainage Intensity (mm/d)	Depth (m)	Spacing (m)	Drainage Intensity (mm/d)	Q	NO_3-N Conc.	NO_3-N Load	
North Carolina	Swine wastewater applied	Plot	0.75	12.5		1.5	25		42%	-217%[a]	26%[b]	Burchell et al. 2005
Minnesota	Poorly drained soils; corn-soybean[c]	Plot	0.9			1.2			20%[d]	N/S	18%[d]	Sands et al. 2008
					13			51	24%[d]	N/S	23%[d]	
			0.9		13	0.9		51	N/S	19%[e]	48%	
			1.2		13	1.2		51	N/S	-15%[e]	-1%	
Illinois[f]	Poorly drained soils; soybeans-corn	Plot	0.61	15.24		0.91	30.48		43%[g]	N/S[e]	37%[h]	Cooke, et al. 2002
			0.61	15.24		1.22	30.48		62%[g]	N/S[e]	51%[h]	
			0.91	30.48		1.22	30.48		33%[g]	N/S[e]	22%[h]	
Indiana	Clermont silt loam, corn for 9 yr, then 6 yr corn-soybean	Plot	0.75	20		0.75	5		42%[i]	N/S	44%[i]	Kladivko et al. 2004
			0.75	20		0.75	10		19%[i]	N/S	21%[i]	
			0.75	10		0.75	5		28%[i]	N/S	28%[i]	
KEY: Q=drainage water discharge, N/S=no significant change												

Notes:

a. Significant increase in 2001 (7.6 mg/L shallow vs. 2.4 mg/L deep), but not significant in 2002 (15.7 mg/L vs. 12.8 mg/L).
b. Significant decrease in 2002 (27.3 kg NO_3-N/ha shallow vs. 36.9 kg NO_3-N/ha deep) but N/S over a 21-month period.
c. NO_3 concentration (4.4 mg/L greater for corn) and load (45% greater for corn) were significantly affected by crop type.
d. Using adjusted means.
e. Flow-weighted concentrations.
f. Findings based on only 1 year of monitoring data.
g. Changes in cumulative flow were greater than changes in flow for discrete events.
h. Similar load reductions were achieved for discrete events.
i. Average of two blocks over 15 years.

A detailed analysis of published field data and simulation results demonstrated that N losses increase with drainage rates or drainage intensity because of lowered water tables, increased mineralization of organic matter, reduced denitrification, and increased rates of subsurface water movement to surface waters (Skaggs et al. 2005). Factors affecting drainage rates include drain depth, drain spacing, soil properties, hydraulic conductivity, drainable porosity, the depth of the profile through which water moves to the drains, surface depressional storage, drain diameter, drain envelopes, the size and configuration of openings in the drain tube walls, the hydraulic capacity of the drainage network to remove water from the field, and management (e.g., controlled drainage) of the drainage outlet. Additional factors affecting NO_3 losses through drain tiles include climate, fertilization rate, and crop rotations.

In a North Carolina study of the effect of subsurface drain depth on NO_3 losses from plots receiving swine wastewater applications, the shallow drainage system (0.75 m deep and 12.5 m apart) had 42 percent less outflow than the deeper drainage system (1.5 m deep and 25 m apart), and NO_3 export from the shallow drains (8 kg/ha in 2001 and 27 kg/ha in 2002) was significantly ($p = 0.10$) lower than from the deeper drains (6 kg/ha in 2001 and 37 kg/ha in 2002) in 2002, but not for the entire 21-month period (Burchell et al. 2005). Lower NO_3 concentrations were observed in the shallow groundwater beneath the shallow drainage plots because of higher water tables and likely increased denitrification, but NO_3 concentrations in the drainage water from the shallow drains increased, possibly because of preferential flow paths to the drains from the surface (hence, shorter retention times) and soil pore flushing near the shallow drains.

Nine subsurface drainage plots in Minnesota were monitored for 5 years to investigate the role of subsurface drainage depth and drainage intensity on NO_3 loads to subsurface drains (Sands et al. 2008). Three plots had a depth of 120 cm (conventional depth) and a spacing of 24 m, resulting in a calculated drainage intensity of 13 mm/d (conventional rate), while two plots had a depth of 90 cm and a spacing of 18 m that was calculated to also achieve the conventional drainage intensity of 13 mm/d. Two plots each had depth/spacing combinations of 120 cm/12 m and 90 cm/9 m, designed to simulate the intensification of drainage systems experienced in the area. Analysis of aggregated data showed that both shallower and less intense drain systems reduced both discharge (20 percent and 24 percent, respectively) and NO_3 loading (18 percent and 23 percent, respectively), but not flow-weighted NO_3-N concentration. Interaction effects, however, indicated that intense drainage increased NO_3 concentration for shallow drainage but diluted NO_3 concentrations for drains at conventional depth. Because of that, NO_3 loads increased significantly for shallow drainage when combined with increased drainage intensity, while NO_3 loads for conventional drainage depth remained at a similar level despite increased drainage intensity.

In a one-year study of tile effluent from drainage tiles installed at different depths in a 16-ha field in Illinois, Cooke et al. (2002) found that tile discharge decreased with decreasing tile depth for tiles at 0.61 m, 0.91 m, and 1.22 m depth. Cumulative discharge from the monitored tile lines at 0.61 m and 0.91m depth were 43 percent and 33 percent less, respectively, than discharge from the tile line at 1.22 m. Average NO_3 load reductions for the 0.61 m and 0.91 m tile lines, when compared to the tile line at 1.22 m, were 51 percent and 22 percent, respectively. There was no relationship between flow-weighted NO_3 concentration and tile depth, and the authors noted a need for more data to validate the findings.

A 15-year drainage study in Indiana to evaluate three drain spacings (5, 10, and 20 m) installed at a depth of 0.75 m showed that both discharge and NO_3 load were reduced significantly as drain spacing increased but that flow-weighted NO_3 concentration did not vary with drain spacing (Kladivko et al. 2004). Differences in NO_3 loads with spacing occurred primarily during the years with continuous corn, high fertilizer N rates, and no cover crop.

Drury et al. (2009) concluded that the lower flow volumes measured for controlled drainage systems were due to the shallower effective tile depth (0.3 m) relative to uncontrolled drainage (0.6 m) because the water level in the soil must reach the 0.3-m level before any water would drain from the tiles. Hence, there is additional storage capacity for water in the soil from the 0.6-m depth to the 0.3-m effective depth with controlled drainage.

4 Implementation Measures and Practices for Cropland Edge-of-Field Trapping and Treatment

Edge-of-field practices remediate or intercept the pollutant before or after it is delivered to the water resource if the pollutants have not been effectively controlled at the source or in the field. Buffers and setbacks, soil amendments, wetlands, drainage water management, and controls in animal agriculture are examples of important *edge-of-field* or *end-of-pipe* measures to prevent nutrient loads to the Chesapeake Bay.

4.1 Buffers and Minimum Setbacks

Buffers are the areas between the cropland or other agricultural land use and the adjacent waterbodies. Buffers are described in detail in Chapter 5 of this document.

Implementation Measure A-16:

Establish manure and chemical fertilizer application buffers or minimum setbacks from in-field ditches, intermittent streams, tributaries, surface waters, open tile line intake structures, sinkholes, agricultural well heads or other conduits to surface waters.

Practice Effectiveness

Merriman et al. (2009) developed a compilation of BMP effectiveness results. Table 2-24 presents a listing of individual results for conservation buffer practices along with percent reductions for TP, TN, and sediment. Additional data on reductions for particulate P, dissolved P, NO_3-N, and ammonium are also available in the document.

Liu et al. (2008) performed an extensive review of sediment trapping efficiencies from more than 80 representative BMP experiments. A summary of their data is presented in Table 2-25. Their analysis of the data indicate that regardless of the area ratio of buffer to agricultural field, a 10-m buffer and a 9 percent slope optimize the sediment-trapping capability of vegetated buffers.

Table 2-24. TP, TN, and sediment reductions for various conservation buffer practices

Reference (as cited by Merriman et al. 1980	State	BMP name	Field plot	3-8	B	TP %	TN %	Total sediment
Bingham et al. 1980	NC	Contour Buffer Strip (3 m)	Field plot	3-8	B	52.77%	18.6%	
Bingham et al. 1980	MO	Contour Buffer Strip (3 m)	Field plot	3	B	7.91%	14.53%	
Udawatta et al. 2002	MO	Contour Buffer Strip (4.5 m)	Small watershed	3	D	26%	20%	19%
Udawatta et al. 2002	MO	Hedgerow Planting	Field plot	3-8	D	26%	20%	19%
Meyer et al. 1999	MS	Hedgerow Planting	Lab plot	3-8	C			76%
Meyer et al. 1995	GA	Hedgerow Planting	Field	3	B			80%
Sheridan et al. 1999	GA	Riparian Forest Buffer	Field	0-3	N/A			95%
Sheridan et al. 1999	GA	Riparian Forest Buffer	Field	0-3	N/A			74%
Sheridan 2005	GA	Riparian Forest Buffer	Farm	0-3	N/A			68%
Blanco-Canqui et al. 2004	GA	Riparian Forest Buffer	Farm	3	D	56%	37%	
Dillaha et al. 2004	MO	Vegetated Filter Strip (VFS)	Field plot	3-8	D			95%
Dillaha et al. 1988	VA	VFS	Field plot	3-8	C	2%	1%	31%
Srivastava et al. 1996	AR	VFS	Field plot	3-8	C	65.5%	67.2%	
Dillaha et al. 1996	AR	VFS	Field plot	8	C	36%	43.9%	
Dillaha et al. 1988	VA	VFS	Field plot	8-15	C	63%	64%	87%
Feagley et al. 1992	AR	VFS	Field plot	N/A	D			78.49%
Chaubey et al. 1995	TX	VFS (15.2 m)	Field plot	3-8	C	86.8%	75.7%	
Sanderson et al. 2001	TX	VFS (16.4 m)	Field plot	N/A	C	47%		
Chaubey et al. 2001	TX	VFS (16.4 m)	Field plot	N/A	C	76%		
Chaubey et al. 1995	AR	VFS (21.4 m)	Field	3-8	C	91.2%	80.5%	
Daniels and Gilliam. 1996	MO	VFS (3 m)	Field	3-8	B	55%	40%	53%
Chaubey et al. 2004	MO	VFS (4 m)	Field plot	3-8	D		77%	91%
Chaubey et al. 1995	AR	VFS (4 m)	Field plot	3-8	C	39.6%	39.2%	
Mendez et al. 2001	VA	VFS (4 m)	Field plot	N/A	N/A	50%	50%	
Mendez et al. 1999	VA	VFS (4.3 m)	Field plot	3-8	C		55.6%	81.9%
Dillaha et al. 1989	VA	VFS (4.6 m)	Field plot	8	C	85%	84%	83%
Dillaha et al. 1989	VA	VFS (4.6 m)	Field plot	15	C	73%	73%	86%
Dillaha et al. 1988	VA	VFS (4.6 m)	Field plot	15-25	C	52%	69%	76%
Dillaha et al. 1989	VA	VFS (4.6 m)	Field	3-8	C	49%	47%	53%
Chaubey et al. 1995	AR	VFS (6 m)	Field	3-8	B	65%	48%	68%
Chaubey et al. 1995	AR	VFS (6.1 m)	Field plot	3-8	C	58.4%	53.5%	

Table 2-24. TP, TN, and sediment reductions for various conservation buffer practices *(continued)*

Reference (as cited by Merriman et al. 1980	State	BMP name	Field plot	3-8	B	TP %	TN %	Total sediment
Mendez et al. 1996	AR	VFS (6.1 m)	Field plot	3-8	C	25.5%	21.4%	
Coyne et al. 1999	VA	VFS (8.5 m)	Field plot	15	C		81.5%	90.2%
Coyne et al. 1995	KY	VFS (9 m)	Field plot	8	B			99%
Dillaha et al. 1988	VA	VFS (9.1m)	Field plot	3-8	C	19%	9%	58%
Dillaha et al. 1989	VA	VFS (9.1m)	Field plot	8	C	87	81%	93%
Dillaha et al. 1988	VA	VFS (9.1m)	Field plot	8-15	C	80%	80%	95%
Dillaha et al. 1989	VA	VFS (9.1m)	Field plot	15	C	93%	93%	98%
Dillaha et al. 1988	VA	VFS (9.1m)	Field plot	15-25	C	57%	72%	88%
Dillaha et al. 1989	VA	VFS (9.1m)	Field plot	3-8	C	65%	59%	70%
Chaubey et al. 1995	AR	VFS (9.2 m)	Field plot	3-8	C	74%	66.6%	

Source: Merriman et al. 2009

Table 2-25. Summary of Vegetated Filter Strip (VFS) characteristics and corresponding sediment-trapping efficiencies

Paper source	BMP	Location	Buffer width	Area ratio	Slope	Sediment trapping efficacy	Inflow	Outflow	Mass sediment reduction
			m	buffer/plot	-----------%-----------		-------------------------kg-------------------------		
Young et al. (1980)	VFS†		4.06	0.028	4	79	35.37	6.4	28.97
Hall et al. (1983)	VFS	Pennsylvania	6	0.27	14	76	0.000008	0.000002	0.000006
Hayes and Hairston (1983)	VFS	Mississippi	2.6		2.35	60			
Dillaha et al. (1989)	VFS	Virginia	9.1	0.5	11	97.5			
	VFS	Virginia	4.6	0.25	11	86			
	VFS	Virginia	9.1	0.5	16	70.5			
	VFS	Virginia	4.6	0.25	16	53.5			
	VFS	Virginia	9.1	0.5	5	93			
	VFS	Virginia	4.6	0.25	5	83.5			
Magette et al. (1989)	VFS	Maryland	9.2	0.42	2.7	92.4	70.8	5.4	65.4
	VFS	Maryland	4.6	0.21	2.7	82.8	70.8	12.2	58.6
	VFS	Maryland	9.2	0.42	2.7	88.3	16.2	1.9	14.3
	VFS	Maryland	4.6	0.21	2.7	64.3	13.6	4.97	11.23
	VFS	Maryland	9.2	0.42	4.1	80.3	13.6	2.68	10.92
	VFS	Maryland	4.6	0.21	4.1	65.8		4.65	8.95
Partons et al. (1990)	VFS	North Carolina	4.3	0.12	3.25	75			
	VFS	North Carolina	8.5	0.23	3.25	85			
Parsons et al. (1994)	VFS	North Carolina	4.3	0.12	1.9	78			
	VFS	North Carolina	8.5	0.23	1.9	81			
Coyne et al. (1995)	VFS	Kentucky	4.6	0.4	9	99	0.014	0.002	0.012
Arora et al. (1996)	VFS	Iowa	20.12	0.033	3	83.6			
	VFS	Iowa	20.12	0.067	3	87.6			

Table 2-25. Summary of Vegetated Filter Strip (VFS) characteristics and corresponding sediment-trapping efficiencies *(continued)*

Paper source	BMP	Location	Buffer width	Area ratio	Slope	Sediment trapping efficacy	Inflow	Outflow	Mass sediment reduction
			m	buffer/plot	-----------%----------		-------------------------kg------------------------		
Daniels and Gilliam (1996)	VFS	North Carolina	3	0.034	4.9	59			
	VFS	North Carolina	6	0.071	4.9	61			
	VFS	North Carolina	3	0.034	2.1	45			
	VFS	North Carolina	6	0.071	2.1	57			
Robinson et al. (1996)	VFS	Iowa	3	0.05	7	70			
	VFS	Iowa	3	0.05	12	80			
	VFS	Iowa	9.1	0.15	12	85			
	VFS	Iowa	9.1	0.15	7	85			
Van Dijk et al. (1996)	VFS	Netherlands	1		5.2	49.5			
	VFS	Netherlands	4		5.2	78.5			
	VFS	Netherlands	5		2.3	73			
	VFS	Netherlands	10		2.3	94			
	VFS	Netherlands	5		2.5	64.5			
	VFS	Netherlands	10		2.5	99			
	VFS	Netherlands	5		8.5	92			
	VFS	Netherlands	10		8.5	97.5			
Patty et al. (1997)	VFS	Brittan, France	6	0.12	7	98.9	493.2	5.44	487.76
	VFS	Brittan, France	12	0.24	7	99	493.2	3.7	489.5
	VFS	Brittan, France	18	0.36	7	99.9	493.2	0.37	492.83
	VFS	Brittan, France	6	0.12	10	87	20.4	2.53	17.87
	VFS	Brittan, France	12	0.24	10	100	20.4	0	20.4
	VFS	Brittan, France	18	0.36	10	100	20.4	0	20.4
	VFS	Brittan, France	6	0.12	15	91	309.16	28.71	280.45
	VFS	Brittan, France	12	0.24	15	97	309.16	8.21	300.95
	VFS	Brittan, France	18	0.36	10	98	309.16	4.8	304.36
Barfield et al. (1998)	VFS	Kentucky	4.57	0.21	9	97	258	8.44	249.56
	VFS	Kentucky	9.14	0.41	9	99.9	212	1.1	210.9
	VFS	Kentucky	13.72	0.62	9	99.7	361	2.06	358.94
Coyne et al. (1998)	VFS	Kentucky	9	0.41	9	99			
	VFS	Kentucky	4.5	0.24	9	95			
	VFS	Kentucky	9	0.67	9	98			
Tingle et al. 1998)	VFS	Mississippi	0.5	0.018	3	88	0.018	0.0022	0.0158
	VFS	Mississippi	1	0.045	3	93	0.036	0.0024	0.0336
	VFS	Mississippi	2	0.09	3	94	0.072	0.004	0.068
	VFS	Mississippi	3	0.14	3	96	0.108	0.0048	0.1032
	VFS	Mississippi	4	0.18	3	98	0.144	0.0032	0.1408
Munoz-Carpena et al. (1999)	VFS	North Carolina	4.3	0.11	6	86	64.76	1.74	63.02
	VFS	North Carolina	8.5	0.22	6	93	54.88	3.99	50.89
Schmitt et al. (1999)	VFS	Nebraska	7.5	0.093	6.5	85	3.99	1.3	2.69
	VFS	Nebraska	15	0.19	6.5	96	3.01	0.84	2.17

Table 2-25. Summary of Vegetated Filter Strip (VFS) characteristics and corresponding sediment-trapping efficiencies *(continued)*

Paper source	BMP	Location	Buffer width	Area ratio	Slope	Sediment trapping efficacy	Inflow	Outflow	Mass sediment reduction
			m	buffer/plot	------------%-----------		-------------------------kg-------------------------		
Sheridan et al. (1999)	VFS	Georgia	8	0.03	2.5	81			
Lee et al. (2000)	VFS	Iowa	7.1	0.32	5	70	2.82	0.85	1.97
Abu-Zreig et al. (2004)	VFS	Canada	2	0.2	2.3	68	5887	1876	4011
	VFS	Canada	15	0.025	2.3	98	9324	219	9105
Blanco-Canqui et al. (2004)	VFS	Columbia, MIssouri	8	0.09	5	90	$1.6*10^{-8}$	$1.3*10^{-10}$	$1.58*10^{-8}$
Borin et al. (2005)	VFS	Northeast Italy	6		1.8	94	3450	200	3250
Helmers et al. (2005)	VFS	Nebraska	13	0.06	1	80	147	29	118
Gharabaghi et al. (2006)	VFS	Ontario, Canada	2.5			50			
	VFS	Ontario, Canada	20			98			
Young et al. (1980)	Riparian buffer		21.3		4	78			
	Riparian buffer		27.4		4	79			
Peterjohn and Correll (1984)	Riparian buffer	Maryland	19		5	90			
	Riparian buffer	Maryland	60		5	94	3.99	1.3	2.69
Dillaha et al. (1988)	Riparian buffer		4.6		11	87			
	Riparian buffer		4.6		16	76			
	Riparian buffer		9.1		11	95			
	Riparian buffer		9.1		16	88			
Dillha et al. (1989)	Riparian buffer		4.6		11	86	$0.1*10^{-6}$	$0.2*10^{-7}$	$0.8*10^{-7}$
	Riparian buffer		4.6		16	53	$2.3*10^{-7}$	$1.1*10^{-7}$	$1.2*10^{-7}$
	Riparian buffer		9.1		11	98	$2*10^{-7}$	$0.1*10^{-7}$	$1.9*10^{-7}$
	Riparian buffer		9.1		16	70	$4.5*10^{-7}$	$1.4*10^{-7}$	$3.1*10^{-7}$
Fiener and Auerswald (2003)	Grassed waterways	Munich	35	0.16	9.3	97	330.72	7.42	323.3
	Grassed waterways	Munich	17.5	0.12	9	77	175.74	40.02	135.72
Fiener and Auerswald (2005)	Grassed waterways	Central Europe	18.5	0.076	3.6	93			

† VFS represents vegetated filter strips.

Source: Liu et al. 2008

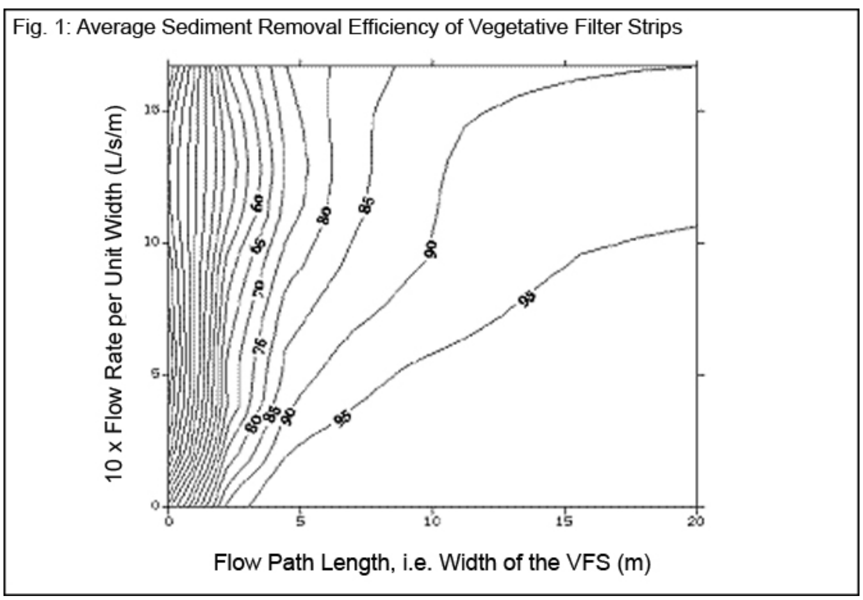
Ghadiri et al. (2001) developed a set of laboratory experiments with a tilting flume to investigate the effects of buffer strips on flow hydrology and sediment transport/deposition in and around the strips. The investigators found that flow retardation initiates above the strip and can begin to remove sediment. The results summarized in Table 2-26 show sediment deposition ranging from 18 to 77 percent, but caution is advised when applying those laboratory results to field conditions. In a study of simulated filter strips, Jin et al. (2002) found that adding a mulch barrier increased the sediment trapping efficiency of filter strips by 10–60 percent compared with the same flow, slope, and filter strip conditions without mulch. The observed interactions of crop residue mulches and filter strips suggest that combining residue management systems with vegetative buffer strips containing an upslope edge of strong vegetation offer potential synergies for increased conservation effectiveness. Jin and Romkens (2001) found that over 80 percent of the sediment trapped by a vegetative (or vegetated) filter strip (VFS) was deposited in the approach channel to the VFS and in the upper half of the VFS. As the slope increased, deposition moved downstream and deposited sediment became larger.

Table 2-26. Effect of high-density grass strip on sediment concentration on different slopes

Slope (%)	Sediment concentration (g/L)			Sediment deposited (%)	
	Unaffected flow	In the backwater	After grass strip	In the backwater	Inside grass strip
1.5	1.25	1.02	1.06	18	– 4
2.0	4.30	3.11	3.20	28	+ 3
3.4	17.44	10.76	11.01	38	– 2
5.2	78.63	18.15	16.81	77	+ 7

Source: Ghadiri et al. 2001

In a field experiment in Ontario, Gharabaghi et al. (2001) compared sediment removal efficiency using a variety of filter widths (2.44, 4.88, 9.67 and 19.52 m), flow rates, and slopes. They found that sediment removal ranged from 50 to 98 percent and generally found little improvement for widths greater than 10 m. Sediment removals are depicted in Figure 2-6.



Source: Gharabaghi et al. 2001

Figure 2-6. Average sediment-removal efficiency of VFS.

In a Raritan Basin (New Jersey) case study, Qiu et al. (2009) compared the placement of fixed-width buffers using regulatory rules, variable-width buffers according to watershed initiatives, and variable source area-based conservation buffer placement strategy derived from an alternative concept of watershed hydrology. The authors showed that there is little difference in cost-effectiveness between fixed- and variable-width buffers but that the variable source area-based buffer placement strategy, which targets the most hydrologically critical source areas in a watershed tier buffer placement, is more cost-effective.

In a riparian buffer in Connecticut, one-half of a 35 m by 250 m riparian buffer cropped in corn was seeded with fine-leaf fescue and allowed to remain idle (Clausen et al. 2000). TKN and TP concentrations significantly (P less than 0.05) increased as groundwater flowed through the restored buffer, while NO_3 concentrations declined significantly with most (52 percent) of the decrease occurring within a 2.5-m wetland adjacent to the stream. An N mass balance for the 2.5-m strip indicated that denitrification accounted for only one percent of the N losses and plant uptake accounted for 7–13 percent of the N losses annually. Groundwater was the dominant source of N to the buffer and also the dominant loss pathway. Restoring the riparian buffer decreased (p less than 0.05) overland flow concentrations of TKN by 70 percent, NO_3-N by 83 percent, TP by 73 percent, and TSS by 92 percent as compared with the control. Restoration reduced (P less than 0.05) NO_3-N concentrations in groundwater by 35 percent as compared with the control. Underestimated denitrification and dilution by upwelling groundwater in the wetland area adjacent to the stream were believed to be primarily responsible for the lower NO_3-N concentrations observed.

In a plot study, Dosskey et al. (2007) examined whether filter strip effectiveness changes over time and if temporal change depends on vegetation type. Plots containing all-grass (New Grass) and grass with trees and shrubs (New Forest) were established in 1995 among plots that contained either grass since 1970 (Old Grass) or were recultivated and replanted annually with grain sorghum (Crop). Once each summer, in 1995, 1996, 1997, 2003, and 2004, identically prepared solutions containing sediment, N and P fertilizer, and bromide tracer were applied to the upper end of each plot during a simulated rainfall event. The authors concluded that filter strip performance improves over time, with most of the change occurring within three growing seasons after establishment. Infiltration characteristics account for most of that change, and grass and forest vegetation are equally effective as filter strips for at least 10 growing seasons after establishment.

Lee et al. (2003) used a field plot study to determine the effectiveness of an established multi-species buffer in trapping sediment, N, and P from cropland runoff during natural rainfall events. A switchgrass buffer removed 95 percent of the sediment, 80 percent of the N, 62 percent of the NO_3-N, 78 percent of the P, and 58 percent of the phosphate-phosphorus (PO_4-P), while a switchgrass/woody buffer removed 97 percent of the sediment, 94 percent of the TN, 85 percent of the NO_3-N, 91 percent of the TP, and 80 percent of the PO_4-P in the runoff. In an earlier study using the same plots, Lee et al. (2000) found generally similar results; during a 2-hour rainfall simulation at 25 mm/h, the switchgrass buffer removed 64, 61, 72, and 44 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively. The switchgrass-woody buffer removed 80, 92, 93, and 85 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively. During a 1-hour rainfall simulation at 69 mm/h, the switchgrass buffer removed 50, 41, 46, and 28 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively, The switchgrass-woody plant buffer removed 73, 68, 81, and 35 percent of the incoming TN, NO_3-N, TP, and PO_4-P, respectively. In both studies, the switchgrass buffer was effective in trapping coarse sediment and sediment-bound nutrients, but the additional buffer width with high infiltration capacity provided by the deep-rooted woody plant zone was effective in trapping the clay and soluble nutrients.

Using a set of 36 field lysimeters with six different ground covers (bare ground, orchardgrass, tall fescue, smooth bromegrass, timothy, and switchgrass), Lin et al. (2007) evaluated the ability of grasses to reduce nutrient levels in soils and shallow groundwater. The leachate from each lysimeter was collected after major rainfall events during a 25-day period, and soil was collected from each lysimeter at the end of the 25-day period. Grass treatments reduced NO_3-N levels in leachate by 74.5 to 99.7 percent compared to the bare ground control, but timothy was significantly less effective at reducing NO_3-N leaching than the other grasses. Switchgrass decreased PO_4-P leaching to the greatest extent, reducing it by 60.0 to 74.2 percent compared to the control. In a separate study, Bedard-Haughn et al. (2005) found that cutting vegetative buffers increased the uptake of NO_3-N 2.3 times that of uncut buffers.

The influence of vegetation characteristics, buffer width, slope, and stubble height on sediment retention was evaluated in a Montana study using three vegetation types (sedge wetland, rush transition, bunchgrass upland) on plots spanning 2 to 20 percent slopes (Hook 2003). Sediment retention was affected strongly by buffer width and moderately by vegetation type and slope, but it was not affected by stubble height. Mean sediment retention ranged from 63 to greater than 99 percent for different combinations of buffer width and vegetation type, with 94 to 99 percent retention in 6-m-wide buffers regardless of vegetation type or slope. Results suggest that rangeland riparian buffers should be at least 6 m wide, with dense vegetation, to be effective and reliable.

Mankin et al. (2007) studied the effectiveness of established grass-shrub riparian buffer systems in reducing TSS, P, and N using simulated runoff on nine plots with buffer widths ranging from 8.3 to 16.1 m. Vegetation types were all natural selection grasses (control), a 2-segment buffer with native grasses and plum shrub, and a 2-segment buffer with natural selection grasses and plum shrub. Removal efficiencies were strongly linked to infiltration, with TSS mass and concentration reductions averaging 99.7 percent and 97.9 percent, TP reductions of

91.8 percent and 42.9 percent, and TN reductions at 92.1 percent and 44.4 percent. Mankin et al. (2007) concluded that adequately designed and implemented grass-shrub buffers with widths of 8 m provide for water quality improvement, particularly if adequate infiltration is achieved.

Hoffman et al. (2009) examined the main hydrological pathways for P losses from and P retention in riparian buffers. They determined that P retention rates of up to 128 kg P/ha-yr can be accounted for by sedimentation, while plant uptake can temporarily immobilize up to 15 kg P/ha-yr. Dissolved P retention is often below 0.5 kg P/ha-yr, and the authors note that several studies have shown significant release of dissolved P up to 8 kg P/ha-yr.

In Finland, the effects of 10-m–wide, annually cut grass buffer zones and vegetated buffer zones under natural vegetation were compared on 70-m-long by 18-m-wide plots with no buffer zone (Uusi-Kamppa 2006). Retention of TS, TP, and PP was greater than 50, 40, and greater than 45 percent, respectively, for both treatments.

In northeast Italy, a 5-m-wide grass strip and a 1-m-wide row of trees were evaluated with corn and wheat from 1997 to 1999 (Borin and Bigon 2002). Under a variety of fertilization levels and tree sizes, water discharged from the strip was always below 2 mg/L NO_3-N. Tree size showed no evident effect on the reduction of the concentration. In a companion study from 1998 to 2001, Borin et al. (2005) evaluated 6-m buffer strips with adjoining fields of corn-wheat-soybeans. The buffer strip was composed of two rows of regularly alternating trees and shrubs, with grass in the inter-rows. Total runoff was reduced by 78 percent. TSS concentrations at the control was 2–7 times greater than the TSS of 0.14 mg/L from the buffer strip. N concentrations through the buffer strip were higher than control, but mass export was reduced from 17.3 to 4.5 kg/ha.

Practice Costs

Contour buffer strips cost about $270/ac in Virginia, and typical total costs are about $2,700 (USDA-NRCS 2010). Filter strips cost about $262 and $322 per acre for warm-season and cool-season grasses, respectively. Total costs are typically $524 for warm-season grasses and $645 for cool-season grasses.

Field borders using grasses cost about $210/ac for warm-season grasses and $330/ac for cool-season grasses, with typical total costs of about $420 and $650, respectively (USDA-NRCS 2010). Various mixtures of peas, mixed shrubs, and Indian grass cost about $300/ac to $400/ac, with total costs of $600 to $800. High-end mixtures including wildflowers can cost $1,300/ac, for a typical total cost of about $2,600. Hedgerow planting with hardwoods costs are approximately $910/ac ($455 total), whereas hedgerow planting with mixed shrub seedlings can range from

$951 to $1,419 per acre ($476 to $709 total cost) depending on the shrubs used (USDA-NRCS 2010).

Riparian forest buffers incorporating hardwoods generally cost around $900 to $1500 per acre in Virginia, with typical total costs ranging from $6,400 to $10,600 (USDA-NRCS 2010).

4.2 Soil Amendment

Implementation Measure A-17:

Treat buffer or riparian soils with alum, WTR, gypsum, or other materials to adsorb P before field runoff enters receiving waters.

It has been widely observed that adding materials like alum, alum-based residuals, gypsum, and other materials to soils can be effective in reducing water-soluble P concentrations in manure-treated soils. Some researchers have evaluated the ability of such soil amendment—either as area-wide applications or as buffer strips—to reduce or intercept nutrient runoff before delivery from upland fields into adjacent waterways.

Gallimore et al. (1999) reported that dissolved P in runoff was reduced by 46 percent by a buffer strip treated with WTR on the lower 25 percent of plots. Soluble NH_4-N was also reduced significantly. Dayton and Basta (2005b) found that adding alum-based residuals to soils as an enhanced buffer strip reduced mean dissolved P in runoff water by 3–38 percent for a 5 Mg/ha application, by 25–50 percent for a 10 Mg/ha addition, and by 67–86 percent for a 20 Mg/ha addition.

DeWolfe (2006) reported that surface application of WTR to soils (previously amended with poultry litter) at 10 Mg/ha decreased runoff P from 53–69 percent; application at 20 Mg/ha decreased runoff P from 68–87 percent. Penn and Bryant (2006) tested several sorbing materials including alum, gypsum, and fly ash to reduce P losses from streamside cattle loafing areas. All amendments reduced runoff dissolved P concentrations initially—alum (98–99 percent), WTR (81 percent), gypsum (74–88 percent) and fly ash (60 percent); however, after 28 days, runoff P concentrations were not significantly different from untreated plots.

Promising research is underway on using materials such as gypsum (Feyeriesen et al. 2008) and steel slag (Weber et al. 2007) for sorption of P in field runoff.

4.3 Wetlands

Implementation Measure A-18:

Restore wetlands and riparian areas from adverse effects. Maintain nonpoint source abatement function while protecting other existing functions of the wetlands and riparian areas such as vegetative composition and cover, hydrology of surface water and groundwater, geochemistry of the substrate, and species composition.

Properly functioning natural wetlands and riparian areas (discussed in Chapter 5) can significantly reduce nonpoint source pollution by intercepting surface runoff and subsurface flow and by settling, filtering, or storing sediment and associated pollutants. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent waterbodies. Loss of natural wetlands and riparian areas allows a more direct contribution of nonpoint source pollutants to receiving waters. Degraded wetlands and riparian areas can even become pollutant sources. Thus, natural wetlands and riparian areas should be protected and should not be used as designated erosion control practices. Their nonpoint source control functions are most effective as part of an integrated land management system focusing on nutrient, sediment, and erosion control practices applied to upland areas.

Protection of the full range of functions for wetlands and riparian areas are discussed in *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution* (USEPA 2005). Protection of wetlands and riparian areas should allow for both nonpoint source pollution control and maintenance of other benefits of other ecosystem services such as wildlife habitat, flood mitigation, and water storage.

The following practices can protect wetlands and riparian areas:

- Identify existing functions of those wetlands and riparian areas with significant nonpoint source control potential when implementing management practices.
- Do not alter wetlands or riparian areas to improve their water quality functions at the expense of their other functions.
- Use appropriate preliminary treatment practices such as erosion control, vegetated treatment systems or detention, or retention basins to prevent adverse effects on wetland functions that affect nonpoint source pollutant abatement from hydrologic changes, sedimentation, or contaminants.

Wetlands and Acreman (2004) gathered data from 57 wetlands from around the world to evaluate nutrient removal efficacy. Table 2-27 displays a list of those wetlands, and Figure 2-7 displays the removal efficiencies for N and P as a function of loading. The correlation for N is statistically significant while the regression line for P is not.

Table 2-27. Summary of wetlands evaluated

Summary of references studied showing wetland name, wetland type and country of location. References are split into those showing an increase in nutrient loading, decrease in nutrient loading and those showing no change.

Author(s)	Date	N or P	Wetland name	Wetland type	Country
Nutrient Retention					
Raisin and Mitchell	1995	TPN	Humphrey's wetland	Mash/swamp	Australia
Raisin and Mitchell	1995	TP	Reid's wetland	Mash/swamp	Australia
Jacobs and Gilliam	1985	NO_3	Unknown	Riparian	USA
Cooper and Gilliam	1987	P	Unknown	Riparian	USA
Lowrance et al.	1984	NO_3	Unknown	Riparian	USA
Cooke	1994	P, NO_3	Unknown	Mash/swamp	New Zealand
Bugenyi	1993	N, P	Unknown	Riparian	Uganda
Patruno and Russell	1994	N, P	Yamba wetland	Marsh/swamp	Australia
Baker and Maltby	1995	NO_3, NO_4	Kismeldon Meadows and Bradford Mill	Riparian	UK
Peterjohn and Correll	1984	sol P	Rhode River drainage basin	Riparian	USA
Jordan et al.	1993	NO_3, TP	Chester River catchment	Floodplain	USA
Gehrels and Mulamootth	1989	TP	Unknown	Marsh/swamp	USA
Burt et al.	1998	NO_3	R. Leach floodplain	Floodplain	UK
Haycock and Burt	1993	NO_3	R. Leach floodplain	Floodplain	UK
Cooper	1994	NO_3	Unknown	Swamp	NZ
Prior	1998	N, P	R. Lambourn floodplain	Floodplain	UK
Haycock and Pinay	1993	NO_3	R. Leach floodplain	Riparian	UK
Chauvelon	1998	N, P	Rhone river delta	Riverine delta	France
Maltby et al.	1995	N	Floodplains in Devon	Floodplain	UK
Osborne and Totome	1994	TP, SRP, NH_4	Waigani	Marsh/swamp	Papua N. Guinea
Cooper	1990	NO_3	Scotsman Valley, NZ	Riparian	New Zealand
Lindkvist and Hakansson	1993	TP	Unknown	Unknown	Sweden
Lindkvist	1992	TP	Unknown	Unknown	Sweden
Mander et al.	1991	TP	Unknown	Various	Estonia
Nunez Delgado et al.	1997	NO_3	Unknown	Riparian	Spain
Mander et al.	1997	N, P	Porijogi River catchment	Riparian	Estonia
Downes et al.	1997	NO_3	Whangamata Stream	Riparian	New Zealand
Brinson et al.	1984	N, P	Tar River floodplain	Riparian	USA
Brunet	1994	PN	Adour River floodplain	Floodplain	France
Tilton and Kadlec	1979	N, P	Unknown	Fen	USA
Burke	1975	N, P	Unknown	Peat land	Ireland
Boyt et al.	1977	P	Unknown	Marsh/swamp	USA
Spangler	1977	P	Unknown	Marsh/swamp	USA
Yonika and Lowry	1979	N	Unknown	Marsh/swamp	USA

Table 2-27. Summary of wetlands evaluated *(continued)*

Author(s)	Date	N or P	Wetland name	Wetland type	Country
Semkin et al.	1976	N, P	Unknown	Marsh/swamp	USA
Semkin et al.	1976	N, P	Unknown	Marsh/swamp	USA
Johnston et al.	1984	N, P	nr White Clay Lake	Marsh/swamp	USA
Johnston et al.	1984	N, P	nr White Clay Lake	Riparian	USA
Pinay and Decamps	1988	N	Garonne Valley	Riparian	France
Jordon et al.	2003	TN, TP	Kent Island	Marsh/swamp	USA
Mwanuzi et al.	2003	$P0_4$	Unknown	Riparian	Tanzania
Rzepecki	2002	sol P	Unknown	Riparian	Poland
Zhang et al.	2000	TN, TP	Unknown	Marsh/swamp	USA
Bratli et al.	1999	N, P	Unknown	Marsh/swamp	Norway
Kellog and Bridgeham	2003	$P0_4$	Unknown	Peat land	USA
Kansiime and Nalubega	1999	N	Unknown	Marsh/swamp	Uganda
Kansiime and Nalubega	1999	N	Unknown	Marsh/swamp	Uganda
Chescheir et al.	1991	TP, NO_3	Unknown	Riparian	USA
Dorge	1994	NO_3	Rabis Baek	Peat land	Denmark
Dorge	1994	NO_3	Syvbaek	Riparian	Denmark
Dorge	1994	NO_3	Glumso	Marsh/swamp	Denmark
Schlosser and Karr	1981	TP	Champaign-Urbana	Riparian	USA
Hanson et al.	1994	NO_3	nr Kingston	Riparian	USA
Schwer and Clausen	1989	TP, TN	nr Charlotte	Riparian	USA
Daniels and Gilliam	1996	N, P	Cecil soil area	Riparian	USA
Nutrient Addition					
Cook	1994	NO_3	Unknown		New Zealand
Peterjohn and Correll	1984	sol P	Unknown	Riparian	USA
Jordan et al.	1993	N, P	Chester River catchment	Floodplain	USA
Gehrels and Mulamootth	1989	sol P	Unknown	Marsh/swamp	USA
Prior	1998	TDN, TDP	R. Lambourne floodplain	Floodplain	UK
Osborne and Totome	1994	NO_2, NO_3	Waigani	Marsh/swamp	Papua N. Guinea
Downes et al.	1997	NO_3, SRP	Whangamata Stream	Riparian	New Zealand
Clausen et al.	1993	TN	Unknown	Riparian	USA
Daniels and Gilliam	1996	N, P	Georgeville soil area	Riparian	USA
No Nutrient Retention/Addition					
Raisin and Mitchell	1995	TPN	Reid's wetland	Marsh/swamp	Australia
Kadlec	1985	P	Unknown	Marsh/swamp	USA
Elder	1985	N	Apalachicola River floodplain	Floodplain	USA
Ontkean et al.	2003	N, P	Hilton Wetland	Pond	Canada
Daniels and Gilliam	1996	TP, PO_4	Georgeville soil area	Riparian	USA

Source: Adapted from Fisher and Acreman 2004

Notes: N = several N species, P = several P species, TP = total phosphorus, TN = total or Kjeldahl N, sol = soluble N or P, SRP = soluble reactive P, TPN = total particulate N, PN = particulate N, PO_4 = orthophosphate, NO_3 = nitrate, NO_2 = nitrate and NH_4 = ammonium, including ammonium-N.

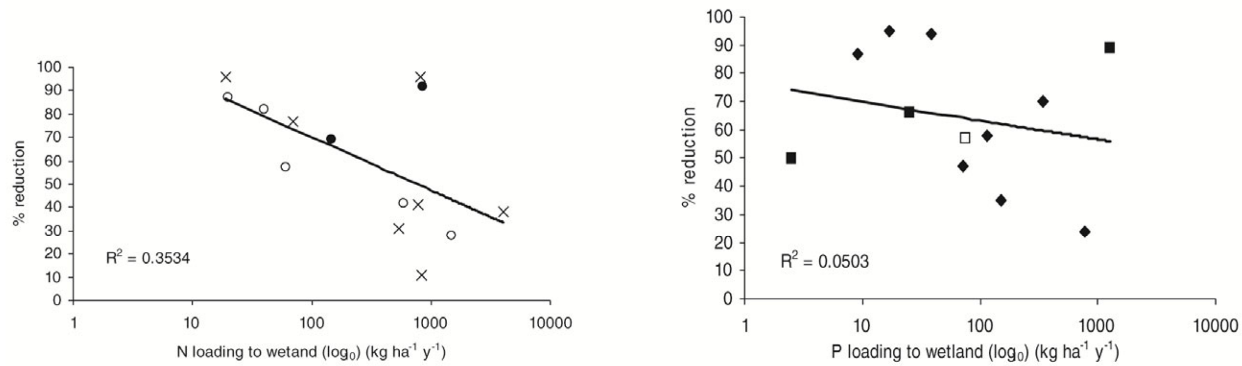


Fig. 4. *Relationship between nutrient reduction within wetlands and the amount of a) N loading to wetlands and b) P loading to wetlands reported in a study. (● = TN, O = nitrate and × = several N species and b) P loading to wetlands, ■ =TP, □ = orthophosphate and ◆ = several P species).*

Source: Fisher and Acreman 2004

Figure 2-7. Percent nutrient reduction as a function of loading.

On Kent Island, Maryland, a 1.3-ha restored wetland received the unregulated inflows from a 14-ha agricultural watershed (Jordan et al. 2003), and the ability of the wetland to remove nutrients was examined over 2 years after its restoration. Most nutrient removal occurred in the first year, which included a 3-month period of decreasing water level in the wetland. In that year, the wetland removed 59 percent of the TP, 38 percent of the TN, and 41 percent of the TOC it received. However, in the second year, which lacked a drying period, there was no significant (P greater than 0.05) net removal of TN or P, although 30 percent of the TOC input was removed. For the entire 2-year period, the wetland removed 25 percent of the ammonium, 52 percent of the NO_3, and 34 percent of the organic carbon it received, but there was no significant net removal of TSS or other forms of N and P.

A wetland mesocosm experiment was conducted in eastern North Carolina to determine if organic matter (OM) addition to soils used for in-stream constructed wetlands would increase NO_3-N treatment (Burchell et al. 2007). Four batch studies, with initial NO_3-N concentrations ranging from 30 to 120 mg/L, were conducted in 2002 in 21 surface-flow wetland mesocosms. The results indicated that increasing the OM content of a Cape Fear loam soil from 50 g/kg to 110 g/kg enhanced NO_3-N wetland treatment efficiency in spring and summer batch studies, but increases to 160 g/kg OM did not. Increased OM addition and biosolids to the Cape Fear loam significantly increased biomass growth in the second growing season when compared to no OM addition. Those findings indicate that increased OM in the substrate will reduce the area required for in-stream constructed wetlands to treat drainage water in humid regions.

A small-scale wetland system was constructed and monitored for several years to quantify nutrient removal near Steamboat Creek, a tributary of the Truckee River in Nevada (Chavan et al. 2007). Results indicated seasonal variations in nutrient removal with 40–75 percent of TN and 30–60 percent of TP being removed, with highest removals during summer and lowest removals during winter. In a following study to evaluate the effectiveness of a large-scale wetland, 10 parallel pilot-scale wetland mesocosms were used to test the effects of drying and rewetting, hydraulic retention time, and high N loading on the efficiency of nutrient and TSS removal (Chavan et al. 2008). During increased influent N loading (9.5 +/- 2.4 mg/L), manipulated mesocosms functioned as sinks for TN with removal efficiency increasing from 45 +/- 13 percent to 87 +/- 9 percent. The average change in TN concentration was 9.1 +/- 2.2 mg/L. TP removal was associated with TSS removal.

Wetlands dominated by submerged aquatic vegetations (SAVs) can take up nutrients, particularly P, from surface flow with high efficiency. In a 1999–2001 study in South Florida, samples were collected from four small constructed test cells (wetlands) (Gu 2008). Test cells receiving higher TP (average = 75 µg/L) displayed a removal efficiency of 60 percent while test cells receiving lower TP (average = 23 µg/L) had a 20 percent removal efficiency. In a similar study, Gu and Dreschel (2008) evaluated the effectiveness of constructed wetlands from 2002–2004. Test cells receiving higher TP (average = 72 µg/L) displayed a removal efficiency of 56–65 percent while test cells receiving lower TP (average = 43 µg/L) had a 35–62 percent removal efficiency with a hydraulic loading rate of 9.27 in/yr.

The restoration plan for the Everglades includes construction of large stormwater treatment areas (STAs) to intercept and treat relatively high nutrient water down to very low TP concentrations (White et al. 2006). One such STA has been in operation for approximately 10 years and contains both emergent aquatic vegetation (EAV) and SAV communities. The authors investigated the interaction of vegetation type (EAV or SAV) and hydrology (continuously flooded or periodic drawdown) on the P removal capacity in mesocosms packed with peat soil obtained from the STA. The surface water had low TP concentrations with an annual mean of 23 µg/L. For SRP and TP, hydrologic fluctuations had no discernable effect on P treatment while vegetation type showed a significant effect. Influent SRP decreased by 49 percent for the SAV treatments compared with 41 percent for the EAV treatments, irrespective of hydrology treatment. The reduction of dissolved organic P was also higher for the SAV treatment, averaging 33 percent, while showing a reduction of 11 percent for the EAV treatments. There was no significant difference in the treatment efficiency of particulate P across the treatments. The SAV treatments removed 45 percent of TP while EAV removed significantly less at 34 percent of TP. By mass calculations, the EAV required 85 percent more P for plant growth than was removed from the water column in one year compared with only 47 percent for the SAV. Therefore, the EAV *mined* substantially more P from the relatively stable peat soil, translocating it into the detrital pool.

In an examination of benefits to water quality provided by a natural, flow-through wetland and a degraded, channelized wetland within the flood-irrigation agricultural landscape of the Sierra

Nevada foothills of northern California, Knox et al. (2008) found that the nondegraded, reference wetland significantly improved water quality by reducing loads of TSS, NO_3, and *E. coli* on average by 77, 60, and 68 percent, respectively. Retention of TN, TP, and SRP was between 35 and 42 percent of loads entering the reference wetland. Retention of pollutant loads by the channelized wetland was significantly lower than by the reference wetland for all pollutants except SRP. A net export of sediment and NO_3 was observed from the channelized wetland. Decreased irrigation inflow rates significantly improved retention efficiencies for NO_3, *E. coli*, and sediments in the reference wetland. It is suggested that maintaining such natural wetlands and regulating inflow rates can be important aspects of a BMP to improve water quality in runoff from irrigated pastures.

Practice Costs

Wetland enhancements costs in Virginia include $0.47/ft^2 ($2,575 typical total cost) for excavated seasonal pools in hydric soil sites, $0.026/ft^2 ($145 total) for broadcasting a wetland plant seed mixture, and $0.98/ac ($5,370 total) for wetland plant plugs (USDA-NRCS 2010).

4.4 Drainage Water Management

Subsurface drainage is a water management practice that is commonly used on many highly productive fields in areas such as the Atlantic Coastal Plain and the Midwest, but because NO_3 carried in drainage water contributes to water quality problems in the Chesapeake Bay (as well as some other waterbodies such as the Gulf of Mexico), strategies are needed to reduce the NO_3 loads while maintaining adequate drainage for crop production (Frankenberger et al. 2006). Drainage is generally achieved with open ditches or buried pipe accompanied by either gravity-based or pumped outlets. Practices that can reduce NO_3 loads on tile-drained soils include the following (Frankenberger et al. 2006):

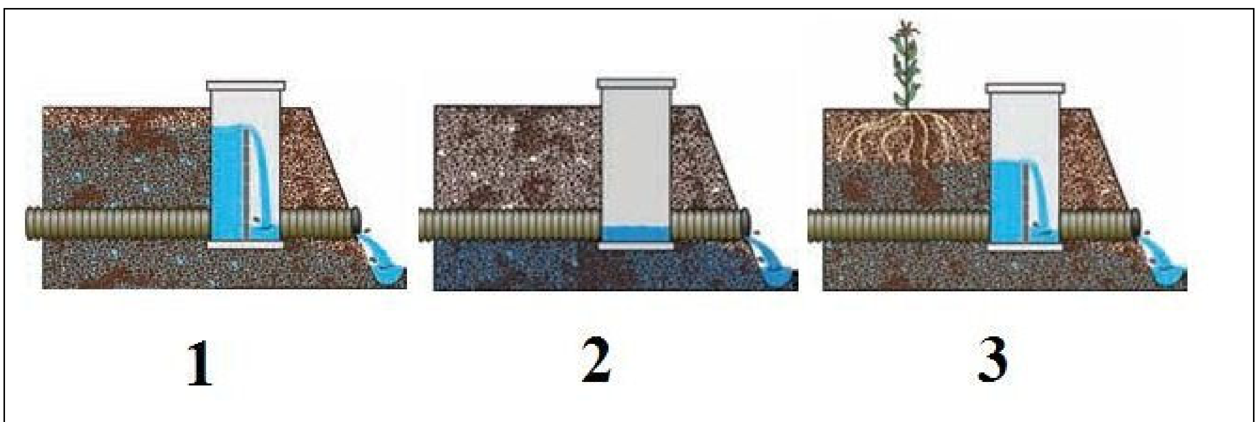
- Fine-tuned fertilizer application rates and timing
- Winter forage or cover crops
- Controlled drainage and water table management
- Ditch management
- Bioreactors to treat drainage water
- Constructed wetlands

Fertilizer management and cover crops are addressed in this document in Sections 2.1 and 3.3 respectively, whereas the other practices are addressed here. In addition, irrigation tailwater recovery systems are not included in this document.

Controlled drainage is the control of surface and subsurface water through use of drainage facilities and water control structures. Water table management is any combination of management, control, or regulation of soil-water conditions in the profile of agricultural soils through the use of water management structures (e.g., subsurface drains, water control structures, and water conveyance facilities) and strategies designed specifically for the given site conditions (Brown 1997) (NRCS Practice Code 554). Graded ditches are used to collect or intercept excess surface or subsurface water and convey it to an outlet (USDA-NRCS 2008). Ditch management includes managing cleanouts and vegetation within the ditch. Bioreactors are one form of edge-of-field treatment of drainage water in which the drainage is diverted into a trench filled with wood chips (Minnesota Department of Agriculture No date). Constructed wetlands are constructed, shallow, earthen impoundments containing hydrophytic vegetation designed to treat both point and nonpoint sources of water (USDA-NRCS 2002).

In drainage water management, a water control structure in a main, sub-main, or lateral drain is used to manipulate the depth of the drainage outlet (Frankenberger et al. 2006). The water table must rise above the outlet depth for drainage to occur, as illustrated in Figure 2-8. The outlet depth, as determined by the control structure, is

- Raised after harvest to limit drainage outflow and reduce the delivery of NO_3 to ditches and streams during the off-season (1 in Figure 2-8)
- Lowered in early spring and again in the fall so the drain can flow freely before field operations such as planting or harvest (2 in Figure 2-8)
- Raised again after planting and spring field operations to create a potential to store water for the crop to use in midsummer (3 in Figure 2-8)



Source: Frankenberger et al. 2006; used with permission

Figure 2-8. Drainage control structure.

Implementation Measure A-19:

For both new and existing surface (ditch) and subsurface (pipe) drainage systems, use controlled drainage, ditch management, and bioreactors as necessary to minimize off-farm transport of nutrients.

Practice Effectiveness

Controlled drainage and water table management practice effectiveness

Numerous studies of the effects of controlled drainage have been conducted in North Carolina, the Midwest, and Canada (Table 2-28). The studies have shown that controlled drainage can significantly reduce discharge volume and NO_3 concentrations.

Table 2-28. Measured effectiveness of controlled drainage

Location	Soils and crops	Study type	Practice	Reference practice	Reduction vs. reference practice: Discharge	Reduction vs. reference practice: NO_3-N conc.	Reduction vs. reference practice: NO_3-N load	Source
North Carolina	Moderately well drained soils	Field	CD-flashboard riser	UD	85%		85%[a]	Gilliam et al. 1979
North Carolina	Poorly drained soils	Field	CD-flashboard riser	UD	50%		50%[b]	Gilliam et al. 1979
Illinois		Field	CD	UD			≤ 47%[c]	Kalita et al. 2007
Ohio	Corn-soybean, poorly drained	Plot	CD	UD	40%		45%	Fausey 2005
Ontario, Canada	Corn	Field	CDS	UD	24%	25%[d]	43%	Drury et al. 1996
Ontario, Canada	Corn	Field	CDS-CT	UD-MP			49%	Drury et al. 1996
Ontario, Canada	Corn	Plot	CDS	UD	-8%	41%[d]	36%	Ng et al. 2001
Ontario, Canada	Corn, soybeans	Plot	CDS	UD	36%	14%[d]	27%[e]	Tan et al. 2003
Ontario, Canada	Sandy loam	Field	CDS	UD	0%	38%[d]	37%	Tan et al. 2004
Ontario, Canada	Clay loam	Plot	CDS	UD	50%	32%	66%	

Table 2-28. Measured effectiveness of controlled drainage *(continued)*

Location	Soils and crops	Study type	Practice	Reference practice	Reduction vs. reference practice			Source
					Discharge	NO_3-N conc.	NO_3-N load	
Ontario, Canada	Corn (150 kg N/ha)-soybean (no N), clay loam	Field	CD	UD			44%[f]	Drury et al. 2009
	Corn (200 kg N/ha)-soybean (50 kg N/ha), clay loam	Field	CD	UD			31%[f]	
	Corn (150 kg N/ha)-soybean (no N), clay loam	Field	CDS	UD			66%[f]	Drury et al. 2009
	Corn (200 kg N/ha)-soybean (50 kg N/ha), clay loam	Field	CDS	UD			68%[f]	
Ontario, Canada	Silt loam, Corn-soybean strip-cropping	Field	CDS - .05 m	UD	–555% to 58%[g,h]	61%–84%[g]	0%–94%[g,i]	Mejia and Mandramootoo 1998
			CDS - .075m	UD	–583% to –70%[g,h]	52%–77%[g]	0%–30%[g,i]	
North Carolina	Various	Review[j]	CD	UD	30%[k,l]	≤20%[l,m]	45%[l,n]	Evans et al. 1996
Various	Various	Review[j]	CD	UD			50%	Appelboom and Fouss 2006
Various	Various	Review[j]	CD	UD	17%–85%		18%–85%	Skaggs and Youssef 2008

KEY: CD = controlled drainage, UD = Uncontrolled or traditional or free-tile drainage, CDS = controlled drainage-subirrigation, CDS-CT = controlled drainage-subirrigation with conservation tillage, UD-MP = Uncontrolled or traditional drainage with moldboard plowing.

Notes:

a. Load reduction due solely to discharge reduction; no change in NO_3-N concentration.
b. Reductions due to increased penetration to deeper soil horizons where denitrification occurred.
c. NO_3 load reductions due mostly to discharge reductions. Phosphate load reductions of up to 83%
d. Flow-weighted mean
e. Also reduced dissolved organic (47%) and dissolved inorganic (54%) P loads
f. TN
g. Monitoring only during growing season (April/May-November).
h. Increased discharge due to lack of management, subirrigation, and high rainfall, resulting in little storage for rainfall under CDS.
i. No significant difference in 1995 (0%), but significant difference in 1996 (94%, 30%).
j. Reviews include some of the field and plot studies shown.
k. When managed year-around; < 15% reduction during growing season.
l. Varies with soil type, rainfall, type of drainage, and management intensity
m. TKN concentration increases slightly. Decreases P concentration for surface drainage systems, but increases P concentration for subsurface systems.
n. NO_3-N + TKN; TP reduced by 35%

Flashboard riser-type water level control structures installed in tile mains or outlet ditches on moderately well-drained soils in the Coastal Plain of North Carolina reduced NO_3 movement through the ditches by 80–95 percent (from 25–40 kg/ha to 1–7 kg/ha) because of a reduction in effluent volume with no indication of increased denitrification in the field (Gilliam et al. 1979). The authors note that the reduction in transport through ditches does not necessarily prevent runoff from entering surface waters through other pathways, but ditch transport would increase the chance of the NO_3 being lost through denitrification or being absorbed by plants as the groundwater moves toward a seep at a lower elevation. In poorly drained soils, a 50 percent reduction in NO_3 movement through the drainage ditches was attributed to increased water movement into and through deeper soil horizons (below one m) where denitrification occurred. Factors considered to explain the reduction in flow volume through ditches were leaking or bypassing of control structures, evapotranspiration, and deep seepage. The authors conclude that evapotranspiration would likely explain some of the difference during the summer but that most of the difference in flow volume was due to an increase in lateral flow from the controlled fields through the sandy layers below the B horizon and above the aquiclude where essentially all the NO_3 would be denitrified. They therefore conclude that the decreased quantities of NO_3-N moving through the ditches in the poorly drained soils under controlled water conditions represented a real decrease in the amount of N entering surface waters.

Variability in the effectiveness of controlled drainage was reflected in two modeling studies in the coastal plain of North Carolina. In one study, it was assumed that controlled drainage reduced N by 40 percent but only if the slope in the channel is less than one percent and where the water table can be kept within 0.9 m of the soil surface for 50 percent of the field area (Wossink and Osmond 2001). Long-term modeling of Core Creek using the DRAINMOD-N model after calibration on a field-by-field basis with monitoring data from 4.5 years indicated that controlled drainage could reduce NO_3 loads by 10–12 percent, and a combination of controlled drainage and nutrient management could reduce NO_3 loads by 25–33 percent (Smeltz et al. 2005). Modeling predicted that controlled drainage would reduce the drainage outflow by 21.3 percent annually versus conventional drainage (accounting for 11.5 percent of the reduction in NO_3-N leaving the watershed), and that there was a potential for 30 percent and 75 percent NO_3 reductions for cotton or soybeans, respectively, as compared to corn.

Studies in the Midwest measured similar NO_3 load reductions from controlled drainage. A review of subsurface drainage in the Midwest revealed that drainage water management has achieved load reductions of up to 47 percent and 83 percent for NO_3 and phosphate, respectively (Kalita et al. 2007). In a replicated field plot experiment to examine the hydrology, water quality, and crop yield effects of controlled drainage, uncontrolled drainage, and subirrigation drainage on Hoytville silty clay soil in Ohio, it was found that controlled drainage during the non-growing season reduced annual flows by 40 percent, yielding a 45 percent reduction in annual NO_3 loads from a corn-soybean production system (Fausey 2005).

In a 3-year study on Nicollet loam and silt-loam soils in Iowa, water-table depths of 0.3, 0.6, and 0.9 m were maintained in field lysimeters at one site, and water-table depths averaging 0.2, 0.3, 0.6, 0.9, and 1.1 m were maintained at a second site to determine the effects of controlled drainage-subirrigation (CDS) on NO_3 concentrations in groundwater (Kalita and Kanwar 1993). The lowest NO_3 concentrations in groundwater were observed under the shallow water-table depths, with NO_3 concentrations in groundwater generally decreasing with increased depths, but average corn yields were 30 percent lower under the shallow water-table depths of 0.2 to 0.3 m compared to depths of 0.9 to 1.1 m.

A fairly large number of studies were conducted in Ontario, Canada, to determine the water quality and yield benefits of controlled drainage systems. In a 3-year evaluation of CDS, conservation tillage, and corn production practices, annual tile drainage volumes were reduced by 24 percent with CDS compared with traditional drainage (UD) (Drury et al. 1996). Flow-weighted mean NO_3 concentration and average annual NO_3 loss in tile drainage water were reduced by 25 and 43 percent, respectively, when using CDS (7.9 mg/L N, 14.6 kg/ha N) instead of UD. The combination of conservation tillage and CDS reduced annual NO_3 losses by 49 percent (11.6 kg/ha N) when compared with conventional moldboard plow tillage and UD. Most (88-95 percent) of the NO_3 losses from all treatments occurred in the non-cropping period from November through April. The increase in NO_3 loss through surface runoff for CDS (1.9 kg/ha N) compared to UD (1.4 kg/ha N) was less than 5 percent of the decrease in loss through tile drainage.

Measurements from a plot study on a sandy loam soil in southwestern Ontario, Canada, showed an 8 percent greater cumulative drainage water volume from the CDS treatment versus the free-tile drainage (UD) treatment but a 41 percent lower flow-weighted mean NO_3 concentration (11.3 mg/L N versus 19.2 mg/L N), a 36 percent lower NO_3 export coefficient (36.8 kg/ha N versus 57.9 kg/ha N), and a 64 percent greater average corn yield (11.0 Mg/ha versus 6.7 Mg/ha) for CDS versus UD (Ng et al. 2001).

A plot study of a wetland-reservoir system for controlled drainage and subirrigation in southwestern Ontario found that a CDS system reduced drainage volume by 36 percent, flow-weighted mean NO_3 concentration in tile drainage water by 14 percent, total NO_3 loss by 27 percent (46.3 kg N/ha versus 63.6 kg N/ha), dissolved organic P by 47 percent, and dissolved inorganic P by 54 percent compared to a free drainage system (UD) (Tan et al. 2003). Tile drainage water and surface runoff water from agricultural fields were routed into a wetland reservoir and then recycled back through the CDS to provide subsurface irrigation during times of crop water deficit. NO_3 uptake by plants and algae in the reservoir and increased corn (91 percent) and soybean (49 percent) yields contributed to the reductions in NO_3 loss for the CDS system.

In a comparison of CDS and UD on a 4-ha farm-scale field, CDS did not change total discharge but reduced flow-weighted mean NO_3 concentration in tile drainage water by 38 percent, reduced total NO_3 load by 37 percent, and increased both tomato (11 percent) and corn (64 percent) yield compared to UD (Tan et al. 2004). During the same period on a 0.4-ha plot-scale field, CDS reduced total tile drainage volume by 50 percent, reduced flow-weighted mean NO_3 concentration in tile drainage water by 32 percent, reduced total NO_3 load by 66 percent, and increased both soybean (17 percent) and corn (9 percent) yield relative to UD.

A study comparing both CD and CDS versus UD at two fertilization rates (N1: 150 kg N/ha applied to corn, no N applied to soybean; N2: 200 kg N/ha applied to corn, 50 kg N/ha applied to soybean) on a clay loam soil in Ontario, Canada, documented that CD and CDS reduced N loads from tile drainage by 44 and 66 percent, respectively, relative to UD at the N1 rate, and by 31 and 68 percent, respectively, at the N2 rate (Drury et al. 2009). The N concentrations in tile flow events with the UD treatment exceeded Ontario's provisional long-term aquatic life limit for freshwater (4.7 mg N L-1) 72 percent and 78 percent of the time at the N1 and N2 rates, respectively, but only 24 percent and 40 percent, respectively, with CDS. Crop yields from CDS were increased by an average of 2.8 percent relative to UD at the N2 rate, but were reduced by an average of 6.5 percent at the N1 rate.

A CDS system managed at a depth of 0.050 m reduced total drain discharge over two growing seasons by 42 percent versus UD in a field study in eastern Ontario (Mejia and Mandramootoo 1998). Growing-season mean NO_3 concentrations in drainage water were reduced by CDS at both a depth of 0.050 m (61–84 percent) and a depth of 0.075 m (52–75 percent) versus UD. Because of high rainfall and failure to manage the CDS under the wet conditions, discharge was over five times greater in 1995 under CDS at each depth, resulting in no significant change in NO_3 load. In 1996, however, growing-season NO_3 loads were reduced by 94 percent and 30 percent by the 0.050 m and 0.075 m CDS, respectively.

Monitoring over 2 years of four replicate plots each of surface runoff, CD at 1.1m below the soil surface, and CDS at 0.8 m in Baton Rouge showed that 67 percent of the annual NO_3 loss in tile drainage for the CD and CDS systems occurred during the 150-day growing season (Grigg et al. 2003). There were no statistical differences between the surface, subsurface, or total NO_3 loads from the CD and CDS systems.

Compilations and reviews of literature on controlled drainage have yielded largely consistent findings. On the basis of approximately 125 site-years of data collected at 14 locations in eastern North Carolina (Evans et al. 1996):

- Controlled drainage, when managed all year, reduces total outflow by approximately 30 percent compared to uncontrolled systems, although outflows vary widely depending on soil type, rainfall, type of drainage system and management intensity. For example, control during only the growing season typically reduces outflow by less than 15 percent. The effect of controlled drainage on peak outflow rates varies seasonally. Drainage control reduces peak outflow rates during dry periods (summer and fall) but can increase peak outflow rates during wet periods (winter and spring), depending on the control strategy.

- Drainage control has little net effect on TN and P concentrations in drainage outflow. Controlled drainage can reduce NO_3-N concentrations in drainage outflow by up to 20 percent , but TKN concentrations are somewhat increased. Controlled drainage tends to decrease P concentrations on predominately surface systems but has the opposite effect on predominately subsurface systems. Seasonal variations can also occur, depending on rainfall, soil type, and the relative contribution of surface or subsurface drainage to total outflow.
- Controlled drainage reduces N and P transport at the field edge, primarily because of the reduction in outflow volume. In 14 field studies, drainage control reduced the annual transport of TN (NO_3-N and TKN) at the field edge by 10 kg/ha, or 45 percent , and TP by 0.12 kg/ha, or 35 percent. Again, the reductions at individual sites were influenced by rainfall, soil type, type of drainage system, and management intensity.

In a broader review of methods to reduce NO_3 in drainage water, it was estimated that the potential for NO_3 load reduction with controlled drainage is approximately 50 percent (Appelboom and Fouss 2006). Skaggs and Youssef (2008) reported a wide range of discharge reduction (17–85 percent) and NO_3 load reduction (18–85 percent) in a summary of studies conducted in North Carolina, Ohio, Sweden, and Canada. The authors note that controlled drainage increases evapotranspiration, surface runoff, and deep and lateral seepage, with evapotranspiration accounting for only 8–15 percent of the reduction in subsurface drainage compared to conventional drainage and seepage effects dependent on the size and boundary conditions of the fields under controlled drainage. The effects of size and boundary condition on discharge were illustrated by the different findings for field and plot studies in Canada (Tan et al. 2004). Reductions in NO_3 concentration from controlled drainage were minimal in most studies, so it is important to know what happens to the NO_3 in the seepage water. Evidence indicates that in poorly or very poorly drained soils, the NO_3 is reduced at depths greater than 1 m or so, providing effective reduction of N losses to the environment.

Ditch management practice effectiveness

In a 2-year study of two experimental farm drainage ditches serving land planted in a summer row crop/winter fallow sequence in northern Mississippi, monthly baseflow and stormflow (28 storms) regression results indicated that drainage ditches reduced NO_3 and ammonia over the length of the ditch for both growing and dormant seasons (Kroger et al. 2007). Ditches reduced the maximum farm effluent dissolved inorganic N load, defined as the highest load attained spatially within the drainage ditch as a result of the combination of surface and subsurface flow processes, by an average of 57 percent.

Sediment from two similar drainage ditches in the Atlantic coastal plain were sampled (0–5 cm) after one of the ditches had been dredged, removing fine-textured sediments (clay = 41 percent) with high organic matter content (85 g/kg) and exposing coarse-textured sediments (clay = 15 percent) with low organic matter content (2.2 g/kg) (Shigaki et al. 2008). Laboratory testing in a flume revealed that under conditions of low initial P concentrations, sediment from the dredged ditch released 13 times less P to the water than did sediment from the ditch that had not been dredged, but the sediments from the dredged ditch removed 19 percent less P from the flume water when it was spiked with dissolved P to approximate long-term runoff concentrations. Irradiation of sediments to destroy microorganisms revealed that biological processes accounted for up to 30 percent of P uptake in the coarse-textured sediment of the dredged ditch and 18 percent in the fine-textured sediment of the undredged ditch.

Because vegetation in ditches increases sediment retention, cycles nutrients, and promotes the development of soil structure, management procedures that encourage ditch vegetation, such as targeted clean-outs and gradual inundation, can increase the stability and ecosystem services of ditch soils (Needelman et al. 2006). A study in Florida to evaluate P characteristics of agricultural ditch soils in the Lake Okeechobee Basin found that in-ditch management practices, such as using soil amendments or controlled drainage, could be useful to reduce P loss from ditch soils (Dunne et al. 2006).

Bioreactors effectiveness

Several studies have measured the effectiveness of bioreactors in removing NO_3 and other contaminants from agricultural drainage water (Table 2-29).

A review of bioreactors in the Midwest found that they could reduce NO_3 levels by 60–100 percent (Kalita et al. 2007). In addition, the authors identified the following advantages of bioreactors:

- They use proven technology
- They require no modification of current practices
- No land needs to be taken out of production
- There is no decrease in drainage effectiveness over time
- They require little or no maintenance
- They can last for up to 20 years

Table 2-29. Measured NO_3 removal rates for bioreactors

Location	Practice	Flow-through rate (L/min)	Removal (%)		Source
			NO_3-N conc.	NO_3-N load	
Iowa	Wood-chip denitrification walls		65%[a]	61%–68%[a]	Jaynes et al. 2004
Minnesota	Wood chip bioreactor		32%		Thorstensen No date
	Denitrification reactor using wood particles—Upflow Design	7.8	52%		
Ontario, Canada	In-ditch wood chip bioreactor	24	78%		Robertson and Merkley 2009
Ontario, Canada	Subsurface wood mulch bioreactor (pilot scale)	0.6–1.4	58%		Robertson et al. 2000
Ontario, Canada	200-L fixed-bed bioreactors with sand, tree bark, wood chips, leaf compost (pilot scale)	0.007–0.042		99%	Blowes et al. 1994
Various	Constructed bioreactors (review article)[b]		60%–90%		Appelboom and Fouss 2006
Various	Constructed bioreactors (review article)[b]		60%–100%		Kalita et al. 2007

Notes:
a. Reduction compared to uncontrolled drainage.
b. Reviews include some of the other studies shown.

In an Iowa study comparing several tile and cropping modifications for reducing NO_3 in tile drainage versus the NO_3 concentration in drainage from a UD treatment (tile at 1.2 m), it was found that denitrification walls (DW) reduced the NO_3 concentration in tile drainage by an average of 65 percent and the tile drainage N load by 61–68 percent compared to UD (Jaynes et al. 2004).

Two denitrification reactor designs (a lateral flow design and an upflow design) using fine and coarse wood particles were tested under baseflow conditions in southern Ontario; the former over a 26-month period on drainage from a cornfield, and the latter over a 20-month period on drainage from a golf course (van Driel et al. 2006). Removal by the reactor at the cornfield site averaged 3.9 mg N/L at an average flow-through rate of 7.7 L/min and an average influent NO_3 concentration of 11.8 mg N/L. With an average flow-through of 7.8 L/min and influent NO_3 concentration of 3.2 mg N/L, removal by the reactor at the golf course site averaged 1.7 mg N/L. Mass balance calculations indicate that carbon consumption from denitrification was less than 2 percent per year, showing the potential for the reactors to operate for a number of years without the need for media replenishment.

A 40-m^3 woodchip bioreactor was trenched into the bottom of an existing agricultural drainage ditch in Ontario, Canada, with flow induced through the reactor by construction of a gravel riffle in the streambed (Robertson and Merkley 2009). Over the first year and a half of operation, a mean influent NO_3 concentration of 4.8 mg/L was reduced to 1.04 mg/L at a mean reactor flow rate of 24 L/min. A series of flow-step tests, facilitated by an adjustable height outlet pipe, demonstrated that NO_3 mass removal generally increased with increasing flow rate. Silt accumulation reduced reactor flow rates over time, but design modifications were implemented to address the problem.

In a 1-year pilot-scale study, two 200-L fixed-bed bioreactors containing coarse sand and organic carbon (tree bark, wood chips, and leaf compost) were used to treat NO_3 contamination from agricultural runoff (Blowes et al. 1994). At inflow rates of 10–60 L/day, NO_3-N concentrations of 3–6 mg/L in farm-field drainage tiles were reduced by the reactors to less than 0.02 mg/L.

In Ontario, a pilot-scale assessment of a plywood-framed (1.9 m^3) subsurface reactor filled with coarse wood mulch documented a 58 percent removal of NO_3 from farm drainage water influent at hydraulic loading rates ranging from 800 to 2,000 L/day (Robertson et al. 2000). NO_3 consumption rates were temperature dependent, ranging from 5 mg/L N per day at 2–5 °C, to 15–30 mg/L N per day at 10–20 °C but did not deteriorate over the 7-year monitoring period. Mass-balance calculations of carbon consumption indicated that the reactor could perform well for at least a decade without carbon replenishment.

In a review of methods to reduce NO_3 in drainage water, it was estimated that the potential for NO_3 reduction is 60 to 90 percent for constructed bioreactors (Appelboom and Fouss 2006).

Constructed wetlands effectiveness

In a review of methods to reduce NO_3 in drainage water, it was estimated that the potential for NO_3 reduction is 37–65 percent for natural/constructed wetlands, with up to an additional 18 percent if a berm is used in creation of the wetland (Appelboom and Fouss 2006). A combination of controlled-drainage, constructed wetland, and in-stream denitrification could result in more than 75 percent NO_3 removal before release to larger streams or other surface waters.

Measurement over 3 years of N removal rates in three large (0.3 to 0.8 ha, 1,200 to 5,400 m^3 in volume) constructed wetlands treating tile drainage from corn and soybean fields in southern Illinois indicated TN removal of 37 percent in the wetlands (Kovacic et al. 2000). The wetlands also decreased NO_3-N concentrations of inlet water by 28 percent, and coupling the wetlands with a 15.3-m buffer strip between the wetlands and the river removed an additional 9 percent of the tile NO_3-N, increasing the N removal efficiency to 46 percent. TP removal was only 2 percent during the 3-year period, with highly variable results in each wetland and year.

Two agricultural runoff wetlands, W1 (area 0.16 ha, volume 660 m^3) and W2 (area 0.4 ha, volume 1,780 m^3), intercepting surface and tile drainage in the Lake Bloomington, Illinois, watershed, achieved a mass NO_3-N retention of 36 percent (Kovacic et al. 2005). Wetlands W1 and W2 reduced overall volume-weighted NO_3 concentrations by 42 percent and 31 percent, respectively. Combined P mass retention was 53 percent, and combined TOC mass retention was 9 percent.

Practice Costs

Dual-purpose drainage/subirrigation systems provide drainage, controlled drainage, and subirrigation (Evans and Skaggs 1996). Systems designed primarily for drainage might need to be redesigned or managed more intensively to serve as dual-purpose systems. The three major expenses of installing and operating a drainage and subirrigation system are the cost of a water supply, underground tubing installation, and land grading (Evans et al. 1996). If subirrigation is not part of the system, a water supply is not needed, but increased yields realized with subirrigation can contribute to NO_3 reductions because of increased crop uptake. On the basis of estimates for 1996, water supply ponds sufficient to irrigate approximately 40 ha would cost about $68,735–$82,381 in 2010 dollars, but other water supplies (e.g., stream) could be much cheaper. Underground tubing installation costs are generally the largest single expense, varying with the total footage, tubing diameter, installation method, and whether filter material is used. The amount of tubing needed depends on the hydraulic conductivity of the soil, with spacing ranging from 40 to 100 feet in North Carolina. The cost of 10-cm tubing ranges from about 76 cents to just over $1 per m (2010 dollars), with filter material adding another 32 to 54 cents per m. The cost to install underground tubing depends on the specific job, but can range from about $1.36/m to $2.27/m for 10-cm tubing. The total cost to install tubing at 10-m spacing is about $2,688/ha (2010 dollars), whereas the cost for 30-m spacing is about $890/ha. Land grading could add $170 to $860/ha to the cost, and the cost of control structures ranges from about $400 to more than $4,000. Finally, installation generally requires field borders to stabilize open ditches at a cost of about $100 per production hectare.

A cost analysis for controlled drainage in the lower coastal plain of North Carolina assumed the need for a surface drainage system of 0.9- to 1.5-m-deep open ditches, a flashboard riser installed in the collector canal, a corrugated metal pipe culvert for an outlet, and concrete to stabilize the riser (Wossink and Osmond 2001). It was assumed that there would be no installation and maintenance costs for ditches because they were part of the preexisting condition. On the basis of a land slope of 0.1 to 0.4 m/km, it was assumed that there would be one structure per mile in the canal on a 0.6- to 0.75-m contour interval, meaning that one control structure in the main canal would serve 130 ha. It was also assumed that under controlled drainage soybeans and cotton yields would increase by 2 percent or more, corn yields would increase by 5 percent or more, and wheat and tobacco yields would not increase. Installation costs for controlled drainage were estimated to be $57.80/ha (2008 dollars), while annual maintenance was estimated at $3.80/ha, and benefits from yield increases were estimated at $6.10/ha to $33.50/ha. Assuming cost-share availability of about $45/ha, the authors concluded that cost-shared controlled drainage was financially practical for the lower coastal plain of NC.

In a demonstration plot in Minnesota, the costs associated with controlled drainage included drainage control structures, design, installation, extra pipe and installation, totaling about $35/ha for a 65-ha field (Binstock 2009). Tile spacing was set at 22.8 m, using 10-cm diameter laterals on a slope of just under 1 percent. It has been estimated that drainage management systems cost about $50 to $500/ha more than conventional drainage systems (Newby 2009).

Water control structures for drainage water management cost from about $535 to $2,120 (2010 dollars) depending on height, size of tile, structure design, manufacturer, and whether it is automated (Frankenberger et al. 2006). Installation costs for structures are about $215 for basic structures, increasing with size and complexity. Assuming flat terrain, a single structure could serve eight hectares at a cost of $70 to $270 per ha. Water control structures cost $2,560 each in Virginia (USDA-NRCS 2010).

Both a lateral flow design and an upflow design bioreactor tested in Ontario were successful in achieving maintenance-free operation during all seasonal conditions, including unassisted startup after drought and freeze periods (van Driel et al. 2006). Construction cost per unit N removal for bioreactors designed to manage baseflow conditions are expected to be similar to the cost for constructed wetlands, but less land is required for the bioreactors.

A woodchip bioreactor (38 m long by 1.8 m deep by 0.6–0.9 m wide) in Minnesota cost approximately $3,200 to construct (Minnesota Department of Agriculture No date). Control structures cost $1,500, trenching cost $1,100, and $600 was spent on woodchips. Serving approximately 3.2 ha, the bioreactor cost is about $990/ha and is expected to work for about 20 years. The cost of a 60-m bioreactor ranges from about $2,900 to $4,300 (2010 dollars) depending on materials and design (Morrison 2008).

4.5 Animal Agriculture

AFOs congregate animals and typically maintain feed, wastes, and production operations on a small land area when under pasture or grazing. Animal production can cause water pollution by leaching and runoff of organic matter, N, P, pathogens, and heavy metals from animal congregation areas or other parts of the facility during regular operation of a facility if not properly managed (for further information regarding storage of manure and wastewater, see Section 2). Key strategies for edge of field trapping and treatment of runoff include VFS and other techniques to capture runoff from feedlots, barnyards, pasture and grazing lands, and other facility areas and remove sediment, nutrients, and other pollutants before delivery to surface waters.

AFOs using grazing and pasture land include nutrients and pathogens in runoff from areas of waste deposition and soil loss from areas of degraded vegetation cover. While livestock exclusion (see Section 2) and pasture management (see Section 3.4) are often the main approaches to managing water quality effects from grazing livestock, non-grazed, vegetated buffer strips or other edge-of-field practices are often recommended to protect waterbodies from sediments and nutrients in runoff from grazed pastures.

Implementation Measure A-20:

Manage runoff from livestock production areas under grazing and pasture to minimize off-farm transport of nutrients and sediment.

Practice Effectiveness

Production area effectiveness

Koelsch et al. (2006) presented the following conclusions about the application of vegetative treatment systems (VTS) to manage runoff from open lot livestock production areas:

- The pollutant reduction resulting from a VTS is based on two primary mechanisms: (1) sedimentation, typically occurring within the first few meters of a VTS, and (2) infiltration of runoff into the soil profile. System design based on sedimentation and infiltration is necessary to achieve a required performance level for concentrated AFO (CAFO) application.
- Critical design factors specific to attaining high levels of pollutant reduction within a VTS include pretreatment, sheet flow, discharge control, siting, and sizing. Critical management factors include maintaining a dense vegetation stand and sheet flow of runoff across VTA as well as minimizing nutrient accumulation.

The authors report numerous pollutant removal rates for a variety of VTS under a broad range of circumstances. While the study focused on VTA specifically related to providing an alternative method of manure and wastewater storage for CAFOs, the practice can be applied more broadly in animal agriculture. In general, the literature reports 70–90 percent TS removal, 80 percent N removal, 70 percent P removal, and 77 percent fecal coliform removal from CAFO runoff treated by VTS.

In Nebraska, Woodbury et al. (2000, 2002) tested a flat-bottom terrace to collect runoff from a beef feedlot to provide temporary liquid storage and accumulate settable solids, while distributing the liquid fraction uniformly across a VFS. No runoff left the VFS, indicating that the basin discharge was used for grass production. In a follow-up study, Woodbury et al. (2003)

reported that the system reduced the cumulative mass of TSS (80 percent), VSS (67 percent), and COD (59 percent).

Kim et al. (2003) studied flow and P transport through a VFS receiving milkhouse wastewater and barnyard runoff from two New York dairy farms. Although 33 m–40 m VFS eventually reduced soluble P to less than 0.2 mg/L, P was less effectively removed where soil saturation occurred. Wastewater entering a VFS should be distributed uniformly to avoid soil saturation.

In Montana, Fajardo et al. (2001) reported on the effectiveness of VFS using tall fescue in treating runoff from livestock manure stockpiles. Runoff NO_3-N concentrations were reduced by 97–99 percent by a VFS. Coliform bacteria counts were reduced by 64–87 percent, although bacteria counts in runoff leaving the VFS remained elevated, even for treatments not receiving manure.

VFS were effective in removing a broad range of constituents from a Kansas beef feedlot runoff pretreated by a settling basin (Mankin and Okoren 2003). The first 30 m provided most or all the reductions found within the 150-m VFS studied: reductions averaged 85 percent of inflow water, 85 percent of sediment, 77 percent of N, and 84 percent of P. Fecal bacteria removal by the VFS was on the order of 1-log: reductions at 30 m ranged from 84 percent for fecal coliform and fecal streptococci to 91 percent for *E. coli*.

In Illinois, Trask et al. (2004) reported that a VFS can be a BMP for controlling the pathogen *Cryptosporidium* in runoff from animal production facilities. The vegetative surface was very effective in reducing *C. parvum* in surface runoff; for all slopes and rainfall intensities, recovery of *C. parvum* oocysts was considerably less from a vegetated surface than from the bare-ground conditions. For a 25.4 mm/h rainfall event, recovery of oocysts in overland flow from the VFS varied from 0.6 to 1.7 percent, while those from the bare ground condition varied from 4.4 to 14.5 percent. For the 63.5 mm/h rainfall, the recovery percentages of oocysts varied from 0.8 to 27.2 percent from the VFS, and 5.3 to 59 percent from bare-ground conditions.

Hubbard et al. (2007) tested the performance of grass-forest vegetated buffers in assimilating N from overland flow application of swine lagoon effluent in Georgia. The buffers approximated 60 m in length by 90 m in width. The upper 10 m of each buffer was in grass, while the downslope area was in mature or newly planted pines. Shallow groundwater under the buffers showed NO_3-N concentrations 20–30 m downslope to be less than 10 mg/L. On those buffers, NO_3-N concentrations in shallow groundwater were near background levels 5 years after wastewater application commenced. This study demonstrated that the ratio of buffer area width to wastewater application area width on the landscape should be at least 1:1.

In Kansas, Mankin et al. (2006) quantified beef cattle feedlot runoff quality, particularly during unstocked conditions, and evaluated reductions of fecal bacteria and nutrients in VFS treating feedlot runoff. Events when few or no cattle were present averaged 17 percent of TN (20 mg/L), 14 percent of TP (6 mg/L), and 2 percent of the fecal coliforms (2.1×10^4 colony forming units/100 mL) of events with cattle present. Measured concentration reductions from all events and VFS averaged 77 percent (fecal coliforms), 83 percent (*E. coli*), 83 percent (fecal streptococci), 66 percent (TN), and 66 percent (TP). VFS allowed no discharges for greater than 90 percent of feedlot runoff events at the sites with the ratio of VFS: drainage area greater than 0.5.

Gilley et al. (2008) compared nutrient transport in runoff from beef feedlots in Nebraska with loose manure surfaces versus compacted surfaces. No significant differences in feedlot soil characteristics or nutrient transport in runoff were found between loose and compacted surfaces. However, concentrations of *E. coli* were significantly greater in runoff from the loose surface feedlots.

In Finland, Narvanen et al. (2008) tested a ferric sulfate dosing system to treat runoff from horse paddocks; runoff was then discharged into a sedimentation pond and sand filter. Dissolved P was reduced by 95 percent, TP by 81 percent.

Robertson and Merkley (2009) demonstrated an in-stream bioreactor using woodchips to promote denitrification of agricultural drainage in Ontario, Canada. Over the first 1.5 years of operation, mean influent NO_3-N of 4.8 mg/L was attenuated to 1.04 mg/L (a 78 percent reduction) at a mean reactor flow rate of 24 L/min. When removal rates were not NO_3-limited, areal mass removal ranged from 11 mg N/m^2/h at 3 °C to 220 mg N/m^{2}hr at 14°C, exceeding rates reported for some surface-flow constructed wetlands by a factor of about 40.

Table 2-30. Summary of reported practice effects resulting from VFS treatment of AFO runoff

Location	Study type	Practice	Practice effects	Source
Various	Review	Vegetated treatment systems	Literature reports removals of about 70%–90% TS, about 80% N, about 70% P, and about 77% fecal coliform from CAFO runoff treated by diverse vegetated treatment systems.	Koelsch et al. 2006
Nebraska	BMP	Settling basin/VFS	No runoff left the VFS treating beef feedlot runoff; the system reduced the cumulative mass of TSS (80%), VSS (67%), and COD (59%)	Woodbury et al. 2000 2002, 2003
New York	BMP	VFS	Although 33–40 m VFS treating milkhouse waste and barnyard runoff reduced soluble P to < 0.2mg/L in most cases; P was less effectively removed in the areas where soil saturation occurred.	Kim et al. 2003

Table 2-30. Summary of reported practice effects resulting from VFS treatment of AFO runoff *(continued)*

Location	Study type	Practice	Practice effects	Source
Montana	BMP	VFS	VFS treating runoff from manure stockpiles reduced NO_3-N concentrations by 97%–99% and coliform bacteria counts by 64%–87%[a]	Fajardo et al. 2001
Kansas	BMP	Settling basin, VFS	Reductions averaged 85% of inflow water, 85% of sediment, 77% of N, and 84% of P. Bacteria reductions at 30 m ranged from 84% for fecal coliform and fecal streptococci to 91% for *E. coli*. The first 30 m provided most or all of the reductions.	Mankin and Okoren 2003
Illinois	BMP	VFS vs. bare soil	Fewer *Cryptosporidium* oocysts were passed in overland flow from a vegetated surface than from the bare-ground conditions. For a 25.4 mm/h rainfall event, oocyst recovery from the VFS were 0.6–1.7%, vs. 4.4–14.5% from bare ground. For the 63.5 mm/h rainfall, the recovery percentages of oocysts varied from 0.8%–27.2% from the VFS, and 5.3%–59% from bare ground.	Trask et al. 2004
Georgia	BMP	Grass-forest buffer[b]	Shallow groundwater under the buffers showed NO_3-N concentrations 20–30 m downslope to be <10 mg/L. On these buffers, NO_3-N concentrations in shallow groundwater were near background levels 5 years after wastewater application began.	Hubbard et al. 2007
Kansas	BMP	VFS, feedlot stocking rate	Runoff when few or no cattle were present averaged 17% of the TN, 14% of the TP, and 2% of the fecal coliforms vs. events with cattle present. Concentration reductions averaged 77% (fecal coliforms), 83% (*E. coli*), 83% (fecal streptococci), 66% (TN), and 66% (TP).	Mankin et al. 2006
Nebraska	BMP	Feedlot surface	No significant differences in nutrient transport in runoff were found between loose and compacted feedlot surfaces. *E. coli* counts were significantly greater in runoff from the loose surface feedlots.	Gilley et al. 2008
Finland	BMP	Ferric sulfate, sand filter	Dissolved P was reduced by 95%, TP by 81% using a ferric sulfate dosing system and sand filter to treat runoff from horse paddocks	Narvanen et al. 2008
Ontario, Canada	BMP	Woodchip bioreactor	Treating AFO drainage, NO_3-N was attenuated to 1.04 mg/L (78% reduction); areal mass removal ranged from 11 mg $N/m^2/h$ at 3 °C to 220 mg N/m^2hr at 14 °C, exceeding rates reported for some surface-flow constructed wetlands by a factor of about 40.	Robertson and Merkley 2009

Notes:

a. Bacteria counts in runoff leaving the VFS remained elevated, even for treatments not receiving manure

b. Upper 10 m in grass, 20-30 m downslope in trees

Buffer/filter strips treating pasture runoff

Sotomayor-Ramirez et al. (2008) tested 10- and 20-m grassed filter strips treating runoff from grazed pasture amended with dairy manure sludge in Puerto Rico. Filter strips reduced TP and dissolved P concentrations by 29 percent and 32 percent at 10 m, and by 57 percent and 49 percent at 20 m, respectively. A 27 percent decrease in TKN concentration was observed in one field as a result of the 20-m filter strip.

Tate et al. (2000) evaluated the potential water quality improvements from 10-m buffer strips on irrigated land in California. The 10-m buffer did not significantly reduce concentrations and load of NO_3-N in runoff from sprinkler and flood irrigated pastures. The buffer also failed to reduce TP concentration under either irrigation system, or TP and TSS load under sprinkler irrigation.

The presence of a vegetated buffer of any size (from 1 to 25 m), generally reduced median fecal coliform bacteria concentrations and loads in runoff from Oregon pasture land by more than 99 percent (Sullivan et al. 2007).

Other practices treating pasture runoff

Tanner et al. (2005) reported on the performance of a surface-flow constructed wetland (occupying about 1 percent of the watershed area) treating subsurface drainage from rain-fed, dairy cattle grazed pasture in New Zealand. TN mass removal efficiency was 79 percent (841 g/m^2 per year) the first year but declined to 21 percent (40 g/m^2 per year) in the second year, associated with changes in the magnitude, speciation and seasonal pattern of N export from the watershed. TP export rose by 101 percent (5.0 g/m per year) after passage through the wetland in the first year but decreased by 12 percent (0.2 g/m^2 per year) in the second year. The results show that constructed wetlands composing similar to 1 percent of watershed area can markedly reduce N export via pastoral drainage but could be net sources of NH_4-N, DRP and TP during establishment.

Knox et al. (2008) examined benefits to water quality provided by a natural, flow-through wetland receiving runoff from irrigated pasture in California. The wetland reduced loads of TSS (77 percent), NO_3 (60 percent), and *E. coli* (68 percent). Retention of TN, TP, and SRP was between 35 and 42 percent of loads entering the wetland.

Table 2-31. Summary of reported practice effects resulting from buffer/wetland treatment of pasture runoff

Location	Study type	Practice	Practice effects	Source
Puerto Rico	BMP	Grassed filter strips	Filter strips treating runoff from grazed pasture reduced TP and dissolved P concentrations by 29% and 32% at 10 m, and by 57% and 49% at 20 m, respectively. A 27% decrease in TKN concentration was observed in one field as a result of the 20-m filter strip	Sotomayor-Ramirez et al. 2008
California	BMP	Buffer	10-m buffer did not significantly reduce concentrations and load of NO_3-N in runoff from sprinkler and flood irrigated pastures. The buffer also failed to reduce TP concentration under either irrigation schemes, or TP and TSS load under sprinkler irrigation	Tate et al. 2000
Oregon	BMP plots	Vegetated buffer	The presence of a vegetated buffer of any size (from 1 to 25 m) reduced median fecal coliform bacteria concentrations and loads in runoff by more than 99%.	Sullivan et al. 2007
New Zealand	BMP	Constructed wetland	Surface-flow constructed wetland (occupying about 1% of watershed area) treating subsurface drainage dairy cattle grazed pasture: TN mass removal efficiency was 79% (841 g/m^2 per year) the first year but declined to 21% (40 g/m^2 per year) in the second year. TP export rose by 101% (5.0 g/m per year) after passage through the wetland in the first year but decreased by 12% (0.2 g/m^2 per year) in the second year.	Tanner et al. 2005
California	BMP	Natural wetland	Wetland receiving runoff from irrigated pasture reduced loads of TSS (77%), NO_3 (60%), and *E. coli* (68%). 35% to 42% of TN, TP, and SRP loads entering the wetland were retained.	Knox et al. 2008

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Appendix 1: USDA National Conservation Practice Standards (Practice Codes)

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

WASTE STORAGE FACILITY

(No.)

CODE 313

DEFINITION

A waste storage impoundment made by constructing an embankment and/or excavating a pit or dugout, or by fabricating a structure.

PURPOSE

To temporarily store wastes such as manure, wastewater, and contaminated runoff as a storage function component of an agricultural waste management system.

CONDITIONS WHERE PRACTICE APPLIES

- Where the storage facility is a component of a planned agricultural waste management system
- Where temporary storage is needed for organic wastes generated by agricultural production or processing
- Where the storage facility can be constructed, operated and maintained without polluting air or water resources
- Where site conditions are suitable for construction of the facility
- To facilities utilizing embankments with an effective height of 35 feet or less where damage resulting from failure would be limited to damage of farm buildings, agricultural land, or township and country roads.
- To fabricated structures including tanks, stacking facilities, and pond appurtenances.

CRITERIA

General Criteria Applicable to All Waste Storage Facilities.

Laws and Regulations. Waste storage facilities must be planned, designed, and constructed to meet all federal, state, and local laws and regulations.

Location. To minimize the potential for contamination of streams, waste storage facilities should be located outside of floodplains. However, if site restrictions require location within a floodplain, they shall be protected from inundation or damage from a 25-year flood event, or larger if required by laws, rules, and regulations. Waste storage facilities shall be located so the potential impacts from breach of embankment, accidental release, and liner failure are minimized; and separation distances are such that prevailing winds and landscape elements such as building arrangement, landforms, and vegetation minimize odors and protect aesthetic values.

Storage Period. The storage period is the maximum length of time anticipated between emptying events. The minimum storage period shall be based on the timing required for environmentally safe waste utilization considering the climate, crops, soil, equipment, and local, state, and federal regulations.

Design Storage Volume. The design storage volume equal to the required storage volume, shall consist of the total of the following as appropriate:

(a) Manure, wastewater, and other wastes accumulated during the storage period

(b) Normal precipitation less evaporation on the surface area (at the design storage volume level) of the facility during the storage period

(c) Normal runoff from the facility's drainage area during the storage period

(d) 25-year, 24-hour precipitation on the surface (at the required design storage volume level) of the facility

(e) 25-year, 24-hour runoff from the facility's drainage area

(f) Residual solids after liquids have been removed. A minimum of 6 inches shall be provided for tanks

(g) Additional storage as may be required to meet management goals or regulatory requirements

Inlet. Inlets shall be of any permanent type designed to resist corrosion, plugging, freeze damage and ultraviolet ray deterioration while incorporating erosion protection as necessary.

Emptying Component. Some type of component shall be provided for emptying storage facilities. It may be a facility such as a gate, pipe, dock, wet well, pumping platform, retaining wall, or ramp. Features to protect against erosion, tampering, and accidental release shall be incorporated as necessary.

Accumulated Solids Removal. Provision shall be made for periodic removal of accumulated solids to preserve storage capacity. The anticipated method for doing this must be considered in planning, particularly in determining the configuration of ponds and type of seal, if any.

Safety. Design shall include appropriate safety features to minimize the hazards of the facility. Ramps used to empty liquids shall have a slope of 4 horizontal to 1 vertical or flatter. Those used to empty slurry, semi-solid, or solid waste shall have a slope of 10 horizontal to 1 vertical or flatter unless special traction surfaces are provided. Warning signs, fences, ladders, ropes, bars, rails, and other devices shall be provided, as appropriate, to ensure the safety of humans and livestock. Ventilation and warning signs must be provided for covered waste holding structures, as necessary, to prevent explosion, poisoning, or asphyxiation. Pipelines shall be provided with a water-sealed trap and vent, or similar device, if there is a potential, based on design configuration, for gases to enter buildings or other confined spaces. Ponds and uncovered fabricated structures for liquid or slurry waste with walls less than 5 feet above ground surface shall be fenced and warning signs posted to prevent children and others from using them for other than their intended purpose.

Erosion Protection. Embankments and disturbed areas surrounding the facility shall be treated to control erosion.

Liners. Liners shall meet or exceed the criteria in Pond Sealing or Lining (521).

__Additional Criteria for Waste Storage Ponds__

Soil and foundation. The pond shall be located in soils with an acceptable permeability that meets all applicable regulation, or the pond shall be lined. Information and guidance on controlling seepage from waste impoundments can be found in the Agricultural Waste Management Field Handbook (AWMFH), Appendix 10D.

The pond shall have a bottom elevation that is a minimum of 2 feet above the seasonal high water table unless features of special design are incorporated that address buoyant forces, pond seepage rate and non-encroachment of the water table by contaminants. The water table may be lowered by use of perimeter drains, if feasible, to meet this requirement.

Maximum Operating Level. The maximum operating level for waste storage ponds shall be the pond level that provides for the required volume less the volume contribution of precipitation and runoff from the 25-year, 24-hour storm event plus the volume allowance for residual solids after liquids have been removed. A permanent marker or recorder shall be installed at this maximum operating level to indicate when drawdown should begin. The marker or recorder shall be referenced and explained in the O&M plan.

Outlet. No outlet shall automatically release storage from the required design volume. Manually operated outlets shall be of permanent type designed to resist corrosion and plugging.

Embankments. The minimum elevation of the top of the settled embankment shall be 1 foot above the waste storage pond's required volume. This height shall be increased by the amount needed to ensure that the top elevation will be maintained after settlement. This increase shall be not less than 5 percent. The minimum top widths are shown in Table 1. The combined side slopes of the settled embankment shall not be less than 5 horizontal to 1 vertical, and neither slope shall be steeper than 2 horizontal to 1 vertical unless provisions are made to provide stability.

Table 1 – Minimum Top Widths

Total embankment Height, ft.	Top Width, ft.
15 or less	8
15 – 20	10
20 – 25	12
25 – 30	14
30 – 35	15

Excavations. Unless supported by a soil investigation, excavated side slopes shall be no steeper than 2 horizontal to 1 vertical.

<u>Additional Criteria for Fabricated Structures</u>

Foundation. The foundations of fabricated waste storage structures shall be proportioned to safely support all superimposed loads without excessive movement or settlement.

Where a non-uniform foundation cannot be avoided or applied loads may create highly variable foundation loads, settlement should be calculated from site-specific soil test data. Index tests of site soil may allow correlation with similar soils for which test data is available. If no test data is available, presumptive bearing strength values for assessing actual bearing pressures may be obtained from Table 2 or another nationally recognized building code. In using presumptive bearing values, adequate detailing and articulation shall be provided to avoid distressing movements in the structure.

Foundations consisting of bedrock with joints, fractures, or solution channels shall be treated or a separation distance provided consisting of a minimum of 1 foot of impermeable soil between the floor slab and the bedrock or an alternative that will achieve equal protection.

Table 2 - Presumptive Allowable Bearing Stress Values[1]

Foundation Description	Allowable Stress
Crystalline Bedrock	12000 psf
Sedimentary Rock	6000 psf
Sandy Gravel or Gravel	5000 psf
Sand, Silty Sand, Clayey Sand, Silty Gravel, Clayey Gravel	3000 psf
Clay, Sandy Clay, Silty Clay, Clayey Silt	2000 psf

[1] Basic Building Code, 12th Edition, 1993, Building Officials and Code Administrators, Inc. (BOCA)

Liquid Tightness. Applications such as tanks, that require liquid tightness shall be designed and constructed in accordance with standard engineering and industry practice appropriate for the construction materials used to achieve this objective.

Structural Loadings. Waste storage structures shall be designed to withstand all anticipated loads including internal and external loads, hydrostatic uplift pressure, concentrated surface and impact loads, water pressure due to seasonal high water table, and frost or ice pressure and load combinations in compliance with this standard and applicable local building codes.

The lateral earth pressures should be calculated from soil strength values determined from the results of appropriate soil tests. Lateral earth pressures can be calculated using the procedures in TR-74. If soil strength tests are not available, the presumptive lateral earth pressure values indicated in Table 3 shall be used.

TABLE 3 - LATERAL EARTH PRESSURE VALUES[1]

		Equivalent fluid pressure (lb/ft²/ft of depth)			
Soil		Above seasonal high water table[2]		Below seasonal high water table[3]	
Description[4]	Unified Classification[4]	Free-standing walls	Frame tanks	Free-standing walls	Frame tanks
Clean gravel, sand or sand-gravel mixtures (maximum 5% fines)[5]	GP, GW, SP, SW	30	50	80	90
Gravel, sand, silt and clay mixtures (less than 50% fines) Coarse sands with silt and and/or clay (less than 50% fines)	All gravel sand dual symbol classifications and GM, GC, SC, SM, SC-SM	35	60	80	100
Low-plasticity silts and clays with some sand and/or gravel (50% or more fines) Fine sands with silt and/or clay (less than 50% fines)	CL, ML, CL-ML SC, SM, SC-SM	45	75	90	105
Low to medium plasticity silts and clays with little sand and/or gravel (50% or more fines)	CL, ML, CL-ML	65	85	95	110
High plasticity silts and clays (liquid limit more than 50)[6]	CH, MH	-	-	-	-

[1] For lightly-compacted soils (85% to 90% maximum standard density.) Includes compaction by use of typical farm equipment.
[2] Also below seasonal high water table if adequate drainage is provided.
[3] Includes hydrostatic pressure.
[4] All definitions and procedures in accordance with ASTM D 2488 and D 653.
[5] Generally, only washed materials are in this category
[6] Not recommended. Requires special design if used.

Lateral earth pressures based upon equivalent fluid assumptions shall be assigned according to the following conditions:

- **Rigid frame or restrained wall.** Use the values shown in Table 3 under the column “Frame tanks,” which gives pressures comparable to the at-rest condition.
- **Flexible or yielding wall.** Use the values shown in Table 3 under the column “Free-standing walls,” which gives pressures comparable to the active condition. Walls in this category are designed on the basis of gravity for stability or are designed as a cantilever having a base wall thickness to height of backfill ratio not more than 0.085.

Internal lateral pressure used for design shall be 65 lb/ft² where the stored waste is not protected from precipitation. A value of 60 lb/ft^2 may be used where the stored waste is protected from precipitation and will not become saturated. Lesser values may be used if supported by measurement of actual pressures of the waste to be stored. If heavy equipment will be operated near the wall, an additional two feet of soil surcharge shall be considered in the wall analysis.

Tank covers shall be designed to withstand both dead and live loads. The live load values for covers contained in ASAE EP378.3, Floor and Suspended Loads on Agricultural Structures Due to Use, and in ASAE EP 393.2, Manure Storages, shall be the minimum used. The actual axle load for tank wagons having more than a 2,000 gallon capacity shall be used.

If the facility is to have a roof, snow and wind loads shall be as specified in ASAE EP288.5, Agricultural Building Snow and Wind Loads. If the facility is to serve as part of a foundation or support for a building, the total load shall be considered in the structural design.

Structural Design. The structural design shall consider all items that will influence the performance of the structure, including loading assumptions, material properties and construction quality. Design assumptions and construction requirements shall be indicated on standard plans.

Tanks may be designed with or without covers. Covers, beams, or braces that are integral to structural performance must be indicated on the construction drawings. The openings in covered tanks shall be designed to accommodate equipment for loading, agitating, and emptying. These openings shall be equipped with grills or secure covers for safety, and for odor and vector control.

All structures shall be underlain by free draining material or shall have a footing located below the anticipated frost depth. Fabricated structures shall be designed according to the criteria in the following references as appropriate:

- Steel: "Manual of Steel Construction", American Institute of Steel Construction.
- Timber: "National Design Specifications for Wood Construction", American Forest and Paper Association.
- Concrete: "Building Code Requirements for Reinforced Concrete, ACI 318", American Concrete Institute.
- Masonry: "Building Code Requirements for Masonry Structures, ACI 530", American Concrete Institute.

Slabs on Grade. Slab design shall consider the required performance and the critical applied loads along with both the subgrade material and material resistance of the concrete slab. Where applied point loads are minimal and liquid-tightness is not required, such as barnyard and feedlot slabs subject only to precipitation, and the subgrade is uniform and dense, the minimum slab thickness shall be 4 inches with a maximum joint spacing of 10 feet. Joint spacing can be increased if steel reinforcing is added based on subgrade drag theory.

For applications where liquid-tightness is required such as floor slabs of storage tanks, the minimum thickness for uniform foundations shall be 5 inches and shall contain distributed reinforcing steel. The required area of such reinforcing steel shall be based on subgrade drag theory as discussed in industry guidelines such as American Concrete Institute, ACI 360, "Design of Slabs-on-Grade".

When heavy equipment loads are to be resisted and/or where a non-uniform foundation cannot be avoided, an appropriate design procedure incorporating a subgrade resistance parameter(s) such as ACI 360 shall be used.

CONSIDERATIONS

Waste storage facilities should be located as close to the source of waste and polluted runoff as practicable.

Non-polluted runoff should be excluded from the structure to the fullest extent possible except where its storage is advantageous to the operation of the agricultural waste management system.

Freeboard for waste storage tanks should be considered.

Solid/liquid separation of runoff or wastewater entering pond facilities should be considered to minimize the frequency of accumulated solids removal and to facilitate pumping and application of the stored waste.

Due consideration should be given to environmental concerns, economics, the overall waste management system plan, and safety and health factors.

Considerations for Minimizing the Potential for and Impacts of Sudden Breach of Embankment or Accidental Release from the Required Volume.

Features, safeguards, and/or management measures to minimize the risk of failure or accidental release, or to minimize or mitigate impact of this type of failure should be considered when any of the categories listed in Table 4 might be significantly affected.

The following should be considered either singly or in combination to minimize the potential of or the consequences of sudden breach of embankments when one or more of the potential impact categories listed in Table 4 may be significantly affected:

1. An auxiliary (emergency) spillway
2. Additional freeboard
3. Storage for wet year rather than normal year precipitation
4. Reinforced embankment -- such as, additional top width, flattened and/or armored downstream side slopes
5. Secondary containment

Table 4 - Potential Impact Categories from Breach of Embankment or Accidental Release

1. Surface water bodies -- perennial streams, lakes, wetlands, and estuaries
2. Critical habitat for threatened and endangered species.
3. Riparian areas
4. Farmstead, or other areas of habitation
5. Off-farm property
6. Historical and/or archaeological sites or structures that meet the eligibility criteria for listing in the National Register of Historical Places.

The following options should be considered to minimize the potential for accidental release from the required volume through gravity outlets when one or more of the potential impact categories listed in Table 4 may be significantly affected:

1. Outlet gate locks or locked gate housing
2. Secondary containment
3. Alarm system
4. Another means of emptying the required volume

Considerations for Minimizing the Potential of Waste Storage Pond Liner Failure.

Sites with categories listed in Table 5 should be avoided unless no reasonable alternative exists. Under those circumstances, consideration should be given to providing an additional measure of safety from pond seepage when any of the potential impact categories listed in Table 5 may be significantly affected.

Table 5 - Potential Impact Categories for Liner Failure

1. Any underlying aquifer is at a shallow depth and not confined
2. The vadose zone is rock
3. The aquifer is a domestic water supply or ecologically vital water supply
4. The site is located in an area of solutionized bedrock such as limestone or gypsum.

Should any of the potential impact categories listed in Table 5 be affected, consideration should be given to the following:

1. A clay liner designed in accordance with procedures of AWMFH Appendix 10D with a thickness and coefficient of permeability so that specific discharge is less than 1 x 10^{-6} cm/sec
2. A flexible membrane liner over a clay liner

3. A geosynthetic clay liner (GCL) flexible membrane liner

4. A concrete liner designed in accordance with slabs on grade criteria for fabricated structures requiring water tightness

Considerations for Improving Air Quality

To reduce emissions of greenhouse gases, ammonia, volatile organic compounds, and odor, other practices such as Anaerobic Digester – Ambient Temperature (365), Anaerobic Digester – Controlled Temperature (366), Waste Facility Cover (367), and Composting Facility (317) can be added to the waste management system.

Adjusting pH below 7 may reduce ammonia emissions from the waste storage facility but may increase odor when waste is surface applied (see Waste Utilization, 633).

Some fabric and organic covers have been shown to be effective in reducing odors.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended use.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for its design.

The plan shall contain the operational requirements for emptying the storage facility. This shall include the requirement that waste shall be removed from storage and utilized at locations, times, rates, and volume in accordance with the overall waste management system plan.

In addition, for ponds, the plan shall include an explanation of the permanent marker or recorder installed to indicate the maximum operating level.

The plan shall include a strategy for removal and disposition of waste with the least environmental damage during the normal storage period to the extent necessary to insure the pond's safe operation. This strategy is for the removal of the contribution of unusual storm events that may cause the pond to fill to capacity prematurely with subsequent design inflow and usual precipitation prior to the end of the normal storage period.

Development of an emergency action plan should be considered for waste storage facilities where there is a potential for significant impact from breach or accidental release. The plan shall include site-specific provisions for emergency actions that will minimize these impacts.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

COVER CROP

(Ac.)

CODE 340

DEFINITION

Crops including grasses, legumes and forbs for seasonal cover and other conservation purposes.

PURPOSE

- Reduce erosion from wind and water.
- Increase soil organic matter content.
- Capture and recycle or redistribute nutrients in the soil profile.
- Promote biological nitrogen fixation.
- Increase biodiversity.
- Weed suppression.
- Provide supplemental forage.
- Soil moisture management.
- Reduce particulate emissions into the atmosphere.
- Minimize and reduce soil compaction.

CONDITIONS WHERE PRACTICE APPLIES

On all lands requiring vegetative cover for natural resource protection and or improvement.

CRITERIA

General Criteria Applicable to All Purposes

Plant species, seedbed preparation, seeding rates, seeding dates, seeding depths, fertility requirements, and planting methods will be consistent with approved local criteria and site conditions.

The species selected will be compatible with other components of the cropping system.

Cover crops will be terminated by harvest, frost, mowing, tillage, crimping, and/or herbicides in preparation for the following crop.

Herbicides used with cover crops will be compatible with the following crop.

Avoid using plants that are on the state's noxious weed or invasive species lists.

Cover crop residue will not be burned.

Additional Criteria to Reduce Erosion from Wind and Water

Cover crop establishment, in conjunction with other practices, will be timed so that the soil will be adequately protected during the critical erosion period(s).

Plants selected for cover crops will have the physical characteristics necessary to provide adequate protection.

The amount of surface and/or canopy cover needed from the cover crop shall be determined using current erosion prediction technology.

Additional Criteria to Increase Soil Organic Matter Content

Cover crop species will be selected on the basis of producing high volumes of organic material and or root mass to maintain or improve soil organic matter.

The NRCS Soil Conditioning Index (SCI) procedure will be used to determine the amount of biomass required to have a positive trend in the soil organic matter subfactor.

The cover crop will be terminated as late as feasible to maximize plant biomass production, considering the time needed to prepare the field for planting the next crop and soil moisture depletion.

Additional Criteria to Capture and Recycle Excess Nutrients in the Soil Profile

Cover crops will be established and actively growing before the expected period(s) of nutrient leaching.

Cover crop species will be selected for their ability to take up large amounts of nutrients from the rooting profile of the soil.

When used to redistribute nutrients from deeper in the profile up to the surface layer, the cover crop will be killed in relation to the planting date of the following crop. If the objective is to best synchronize the use of cover crop as a green manure to cycle nutrients, factors such as the carbon/nitrogen ratios may be considered to kill early and have a faster mineralization of nutrients to match release of nutrient with uptake by following cash crop. A late kill may be used if the objectives are to use as a biocontrol and maximize the addition of organic matter. The right moment to kill the cover crop will depend on the specific rotation, weather and objectives.

Additional Criteria to Promote Biological Nitrogen Fixation

Only legumes or legume-grass mixtures will be established as cover crops.

The specific Rhizobium bacteria for the selected legume will either be present in the soil or the seed will be inoculated at the time of planting.

Additional Criteria to Increase Biodiversity

Cover crop species shall be selected that have different maturity dates, attract beneficial insects, increase soil biological diversity, serve as a trap crop for damaging insects, and/or provide food and cover for wildlife habitat management.

Additional Criteria for Weed Suppression

Species for the cover crop will be selected for their chemical or physical characteristics to suppress or compete with weeds.

Cover crops residues will be left on the soil surface to maximize allelopathic (chemical) and mulching (physical) effects.

For long-term weed suppression, reseeding annuals and/or biennial species can be used.

Additional Criteria to Provide Supplemental Forage

Species selected will have desired forage traits, be palatable to livestock, and not interfere with the production of the subsequent crop.

Forage provided by the cover crop may be hayed or grazed as long as sufficient biomass is left for resource protection.

Additional Criteria for Soil Moisture Management

Terminate growth of the cover crop sufficiently early to conserve soil moisture for the subsequent crop. Cover crops established for moisture conservation shall be left on the soil surface.

In areas of potential excess soil moisture, allow the cover crop to grow as long as possible to maximize soil moisture removal.

Additional Criteria to Reduce Particulate Emissions into the Atmosphere

Manage cover crops and their residues so that at least 80% ground cover is maintained during planting operations for the following crop.

Additional Criteria to Minimize and Reduce Soil Compaction

Select and manage cover crop species that will produce deep roots and large amounts of surface or root biomass to increase soil organic matter, improve soil structure and increase soil moisture through better infiltration.

CONSIDERATIONS

Plant cover crop in a timely matter to establish a good stand.

Maintain an actively growing cover crop as late as feasible to maximize plant growth, allowing time to prepare the field for the next crop and moisture depletion.

Use deep-rooted species to maximize nutrient recovery.

Use grasses to utilize more soil nitrogen, and legumes utilize both nitrogen and phosphorus.

Avoid cover crop species that harbor or carryover potentially damaging diseases or insects.

For most purposes for which cover crops are established, the combined canopy and surface cover is at nearly 90 percent or greater, and the above ground (dry weight) biomass production is at least 4,000 lbs/acre.

Cover crops may be used to improve site conditions for establishment of perennial species.

Use plant species that enhance bio-fuels opportunities.

Use plant species that enhance forage opportunities for pollinators.

PLANS AND SPECIFICATIONS

Plans and specifications will be prepared for the practice site. Plans for the establishment of cover crops shall include:

- Species or species of plants to be established.
- Seeding rates.
- Recommended seeding dates.
- Establishment procedure.
- Planned rates and timing of nutrient application.
- Planned dates for destroying cover crop.
- Other information pertinent to establishing and managing the cover crop.

Plans and specifications for the establishment and management of cover crops may be recorded in narrative form, on job sheets, or on other forms.

OPERATION AND MAINTENANCE

Control growth of the cover crop to reduce competition from volunteer plants and shading.

Control weeds in cover crops by mowing or by using other pest management techniques.

Control soil moisture depletion by selecting water efficient plant species and terminating the cover crop before excessive transpiration.

REFERENCES

Bowman, G., C. Cramer, and C. Shirley. A. Clark (ed.). 1998. Managing cover crops profitably. 2nd ed. Sustainable Agriculture Network Handbook Series; bk 3. National Agriculture Library. Beltsville, MD.

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Magdoff, F. and H. van Es. Cover Crops. 2000. p. 87-96 *In* Building soils for better crops. 2nd ed. Sustainable Agriculture Network Handbook Series; bk 4. National Agriculture Library. Beltsville, MD.

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NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

WASTE TREATMENT LAGOON

(No.)

CODE 359

DEFINITION

A waste treatment impoundment made by constructing an embankment and/or excavating a pit or dugout.

PURPOSE

To biologically treat waste, such as manure and wastewater, and thereby reduce pollution potential by serving as a treatment component of a waste management system.

CONDITIONS WHERE PRACTICE APPLIES

- Where the lagoon is a component of a planned agricultural waste management system.
- Where treatment is needed for organic wastes generated by agricultural production or processing.
- On any site where the lagoon can be constructed, operated and maintained without polluting air or water resources.
- To lagoons utilizing embankments with an effective height of 35 feet or less where damage resulting from failure would be limited to damage of farm buildings, agricultural land, or township and country roads.

CRITERIA

General Criteria for All Lagoons

Laws and Regulations. All Federal, state, and local laws, rules, and regulations governing the construction and use of waste treatment lagoons must be followed.

Location. To minimize the potential for contamination of streams, lagoons should be located outside of floodplains. However, if site restrictions require location within a floodplain, they shall be protected from inundation or damage from a 25-year flood event, or larger if required by laws, rules, and regulations. Lagoons shall be located so the potential impacts from breach of embankment, accidental release, and liner failure are minimized; and separation distances are such that prevailing winds and landscape elements such as building arrangement, landforms, and vegetation minimize odors and protect aesthetic values.

Lagoons should be located so they have as little drainage area as possible. If a lagoon has a drainage area, the volume of normal runoff during the treatment period and 25-year, 24-hour storm event runoff shall be included in the required volume of the lagoon.

Soils and Foundation. The lagoon shall be located in soils with an acceptable permeability that meets all applicable regulations, or the lagoon shall be lined. Information and guidance on controlling seepage from waste impoundments can be found in the Agricultural Waste Management Field Handbook (AWMFH), Appendix 10D.

The lagoon shall have a bottom elevation that is a minimum of 2 feet above the seasonal high water table unless special design features are incorporated that address buoyant forces, lagoon seepage rates, and non-encroachment of the water table by contaminants. The water table may be lowered by use of perimeter drains to meet this requirement.

Flexible Membranes. Flexible membrane liners shall meet or exceed the requirements of flexible membrane linings specified in Pond Sealing or Lining, Flexible Membrane (code 521A).

Required Volume. The lagoon shall have the capability of storing the following volumes:

- Volume of accumulated sludge for the period between sludge removal events;
- Minimum treatment volume (anaerobic lagoons only);
- Volume of manure, wastewater, and other wastes accumulated during the treatment period;
- Depth of normal precipitation less evaporation on the surface area (at the required volume level) of the lagoon during the treatment period;
- Depth of the 25-year, 24-hour storm precipitation on the surface area (at the required volume level) of the lagoon.

Treatment Period. The treatment period is the detention time between drawdown events. It shall be the greater of either 60 days; or the time required to provide the storage that allows environmentally safe utilization of waste considering the climate, crops, soil, and equipment requirements; or as required by local, state, and Federal regulations.

Waste Loading. Daily waste loading shall be based on the maximum daily loading considering all waste sources that will be treated by the lagoon. Reliable local information or laboratory test data should be used if available. If local information is not available Chapter 4 of the AWMFH may be used for estimating waste loading.

Embankments. The minimum elevation of the top of the settled embankment shall be 1 foot above the lagoon's required volume. This height shall be increased by the amount needed to ensure that the top elevation will be maintained after settlement. This increase shall be not less than 5 percent. The minimum top widths are shown in Table 1. The combined side slopes of the settled embankment shall not be less than 5 horizontal to 1 vertical, and neither slope shall be steeper than 2 horizontal to 1 vertical unless provisions are made to provide stability.

Table 1 – Minimum Top Widths

Total embankment Height, ft.	Top Width, ft.
15 or less	8
15 – 20	10
20 – 25	12
25 – 30	14
30 – 35	15

Excavations. Unless supported by a soil investigation, excavated side slopes shall be no steeper than 2 horizontal to 1 vertical.

Inlet. Inlets shall be of any permanent type designed to resist corrosion, plugging, freeze damage, and ultraviolet ray deterioration, while incorporating erosion protection as necessary. Inlets shall be provided with a water-sealed trap and vent, or similar device if there is a potential, based on design configuration, for gases to enter buildings or other confined spaces.

Outlet. Outlets from the required volume shall be designed to resist corrosion and plugging. No outlet shall automatically discharge from the required volume of the lagoon.

Facility for Drawdown. Measures that facilitate safe drawdown of the liquid level in the lagoon shall be provided. Access areas and ramps used to withdraw waste shall have slopes that facilitate a safe operating environment. Docks, wells, pumping platforms, retaining walls, etc. shall permit drawdown without causing erosion or damage to liners.

Sludge Removal. Provision shall be made for periodic removal of accumulated sludge to preserve the treatment capacity of the lagoon.

Erosion Protection. Embankments and disturbed areas surrounding the lagoon shall be treated to control erosion. This includes the inside slopes of the lagoon as needed to protect the integrity of the liner.

Safety. Design shall include appropriate safety features to minimize the hazards of the lagoon. The lagoon shall be fenced around the perimeter and warning signs posted to prevent children and others from using it for other than its intended purpose.

Additional Criteria for Anaerobic Lagoons

Loading Rate. Anaerobic lagoons shall be designed to have a minimum treatment volume based on Volatile Solids (VS) loading per unit of volume. The maximum loading rate shall be as indicated in AWMFH Figure 10-22 or according to state regulatory requirements, whichever is more stringent.

Operating Levels. The maximum operating level shall be the lagoon level that provides the required volume less the 25-year, 24-hour storm event precipitation on the surface of the lagoon. The maximum drawdown level shall be the lagoon level that provides volume for the required minimum treatment volume plus the volume of accumulated sludge between sludge removal events. Permanent markers shall be installed at these elevations. The proper operating range of the lagoon is above the maximum drawdown level and below the maximum operating level. These markers shall be referenced and described in the O&M plan.

Depth Requirements. The minimum depth at maximum drawdown shall be 6 feet. If subsurface conditions prevent practicable construction to accommodate the minimum depth at maximum drawdown, a lesser depth may be used, if the volume requirements are met.

Additional Criteria for Naturally Aerobic Lagoons

Loading Rate. Naturally aerobic lagoons shall be designed to have a minimum treatment surface area as determined on the basis of daily BOD_5 loading per unit of lagoon surface. The required minimum treatment surface area shall be the surface area at maximum drawdown. The maximum loading rate shall be as indicated by AWMFH Figure 10-25 or according to state regulatory requirements, whichever is more stringent.

Operating Levels. The maximum operating level shall be the lagoon level that provides the required volume less the 25-year, 24-hour storm event on the lagoon surface. The maximum drawdown level shall be the lagoon level that provides volume for the volume of manure, wastewater, and clean water accumulated during the treatment period plus the volume of accumulated sludge between sludge removal events. Permanent markers shall be installed at these elevations. The proper operating range of the lagoon is above the maximum drawdown level and below the maximum operating level. These markers shall be referenced and described in the O&M plan.

Depth Requirements. The minimum depth at maximum drawdown shall be 2 feet. The maximum liquid level shall be 5 feet.

Additional Criteria for Mechanically Aerated Lagoons

Loading Rate. Mechanically aerated waste treatment lagoons' treatment function shall be designed on the basis of daily BOD_5 loading and aeration equipment manufacturer's performance data for oxygen transfer and mixing. Aeration equipment shall provide a minimum of 1 pound of oxygen for each pound of daily BOD_5 loading.

Operating Levels. The maximum operating level shall be the lagoon level that provides the required lagoon volume less the 25-year, 24-hour storm event precipitation and shall not exceed the site and aeration equipment limitations. A permanent marker or recorder shall be installed at this elevation. The proper operating range of the lagoon is below this elevation and above the minimum treatment elevation established by the manufacturer of the aeration equipment. This marker shall be referenced and described in the O&M plan.

CONSIDERATIONS

General

Lagoons should be located as close to the source of waste as possible.

Solid/liquid separation treatment should be considered between the waste source and the lagoon to reduce loading.

The configuration of the lagoon should be based on the method of sludge removal and method of sealing.

Due consideration should be given to economics, the overall waste management system plan, and safety and health factors.

Considerations for Minimizing the Potential for and Impacts of Sudden Breach of Embankment or Accidental Release from the Required Volume

Features, safeguards, and/or management measures to minimize the risk of embankment failure or accidental release, or to minimize or mitigate impact of this type of failure should be considered when any of the categories listed in Table 2 might be significantly affected.

The following should be considered either singly or in combination to minimize the potential of or the consequences of sudden breach of embankments when one or more of the potential impact categories listed in Table 2 may be significantly affected:

- An auxiliary (emergency) spillway
- Additional freeboard
- Storage volume for the wet year rather than normal year precipitation
- Reinforced embankment -- such as, additional top width, flattened and/or armored downstream side slopes
- Secondary containment
- Water level indicators or recorders

Table 2- Potential Impact Categories from Breach of Embankment or Accidental Release
1. Surface water bodies -- perennial streams, lakes, wetlands, and estuaries
2. Critical habitat for threatened and endangered species
3. Riparian areas
4. Farmstead, or other areas of habitation
5. Off-farm property
6. Historical and/or archaeological sites or structures that meet the eligibility criteria for listing in the National Register of Historical Places

The following should be considered to minimize the potential for accidental release from the required volume through gravity outlets when one or more of the potential impact categories listed in Table 2 may be significantly affected:

- Outlet gate locks or locked gate housing
- Secondary containment
- Alarm system
- Another means of emptying the required volume

Considerations for Minimizing the Potential of Lagoon Liner Seepage

Consideration should be given to providing an additional measure of safety from lagoon seepage when any of the potential impact categories listed in Table 3 may be affected.

Table 3 - Potential Impact Categories for Liner Seepage
1. Any underlying aquifer is at a shallow depth and not confined
2. The vadose zone is rock
3. The aquifer is a domestic water supply or ecologically vital water supply
4. The site is located in an area of carbonate rock (limestone or dolomite)

Should any of the potential impact categories listed in Table 3 be affected, consideration should be given to the following:

- A clay liner designed in accordance with procedures of AWMFH, Appendix 10D with a thickness and coefficient of permeability so that specific discharge is less than 1 x 10^{-6} cm/sec.
- A flexible membrane liner
- A geosynthetic clay liner (GCL) flexible membrane liner
- A concrete liner designed in accordance with slabs on grade criteria, Waste Storage Facility (313), for fabricated structures requiring water tightness.

Considerations for Improving Air Quality

To reduce emissions of greenhouse gases, ammonia, volatile organic compounds, and odor:

- Reduce the recommended loading rate for anaerobic lagoons to one-half the values given in AWMFH Figure 10-22.

- Use additional practices such as Anaerobic Digester – Ambient Temperature (365), Anaerobic Digester – Controlled Temperature (366), Waste Facility Cover (367) and Composting Facilities (code 317) in the waste management system.
- Liquid/solid separation prior to discharge to lagoon will reduce volatile solids (VS) loading resulting in reduced gaseous emissions and odors. Composting of solids will further reduce emissions.
- Design lagoons to be naturally aerobic or to allow mechanical aeration.

Adjusting pH below 7 may reduce ammonia emissions from the lagoon but may increase odor when waste is surface applied (See Waste Utilization, code 633).

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended use.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for design. The plan shall contain the operational requirements for drawdown and the role of permanent markers. This shall include the requirement that waste be removed from the lagoon and utilized at locations, times, rates, and volume in accordance with the overall waste management system plan. In addition, the plan shall include a strategy for removal and disposition of waste with least environmental damage during the normal treatment period to the extent necessary to insure the lagoon's safe operation. This strategy shall also include the removal of unusual storm events.

Development of an emergency action plan should be considered for lagoons where there is a potential for significant impact from breach or accidental release. The plan shall include site-specific provisions for emergency actions that will minimize these impacts.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

DIVERSION

(Ft.)

CODE 362

DEFINITION

A channel constructed across the slope generally with a supporting ridge on the lower side.

PURPOSE

This practice may be applied as part of a resource management system to support one or more of the following purposes.

- Break up concentrations of water on long slopes, on undulating land surfaces, and on land that is generally considered too flat or irregular for terracing.
- Divert water away from farmsteads, agricultural waste systems, and other improvements.
- Collect or direct water for water-spreading or water-harvesting systems.
- Increase or decrease the drainage area above ponds.
- Protect terrace systems by diverting water from the top terrace where topography, land use, or land ownership prevents terracing the land above.
- Intercept surface and shallow subsurface flow.
- Reduce runoff damages from upland runoff.
- Reduce erosion and runoff on urban or developing areas and at construction or mining sites.
- Divert water away from active gullies or critically eroding areas.
- Supplement water management on conservation cropping or stripcropping systems.

CONDITIONS WHERE PRACTICE APPLIES

This applies to all cropland and other land uses where surface runoff water control and or management is needed. It also applies where soils and topography are such that the diversion can be constructed and a suitable outlet is available or can be provided.

CRITERIA

Capacity. Diversions as temporary measures, with an expected life span of less than 2 years, shall have a minimum capacity for the peak discharge from the 2-year frequency, 24-hour duration storm.

Diversions that protect agricultural land shall have a minimum capacity for the peak discharge from a 10-year frequency, 24 -hour duration storm.

Diversions designed to protect areas such as urban areas, buildings, roads, and animal waste management systems shall have a minimum capacity for the peak discharge from a storm frequency consistent with the hazard involved but not less than a 25-year frequency, 24-hour duration storm. Freeboard shall be not less than 0.3 ft.

Design depth is the channel storm flow depth plus freeboard, where required.

Cross section. The channel may be parabolic, V-shaped, or trapezoidal. The diversion shall be designed to have stable side slopes.

The ridge shall have a minimum top width of 4 feet at the design depth. The ridge height shall include an adequate settlement factor.

The ridge top width may be 3 feet at the design depth for diversions with less than 10 acres drainage area above cropland, pastureland, or woodland.

The top of the constructed ridge at any point shall not be lower than the design depth plus the specified overfill for settlement.

The design depth at culvert crossings shall be the culvert headwater depth for the design storm plus freeboard.

Grade and velocity. Channel grades may be uniform or variable. Channel velocity shall not exceed that considered non-erosive for the soil and planned vegetation or lining.

Maximum channel velocities for permanently vegetated channels shall not exceed those recommended in the NRCS Engineering Field Handbook (EFH) Part 650, Chapter 7, or Agricultural Research Service (ARS) Agricultural Handbook 667, Stability Design of Grass-Lined Open Channels (Sept. 1987).

When the capacity is determined by the formula Q = A V and the V is calculated by using Manning's equation, the highest expected value of "n" shall be used.

Location. The outlet conditions, topography, land use, cultural operations, cultural resources, and soil type shall determine the location of the diversion.

Protection against sedimentation. Diversions normally should not be used below high sediment producing areas. When they are, a practice or combination of practices needed to prevent damaging accumulations of sediment in the channel shall be installed. This may include practices such as land treatment erosion control practices, cultural or tillage practices, vegetated filter strip, or structural measures. Install practices in conjunction with or before the diversion construction.

If movement of sediment into the channel is a problem, the design shall include extra capacity for sediment or periodic removal as outlined in the operation and maintenance plan.

Outlets. Each diversion must have a safe and stable outlet with adequate capacity. The outlet may be a grassed waterway, a lined waterway, a vegetated or paved area, a grade stabilization structure, an underground outlet, a stable watercourse, a sediment basin, or a combination of these practices. The outlet must convey runoff to a point where outflow will not cause damage. Vegetative outlets shall be installed and established before diversion construction to insure establishment of vegetative cover in the outlet channel.

The release rate of an under ground outlet, when combined with storage, shall be such that the design storm runoff will not overtop the diversion ridge.

The design depth of the water surface in the diversion shall not be lower than the design elevation of the water surface in the outlet at their junction when both are operating at design flow.

Vegetation. Disturbed areas that are not to be cultivated shall be seeded as soon as practicable after construction.

Lining. If the soils or climatic conditions preclude the use of vegetation for erosion protection, non-vegetative linings such as gravel, rock riprap, cellular block, or other approved manufactured lining systems may be used.

CONSIDERATIONS

A diversion in a cultivated field should be aligned and spaced from other structures or practices to permit use of modern farming equipment. The side slope lengths should sized to fit equipment widths when cropped.

At non-cropland sites, consider planting native vegetation in areas disturbed due to construction.

Maximize wetland functions and values with the diversion design. Minimize adverse effects to existing functions and values. Diversion of upland water to prevent entry into a wetland may convert a wetland by changing the hydrology. Any construction activities should minimize disturbance to wildlife habitat. Opportunities should be explored to restore and improve wildlife habitat, including habitat for threatened, endangered, and other species of concern.

On landforms where archeological sites are likely to occur, use techniques to maximize identification of such sites prior to planning, design, and construction.

PLANS AND SPECIFICATIONS

Plans and specification for installing diversions shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be prepared for use by the client. The plan shall include specific instructions for maintaining diversion capacity, storage, ridge height, and outlets.

The minimum requirements to be addressed in the operation and maintenance plan are:

1. Provide periodic inspections, especially immediately following significant storms.
2. Promptly repair or replace damaged components of the diversion as necessary.
3. Maintain diversion capacity, ridge height, and outlet elevations especially if high sediment yielding areas are in the drainage area above the diversion. Establish necessary clean-out requirements.
4. Each inlet for underground outlets must be kept clean and sediment buildup redistributed so that the inlet is at the lowest point. Inlets damaged by farm machinery must be replaced or repaired immediately.
5. Redistribute sediment as necessary to maintain the capacity of the diversion.
6. Vegetation shall be maintained and trees and brush controlled by hand, chemical and/or mechanical means.
7. Keep machinery away from steep sloped ridges. Keep equipment operators informed of all potential hazards.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

FENCE

(Ft.)

CODE 382

DEFINITION

A constructed barrier to animals or people.

PURPOSE

This practice facilitates the accomplishment of conservation objectives by providing a means to control movement of animals and people, including vehicles.

CONDITIONS WHERE PRACTICE APPLIES

This practice may be applied on any area where management of animal or human movement is needed.

CRITERIA

General Criteria Applicable to All Purposes

Fencing materials, type and design of fence installed shall be of a high quality and durability. The type and design of fence installed will meet the management objectives and site challenges. Based on need, fences may be permanent, portable, or temporary.

Fences shall be positioned to facilitate management requirements. Ingress/egress features such as gates and cattle guards shall be planned. The fence design and installation should have the life expectancy appropriate for management objectives and shall follow all federal, state and local laws and regulations.

Height, size, spacing and type of materials used will provide the desired control, life expectancy, and management of animals and people of concern.

CONSIDERATIONS

The fence design and location should consider: topography, soil properties, livestock management and safety, livestock trailing, wildlife class and movement, location and adequacy of water facilities, development of potential grazing systems, human access and safety, landscape aesthetics, erosion problems, moisture conditions, flooding potential, stream crossings, and durability of materials. When appropriate, natural barriers should be utilized instead of fencing.

Where applicable, cleared rights-of-way may be established which would facilitate fence construction and maintenance. Avoid clearing of vegetation during the nesting season for migratory birds.

Fences across gullies, canyons or streams may require special bracing, designs or approaches.

Fence design and location should consider ease of access for construction, repair and maintenance.

Fence construction requiring the removal of existing unusable fence should provide for the proper disposal of scrap materials to prevent harm to animals, people and equipment.

PLANS AND SPECIFICATIONS

Plans and specifications are to be prepared for all fence types, installations and specific sites. Requirements for applying the practice to achieve all of its intended purposes shall be described.

OPERATION AND MAINTENANCE

Regular inspection of fences should be part of an ongoing maintenance program. Inspection of fences after storms and other disturbance events is necessary to insure the continued proper function of the fence. Maintenance and repairs will be performed in a timely manner as needed, including tree/limb removal and water gap replacement.

Remove and properly discard all broken fencing material and hardware. All necessary precautions should be taken to ensure the safety of construction and maintenance crews.

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NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

ACCESS CONTROL

(Ac.)

CODE 472

DEFINITION

The temporary or permanent exclusion of animals, people, vehicles, and/or equipment from an area.

PURPOSE

Achieve and maintain desired resource conditions by monitoring and managing the intensity of use by animals, people, vehicles, and/or equipment in coordination with the application schedule of practices, measures and activities specified in the conservation plan.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies on all land uses.

CRITERIA

Use-regulating activities (e.g., posting of signs, patrolling, gates, fences and other barriers, permits) shall achieve the intended purpose and include mitigating associated resource concerns to acceptable levels during their installation, operation, and maintenance. Activities will complement the application schedule and life span of other practices specified in the conservation plan.

Each activity or measure will identify the entity to be monitored and regulated (animals, people, vehicles and/or equipment) and specify the intent, intensity, amounts, and timing of exclusion by that entity. Activities may involve temporary to permanent exclusion of one to all entities.

Placement, location, dimensions and materials (e.g., signs, gates), and frequency of use (e.g., continuous, specific season, or specific dates) shall be described for each activity including monitoring frequency.

CONSIDERATIONS

Even though usage of the area is monitored and controlled, the land manager and/or tenant should be advised about emergency preparedness agencies and related information, e.g., the local fire/wildfire control agency and pumper truck water sources on or near the area. Information should be designated initially and re-designated annually.

PLANS AND SPECIFICATIONS

Specifications for applying this practice shall be prepared for each area and recorded using approved specification sheets, job sheets, and narrative statements in the conservation plan, or other acceptable documentation.

OPERATION AND MAINTENANCE

Monitoring of the effectiveness of use-regulating activities will be performed routinely and at least annually with changes made to specifications and operation and maintenance requirements as necessary.

Modifications to activities and use of measures are allowed temporarily to accommodate emergency-level contingencies such as wildfire, hurricane, drought, or flood as long as resource conditions are maintained.

REFERENCES

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NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

DRAINAGE WATER MANAGEMENT

(Ac.)

CODE 554

DEFINITION

The process of managing water discharges from surface and/or subsurface agricultural drainage systems.

PURPOSE

The purpose of this practice is:

- Reduce nutrient, pathogen, and/or pesticide loading from drainage systems into downstream receiving waters
- Improve productivity, health, and vigor of plants
- Reduce oxidation of organic matter in soils
- Reduce wind erosion or particulate matter (dust) emissions
- Provide seasonal wildlife habitat

CONDITIONS WHERE PRACTICE APPLIES

This practice is applicable to agricultural lands with surface or subsurface agricultural drainage systems that are adapted to allow management of drainage discharges.

The practice may not apply where saline or sodic soil conditions require special considerations.

This practice does not apply to the management of irrigation water supplied through a subsurface drainage system. For that purpose, use NRCS Conservation Practice Standard, Irrigation Water Management (449).

CRITERIA

General Criteria Applicable to All Purposes

The management of gravity drained outlets shall be accomplished by adjusting the elevation of the drainage outlet.

The management of pumped drainage outlets shall be accomplished by raising the on-off elevations for pump cycling.

Structures and pumps shall be located where they are convenient to operate and maintain.

Raising the outlet elevation of the flowing drain shall result in an elevated free water surface within the soil profile.

When operated in free drainage mode, water control structures shall not restrict the flow of the drainage system.

Drainage discharges and water levels shall be managed in a manner that does not cause adverse impacts to other properties or drainage systems.

Release of water from control structures shall not allow flow velocities in surface drainage system components to exceed acceptable velocities prescribed by NRCS Conservation Practice Standard, Surface Drainage, Main or Lateral (608).

Release of water from flow control structures shall not allow flow velocities in subsurface drains to exceed velocities prescribed by NRCS Conservation Practice Standard, Subsurface Drain (606).

Additional Criteria to Reduce Nutrient, Pathogen, and/or Pesticide Loading

During non-cropped periods, the system shall be in managed drainage mode within 30 days after the season's final field operation, until at least 30 days before commencement of the next season's field operations, except during system maintenance periods or to provide trafficability when field operations are necessary.

The drain outlet shall be raised prior to and during liquid manure applications to prevent direct leakage of manure into drainage pipes through soil macro pores (cracks, worm holes, root channels).

Manure applications shall be in accordance with NRCS Conservation Practice Standards, Nutrient Management (590) and Waste Utilization (633).

Additional Criteria to Improve Productivity, Health, and Vigor of Plants

When managing drainage outflow to maintain water in the soil profile for use by crops or other vegetation, the elevation at which the outlet is set shall be based on root depth and soil type.

If using this practice to control rodents, apply in conjunction with NRCS Conservation Practice Standard, Pest Management (595).

Additional Criteria to Reduce Oxidation of Organic Matter in Soils

Drainage beyond that necessary to provide an adequate root zone for the crop shall be minimized.

To reduce oxidation of organic matter, the outlet elevation shall be set to enable the water table to rise to the ground surface, or to a designated maximum elevation, for sufficient time to create anaerobic soil conditions. The implementation of this practice must result in a reduced average annual thickness of the aerated layer of the soil.

Additional Criteria to Reduce Wind Erosion or Particulate Matter (Dust) Emissions

When the water table is at the design elevation, the system shall provide a moist field soil surface, either by ponding or through capillary action from the elevated water table.

Additional Criteria to Provide Seasonal Wildlife Habitat

During the non-cropped season, the elevation of the drainage outlet shall be managed in a manner consistent with a habitat evaluation procedure that addresses targeted species.

CONSIDERATIONS

In-field water table elevation monitoring devices can be used to improve water table management.

Reducing mineralization of organic soils may decrease the release of soluble phosphorus, but water table management may increase the release of soluble phosphorus from mineral soils.

Elevated water tables may increase the runoff portion of outflow from fields. Consider conservation measures that control sediment loss and associated nutrient discharge to waterways.

Elevate the drainage outlet for subsurface drains during and after manure applications to decrease potential for nutrient and pathogen loading to receiving waters.

Consider manure application setbacks from streams, flowing drain lines, and sinkholes, to reduce risk of contamination.

To maintain proper root zone development and aeration, downward adjustments of the drainage outlet control elevation may be necessary, especially following significant rainfall events.

Monitoring of root zone development may be necessary if the free water surface in the soil profile is raised during the growing season.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard as necessary and shall describe the requirements for applying the practice to achieve its intended purpose(s).

OPERATION AND MAINTENANCE

An Operation and Maintenance plan shall be provided that identifies the intended purpose of the practice, practice life safety requirements, and water table elevations and periods of operation necessary to meet the intended purpose. If in-field water table observation points are not used, the relationship of the control elevation settings relative to critical field water table depths shall be provided in the operation plan.

The Operation and Maintenance Plan shall include instructions for operation and maintenance of critical components of the drainage management system, including instructions necessary to maintain flow velocities within allowable limits when lowering water tables.

To prevent leakage of liquid manure applications into drain pipes, the plan shall specify the elevation of the raised drainage outlet and the number of days prior to and after the application that a raised outlet elevation is to be maintained.

Replace warped flashboards that cause structure leakage.

REFERENCES

USDA, NRCS. 2001. National Engineering Handbook, Part 624, Sec. 16, Drainage of agricultural land.

USDA, NRCS. 2001. National Engineering Handbook, Part 650, Engineering Field Handbook, Chapter 14, Water management (Drainage).

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

ROOF RUNOFF STRUCTURE

(No.)

CODE 558

DEFINITION

Structures that collect, control, and transport precipitation from roofs.

PURPOSE

To improve water quality, reduce soil erosion, increase infiltration, protect structures, and/or increase water quantity.

CONDITIONS WHERE PRACTICE APPLIES

Where roof runoff from precipitation needs to be:

- diverted away from structures or contaminated areas;
- collected, controlled, and transported to a stable outlet; or
- collected and used for other purposes such as irrigation or animal watering facility.

CRITERIA

General Criteria Applicable to All Purposes

The minimum design capacity for roof runoff structures shall be a 10-year storm frequency, 5-minute rainfall precipitation event, except where excluding roof runoff from manure management facilities. In that case, a 25-year frequency, 5-minute precipitation event shall be used to design roof runoff structures (Refer to Agricultural Waste Management Field Handbook, NEH Part 651 Chapter 10 Appendix 10B). When gutters are used, the capacity of the downspout(s) must equal or exceed the gutter flow rate.

Runoff may empty into surface or underground outlets, or onto the ground surface. Surface and underground outlets shall be sized to ensure adequate design capacity and shall provide for clean-out as appropriate. When runoff from roofs empties onto the ground surface, a stable outlet shall be provided. When runoff is conveyed through a gutter and downspout system, an elbow and energy dissipation device shall be placed at the end of the downspout to provide a stable outlet and direct water away from the building.

Surface or ground outlets such as rock pads, rock filled trenches with subsurface drains, concrete and other erosion-resistant pads, or preformed channels may be used, particularly where snow and ice are a significant load component on roofs.

In regions where snow and ice will accumulate on roofs, guards and sufficient supports to withstand the anticipated design load shall be included.

Roof runoff structures shall be made of durable materials with a minimum design life of ten years. Roof gutters and downspouts may be made of aluminum, galvanized steel, wood, or plastic. Aluminum gutters and downspouts shall have a minimum nominal thickness of 0.027 inches and 0.020 inches, respectively. Galvanized steel gutters and downspouts shall be a minimum 28 gauge. Wood shall be clear and free of knots. Wood may be redwood, cedar, cypress, or other species that has the desired longevity. Plastics shall contain ultraviolet stabilizers. Dissimilar metals shall not be in contact with each other.

Rock-filled trenches and pads shall consist of poorly graded rock (all rock fragments approximately the same size) and be free of appreciable amounts of sand and/or soil particles. Crushed limestone shall not be used for backfill material unless it has been washed. Subsurface drains or outlets shall meet the material requirements of the applicable NRCS conservation practice standard.

Concrete appurtenances used shall meet the requirements of NRCS NEH Part 642, Chapter 2, Construction Specification 32 Structure Concrete.

Roof runoff structures shall be protected from damage by livestock and equipment.

Additional Criteria to Increase Infiltration

Runoff shall be routed onto pervious landscaped areas (e.g., lawns, mass planting areas, infiltration trenches, and natural areas) to increase infiltration of runoff. These areas shall be capable of infiltrating the runoff in such a way that replenishes soil moisture without adversely affecting the desired plant species.

Additional Criteria to Protect Structures

Runoff shall be directed away from structure foundations to avoid wetness and hydraulic loading on the foundation.

On expansive soils or bedrock, downspout extensions shall be used to discharge runoff a minimum of five (5) feet from the structure.

The discharge area for runoff must slope away from the protected structure.

Additional Criteria to Increase Water Quantity

Storage structures for non-potable purposes such as irrigation water shall be designed in accordance with NRCS conservation practice standards, as appropriate.

Potable water storage structures shall be constructed of materials and in a manner that will not increase the contamination of the stored water. Roof runoff collected and stored for potable uses must be treated prior to consumption and shall be tested periodically to assure that adequate quality is maintained for human consumption.

CONSIDERATIONS

Avoid discharging outlets near wells and sinkholes.

Some designs may provide secondary benefits, e.g. rock pads may also reduce rodent problems around livestock and poultry barns.

PLANS AND SPECIFICATIONS

The plans and specifications shall show the location, spacing, size, and grade of all gutters and downspouts and type and quality of material to be used. Plans and specifications for other practices essential to the proper functioning of the roof runoff structure, such as underground outlet, shall be included.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for the design. The plan shall contain, but not be limited to, the following provisions:

- Keep roof runoff structures clean and free of obstructions that reduce flow.
- Make regular inspections and perform repair maintenance as needed to ensure proper functioning of the roof runoff structures.

REFERENCES

USDA-NRCS. 1999. National Engineering Handbook, Part 651, Agricultural Waste Management Field Handbook.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

NUTRIENT MANAGEMENT

(Ac.)

CODE 590

DEFINITION

Managing the amount, source, placement, form and timing of the application of plant nutrients and soil amendments.

PURPOSE

- To budget and supply nutrients for plant production.
- To properly utilize manure or organic by-products as a plant nutrient source.
- To minimize agricultural nonpoint source pollution of surface and ground water resources.
- To protect air quality by reducing nitrogen emissions (ammonia and NO_x compounds) and the formation of atmospheric particulates.
- To maintain or improve the physical, chemical and biological condition of soil.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all lands where plant nutrients and soil amendments are applied.

CRITERIA

General Criteria Applicable to All Purposes

A nutrient budget for nitrogen, phosphorus, and potassium shall be developed that considers all potential sources of nutrients including, but not limited to animal manure and organic by-products, waste water, commercial fertilizer, crop residues, legume credits, and irrigation water.

Realistic yield goals shall be established based on soil productivity information, historical yield data, climatic conditions, level of management and/or local research on similar soil, cropping systems, and soil and manure/organic by-products tests.

For new crops or varieties, industry yield recommendations may be used until documented yield information is available.

Plans for nutrient management shall specify the source, amount, timing and method of application of nutrients on each field to achieve realistic production goals, while minimizing movement of nutrients and other potential contaminants to surface and/or ground waters.

Areas contained within established minimum application setbacks (e.g., sinkholes, wells, gullies, ditches, surface inlets or rapidly permeable soil areas) shall not receive direct application of nutrients.

The amount of nutrients lost to erosion, runoff, irrigation and drainage, shall be addressed, as needed.

Soil and Tissue Sampling and Laboratory Analyses (Testing). Nutrient planning shall be based on current soil and tissue (where used as a supplement) test results developed in accordance with Land Grant University guidance, or industry practice if recognized by the Land Grant University. Current soil tests are those that are no older than five years.

Soil and tissue samples shall be collected and prepared according to the Land Grant University guidance or standard industry practice. Soil and tissue test analyses shall be performed by laboratories that are accepted in one or more of the following:

- Laboratories successfully meeting the requirements and performance standards of the North American Proficiency Testing Program (NAPT) under the auspices of the Soil Science Society of America, or

- State recognized program that considers laboratory performance and proficiency to assure accuracy of soil test results.

Soil and tissue testing shall include analyses for any nutrients for which specific information is needed to develop the nutrient plan. Request analyses pertinent to monitoring or amending the annual nutrient budget, e.g. pH, electrical conductivity (EC), soil organic matter, nitrogen, phosphorus and potassium.

Nutrient Application Rates. Soil amendments shall be applied, as needed, to adjust soil pH to an adequate level for crop nutrient availability and utilization.

Recommended nutrient application rates shall be based on Land Grant University recommendations (and/or industry practice when recognized by the university) that consider current soil test results, realistic yield goals and management capabilities. If the Land Grant University does not provide specific recommendations, application shall be based on realistic yield goals and associated plant nutrient uptake rates.

The planned rates of nutrient application, as documented in the nutrient budget, shall be determined based on the following guidance:

- Nitrogen Application **-** Planned nitrogen application rates shall match the recommended rates as closely as possible, except when manure or organic by-products are a source of nutrients. When manure or organic by-products are a source of nutrients, see “Additional Criteria” below.

- Phosphorus Application **-** Planned phosphorus application rates shall match the recommended rates as closely as possible, except when manure or organic by-products are sources of nutrients. When manure or organic by-products are a source of nutrients, see “Additional Criteria” below.

- Potassium Application - Potassium shall not be applied in situations in which excess (greater than soil test potassium recommendation) causes unacceptable nutrient imbalances in crops or forages. When forage quality is an issue associated with excess potassium application, state standards shall be used to set forage quality guidelines.

- Other Plant Nutrients - The planned rates of application of other nutrients shall be consistent with Land Grant University guidance or industry practice if recognized by the Land Grant University in the state.

- Starter Fertilizers - When starter fertilizers are used, they shall be included in the overall nutrient budget, and applied in accordance with Land Grant University recommendations, or industry practice if recognized by the Land Grant University within the state.

Nutrient Application Timing. Timing and method of nutrient application (particularly nitrogen) shall correspond as closely as possible with plant nutrient uptake characteristics, while considering cropping system limitations, weather and climatic conditions, risk assessment tools (e.g., leaching index, P index) and field accessibility.

Nutrient Application Methods. Application methods to reduce the risk of nutrient transport to surface and ground water, or into the atmosphere shall be employed.

To minimize nutrient losses:

- Apply nutrient materials uniformly to application area(s).

- Nutrients shall not be applied to frozen, snow-covered or saturated soil if the potential risk for runoff exists.

- Nutrients shall be applied considering the plant growth habits, irrigation practices, and other conditions so as to maximize availability to the plant and minimize the risk of runoff, leaching, and volatilization losses.

- Nutrient applications associated with irrigation systems shall be applied in a manner that prevents or minimizes resource impairment.

Conservation Management Unit (CMU) Risk Assessment. In areas with identified or designated nutrient related water quality impairment, a CMU specific risk assessment of the potential for nutrient transport from the area shall be completed.

States that utilize a threshold prescreening procedure to trigger CMU risk assessment shall follow approved procedures as recommended by the respective state or Land Grant University.

Use an appropriate nutrient risk assessment tool for the nutrient in question (e.g., leaching index, phosphorus index) or other state recognized assessment tool.

Additional Criteria Applicable to Manure and Organic By-Products or Biosolids Applied as a Plant Nutrient Source

When animal manures or organic by-products are applied, a risk assessment of the potential for nutrient transport from the CMU shall be completed to adjust the amount, placement, form and timing of application of nutrient sources, as recommended by the respective state or Land Grant University.

Nutrient values of manure and organic by-products (excluding sewage sludge or biosolids) shall be determined prior to land application. Samples will be taken and analyzed with each hauling/emptying cycle for a storage/treatment facility. Manure sampling frequency may vary based on the operation's manure handling strategy and spreading schedule. If there is no prior sampling history, the manure shall be analyzed at least annually for a minimum of three consecutive years. A cumulative record shall be developed and maintained until a consistent (maintaining a certain nutrient concentration with minimal variation) level of nutrient values is realized. The average of results contained in the operation's cumulative manure analyses history shall be used as a basis for nutrient allocation to fields. Samples shall be collected and prepared according to Land Grant University guidance or industry practice.

In planning for new operations, acceptable "book values" recognized by the NRCS and/or the Land Grant University may be used if they accurately estimate nutrient output from the proposed operation (e.g., NRCS Agricultural Waste Management Field Handbook).

Biosolids (sewage sludge) shall be applied in accordance with USEPA regulations. (40 CFR Parts 403 (Pretreatment) and 503 (Biosolids) and other state and/or local regulations regarding the use of biosolids as a nutrient source.

Manure and Organic By-Product Nutrient Application Rates. Manure and organic by-product nutrient application rates shall be based on nutrient analyses procedures recommended by the respective state or Land Grant University. As indicated above, "book values" may be used in planning for new operations. At a minimum, manure analyses shall identify nutrient and specific ion concentrations, percent moisture, and percent organic matter. Salt concentration shall be monitored so that manure applications do not cause plant damage or negatively impact soil quality.

The application rate (in/hr) of liquid materials applied shall not exceed the soil intake/infiltration rate and shall be adjusted to minimize ponding and to avoid runoff. The total application shall not exceed the field capacity of the soil and shall be adjusted, as needed, to minimize loss to subsurface tile drains.

The planned rates of nitrogen and phosphorus application recorded in the plan shall be determined based on the following guidance:

Nitrogen Application Rates

- When manure or organic by-products are used, the nitrogen availability of the planned application rates shall match plant uptake characteristics as closely as possible, taking into consideration the timing of nutrient application(s) in order to minimize leaching and atmospheric losses.
- Management activities and technologies shall be used that effectively utilize mineralized nitrogen and that minimize nitrogen losses through denitrification and ammonia volatilization.

- o Manure or organic by-products may be applied on legumes at rates equal to the estimated removal of nitrogen in harvested plant biomass.
- o When the nutrient management plan component is being implemented on a phosphorus basis, manure or organic by-products shall be applied at rates consistent with a phosphorus limited application rate. In such situations, an additional nitrogen application, from non-organic sources, may be required to supply, but not exceed, the recommended amounts of nitrogen in any given year.

Phosphorus Application Rates

- o When manure or organic by-products are used, the planned rates of phosphorus application shall be consistent with any one of the following options:
  - ◊ Phosphorus Index (PI) Rating. Nitrogen-based manure application on Low or Medium Risk Sites; phosphorus-based or no manure application on High and Very High Risk Sites.**
  - ◊ Soil Phosphorus Threshold Values. Nitrogen-based manure application on sites on which the soil test phosphorus levels are below the threshold values; Phosphorus-based or no manure application on sites on which soil phosphorus levels equal or exceed threshold values.**
  - ◊ Soil Test. Nitrogen-based manure application on sites for which the soil test recommendation calls for phosphorus application; phosphorus-based or no manure application on sites for which the soil test recommendation calls for no phosphorus application. ‡

  ** Acceptable phosphorus-based manure application rates shall be determined as a function of soil test recommendation or estimated phosphorus removal in harvested plant biomass. Guidance for developing these acceptable rates is found in the NRCS General Manual, Title 190, Part 402 (Ecological Sciences, Nutrient Management, Policy), and the National Agronomy Manual, Section 503 (to be developed).
- o The application of phosphorus applied as manure may be made at a rate equal to the recommended phosphorus application or estimated phosphorus removal in harvested plant biomass for the crop rotation or multiple years in the crop sequence. When such applications are made, the application rate shall:
  - ◊ Not exceed the recommended nitrogen application rate during the year of application, or
  - ◊ Not exceed the estimated nitrogen removal in harvested plant biomass during the year of application when there is no recommended nitrogen application.
  - ◊ Not be made on sites considered vulnerable to off-site phosphorus transport unless appropriate conservation practices, best management practices or management activities are used to reduce the vulnerability.

Heavy Metal Monitoring. When sewage sludge (biosolids) is applied, the accumulation of potential pollutants (including arsenic, cadmium, copper, lead, mercury, selenium, and zinc) in the soil shall be monitored in accordance with the US Code, Reference 40 CFR, Parts 403 and 503, and/or any applicable state and local laws or regulations.

Additional Criteria to Protect Air Quality by Reducing Nitrogen and/or Particulate Emissions to the Atmosphere

In areas with an identified or designated nutrient management related air quality concern, any component(s) of nutrient management (i.e., amount, source, placement, form, timing of application) identified by risk assessment tools as a potential source of atmospheric pollutants shall be adjusted, as necessary, to minimize the loss(es).

When tillage can be performed, surface applications of manure and fertilizer nitrogen formulations that are subject to volatilization on the soil surface (e.g., urea) shall be incorporated into the soil within 24 hours after application.

When manure or organic by-products are applied to grassland, hayland, pasture or minimum-till areas the rate, form and timing of application(s) shall be managed to minimize volatilization losses.

When liquid forms of manure are applied with irrigation equipment, operators will select weather conditions during application that will minimize volatilization losses.

Operators will handle and apply poultry litter or other dry types of animal manures when the potential for wind-driven loss is low and there is less potential for transport of particulates into the atmosphere.

Weather and climatic conditions during manure or organic by-product application(s) shall be recorded and maintained in accordance with the operation and maintenance section of this standard.

Additional Criteria to Improve the Physical, Chemical and Biological Condition of the Soil

Nutrients shall be applied and managed in a manner that maintains or improves the physical, chemical and biological condition of the soil.

Minimize the use of nutrient sources with high salt content unless provisions are made to leach salts below the crop root zone.

To the extent practicable nutrients shall not be applied when the potential for soil compaction and rutting is high.

CONSIDERATIONS

The use of management activities and technologies listed in this section may improve both the production and environmental performance of nutrient management systems. The addition of these management activities, when applicable, increases the management intensity of the system and is recommended in a nutrient management system.

Action should be taken to protect National Register listed and other eligible cultural resources.

The nutrient budget should be reviewed annually to determine if any changes are needed for the next planned crop.

For sites on which there are special environmental concerns, other sampling techniques may be appropriate. These include soil profile sampling for nitrogen, Pre-Sidedress Nitrogen Test (PSNT), Pre-Plant Soil Nitrate Test (PPSN) or soil surface sampling for phosphorus accumulation or pH changes.

Additional practices to enhance manure management effectively include modification of the animal's diet to reduce the manure nutrient content, or utilizing manure amendments that stabilize or tie-up nutrients.

Soil test information should be no older than one year when developing new plans, particularly if animal manures are to be used as a nutrient source.

Excessive levels of some nutrients can cause induced deficiencies of other nutrients.

If increases in soil phosphorus levels are expected, consider a more frequent (annual) soil testing interval.

To manage the conversion of nitrogen in manure or fertilizer, use products or materials (e.g. nitrification inhibitors, urease inhibitors and slow or controlled release fertilizers) that more closely match nutrient release and availability for plant uptake. These materials may improve the nitrogen use efficiency (NUE) of the nutrient management system by reducing losses of nitrogen into water and/or air.

Considerations to Minimize Agricultural Nonpoint Source Pollution of Surface and Ground Water.

Erosion control and runoff reduction practices can improve soil nutrient and water storage, infiltration, aeration, tilth, diversity of soil organisms and protect or improve water and air quality (Consider installation of one or more NRCS FOTG, Section IV – Conservation Practice Standards).

Cover crops can effectively utilize and/or recycle residual nitrogen.

Apply nutrient materials uniformly to the application area. Application methods and timing that reduce the risk of nutrients being transported to ground and surface waters, or into the atmosphere include:

- Split applications of nitrogen to provide nutrients at the times of maximum crop utilization,
- Use stalk-test to minimize risk of over applying nitrogen in excess of crop needs.
- Avoid winter nutrient application for spring seeded crops,
- Band applications of phosphorus near the seed row,
- Incorporate surface applied manures or organic by-products as soon as possible after application to minimize nutrient losses,
- Delay field application of animal manures or organic by-products if precipitation capable of producing runoff and erosion is forecast within 24 hours of the time of the planned application.

Considerations to Protect Air Quality by Reducing Nitrogen and/or Particulate Emissions to the Atmosphere.

Odors associated with the land application of manures and organic by-products can be offensive to the occupants of nearby homes. Avoid applying these materials upwind of occupied structures when residents are likely to be home (evenings, weekends and holidays).

When applying manure with irrigation equipment, modifying the equipment can reduce the potential for volatilization of nitrogen from the time the manure leaves the application equipment until it reaches the surface of the soil (e.g., reduced pressure, drop down tubes for center pivots). N volatilization from manure in a surface irrigation system will be reduced when applied under a crop canopy.

When planning nutrient applications and tillage operations, encourage soil carbon buildup while discouraging greenhouse gas emissions (e.g., nitrous oxide N_2O, carbon dioxide CO_2).

Nutrient applications associated with irrigation systems should be applied in accordance with the requirements of Irrigation Water Management (Code 449).

CAFO operations seeking permits under USEPA regulations (40 CFR Parts 122 and 412) should consult with their respective state permitting authority for additional criteria.

PLANS AND SPECIFICATIONS

Plans and specifications for nutrient management shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose(s), using nutrients to achieve production goals and to prevent or minimize resource impairment.

Nutrient management plans shall include a statement that the plan was developed based on requirements of the current standard and any applicable Federal, state, or local regulations, policies, or programs, which may include the implementation of other practices and/or management activities. Changes in any of these requirements may necessitate a revision of the plan.

The following components shall be included in the nutrient management plan:

- aerial site photograph(s) or site map(s), and a soil survey map of the site,
- location of designated sensitive areas or resources and the associated, nutrient management restriction,
- current and/or planned plant production sequence or crop rotation,
- results of soil, water, manure and/or organic by-product sample analyses,
- results of plant tissue analyses, when used for nutrient management,
- realistic yield goals for the crops,

- complete nutrient budget for nitrogen, phosphorus, and potassium for the crop rotation or sequence,
- listing and quantification of all nutrient sources,
- CMU specific recommended nutrient application rates, timing, form, and method of application and incorporation, and
- guidance for implementation, operation, maintenance, and recordkeeping.

If increases in soil phosphorus levels are expected, the nutrient management plan shall document:

- the soil phosphorus levels at which it may be desirable to convert to phosphorus based planning,
- results of appropriate risk assessment tools to document the relationship between soil phosphorus levels and potential for phosphorus transport from the field,
- the potential for soil phosphorus drawdown from the production and harvesting of crops, and
- management activities or techniques used to reduce the potential for phosphorus loss.

OPERATION AND MAINTENANCE

The owner/client is responsible for safe operation and maintenance of this practice including all equipment. Operation and maintenance addresses the following:

- periodic plan review to determine if adjustments or modifications to the plan are needed. As a minimum, plans will be reviewed and revised with each soil test cycle.
- significant changes in animal numbers and/or feed management will necessitate additional manure sampling and analyses to establish a revised average nutrient content.
- protection of fertilizer and organic by-product storage facilities from weather and accidental leakage or spillage.
- calibration of application equipment to ensure uniform distribution of material at planned rates.
- documentation of the actual rate at which nutrients were applied. When the actual rates used differ from the recommended and planned rates, records will indicate the reasons for the differences.
- Maintaining records to document plan implementation. As applicable, records include:
  - Soil, plant tissue, water, manure, and organic by-product analyses resulting in recommendations for nutrient application,
  - quantities, analyses and sources of nutrients applied,
  - dates and method(s) of nutrient applications,
  - weather conditions and soil moisture at the time of application; lapsed time to manure incorporation, rainfall or irrigation event.
  - crops planted, planting and harvest dates, yields, and crop residues removed,
  - dates of plan review, name of reviewer, and recommended changes resulting from the review.

Records should be maintained for five years; or for a period longer than five years if required by other Federal, state or local ordinances, or program or contract requirements.

Workers should be protected from and avoid unnecessary contact with plant nutrient sources. Extra caution must be taken when handling ammoniacal nutrient sources, or when dealing with organic wastes stored in unventilated enclosures.

Material generated from cleaning nutrient application equipment should be utilized in an environmentally safe manner. Excess material should be collected and stored or field applied in an appropriate manner.

Nutrient containers should be recycled in compliance with state and local guidelines or regulations.

REFERENCES

Follett, R.F. 2001. Nitrogen Transformation and Transport Processes. pp. 17-44, In R.F. Follett and J. Hatfield. (eds.). 2001. Nitrogen in the Environment; Sources, Problems, and Solutions. Elsevier Science Publishers. The Netherlands. 520 pp.

Sims, J.T. (ed.) 2005. Phosphorus: Agriculture and the Environment. Agron. Monogr. 46. ASA, CSSA, and SSSA, Madison, WI.

Stevenson, F.J. (ed.) 1982. Nitrogen in Agricultural Soils. Agron. Series 22. ASA, CSSA, and SSSA, Madison, WI.

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

WATERING FACILITY

(No.)

CODE 614

DEFINITION

A permanent or portable device to provide an adequate amount and quality of drinking water for livestock and or wildlife.

PURPOSE

To provide access to drinking water for livestock and/or wildlife in order to:

- Meet daily water requirements
- Improve animal distribution

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all land uses where there is a need for new or improved watering facilities for livestock and/or wildlife.

CRITERIA

General Criteria Applicable To All Purposes

Design watering facilities with adequate capacity and supply to meet the daily water requirements of the livestock and/or wildlife planned to use the facility. Include the storage volume necessary to provide water between periods of replenishment. Refer to the National Range and Pasture Handbook for guidance on livestock water quantity and quality requirements. For wildlife, base water quantity and quality requirements on targeted species needs.

Locate facilities to promote even grazing distribution and reduce grazing pressure on sensitive areas.

Design the watering facility to provide adequate access to the animals planned to use the facility. Incorporate escape features into the watering facility design where local knowledge and experience indicate that wildlife may be at risk of drowning.

Include design elements to meet the specific needs of the animals that are planned to use the watering facility, both livestock and wildlife.

Protect areas around watering facilities where animal concentrations or overflow from the watering facility will cause resource concerns. Use criteria in NRCS Conservation Practice Standard 561, Heavy Use Area Protection to design the protection.

Install permanent watering facilities on a firm, level, foundation that will not settle differentially. Examples of suitable foundation materials are bedrock, compacted gravel and stable, well compacted soils.

Design and install watering facilities to prevent overturning by wind and animals.

Design watering facilities and all valves and controls to withstand or be protected from damage by livestock, wildlife, freezing and ice damage.

Construct watering facilities from durable materials that have a life expectancy that meets or exceeds the planned useful life of the installation. Follow appropriate NRCS design procedures for the material being used or industry standards where NRCS standards do not exist.

Use the criteria in NRCS Conservation Practice Standard 516, Pipeline to design piping associated with the watering facility. Include backflow prevention devices on facilities connected to wells, domestic or municipal water systems.

CONSIDERATIONS

Design fences associated with the watering facilities to allow safe access and exit for area wildlife species. To protect bats and other species that access water by skimming across the surface, fencing material should not extend across the water surface. If fencing across the water is necessary it should be made highly visible by avoiding the use of single wire fences and using fencing materials such as woven wire or by adding streamers or coverings on the fence.

For watering facilities that will be accessible to wildlife, give consideration to the effects the location of the facility will have on target and non-target species. Also consider the effect of introducing a new water source within the ecosystem in the vicinity of the facility. This should include things such as the concentration of grazing, predation, entrapment, drowning, disease transmission, hunting and expansion of the wildlife populations beyond the carrying capacity of available habitat.

Consider the following guidelines for materials commonly used for watering facilities.

Concrete	3000 psi compressive strength
Galvanized Steel	20 gauge thickness
Plastic	Ultraviolet resistance
Fiberglass	Ultraviolet resistance

Where water is supplied continuously or under pressure to the watering facility consider the use of automatic water level controls to control the flow of water to the facility and to prevent unnecessary overflows.

Watering facilities often collect debris and algae and should be cleaned on a regular basis. Consider increasing the pipe sizes for inlets and outlets to reduce the chances of clogging. Maintenance of a watering facility can be made easier by providing a method to completely drain the watering facility.

Steep slopes leading to watering facilities can cause erosion problems from over use by animals as well as problems with piping and valves from excess pressure. Choose the location of watering facilities to minimize these problems from steep topography.

PLANS AND SPECIFICATIONS

Plans and specifications for watering facilities shall provide the information necessary to install the facility. As a minimum this shall include the following:

- A map or aerial photograph showing the location of the facility
- Detail drawings showing the facility, necessary appurtenances (such as foundations, pipes and valves) and stabilization of any areas disturbed by the installation of the facility
- Construction specifications describing the installation of the facility

OPERATION AND MAINTENANCE

Provide an O&M plan specific to the type of watering facility. to the landowner. As a minimum include the following items in the plan:

- a monitoring schedule to ensure maintenance of adequate inflow and outflow;
- checking for leaks and repair as necessary;
- if present, the checking of the automatic water level device to insure proper operation;
- checking to ensure that adjacent areas are protected against erosion;
- if present, checking to ensure the outlet pipe is freely operating and not causing erosion problems;
- a schedule for periodic cleaning of the facility.

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Yoakum, J. and W.P. Dasmann. 1971. Habitat manipulation practices. Ch. 14 in Wildlife Management Techniques, Third Edition. Ed. Robert H. Giles, Jr. Pub. The Wildlife Society. 633 pp.

National Engineering Handbook, Part 650 Engineering Field Handbook, Chapters 5, 11 & 12, USDA Natural Resources Conservation Service.

National Range and Pasture Handbook, Chapter 6, Page 6-12, Table 6-7 & 6-8, USDA-Natural Resources Conservation Service.

National Research Council, 1996 Nutrient Requirements of Domestic Animals, National Academy Press.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

WASTE UTILIZATION

(Ac.)

CODE 633

DEFINITION

Using agricultural wastes such as manure and wastewater or other organic residues.

PURPOSE

- Protect water quality
- Protect air quality
- Provide fertility for crop, forage, fiber production and forest products
- Improve or maintain soil structure
- Provide feedstock for livestock
- Provide a source of energy

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where agricultural wastes including animal manure and contaminated water from livestock and poultry operations; solids and wastewater from municipal treatment plants; and agricultural processing residues are generated, and/or utilized

CRITERIA

General Criteria Applicable to All Purposes

All federal, state and local laws, rules and regulations governing waste management, pollution abatement, health and safety shall be strictly adhered to. The owner or operator shall be responsible for securing all required permits or approvals related to waste utilization, and for operating and maintaining any components in accordance with applicable laws and regulations.

Use of agricultural wastes shall be based on at least one analysis of the material during the time it is to be used. In the case of daily spreading, the waste shall be sampled and analyzed at least once each year. As a minimum, the waste analysis should identify nutrient and specific ion concentrations. Where the metal content of municipal wastewater, sludge, septage and other agricultural waste is of a concern, the analysis shall also include determining the concentration of metals in the material.

When agricultural wastes are land applied, application rates shall be consistent with the requirements of the NRCS conservation practice standard for nutrient management (590).

Where agricultural wastes are to be spread on land not owned or controlled by the producer, the waste management plan, as a minimum, shall document the amount of waste to be transferred and who will be responsible for the environmentally acceptable use of the waste.

Records of the use of wastes shall be kept a minimum of five years as discussed in OPERATION AND MAINTENANCE, below.

Additional Criteria to Protect Water Quality

All agricultural waste shall be utilized in a manner that minimizes the opportunity for contamination of surface and ground water supplies.

Agricultural waste shall not be land-applied on soils that are frequently flooded, as defined by the National Cooperative Soil Survey, during the period when flooding is expected.

When liquid wastes are applied, the application rate shall not exceed the infiltration rate of the soil, and the amount of waste applied shall not exceed the moisture holding capacity of the soil profile at the time of application. Wastes shall not be applied to frozen, snow-covered or saturated soil if the potential risk for runoff exists. The basis for the decision to apply waste under these conditions shall be documented in the waste management plan.

Additional Criteria to Protect Air Quality

Incorporate surface applications of solid forms of manure or other organic by-products into the soil within 24 hours of application to minimize emissions and to reduce odors.

When applying liquid forms of manure with irrigation equipment select application conditions where there is high humidity, little/no wind blowing, a forthcoming rainfall event and/or other conditions that will minimize volatilization losses into the atmosphere. The basis for applying manure under these conditions shall be documented in the nutrient management plan.

Handle and apply poultry litter or other dry types of animal manure or other organic by-products when weather conditions are calm and there is less potential for blowing and emission of particulates in the atmosphere. The basis for applying manure under these conditions shall be documented in the nutrient management plan.

When sub-surface applied using an injection system, waste shall be placed at a depth and applied at a rate that minimizes leaks onto the soil surface, while minimizing disturbance to the soil surface and plant community.

All materials shall be handled in a manner to minimize the generation of particulate matter, odors and greenhouse gases.

Additional Criteria for Providing Fertility for Crop, Forage and Fiber Production and Forest Products

Where agricultural wastes are utilized to provide fertility for crop, forage, fiber production and forest products, the practice standard Nutrient Management (590) shall be followed.

Where municipal wastewater and solids are applied to agricultural lands as a nutrient source, the single application or lifetime limits of heavy metals shall not be exceeded. The concentration of salts shall not exceed the level that will impair seed germination or plant growth.

Additional Criteria for Improving or Maintaining Soil Structure

Wastes shall be applied at rates not to exceed the crop nutrient requirements or salt concentrations as stated above.

Residue management practices shall be used for maintenance of soil structure.

Additional Criteria for Providing Feedstock for Livestock

Agricultural wastes to be used for feedstock shall be handled in a manner to minimize contamination and preserve its feed value. Chicken litter stored for this purpose shall be covered. A qualified animal nutritionist shall develop rations that utilize wastes.

Additional Criteria for Providing a Source of Energy

Use of agricultural waste for energy production shall be an integral part of the overall waste management system.

All energy producing components of the system shall be included in the waste management plan and provisions for utilization of residues of energy production identified.

Where the residues of energy production are to be land-applied for crop nutrient use or soil conditioning, the criteria listed above shall apply.

CONSIDERATIONS

The effect of Waste Utilization on the water budget should be considered, particularly where a shallow ground water table is present or in areas prone to runoff. Limit waste application to the volume of liquid that can be stored in the root zone.

Agricultural wastes contain pathogens and other disease-causing organisms. Wastes should be utilized in a manner that minimizes their disease potential.

Priority areas for land application of wastes should be on gentle slopes located as far as possible from waterways. When wastes are applied on more sloping land or land adjacent to waterways, other conservation practices should be installed to reduce the potential for offsite transport of waste.

It is preferable to apply wastes on pastures and hayland soon after cutting or grazing before re-growth has occurred.

Minimize environmental impact of land-applied waste by limiting the quantity of waste applied to the rates determined using the practice standard Nutrient Management (590) for all waste utilization.

Consider the net effect of waste utilization on greenhouse gas emissions and carbon sequestration.

PLANS AND SPECIFICATIONS

Plans and specifications for Waste Utilization shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose. The waste management plan is to account for the utilization or other disposal of all animal wastes produced, and all waste application areas shall be clearly indicated on a plan map.

OPERATION AND MAINTENANCE

Records shall be kept for a period of five years or longer, and include when appropriate:

- Quantity of manure and other agricultural waste produced and their nutrient content.
- Soil test results.
- Dates and amounts of waste application where land applied, and the dates and amounts of waste removed from the system due to feeding, energy production or export from the operation.
- Describe climatic conditions during waste application such as: time of day, temperature, humidity, wind speed, wind direction and other factors as necessary.
- Waste application methods.
- Crops grown and yields (both yield goals and measured yield).
- Other tests, such as determining the nutrient content of the harvested product.
- Calibration of application equipment.

The operation and maintenance plan shall include the dates of periodic inspections and maintenance of equipment and facilities used in waste utilization. The plan should include what is to be inspected or maintained, and a general time frame for making necessary repairs.

Appendix 2: Agricultural Tools in Support of Section 502 Technical Guidance

Included in this appendix are summaries of online tools that can be used to develop plans for these practices.

A range of information and expertise is available to help in developing management plans for agricultural lands, including information derived from USDA, universities, soil and water conservation districts, agricultural producers, and the private sector. A range of tools and resources are summarized in the table below and represent those that are generally used by experts (e.g., USDA field technicians and engineers) to work with clients to design appropriate conservation plans for their lands. Most of the tools listed below are available for free.

#	Tool name and document link	Applicable practices[a]	Source and Web link
I.	**Software and Models**		
1	NuMan Pro	NM	Univ. Maryland
2	Animal Waste Management Software	AWM	USDA-NRCS
3	Manure Management Planner (MMP) Software	AWM, NM	Purdue University
4	National Nutrient Management Data Download	NM, AWM	Univ. Missouri
5	Spatial Nutrient Management Planner	NM, AWM	Univ. Missouri
6	Win Max	NM, AWM	Purdue University
7	MapWindow GIS + MMP Tools	AWM, NM	Purdue University
8	Revised Universal Soil Loss Equation, Version 2 (RUSLE2)	ESC	USDA-NRCS
9	Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment	ESC	USDA-NRCS
10	Vegetative Filter Strip Modeling System (VFSMOD)	ESC	Univ. Florida
11	Integrated Farm System Model (IFSM)	AWM, NM, ESC, GM	USDA-ARS
12	Dairy Greenhouse Gas Model (DairyGHG)	AWM, NM	USDA-ARS
13	Cropware	NM, AWM	Cornell University
14	Soil Test Conversion Tools	NM	Cornell University
15	Great Plains Framework for Agricultural Resource Management (GPFARM)	AWM, NM, ESC, GM	USDA-ARS

#	Tool name and document link	Applicable practices[a]	Source and Web link
16	Soil - Plant - Atmosphere—Water Field & Pond Hydrology (SPAW)	DWM	USDA-ARS
II.	**Calculators, Spreadsheets, and Graphical Tools**		
17	Dairy Cattle N Excretion Calculator	AWM, NM	Cornell University
18	Corn N Calculator	NM	Cornell University
19	Total N Available from Manure Applications	AWM, NM	Cornell University
20	Other Calculators	AWM, NM	Cornell University
21	Nutrient Management Spreadsheets	AWM, NM	Univ. of Delaware
22	Crop Nutrient Tool	NM	USDA-NRCS
23	Crop Fertilizer Recommendation Calculator	NM	Purdue University
24	Manure Nutrient Availability Calculator	AWM, NM	Purdue University
25	Conservation Buffers	ESC	USDA NAC
26	Farm*A*Syst	AWM, NM	Univ. of Wisconsin
27	Virginia Phosphorus Index	NM	Virginia Tech
III.	**Compilations of Tools**		
28	Technical Resources Main Page	AWM, DWM, ESC, GM, NM	USDA NRCS
29	Animal Feeding Operations (AFO) Virtual Information Center	AWM, NM	USEPA
30	Software Products	AWM, DWM, ESC, GM, NM	USDA-ARS
31	Nutrient Management Planning Software and Support	NM, AWM	Univ. Missouri
IV.	**Guidance and Other Technical Resources**		
32	Nutrient and Pest Management Tools and Information	NM	USDA-NRCS
33	Conservation Practices	AWM, DWM, ESC, GM, NM	USDA-NRCS
34	Agronomy and Erosion	ESC	USDA-NRCS
35	Animal Feeding Operations	AWM, NM	USDA-NRCS
36	Nutrient Management Technical Notes	NM, AWM	USDA-NRCS
37	National Range and Pasture Handbook	GM, ESC	USDA-NRCS
38	Phosphorus Index	NM	USDA-NRCS
39	SERA-17 Publications and BMP Fact Sheets	NM	SERA-17
40	Managing Cover Crops Profitably, 3rd Edition	Cover Crops	SARE

#	Tool name and document link	Applicable practices[a]	Source and Web link
41	Precision Feed Management Certification for Dairy Professionals	AWM, NM	Mid-Atlantic Water Program
42	Mid-Atlantic Better Composting School	AWM, NM	Mid-Atlantic Water Program
43	Environmental Management System for Manure	AWM	Mid-Atlantic Water Program
44	Mid-Atlantic Nutrient Management Handbook	NM	Mid-Atlantic Water Program
45	Information on Nutrient and Sediment Best Management Practices	NM, ESC	Chesapeake Bay Program
46	Fact Sheets	NM, AWM	Univ. Delaware
47	Nutrient Management	NM	MD Dept. Agriculture
48	Nutrient Management Program	NM	Univ. Maryland
49	Nutrient Management Plan Writing Tools	NM	Univ. Maryland
50	Phosphorus Site Index	NM	Univ. Maryland
51	Nutrient Management Software and Publications	NM	Univ. Maryland
52	Nutrient Management Spear Program	AWM, NM	Cornell Univ.
53	Manure Management	AWM, NM	Penn State Univ.
54	Pennsylvania Nutrient Management Program	NM	Penn State Univ.
55	Planning Tools and Resources	NM	Penn State Univ.
56	Nutrient Management Technical Manual	NM, AWM	Penn State Univ.
57	Educational Materials	NM, AWM	Penn State Univ.
58	Fact Sheets on Agriculture and Environmental Quality	NM, AWM, GM	Virginia Tech Univ.
59	Virginia Agricultural BMP Cost Share and Tax Credit Programs	AWM, DWM, ESC, GM, NM	Virginia Dept. Conservation and Recreation
60	Nutrient and Waste Management	NM, AWM	Univ. West Virginia
61	Comprehensive Livestock Environmental Assessments and Nutrient (CLEANEast) Management Plan program	NM, AWM	RTI International and North Carolina State Univ.
62	Comprehensive Nutrient Management Planning (CNMP)	NM, AWM	eXtension
63	CNMP Core Curriculum	NM, AWM, ESC, GM	Iowa State Univ.
64	Manure Management Planner Tutorials	AWM, NM	Univ. Missouri

Note:

a. AWM = animal waste management, DWM = drainage water management, ESC = erosion and sediment control, GM = grazing management, NM=nutrient management

I. Software and Models

1. Nutrient Management Planning (NMP) Software for Professionals (NuMan Pro)—Univ. Maryland Extension

Nutrient Management for Maryland Professional Edition (NuMan Pro) is an integrated software program that permits comprehensive NMP. The Maryland Phosphorus Site Index (PSI) has been integrated into the program so that warnings are given when a PSI calculation could be required based on soil test results. A simplified version of the Revised Universal Soil Loss Equation (RUSLE) model to predict soil erosion losses has been included in the program in support of the Maryland PSI assessment. Values for rainfall erosivity (R) and soil erodibility (K) factors are determined from field location and soils information entered in the initial portions of the program. Soil slope/steepness (LS), cropping management (C), and conservation management (P) factors are determined from simplified user inputs. Part A and Part B of the Maryland PSI are presented in a color-code scheme for user ease. Once slopes have been identified in the field, it is estimated that an experienced user can determine the Maryland PSI in less than 10 minutes.

Link: http://anmp.umd.edu/numan/numanpro.htm Accessed January 28, 2010

2. Animal Waste Management Software—USDA-NRCS

AWM 2.4.0, like the previous version, is a planning/design tool for animal feeding operations that can be used to estimate the production of manure, bedding, and process water and determine the size of storage/treatment facilities. The procedures and calculations used in AWM are based on the USDA-NRCS *Agricultural Waste Management Field Handbook.*

The AWM has been upgraded with the capability to evaluate existing facilities. The results from the evaluation are incorporated into the design processes for new facilities. The user can design the new facility either for the *Additional* waste not handled by the existing facility, or for the *Total* waste flowing into the structure.

The evaluation process involves the user entering the basic dimensions of an existing storage facility along with other parameters such as herd size, local climatic condition (monthly rainfall), and details about the additions such as bedding, wash water and flush water. With these inputs, the system estimates the total waste flowing into the structure identified in the management train for the selected storage period and compares it to the available storage volume. It then presents an on-screen color-coded report (red for inadequate and green for the adequate structure.) The report helps recognize if the structure is adequately designed or not easily and quickly. The user can also print a hardcopy of the report.

The AWM process of evaluating existing structures can help producers in deciding if they would like to go for the *No Discharge* declaration within the EPA 2008 CAFO rule. The facility design for the Total waste or for the Additional waste not handled by the existing structure is easily done by selecting the appropriate radio button on the AWM design screen. In addition, several improvements and bug fixes, listed below, have been incorporated to further improve AWM functions and capabilities.

Link: http://www.wsi.nrcs.usda.gov/products/W2Q/AWM/pgrm24.html Accessed January 22, 2010

3. Manure Management Planner (MMP) Software—Purdue University

Manure Management Planner (MMP) is a Windows-based computer program developed at Purdue University that is used to create manure management plans for crop and animal feeding operations. The user enters information about the operation's fields, crops, storage, animals, and application equipment. MMP helps the user allocate manure (where, when and how much) on a monthly basis for the length of the plan (1–10 years). This allocation process helps determine if the current operation has sufficient crop acreage, seasonal land availability, manure storage capacity, and application equipment to manage the manure produced in an environmentally responsible manner. MMP is also useful for identifying changes that could be needed for a non-sustainable operation to become sustainable, and determine what changes might be needed to keep an operation sustainable if the operation expands.

MMP supports 34 states including Delaware, Maryland, and Pennsylvania (support for Virginia is underway), by automatically generating fertilizer recommendations and estimating manure N availability based on each state's Extension and/or NRCS guidelines. It should be noted, however, that MMP is not generally used in Maryland. Questions about MMP can be addressed to the authors using contact information provided at the Web site.

Link: http://www.agry.purdue.edu/mmp/ Accessed January 22, 2010

4. National Nutrient Management Data Download—Univ. of Missouri Extension

The data download Web site helps to address nutrient management software data requirements by providing a way for users to locate the farm of interest, define an area of interest and submit a data request.

- The Spatial Nutrient Management Planner (SNMP) requires geo-referenced aerial photographs, data from the soils survey, a topographic map and state-specific data on manure application setback requirements.

- Manure Management Planner (MMP) needs data from the soils survey and crop and climatology data from Natural Resource Conservation Service (NRCS).
- The data download also includes data needed by the Revised Soil Loss Equation version 2 (RUSLE(2)).

The data-finder packages the data in a compressed file that can be downloaded onto a computer hard drive. The file is then un-compressed in the same folder on the computer the holds the working SNMP and MMP files for that farm. This tool will generate a ZIP file containing the aerial photo image, topographic map image, and soils data needed for SNMP, MMP and RUSLE(2). The data is obtained from various USDA-NRCS data servers for any area with spatial data in the NRCS Soils Data Mart (see Status Map). Google Maps is used to locate farms and define a download area which includes the farm.

Link: http://www.nmplanner.missouri.edu/software/national_data.asp Accessed January 22, 2010

5. Spatial Nutrient Management Planner—Univ. of Missouri Extension

The Spatial Nutrient Management Planner (SNMP) is a decision support tool that facilitates the collection, analysis and presentation of spatial data related to NMP. Capabilities of SNMP include:

- The SNMP interface simplifies the GIS program ArcMap for nutrient management planners.
- With a click of a mouse, data can be imported and exported from Purdue's Manure Management Planner (MMP).
- SNMP simplifies the creation of maps required for NRCS comprehensive nutrient management plans
- Compatibility with NRCS Toolkit 9.x.

Link: http://projects.cares.missouri.edu/snmp/nrcsdata/aoilist.asp Accessed January 22, 2010

6. Win Max—Purdue University

WinMax is a computer program developed at Purdue University to calculate and compare economic returns on crop production. WinMax manages crop input data, calculates crop fertilizer recommendations, generates production cost and nutrient management worksheets, and allows sets of custom input costs to be created and used in all calculations. WinMax supports the import of data from a manure management plan created with MMP, as well as the export of WinMax data to an MMP plan. Various management options, such as tillage, pest control and fertilizer strategies, can be compared to help assess which practices are both economically efficient and environmentally sound.

Link: http://www.agry.purdue.edu/max/ Accessed January 22, 2010

7. MapWindow GIS + MMP Tools—Purdue University

MapWindow GIS + MMP Tools is a free GIS that can be used as a front-end to MMP and WinMax.

Link: http://www.agry.purdue.edu/mmp/mapwindow/ Accessed January 22, 2010

8. Revised Universal Soil Loss Equation, Version 2 (RUSLE2)—USDA-NRCS

This site contains the official NRCS version of RUSLE2. It is the only version of RUSLE2 to be used for official purposes by NRCS field offices. The NRCS developed and maintains the database components on this site.

RUSLE2 is an upgrade of the text-based RUSLE DOS version 1. It is a computer model containing both empirical and process-based science in a Windows environment that predicts rill and interrill erosion by rainfall and runoff. The USDA-Agricultural Research Service (ARS) is the lead agency for developing the RUSLE2 model. The ARS, through university and private contractors, is responsible for developing the science in the model and the model interface.

Link: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm Accessed January 22, 2010

9. Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment—USDA-NRCS

The Revised Universal Soil Loss Equation, Version 2, (RUSLE2) can also be used to design and predict the expected lifespan of a VFS designed for the purpose of sediment removal based on the procedures developed by Dillaha and Hayes. The following information is needed:

- Sediment delivery rate at the upper edge of the VFS for the *contributing area* to the VFS—calculated by RUSLE2 using the *overland flow slope length*.
- Sediment Trapping Efficiency—calculated from RUSLE2 results.
- Ratio of Contributing Area to VFS Area.

This publication requires Microsoft Excel® and uses the following spreadsheet:
Filter Strip Life Span Design for Sediment (XLS; 24 KB)

Link: http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18578.wba
Accessed January 22, 2010

Additional Reference: USDA-NRCS. 2007. Agronomy Technical Note No. 2, Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment, 8pp.

10. Vegetative Filter Strip Modeling System (VFSMOD)—University of Florida

VFSMOD-W is a design-oriented vegetative filter strip modeling system. The MS-Windows graphical user interface (GUI) integrates the numerical model VFSMOD, a utility to generate source (upslope disturbed area) inputs for the model based on readily available NRCS site characteristics (UH), and advanced uncertainty and sensitivity analysis, inverse calibration and design menu-driven components. VFSMOD, the core of the modeling system, is a computer simulation model created to study hydrology, sediment and pollutant transport through vegetative filter strips (VFS). The model is targeted at studying VFS performance on an event-by-event basis and when combined with the upslope source area input preparation utility (UH or others like PRZM), becomes a powerful and objective VFS design tool. The design paradigm implemented in VFSMOD-W seeks to identify optimal filter constructive characteristics (length, slope, vegetation) to reduce (to a prescribed reduction target like a TMDL) the outflow of pollutants from a given disturbed area (soil, crop, area, management practices, design storm return period).

VFSMOD has been tested in a variety of settings (agroforestry, mining and roads) with good model predictions against measured values of infiltration, outflow, and vegetation trapping efficiency for sediments, P, and pesticides. Although the model was originally developed as research tool, is now widely used by consultants, planners and regulators to design optimal filter strips for specific scenarios or to assess effectiveness of existing VFS.

Link: http://carpena.ifas.ufl.edu/vfsmod/ Accessed January 28, 2010

11. Integrated Farm System Model (IFSM)—USDA-ARS

The Integrated Farm System Model (IFSM) is a process-based simulation of dairy, beef, and crop farming systems. This farm model provides a tool for evaluating the long-term performance, economics, and environmental impacts of production systems over many years of weather. Environmental impacts include volatile N losses, NO_3 loss to groundwater, erosion, soluble and sediment P losses to surface water, and greenhouse gas emissions.

Link: http://www.ars.usda.gov/Main/docs.htm?docid=8519 Accessed January 27, 2010

12. Dairy Greenhouse Gas Model (DairyGHG)—USDA-ARS

The Dairy Greenhouse Gas Model (DairyGHG) is an easy to use software tool that estimates total greenhouse gas emissions and the carbon footprint of a dairy production system. DairyGHG uses a relatively simple process-based model to predict the primary GHG emissions from the production system, which include the net emission of carbon dioxide plus all emissions of methane and nitrous oxide. Emissions are predicted through a daily simulation of feed use and manure handling where daily values of each gas are summed to obtain annual values. A carbon footprint is then calculated as the sum of both primary and secondary emissions in CO_2 equivalent units divided by the milk produced. Secondary emissions are those occurring during the production of resources used including machinery, fuel, electricity, fertilizer, pesticides, and plastic. DairyGHG is available for download from our Internet site (http://ars.usda.gov/naa/pswmru). The model includes a fully integrated help system with a reference manual that documents the relationships used to predict emissions.

Link: http://www.ars.usda.gov/Main/docs.htm?docid=17355 Accessed January 27, 2010

13. Cropware—Cornell University Extension

Cropware is used to develop plans in accordance with the NRCS Nutrient Management Standard (Standard 590), making the output of Cropware a key component of Comprehensive Nutrient Management Plans. Cornell Cropware integrates the following tools for effective nutrient management planning:

- Cornell crop nutrient guidelines for a full range of agronomic and vegetable crops.
- Nutrient credits from many sources, including manure, soil, sod, and fertilizer.
- Equations for the conversion of soil test values from other laboratories into Cornell Morgan equivalents.
- Environmental risk indices, including the New York State Phosphorus Runoff Index and the Nitrate Leaching Index.
- On-farm logistics, such as manure production, storage, and inventories Report generation for guiding on-farm implementation.

Link: http://nmsp.cals.cornell.edu/software/cropware.html Accessed January 27, 2010

14. Soil Test Conversion Tools—Cornell University Extension

This program converts soil test results from Brookside Laboratories Inc. (Mehlich 3 P, K, Ca, Mg), Spectrum Analytic Inc. (Mehlich 3 P, K, Ca, and Mg and Morgan P, K, Ca, and Mg), A&L Laboratories Inc. (Mehlich 3 P, K, Ca, Mg and Modified Morgan P), and the soil testing laboratories from the University of New Hampshire (Mehlich 3 P, K, Ca and Mg), University of Massachusetts (Morgan P, K, Ca, and Mg) and the Universities of Vermont and Maine (Modified Morgan P, K, Ca, Mg) to Cornell University Morgan Equivalents. P conversions from Mehlich 3 data require measured values for soil pH, Mehlich 3 P, Ca, and Al. For each test, the range of valid input data is given by a minimum value (min) and a maximum value (max). Also given are the correlation coefficients (r^2) for each of the conversion models. Conversions with larger r^2 values are more reliable. Models were derived using New York soils. There is uncertainty involved with each of the conversions and we now know there is seasonality in the conversions with the most reliable conversions obtained when samples are taken after harvest and before manure application. The user assumes all risk and it is recommended to submit samples for the Cornell Morgan test to check on the accuracy of the conversion models for your farm or the farm you work with. It is also recommended to take three subsamples per acre if you use conversion models to derive Cornell Morgan soil test equivalents.

Link: http://nmsp.cals.cornell.edu/software/conv-tools.html Accessed January 27, 2010

15. Great Plains Framework for Agricultural Resource Management (GPFARM)—USDA-ARS

Great Plains Framework for Agricultural Resource Management (GPFARM) is a simulation model computer application that incorporates state-of-the-art knowledge of agronomy, animal science, economics, weed science, and risk management into a user-friendly, decision-support tool. Producers and others can use GPFARM to test alternative management strategies with regard to sustainability, pollution reduction, and economic return.

Link: http://www.ars.usda.gov/services/software/download.htm?softwareid=234 Accessed January 27, 2010

16. Soil - Plant - Atmosphere—Water Field & Pond Hydrology (SPAW)—USDA-ARS

SPAW is a daily hydrologic budget model for agricultural fields and ponds (wetlands, lagoons, ponds and reservoirs). Included are irrigation scheduling and soil N. Companion models for soil water characteristics and chemical budgets are included. Data input and results are graphical screens.

Link: http://hydrolab.arsusda.gov/SPAW/Index.htm Accessed January 28, 2010

II. Calculators, Spreadsheets, and Graphical Tools

17. Dairy Cattle N Excretion Calculator—Cornell University Extension

The Dairy Cattle N Excretion Calculator enables users to quickly characterize rations, individual dairy cattle, and groups of dairy cattle to predict the N partitioned to growth, milk production, pregnancy, urine, and feces. From there, N use efficiency and N volatilization from the barn floor are estimated.

Link: http://www.dairyn.cornell.edu/pages/40dairy/420precision/424herdspread.shtml Accessed January 27, 2010

18. Corn N Calculator—Cornell University Extension

This calculator factors in soil type, drainage, and other factors to estimate corn N requirements.

Link: http://www.dairyn.cornell.edu/pages/20cropsoil/240guides/245corn.shtml Accessed January 27, 2010

19. Total N Available from Manure Applications—Cornell University Extension

N from urine (ammonium N) is quickly available for crop uptake, while N from feces (organic N) is more slowly released. Manure represents a mix of both urine and feces, so estimations of the amount of plant available N from manure should be based on both.

The total manure N calculator uses factors such as animal type, percent dry matter, organic N content, and application rate to estimate the combined contributions of organic N and ammonium N to the total pool of plant available N from manure.

Link: http://www.dairyn.cornell.edu/pages/20cropsoil/250credits/256totalN.shtml Accessed January 27, 2010

20. Other Calculators—Cornell University Extension

This page provides links to calculators for corn N needs, manure nutrients, N credits from plowed sods, and whole-farm nutrient balancing.

Link: http://nmsp.cals.cornell.edu/software/calculators.html Accessed January 27, 2010

21. Nutrient Management Spreadsheets—University of Delaware Cooperative Extension

This page includes links to two spreadsheets, one for estimating animal waste quantity, and the other for estimating poultry litter quantity.

Link: http://ag.udel.edu/extension/NutriManage/spreadsheets.htm Accessed January 27, 2010

22. Crop Nutrient Tool—USDA-NRCS

This is a tool for calculating the approximate amount of N, P, and potassium that is removed by the harvest of agricultural crops.

Link: http://plants.usda.gov/npk/main Accessed January 22, 2010

23. Crop Fertilizer Recommendation Calculator—Purdue University

This calculator is supported for Delaware, Maryland, and Pennsylvania.

Link: http://www.agry.purdue.edu/mmp/webcalc/fertRec.asp Accessed January 22, 2010

24. Manure Nutrient Availability Calculator—Purdue University

This calculator is supported for Delaware, Maryland, and Pennsylvania.

Link: http://www.agry.purdue.edu/mmp/webcalc/nutAvail.asp Accessed January 22, 2010

25. Conservation Buffers—USDA National Agroforestry Center

At any given site, the level of pollutant removal from surface runoff depends primarily on buffer width. The graph and tables at this site can be used to estimate a buffer width that will achieve a desired level of pollutant removal. The tool is designed to quickly generate estimates of design width for a broad range of site conditions. Adjustments are made for land slope, soil texture, field size, and soil surface condition. The tool can be used for sediment, sediment-bound pollutants, and dissolved pollutants. The tool was developed for agricultural runoff using VSFMOD (Vegetative Filter Strip Model) but can be applied in a more general way to other land uses as well.

Link: http://www.unl.edu/nac/bufferguidelines/guidelines/1_water_quality/19.html Accessed January 26, 2010

26. Farm*A*Syst—University of Wisconsin Extension

Farm*A*Syst is a partnership between government agencies and private business that enables landowners to prevent pollution on farms, ranches, and in homes using confidential environmental assessments. A system of step-by-step factsheets and worksheets helps landowners identify the behaviors and practices that create risks associated with livestock waste storage, nutrient management, wells, hazardous wastes, and petroleum products.

Link: http://www.uwex.edu/farmasyst/ Accessed January 27, 2010

27. Virginia Phosphorus Index —Virginia Tech

The Virginia Phosphorus Index (P-Index) is a field-level assessment tool that integrates soil, management, environmental, and hydrologic (transport) characteristics to estimate the relative risk of phosphorus (P) losses through erosion, surface runoff and subsurface transport to water bodies.

Link: http://p-index.agecon.vt.edu/ Accessed April 22, 2010

III. Compilations of Tools

28. Technical Resources Main Page—USDA-NRCS

This page serves as the gateway to a wide range of technical resources provided by USDA.

Link: http://www.nrcs.usda.gov/technical/

29. Animal Feeding Operations (AFO) Virtual Information Center—EPA

The AFO Virtual Information Center is a tool to facilitate quick access to livestock agricultural information in the United States. This site is a single point of reference to obtain links to state regulations, Web sites, permits and policies, nutrient management information, livestock and trade associations, federal Web sites, best management practices and controls, cooperative extension and land grant universities, research, funding, and information on environmental issues. The nutrient management information page has links to nutrient management resources for Delaware, Maryland, Pennsylvania, Virginia, and West Virginia.

Link: http://cfpub.epa.gov/npdes/afo/virtualcenter.cfm Accessed January 28, 2010

30. Software Products—USDA-ARS

This page provides updated information on software tools available from USDA-ARS. Additional information on ARS models and projects can be found here.

Link: http://www.ars.usda.gov/Services/software/software.htm Accessed January 27, 2010

31. Nutrient Management Planning Software and Support—Univ. of Missouri Extension

This page provides links to national resources that facilitate writing a nutrient management plan. The listed resources contribute to a unified system for writing a nutrient management plan that meets national standards for NRCS and EPA.

a. Nutrient Management Data Download: Use the Nutrient Management Data Finder to obtain data needed by nutrient management software to complete a plan.

b. Spatial Nutrient Management Planner (SNMP): Use the SNMP to collect and analyze spatial information and create maps needed for completing a nutrient management plan.

c. Purdue's Manure Management Planner (MMP): Use MMP to determine fertilizer and manure application rates and generate the nutrient management plan.

d. Manure Management Planner (MMP) Tutorials: Tutorials on how to use MMP to develop a swine, poultry or fertilizer only plan.

e. National Setbacks Database: Access a database on the Web that reports setback requirements for the 34 states supported by SNMP and MMP.

Link: http://www.nmplanner.missouri.edu/software/ Accessed January 22, 2010

IV. Guidance and Other Technical Resources

32. Nutrient and Pest Management Tools and Information— USDA-NRCS

Users will find fact sheets on practices and links to various tools for nutrient and pest management at this site.

Link: http://www.nrcs.usda.gov/technical/nutrient.html Accessed January 26, 2010

33. Conservation Practices—USDA-NRCS

At this site, users will find links to the Field Office Technical Guide and the National Handbook of Conservation Practices. Links to each state's electronic Field Office Technical Guide (eFOTG) can be found here.

Link: http://www.nrcs.usda.gov/technical/standards/ Accessed January 26, 2010

34. Agronomy and Erosion—USDA-NRCS

This site has links to the *National Agronomy Manual*, a publication on using RUSLE2 to design and predict the effectiveness of vegetative filter strips for sediment control, Core 4 Conservation, and other resources.

http://www.nrcs.usda.gov/technical/agronomy.html Accessed January 27, 2010

35. Animal Feeding Operations—USDA-NRCS

This page provides information on CNMPs and links to the MMP and the CNMP field handbook.

Link: http://www.nrcs.usda.gov/technical/afo/index.html Accessed January 27, 2010

36. Nutrient Management Technical Notes—USDA-NRCS

This page includes links to several fact sheets on diet and feed management for various types of livestock. The page also includes links for National Conservation Practice Standards for nutrient management (NRCS Practice Code 590) and waste utilization (NRCS Practice Code 633).

Link: http://www.nrcs.usda.gov/technical/ECS/nutrient/documents.html Accessed January 22, 2010

37. National Range and Pasture Handbook—USDA-NRCS

This handbook includes chapters on grazing management and conservation planning for grazing lands.

Link: http://www.glti.nrcs.usda.gov/technical/publications/nrph.html Accessed January 27, 2010

38. Phosphorus Index—USDA-NRCS

This page provides background on the Phosphorus Index, which is intended to provide field staffs, watershed planners, and land users with a tool to assess the various landforms and management practices for potential risk of P movement to waterbodies.

USDA is careful to point out,

> The Phosphorus Index is not intended to be an evaluation scale for determining whether land users are abiding within water quality or nutrient management standards that have been established by local, state, or federal agencies. Any attempt to use this index as a regulatory scale would be grossly beyond the intent of the assessment tool and the concept and philosophy of the working group that developed it. The Phosphorus Index is proposed to be adapted to local conditions by a process of regional adaptations of the site characteristic parameters. This local development process must involve those local and state agencies and resource groups that are concerned with the management of phosphorus. After the index is adapted to a locality, it must be tested by the development group to assure that the assessments are giving valid and reasonable results for that region. Field testing of the index is one of the most appropriate methods for assessing the value of the index.

Link: http://www.nrcs.usda.gov/technical/ecs/nutrient/pindex.html Accessed January 29, 2010

39. SERA-17 Publications and BMP Fact Sheets

SERA-17 is an organization of research scientists, policy makers, extension personnel, and educators whose mission is to develop and promote innovative solutions to minimize phosphorus losses from agriculture by supporting

- Information exchange between research, extension, and regulatory communities
- Recommendations for phosphorus management and research
- Initiatives that address phosphorus loss in agriculture

Link: http://www.sera17.ext.vt.edu/SERA_17_Publications.htm Accessed January 22, 2010

40. Managing Cover Crops Profitably, 3rd Edition—SARE

This 2007 update from Sustainable Agriculture Research and Education (SARE) includes information on the benefits of cover crops, selecting cover crops, the use of cover crops with conservation tillage, crop rotations, and a wide range of legume and non-legume cover crops. Appendix E contains contact information for regional cover crop experts

Link: http://www.sare.org/publications/covercrops/index.shtml Accessed January 27, 2010

41. Precision Feed Management Certification for Dairy Professionals—Mid-Atlantic Water Program

To help reduce nutrient pollution and implement the NRCS Feed Management Standard 592, specialists in Pennsylvania, Maryland, and Virginia are working with NRCS and the American Registry of Professional Animal Scientists to develop a process to certify nutritionists as feed management planners. With few areas in the nation working with the dairy industry and NRCS on feed management, the mid-Atlantic is being looked at as a potential standard for how other states can train nutritionists for a feed management certification and meet their post-certification, professional needs. This page provides current information on precision feed management certification, including contact information for leaders from Maryland, Pennsylvania, and Virginia.

Link: http://mawaterquality.org/industry_change/precision_feed_mgmt.html Accessed January 27, 2010

42. Mid-Atlantic Better Composting School—Mid-Atlantic Water Program

Because commercial compost can be manufactured from a variety of waste materials, a variety of standards have been established based on end uses. Managers of composting facilities should be familiar with these standards and with the waste materials and composting systems that can best produce the desired products. Composting to produce a product that is consistent in quality will require good management and quality control.

By enrolling in the Mid-Atlantic Better Composing School, participants will not only learn the basics of making good compost, but they will also have the opportunity to tour commercial operations, perform product sampling, and learn simple procedures for compost testing.

Link: http://mawaterquality.org/industry_change/ma_composting_school.html Accessed January 27, 2010

43. Environmental Management System for Manure—Mid-Atlantic Water Program

Members from the Mid-Atlantic Water Program (MAWP) are collaborating with CLEANeast to assess livestock and poultry operations in sensitive watersheds across PA, MD, and VA using an Environmental Management Systems (EMS) model. An EMS is a voluntary, flexible business management system that helps farmers and managers to develop their own strategies for integrating environmental considerations into the daily operations of a farm.

By implementing pilot assessments across farms in Pennsylvania, Virginia, and Maryland, team members will demonstrate how an EMS can not only reduce pollution from farms, but also increase operating efficiency, achieve public acceptance without regulatory oversight, and elicit confidence in citizens that the wastes are being handled in an environmentally sound manner.

This page also provides state contacts information.

Link: http://mawaterquality.org/industry_change/env_mgmt_system_manure.html Accessed January 27, 2010

44. Mid-Atlantic Nutrient Management Handbook—Mid-Atlantic Water Program

The *Mid-Atlantic Nutrient Management Handbook* was written as a reference text for nutrient management training programs offered by state regulatory agencies. The handbook was based off an earlier nutrient management training manual that was widely used in the Chesapeake Bay watershed but revised to incorporate advances in soil, crop, and nutrient management research and the techniques used to protect surfacewater and groundwater.

Link: http://mawaterquality.org/capacity_building/ma_nutrient_mgmt_handbook.html Accessed January 27, 2010

45. Information on Nutrient and Sediment Best Management Practices—Chesapeake Bay Program

This report led by the University of Maryland Mid-Atlantic Water Program includes nutrient and sediment reduction effectiveness estimates of select agricultural, stormwater and forestry best management practices (BMPs). With funding from the Chesapeake Bay Program Office, the Mid-Atlantic Water Program developed definitions and effectiveness estimates for BMPs that states were implementing or proposing to implement as part of their efforts to meet the nutrient and sediment reduction goals necessary to restore the Bay. The report provides realistic, science-based estimates of expected nutrient and sediment reduction performance from these BMPs and reflects current research and knowledge as well as average operational conditions representative of the entire Chesapeake Bay watershed.

Link: http://www.chesapeakebay.net/marylandbmp.aspx?menuitem=34449 Accessed January 27, 2010

46. Fact Sheets—University of Delaware Cooperative Extension

This page contains links to several fact sheets on nutrient management, poultry litter management, and animal waste management.

Link: http://ag.udel.edu/extension/NutriManage/publications.htm Accessed January 27, 2010

47. Nutrient Management—Maryland Department of L., J. A. Nienaber, et al. (2003). Performance of a passive feedlot runoff control and treatment system. Transactions of the ASAE 46(6):1525–1530.

Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J. and van Kessel, C. 2005. Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. *Advances in Agronomy* 87:85-156.

Mosier, A.R., J.K. Syers, and J.R. Freney. 2004. Ch. 1-Nitrogen fertilizer: an essential component of increased food, feed, and fiber production. pp. 3-15. *In* A.R. Mosier, J.K. Syers, and J.R. Freney (eds.). Agriculture and the Nitrogen Cycle. Assessing the impacts

This page provides various links to nutrient management fact sheets, recommendations, and training opportunities.

Link: http://www.mda.state.md.us/resource_conservation/nutrient_management/index.php Accessed January 27, 2010

48. Nutrient Management Program—University of Maryland Extension

The Agricultural Nutrient Management Program is a component of the University of Maryland's College of Agriculture and Natural Resources Nutrient Management Programs and focuses on reducing the pollution of the Chesapeake Bay by plant nutrients from cropland. The program provides nutrient planning services to Maryland farmers via a network of nutrient management advisors in all county Extension offices and provides continuing education and technical support to certified nutrient management consultants via state and regional nutrient management specialists.

One of these services is the development of nutrient management plans, which are documents that incorporate soil test results, yield goals, and estimates of residual N to generate field-by-field nutrient recommendations.

Link: http://anmp.umd.edu/ Accessed January 27, 2010

49. Nutrient Management Plan Writing Tools—University of Maryland Extension

A nutrient management plan is a formal document that balances crop nutrient needs with nutrients that are applied in the form of commercial fertilizer, animal manure, or biosolids. The plan contains soil test results, manure and biosolids analyses (where applicable), yield goals, and estimates of residual N to generate field-by-field nutrient recommendations. The following information sheets and work sheets will help producers in the plan writing process.

Link: http://anmp.umd.edu/Plan/Plan_Writing.html Accessed January 27, 2010

50. Phosphorus Site Index—University of Maryland Extension

The Phosphorus Site Index, or PSI, is an integral part of a nutrient management plan. If a producer intends to add P in commercial or organic forms (including starter fertilizer) to a field and the soil test indicates a P fertility index value (FIV-P) of 150 or more for that field, the PSI should be calculated. The PSI takes into consideration P loss potential due to site and transport characteristics and management and source characteristics.

Link: http://anmp.umd.edu/PSI/PSI.html Accessed January 27, 2010

51. Nutrient Management Software and Publications—University of Maryland Extension

This page provides summary information and links to available publications and software for nutrient management in Maryland.

Link: http://anmp.umd.edu/Pubs/Pubs.html Accessed January 27, 2010

52. Nutrient Management Spear Program—Cornell University

The vision of the Cornell University's Nutrient Management Spear Program is to assess current knowledge, identify research and educational needs, conduct applied, field and laboratory-based research, facilitate technology and knowledge transfer, and aid in the on-farm implementation of strategies for field crop nutrient management, including timely application of organic and inorganic nutrient sources to improve profitability and competitiveness of New York State farms while protecting the environment.

This page has links to a variety of nutrient management resources, including nutrient guidelines, N management, and the New York State Phosphorus Runoff Index. These links provide additional links to tools and resources such as Cropware and other nutrient management calculators.

Link: http://nmsp.cals.cornell.edu/index.html Accessed January 27, 2010

53. Manure Management—Penn State College of Agricultural Sciences

This page provides information on manure management at animal operations, including links to information specific to Pennsylvania.

Link: http://www.das.psu.edu/research-extension/nutrient-management/manure Accessed January 27, 2010

54. Pennsylvania Nutrient Management Program—Penn State University

This Web site provides a comprehensive source of information about Pennsylvania's Nutrient Management Act (Act 38, 2005) Program, and associated technical guidance and educational information. It also provides limited information concerning related programs. The Web site has been developed and is maintained through a workgroup representing various partnering agencies actively involved with the Pennsylvania Nutrient Management Act Program. Contributions to this site represent the collective efforts of that workgroup

Link: http://panutrientmgmt.cas.psu.edu/ Accessed January 27, 2010

55. Planning Tools and Resources—Penn State University

This page provides links to the nutrient management plan standard format, a nutrient balance spreadsheet, the Pennsylvania Phosphorus Index spreadsheet, a pasture nutrient calculator, and other resources associated with nutrient management in Pennsylvania. The Phosphorus Index spreadsheet contains contact information for state experts.

Link: http://panutrientmgmt.cas.psu.edu/main_planning_tools.htm Accessed January 27, 2010

56. Nutrient Management Technical Manual—Penn State University

This is the technical manual for Pennsylvania's Nutrient Management Act Program.

Link: http://panutrientmgmt.cas.psu.edu/main_technical_manual.htm Accessed January 27, 2010

57. Educational Materials—Penn State University

This page provides links to fact sheets and publications addressing of wide range of topics associated with nutrient management and manure management in Pennsylvania.

Link: http://panutrientmgmt.cas.psu.edu/em_publications.htm Accessed January 27, 2010

58. Fact Sheets on Agriculture and Environmental Quality—Virginia Tech Extension

The page provides links to fact sheets covering a range of topics including composting, P management, and livestock exclusion.

Link: http://pubs.ext.vt.edu/category/environmental-quality.html Accessed January 27, 2010

59. Virginia Agricultural BMP Cost Share and Tax Credit Programs—Virginia Department of Conservation and Recreation

This page provides information and links associated with agricultural BMPs in Virginia, including the Virginia agricultural BMP manual and BMP cost-sharing.

Link: http://www.dcr.virginia.gov/soil_and_water/costshar.shtml Accessed January 27, 2010

60. Nutrient and Waste Management—West Virginia University Extension Service

This page provides links to nutrient management training courses including the P index, information on nutrient management consultant certification, manure sampling and analysis methods, and related Web sites.

Link: http://www.wvu.edu/~agexten/wastmang/index.html Accessed January 28, 2010

61. Comprehensive Livestock Environmental Assessments and Nutrient (CLEANEast) Management Plan program—RTI International and North Carolina State University

CLEANEast provides confidential, free technical support to farms including beef, dairy, swine, or poultry operations located in 27 eastern states. It helps farm operators identify and implement farm management practices that protect the environment. CLEANEast is a voluntary program to which farm operators can apply for on-site support services from a qualified Technical Assistance Professional to:

- Conduct an Environmental Assessment
- Update an existing Nutrient Management Plan
- Prepare a new Nutrient Management Plan

Link: https://livestock.rti.org/ Accessed January 28, 2010

62. Comprehensive Nutrient Management Planning (CNMP)— eXtension

The details of a Comprehensive Nutrient Management Plan (CNMP) are described at this site, including links to various handbooks and guidance documents important to the development of a CNMP for an AFO. For example, a key objective of a CNMP is to document the plans of an animal feeding operation owner/operator to manage manure and organic by-products in combination with conservation practices and facility management activities to protect or improve water quality. NRCS has listed six elements of a CNMP that should be considered during preparation of the plan, though a CNMP is not required to contain all six elements. The components that should be considered are the following:

- Manure and Wastewater Storage and Handling
- Land Treatment Practices
- Nutrient Management
- Record Keeping
- Feed Management
- Other Utilization Activities

USDA-NRCS provides technical information for Comprehensive Nutrient Management Plans, including a complete description of these elements and what each element specifically covers in National Instruction 190-304. Users should check with their agriculture and natural resources agencies to see if their state has its own specific CNMP requirements and guidance.

Link:
http://www.extension.org/pages/Comprehensive_Nutrient_Management_Planning_%28CNMP%29
Accessed January 22, 2010

63. CNMP Core Curriculum—Iowa State University

There are several sources for additional information about Comprehensive Nutrient Management Plans (CNMPs). Many land grant universities and other commodity/producer organizations provide informational literature and Web sites. Additionally, state NRCS offices often maintain CNMP/TSP informational Web pages. A source of information about CNMPs is the CNMP Core Curriculum training modules maintained by Iowa State University and available through the Midwest Plan Service. The CNMP Core Curriculum is also a good resource for educators interested in providing training on CNMP development. Also, the breadth of information covered in the topic areas make the curriculum a good source of materials for smaller scale trainings, such as shorter, topic specific extension programs. The CNMP Core Curriculum provides a consistent background and framework from which state or regionally specific CNMP courses can be developed. There are ten sections in the CNMP Core Curriculum. The section topics are:

- Introduction to a Comprehensive Nutrient Management Plan
- Conservation Planning

- Land Treatment Practices
- Manure and Wastewater Storage and Handling
- Nutrient Management
- Feed Management
- Record Keeping
- Air Quality
- Alternative Utilization
- TSP Certification

Link: http://www.abe.iastate.edu/wastemgmt/cnmp-curriculum.html Accessed January 26, 2010

64. Manure Management Planner Tutorials—Univ. of Missouri Extension

These tutorials were part of a training program for Missouri nutrient management planners. The tutorials outline many of the steps in developing a nutrient management plan in MMP. Many of the steps in using MMP are universal among all states. These tutorials were developed in 2005 for an earlier version of MMP, but the authors believe that the tutorials are still mostly applicable to the planning process when using MMP. Separate tutorials were developed for a swine operation (liquid manure), poultry operation (solid manure) and fertilizer plan (no manure).

Link: http://www.nmplanner.missouri.edu/software/mmp_tutorial.asp Accessed January 22, 2010

Chapter 3.
Urban and Suburban

Contents

1 Introduction

1.1 Need for Urban and Suburban Runoff Guidance Update

1.1.1 Purpose

This chapter was developed to provide guidance on the most up-to-date, proven, and cost-effective practices for controlling urban and suburban runoff for federal land management in the Chesapeake Bay region, as required by Executive Order 13508. Federal agencies in the Chesapeake Bay watershed will find this guidance useful in managing urban runoff from the development and redevelopment of federal facilities and other land areas owned or managed by the federal government.

At the same time, EPA recognizes that the great majority of land in the Chesapeake Bay watershed is nonfederal land and is managed by private landowners, states, and local governments. Indeed, the vast majority of actions to restore the Chesapeake Bay will need to take place on nonfederal lands and will need to be implemented by nonfederal actors. From the perspective of land management and water quality restoration/protection, the same set of “proven cost-effective tools and practices that reduce water pollution” are appropriate for both federal and nonfederal land managers to restore and protect the Chesapeake Bay.

Therefore, states and others (e.g., states, local governments, conservation districts, watershed groups, developers, and other citizens in the Chesapeake Bay watershed) could choose to use this guidance document to the extent that they find it relevant and useful to their needs. The document presents practices and actions that are not unique to federal lands and thus will often be applicable to lands that are managed by nonfederal land managers. Thus, while this document has been written specifically to address the needs of federal land managers, other parties might also find it a useful guide to implementing the most effective and cost-effective practices available to restore and protect the Chesapeake Bay.

In addition, many of the nutrient and sediment sources in the Chesapeake Bay watershed are similar to sources in other watersheds around the country. Many of the practices needed to protect and restore the Chesapeake Bay are the same as or very similar to those used in other watersheds. Indeed, while great efforts have been made in preparing this document to assure the consideration of all relevant data for the Chesapeake Bay watershed, has been considered and used as appropriate in preparing and publishing this guidance, EPA has also employed data from outside the Chesapeake Bay watershed when it was deemed to be relevant and applicable to the Chesapeake Bay. For that reason, much of the information provided in this chapter is relevant to other areas of the United States. Therefore, practitioners outside the watershed might wish to consider this chapter as they develop and implement their own watershed plans and strategies to address nutrient and sediment pollution from nonpoint sources.

The primary approaches recommended in this chapter to protect the Chesapeake Bay and its tributaries—as well as waters in much of the rest of the United States—from the effects of development are to use green infrastructure/low impact development (LID) approaches and planning and development techniques, such as smart growth, that minimize the detrimental effects of development on the environment. Section 2 of this chapter focuses on such approaches.

The objective of green infrastructure/LID is to maintain or restore the predevelopment site hydrology in regard to the temperature, rate, volume, and duration of runoff flow. That can be accomplished during development, redevelopment, or retrofit. In some cases, achieving more runoff retention might be necessary for water quality protection, and this document does not preclude setting that performance objective. More specifically, this approach is intended to maintain or restore stream flows such that receiving waters, and stream channels, are not negatively affected by changes in runoff. That approach protects predevelopment hydrology and provides significant reductions in pollutant runoff. However, in some circumstances, specific additional pollutant control practices, (e.g., source controls) will need to be implemented to address pollutant runoff, and Section 3 of this chapter addresses those practices.

Planning can help guide development to areas that minimize effects on sensitive resources and natural areas. Planning can help ensure that new and redevelopment sites are designed to reduce runoff volume through on-site stormwater retention.

This chapter

- Emphasizes replicating predevelopment hydrology with respect to runoff volume, temperature, rate, and duration as a more reliable and effective stormwater management practice than traditional approaches that focus on pollutants without addressing hydrology. That emphasis is already expressed in a number of recent EPA documents and numerous states, cities, and expert groups, including the National Academy of Sciences (http://epa.gov/greeninfrastructure).
- Incorporates by reference the *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*, EPA 841-B-09-001 (USEPA 2009e), which provides the hydrologic analysis for this approach. Elements of that document are referenced here,

but it is not repeated in its entirety; it is provided at http://www.epa.gov/owow/nps/lid/section438/.

- Builds on that technical guidance by providing users with sources to the newest research on key management practices and approaches and refers the reader to other resources where appropriate.
- Emphasizes those practices that can have multiple associated benefits, including cost-effectiveness and energy-savings. Some of those practices, in fact, cost less than the conventional stormwater management alternative in addition to providing other environmental and societal benefits.
- Addresses technical management practices for restoring and maintaining surface water quality. Green infrastructure/LID is generally used for managing smaller storm events that compose the bulk of annual rainfall and therefore contributes the most to both pollutant loading and stream degradation. This document does not address other stormwater issues, primarily flood-control or stormwater program management. However, those issues are addressed at length in documents referenced here.

Such an approach of maintaining predevelopment hydrology is already required for federal facilities by the Energy Independence and Security Act (EISA) of 2007 (P.L. 110-140, H.R. 6) section 438. Subsequent EPA guidance (EPA 841-B-09-001) (USEPA 2009e) provides advice on how to implement it at federal facilities.

EISA mandates certain federal facilities to comply with the following:

> **Stormwater runoff requirements for federal development projects.** The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

State and local stormwater programs established under the Clean Water Act Amendments of 1987 were traditionally established to control pollutants that are associated with municipal and industrial discharges, e.g., nutrients, sediment, and metals. Increases in runoff volume and peak discharge rates have been regulated through state and local flood control programs but in many states have not been significantly addressed with regard to their role in water quality and habitat protection. Knowledge accumulated during the past 20 years has led to the conclusion that conventional approaches to control runoff have not resulted in adequate protection of the nation’s water resources, and, in fact, have had detrimental effects associated with increased volumes of runoff (National Research Council 2008).

An example of that detrimental effect is referenced in Figure 3-1.

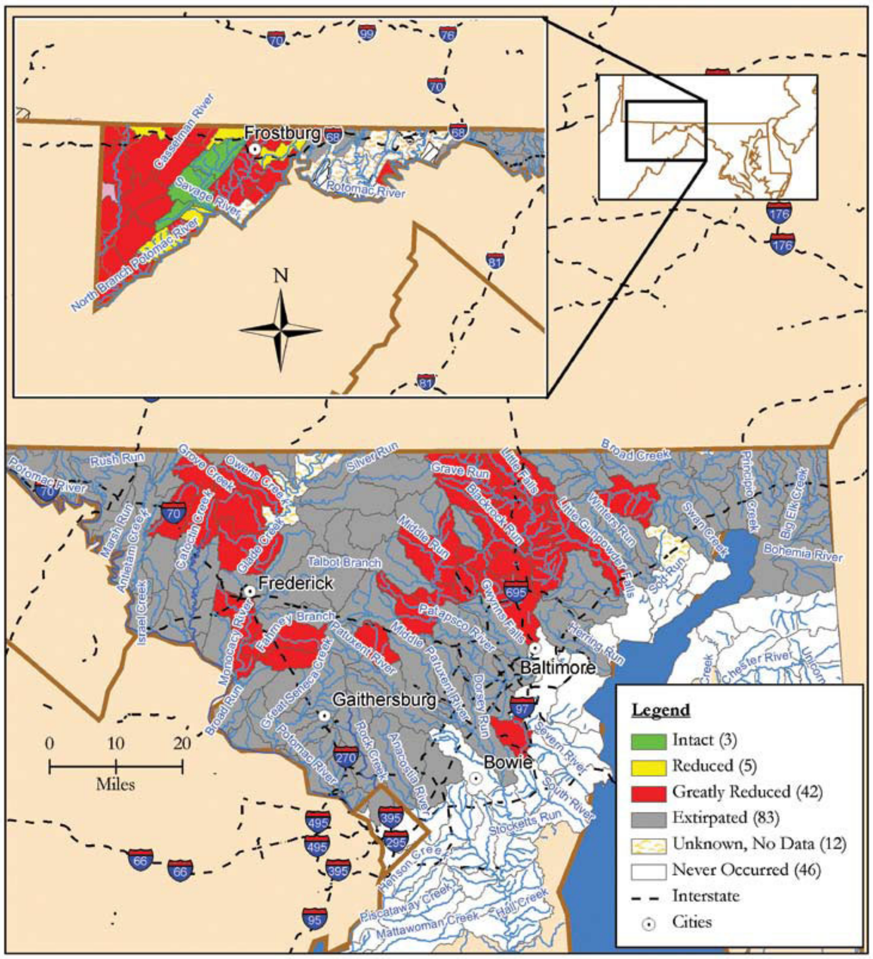
This chapter emphasizes site-specific management practices from green infrastructure/LID that are driven by locally applicable performance objectives. Each site or watershed has its own unique circumstances—a combination of land uses, water resource needs, environmental conditions, regulatory drivers, and community attributes—that will affect which approaches are the most successful in terms of effectiveness and community acceptance. The means selected will vary depending on the development setting and site-specific opportunities and constraints; however, designing to replicate predevelopment hydrology is the overall goal that best ensures achieving full designated uses of the waters. In cases where green infrastructure/LID is not feasible on-site or is otherwise inadequate to meet water quality objectives, additional measures should be considered, as discussed in Section 3 of this chapter.

The past decade has brought significant growth in the use of approaches that seek to control runoff volume at the site scale using a variety of decentralized stormwater controls and runoff retention methods that have the objective of replicating the predevelopment hydrology as much as technically feasible. That type of holistic, hydrology-based approach to urban runoff management is termed *low impact development* or LID (also referred to variously as better site design, environmentally sensitive design, sustainable stormwater management, and *green infrastructure*, among others). The approach has been proven to be technically achievable and cost-effective; examples demonstrating this are provided in Figures 3-2 and 3-3 that describe projects in Portland, Oregon, and in coastal North Carolina.

The purpose of this chapter is to present an overview of the practices and resources available for federal facilities and others to achieve water quality goals in the most cost-effective and potentially successful manner, with the overall objective of improving water quality, habitat, and the environmental and economic resources of the Chesapeake Bay and its tributaries.

A Maryland Department of Natural Resources (DNR) study highlights the detrimental impact that development, loss of forest, and temperature changes have had on brook trout, Maryland's only native trout species, based on three decades of study.

For every one percent increase in impervious land cover in a stream's watershed, the odds of brook trout survival decreased by nearly 60 percent (Stranko, et.al. 2008).



Map data derived from state and federal data and compiled in EBTJV assessment results titled, *Distribution, status, and perturbations to brook trout within the eastern United States, 2006.* Authored by Mark Hudy, US Forest Service; Teresa Thieling, James Madison University; Nathaniel Gillespie, Trout Unlimited; Eric Smith, Virginia Tech. Map created on 2/24/06 by Nathaniel Gillespie, Source: *Eastern Brook Trout: Status and Threats, Maryland,* Trout Unlimited, brochure. www.tu.org/atf/cf/%7BED0023C4-EA23-4396-9371-8509DC5B4953%7D/brookie_MD.pdf. Eastern Brook Joint Trout Venture.

Figure 3-1. Maryland Department of Natural Resources study (2008) and Trout Unlimited mapping (2006) document the extensive loss of brook trout from development impacts.

Portland Bureau of Environmental Services (BES) Tabor to the River project integrates hundreds of sewer, green stormwater management, tree planting and other watershed projects to improve sewer system reliability, stop sewer backups in basements and street flooding, control combined sewer overflows (CSOs) to the Willamette River, and restore watershed health.

The 1,472-acre basin is high-density residential development, with commercial land use, and approximately 37% impervious. The Tabor to the River project will address stormwater management and watershed health by

- Adding 500 LID facilities in the public right-of-way (curb extensions, vegetated planters, and flow restrictors)
- Addressing Runoff from 8 acres of parking and rooftops on private property controlled by LID facilities (e.g., vegetated planters, rain gardens, eco-roofs)
- Planting two revegetation projects to remove invasive species
- Planting 3,500 trees in the city's right-of-way
- Conducting Neighborhood education and project outreach
- Improving access to the Willamette River from an adjacent neighborhood

Sources:
Portland BES Web site for Tabor to the River: http://www.portlandonline.com/bes/index.cfm?c=47591

Tsurumi, Naomi and Bill Owen *Painting it Green—Replacing an All-Pipe Solution with an Integrated Solution Emphasizing Low Impact Development;* American Society of Civil Engineers (ASCE), Low Impact Development Conference Proceedings, 2008.

Figure 3-2. LID *Green Streets* save Portland, Oregon, nearly $60 million while restoring water quality.

Using LID on a development project in Middlesound, North Carolina, where LID is encouraged to protect shellfish beds and coastal recreational waters, the developer saved money and realized marketing advantages compared to tradition stormwater design:

- Gained 3 to 4 additional lots (from 56 to 59)
- Reduced stormwater pipe by 89%
- Decreased road widths 9%
- Eliminated 9,000-ft curb and gutter
- Eliminated 5 infiltration basins
- Eliminated 5 monitoring wells
- Eliminated 10,000 linear feet of stormwater force main
- Saved $1.5 million in fill material
- Increased localized stormwater infiltration
- Eliminated 3 stormwater pumps
- Increased functional and recreation open space
- Minimized wetlands intrusion and wildlife impacts
- Buyers prefer *green* real estate
- Promotes good neighbor
- Decreased construction traffic

"Your ideas and preliminary plans for incorporating LID for Ridgefield are proving invaluable. After having it approved for a conventional stormwater system, we were concerned with the extreme costs of the system and development's financial feasibility. However, with the utilization of an LID stormwater system we can dramatically reduce the costs and make the project viable again. In our estimates we are projecting a savings up to $1.5 million and adding 4 lots. In addition, we will be saving many of the natural features and topography resulting in a 'greener,' more conservation oriented neighborhood."

—Ridgefield Property Developer, February 2009

Source:
Todd Miller, North Carolina Coastal Federation; Heather Burkert, and H.K Burkert & Co.

Figure 3-3. Developer realizes savings and marketing value with LID while better protecting coastal waters.

1.1.2 Intended Audience

The primary audience for this chapter is stormwater managers in federal agencies and at the local, state, and federal levels who are responsible for meeting water quality goals and implementing water quality programs in developing and developed areas.

Others who can benefit from the information in this chapter include the development community and its multidiscipline designers, because new and redevelopment projects offer the best opportunity to implement stormwater controls to mitigate development's effects on water resources; local public officials responsible for land use and water quality decision making, academia and research groups, environmental and community organizations, and the business community.

1.1.3 Water Quality Significance of Urban Runoff in the Chesapeake Bay Watershed

Urban stormwater runoff is responsible for a significant portion of the nitrogen (N), phosphorus (P), and sediment loading to the Chesapeake Bay. The loading has been continuing to increase over time because of development. Understanding the core cause of this problem is essential to reducing this source.

This section contains background information on the causes and consequences of stormwater discharges, i.e., the alterations to natural hydrology and the resulting impacts, and solutions that can be used to address the causes and consequences of stormwater discharges, and how to implement those solutions such that they will be applicable to all areas of the country and comply with section 438 of EISA.

Under natural, undisturbed conditions in the mid-Atlantic region, most rainfall is intercepted by vegetation, infiltrates into the soil where it feeds streams and aquifers, or is returned to the atmosphere via evapotranspiration. Very little rainfall becomes stormwater runoff, and runoff generally occurs only with larger precipitation events. Traditional development practices cover large areas of the ground with impervious surfaces such as roads, parking lots, driveways, sidewalks, and buildings. Once such development occurs, rainwater cannot infiltrate into the ground and as a result, runs off the site at rates and volumes that are much higher than would naturally occur. Under developed conditions, runoff occurs even during small precipitation events that would normally be absorbed by the soil and vegetation. The collective force of the increased runoff scours streambeds, erodes streambanks, and causes large quantities of sediment and other entrained pollutants to enter the waterbody each time it rains (Shaver et al. 2007; Walsh et al. 2005; Booth testimony 2008). Such change in runoff with urbanization is illustrated in Figure 3-4. Studies of historical temperature patterns in streams recently documented increases in temperature in many areas; areas in the Chesapeake Bay region where statistically significant stream temperature increases have occurred include the Potomac River, the Patuxent River, and the Delaware River near Chester, Pennsylvania (Kauskai 2010; http://www.chesapeakebay.net/news_streamtemps10.aspx?menuitem=50656).

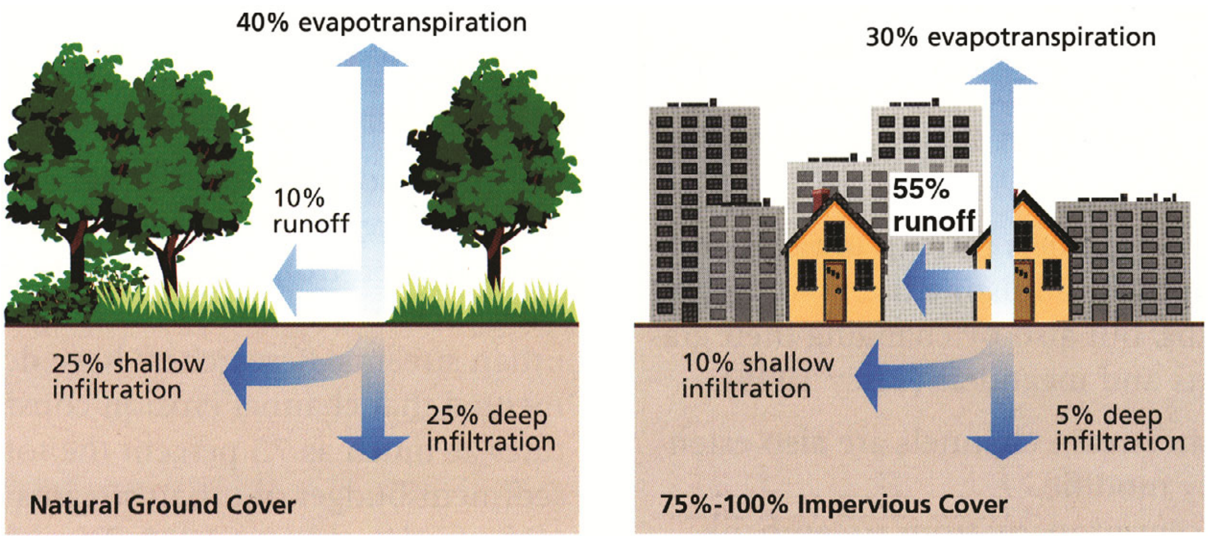


Figure 3-4. Predevelopment and post-development hydrology (USDA).

In recognition of those problems, stormwater managers employed extended detention approaches to mitigate the effects of increased runoff peak runoff rates. However, wet ponds and similar practices inadequately protect downstream hydrology because of the following inherent limitations of the conventional practices (National Research Council 2008; Shaver et al. 2007):

- Poor peak control for small, frequently occurring storms
- Negligible volume reduction
- Increased duration of peak flow

Detention storage targets relatively large, infrequent storms, such as the 2- and 10-year/24-hour storms for peak flow rate control. As a result of that design limitation, flow rates from smaller, frequently occurring storms typically exceed those that existed on-site before land development occurred, and those increases in runoff volumes and velocities typically result in flows erosive to stream channel stability (Shaver et al. 2007). Section 438 of EISA is intended to address the inadequacies of the historical detention approach to managing stormwater and promote more sustainable practices that have been selected to maintain or restore predevelopment site hydrology.

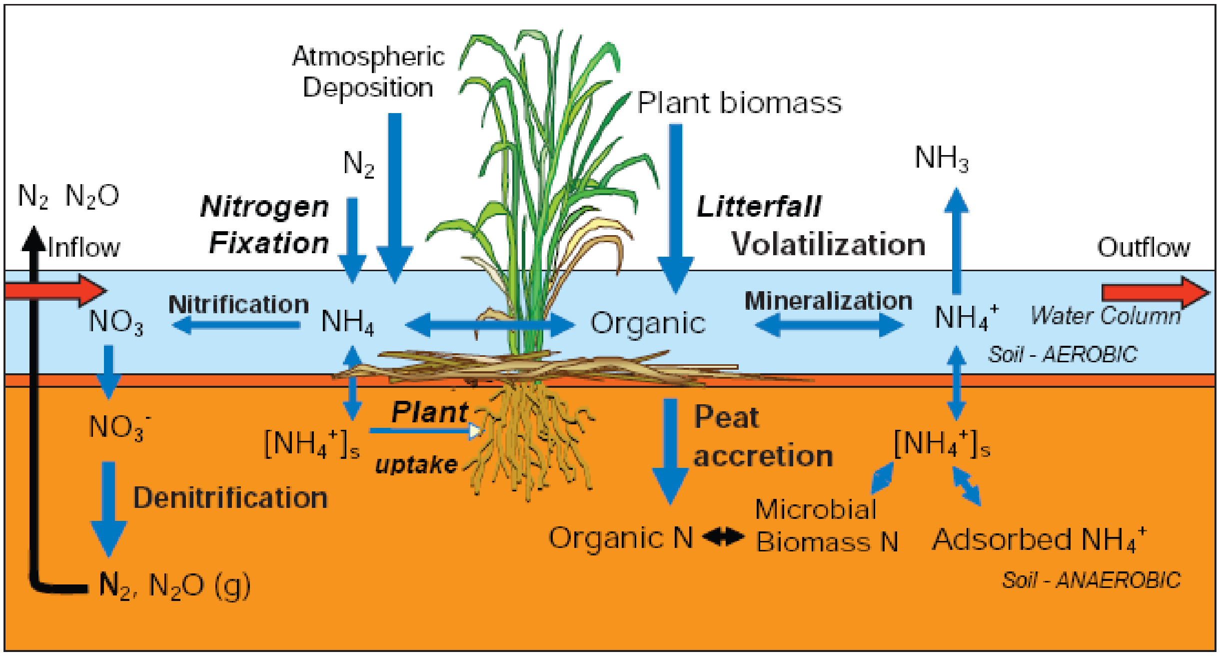
A 2008 National Research Council report on urban stormwater confirmed the shortcomings of current stormwater control efforts. Three of the report's findings on stormwater management approaches are particularly relevant (National Research Council 2008).

- Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds.
- Stormwater control measures such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from new development.
- Stormwater control measures that harvest, infiltrate, and evapotranspire stormwater are critical to reducing the volume and pollutant loading of small storms.

The amount of water on Earth today is the same as it was billions of years ago. Water is continually recycled through the water cycle (or hydrologic cycle), a system that moves rainfall from the atmosphere to land, through surface and groundwater systems, to the ocean, and back into the atmosphere. Water changes its form throughout this cycle between solid, liquid, and gas—and it moves over the Earth's surface, underground, or through the atmosphere.

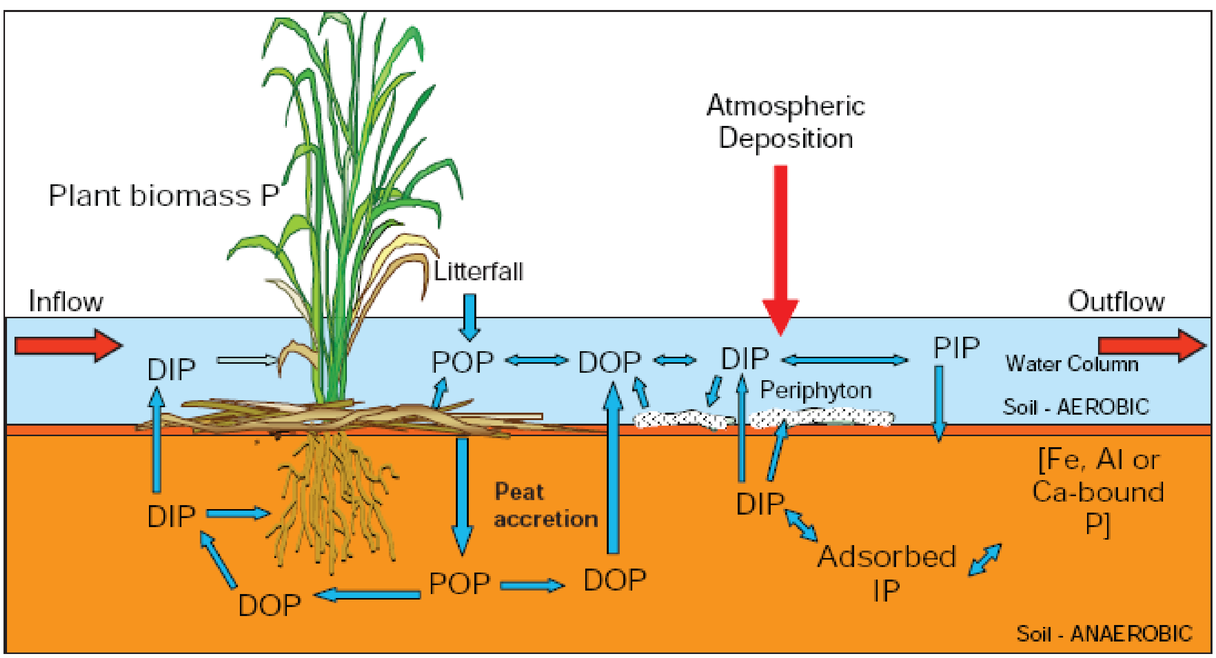
The hydrologic cycle is a dynamic system of interdependent parts in constant movement. Altering one part of the cycle affects other parts because the overall water balance must be maintained. Removing trees and paving land surfaces, for example, reduces the amount of infiltration and evapotranspiration and increases the amount of runoff. Additional information on the hydrologic cycle and how it affects the design of stormwater management practices is in *Stormwater Best Management Practice Design Guide* (EPA/600/R-04/121, September 2004, http://www.epa.gov/nrmrl/pubs/600r04121/600r04121.pdf).

The nutrient cycle is also a dynamic, interdependent process. Development affects soil, groundwater, and surface water and disrupts the balance, ultimately resulting in damaging environmental conditions such as those present in the Chesapeake Bay. Schematic representations of the N and P cycles in wetlands are provided in Figures 3-5 and 3-6. Additional information on nutrient cycling is available in *Nutrient Criteria Technical Guidance Manual, Wetlands* (EPA-822-B-08-001, 2008f).



Source: USEPA 2008f

Figure 3-5. N cycling in wetlands.



Source: USEPA 2008f

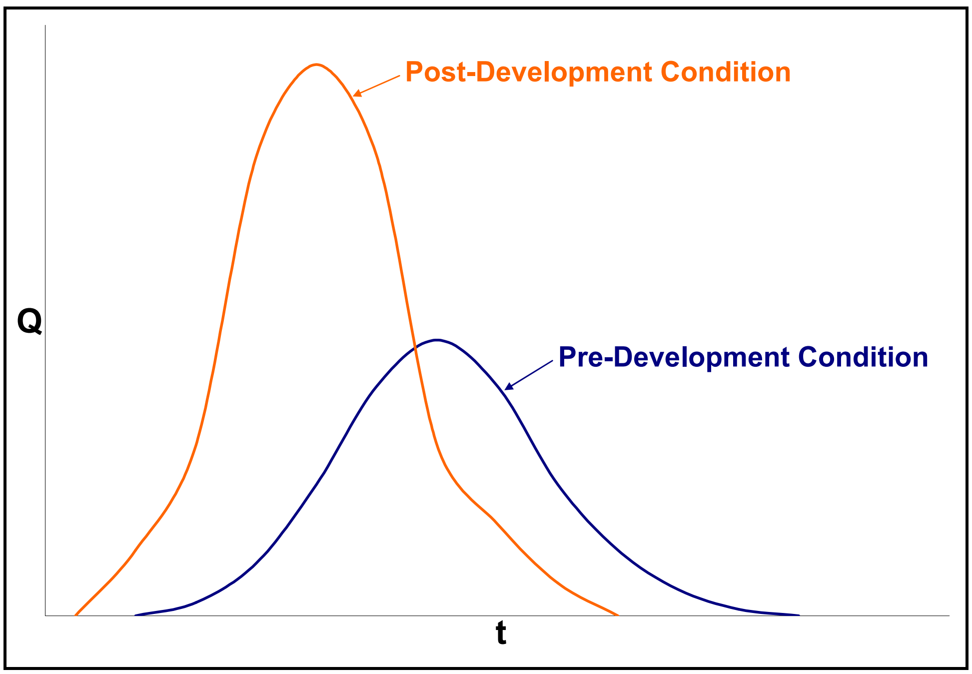
Figure 3-6. P cycling in wetlands shown dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), particulate organic phosphorus (POP).

Land cover changes that result from site development include increased imperviousness, soil compaction, loss of vegetation, and loss of natural drainage patterns resulting in increased runoff volumes and peak runoff rates. The cumulative effects of the land cover changes result in alterations of the natural hydrology of a site, which disrupts the natural water balance and changes water flow paths. The consequences of these impacts include the following:

- *Increased volume of runoff.* With decreased area for infiltration and evapotranspiration because of development, a greater amount of rainfall is converted to overland runoff, which results in larger stormwater discharges.
- *Increased peak flow of runoff*. Increased impervious surface area and higher connectivity of impervious surfaces and stormwater conveyance systems increase the flow rate of stormwater discharges and increase the energy and velocity of discharges into the stream channel.
- *Increased duration of discharge*. Detention systems generate greater flow volumes for extended periods. Those prolonged, higher discharge rates can undermine the stability of the stream channel and induce erosion, channel incision and bank cutting.
- *Decreased baseflow and increased flash flooding*. Changes to baseflow are caused by alterations to the hydrologic cycle created by land cover changes and increased imperviousness, which prevents rain from recharging groundwater, where it serves as baseflow for streams. Such changes increase the *flashiness* of streams, resulting in elevated flows during or after storm events, and greatly diminished baseflows in between storms.
- *Increased pollutant loadings*. Impervious areas are a collection site for pollutants. When rainfall occurs, the pollutants are mobilized and transported directly to stormwater conveyances and receiving streams via the impervious surfaces.
- *Increased temperature of runoff*. Impervious surfaces absorb and store heat and transfer it to stormwater runoff. Higher runoff temperatures can have detrimental effects on receiving streams. Detention basins magnify this problem by trapping and discharging runoff that is heated by solar radiation (Galli 1991; Schueler and Helfrich 1988).
- *Habitat modifications and stream morphology changes.* Increased runoff rate and volume alter stream morphology. Highly erosive stormwater can wash out in-stream structures that serve as habitat. Large storms deepen, widen, and straighten channels, disconnecting streams from their floodplains and destroying meanders that serve to dissipate hydraulic energy (Walsh et al. 2005).

The resulting increases in volume, peak flow, and duration are illustrated in the hydrograph in Figure 3-7, which is a representation of a site's stormwater discharge with respect to time. The hydrograph illustrates the effects of development on runoff volume and timing of the runoff.

Individual points on the curve represent the rate of stormwater discharge at a given time. The graph illustrates that development and corresponding changes in land cover result in greater discharge rates, greater volumes, and shorter discharge periods. In a natural condition, runoff rates are slower than those on developed sites, and the discharges occur over a longer period. The predevelopment peak discharge rate is also much lower than the post-development peak discharge rate because of attenuation and absorption by soils and vegetation. In the post-development condition, there is generally a much shorter time before runoff begins because of increased impervious surface area, a higher degree of connectivity of those areas, and the loss of soils and vegetative cover that slow or reduce runoff. Simply reducing the peak flow rate, and extending the duration of the predevelopment peak flow, is not effective because as the different discharge sources enter a stream, the hydrographs are additive, and the extended predevelopment peak flows combine to produce an overall higher than natural peak. The result is the pervasive condition of channel incising, erosion, and loss of natural stream biological and chemical function as observed in Figure 3-8.



Note: Q = volumetric flow rate; t = time

Figure 3-7. Post-development hydrograph shows how development results in increased peak flow, shorter duration, and increased overall volume.

Figure 3-8. Stream displaying the effects of stormwater runoff and channel downcutting.

1.1.4 Managing Urban Runoff to Reduce Nutrients and Sediment Loss

1.1.4.1 Preserving and Restoring Hydrology

Green infrastructure practices include a wide variety of practices that use such mechanisms. They can be used at the site (Figure 3-9), neighborhood, and watershed/regional scales. In this document, the focus is on site-level practices, such as bioretention and water harvesting, but it also addresses the land management scales of planning (i.e., planning techniques such as smart growth), and site design (i.e., site design techniques such as conservation development).

Restoring or maintaining predevelopment hydrology has emerged as a control approach for several reasons. Most importantly, the approach is intended to directly address the root cause of impairment. Current control approaches have been selected in an attempt to control the symptoms (peak flow, and excess pollutants), but the strategy is ineffectual in many cases because of the scale of the problem, the cumulative effects of multiple developments and the need to manage both site and watershed level effects. With current approaches, it is also difficult to adequately protect and improve water quality because the measures employed are not addressing the root problem, which is a hydrologic imbalance.

Designing facilities with the goal of maintaining or restoring predevelopment hydrology provides a site-specific basis and an objective methodology with which to determine appropriate practices to protect the receiving environment.

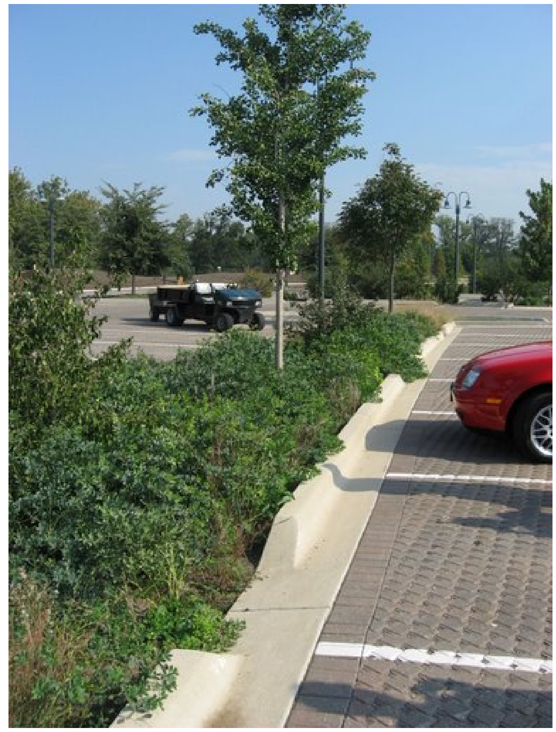


Figure 3-9. Parking lot bioswale and permeable pavers in Chicago.

Using predevelopment hydrology as the guiding control principle also allows the designer to consider climatic and geologic variability, and tailor the solutions to the project location. Thus, the one-size-fits-all approach is not appropriate because the design objective is dictated by the predevelopment site conditions and other technicalities of the project site and facility use. Site assessments of historical infiltration and runoff rates will inform the designer and provide the basis for a suitable design. The use of this approach will minimize compliance complications that can arise from prescriptive design approaches that do not account for the variability of precipitation frequencies, rainfall intensities, and land cover and soil conditions that influence infiltration and runoff.

More information on addressing hydromodification and riparian buffers are provided in separate volumes of this document.

1.1.4.2 Defining Green Infrastructure/LID

LID is a stormwater management strategy that many localities across the country have adopted. Green infrastructure is a term also used to describe LID practices, with the connotation that such practices can be thought of as infrastructure, just like a pipe or other structural management practice. Green infrastructure/LID is a stormwater management approach and set of practices that can be used to reduce runoff and pollutant loadings by managing the runoff as close to its source(s) as possible. A set or system of small-scale practices, linked together on the site, is often used. LID approaches can be used to reduce the effects of development and redevelopment activities on water

Examples of LID Practices

- Infiltration basins and trenches
- Permeable pavement
- Disconnected downspouts
- Rain gardens and other vegetated treatment systems

resources. In the case of new development, LID is typically used to achieve or pursue the goal of maintaining or closely replicating the predevelopment hydrology of the site. In areas where development has already occurred, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall effects of existing development on the affected receiving waters.

In general, implementing integrated LID practices can result in enhanced environmental performance while at the same time reduce development costs when compared to traditional stormwater management approaches of collection, piping, and pond storage for treatment by settling. LID techniques promote the use of natural systems, which can effectively reduce nutrients, pathogens, and metals from stormwater through runoff volume reduction, filtration, and other processes. These systems can be designed to accommodate or bypass larger flows when large rain events occur, when the LID practice is sized for small rain events.

Cost savings can be achieved in reduced infrastructure, particularly in new development where land is available for surface practices, because the total volume of runoff to be managed is minimized through infiltration and evapotranspiration. By working to mimic the natural water cycle, LID practices protect downstream resources from pollutants and adverse hydrologic impacts that can degrade stream channels and harm aquatic life.

The use of LID does present challenges in operations and maintenance (O&M) because of the highly distributed nature of the controls. The large number and distributed nature of LID practices makes it challenging to track, inspect and maintain them. Depending on how the program is implemented, many LID practices can be on private property within drainage easements obtained for that purpose. New institutional frameworks for managing LID operations responsibly are being developed and will continue to be developed.

It is important to note that LID designs usually incorporate more than one type of practice or technique—in series as a treatment train or parallel to manage small drainage areas. That approach helps to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bioretention area in each yard, disconnect downspouts from driveway surfaces, remove curbs or cut out drainage slots into curbs, and install grassed swales in common areas. The basis of LID is integrating small practices throughout a site instead of using extended detention wet ponds for treatment purposes.

Planning techniques such as smart growth minimize runoff by approaches such as enhancing density along existing transportation and other infrastructure corridors, and reducing sprawl and greenfield development. While one aspect of smart growth—increased population density where appropriate—has been perceived as potentially conflicting with LID approaches that have typically been considered as land-intensive for infiltration, in actuality they can be compatible and complementary. In dense, high-rise urban areas, stormwater management practices such as expanded street tree boxes, building-front infiltration planter boxes, green roofs and permeable pavement with infiltration potential, can provide improved water quality and needed aesthetic relief from endless paved and concrete surfaces. During warm weather, the urban heat island effect is intensified by the paved surfaces. The need for integrating green stormwater management will become more essential as people move into and live in dense areas.

Smart Growth Includes:

- Conservation of resources by reinvesting in existing infrastructure, infill development, reclaiming historic buildings, with denser growth along transit.
- Design of neighborhoods that have shops, offices, schools and other amenities near homes, giving residents and visitors the option of walking, bicycling, taking public transportation, or driving
- Economically competitive, desirable places to live, work, play

Conservation designs minimize runoff by conserving undeveloped land and reducing the amount of impervious surface, which can cause increased runoff volumes. Open space can be used to treat the increased runoff from the built environment through infiltration and evapotranspiration. For example, developers can use conservation designs to preserve important features on the site such as wetland and riparian areas, forested tracts, and areas of pervious soils. Development plans that outline the smallest site disturbance minimize stripping topsoil and compacting subsoil. Such simplistic, nonstructural methods reduce the need to build runoff controls like retention ponds for treatment and larger stormwater conveyance systems, thereby decreasing the overall project cost. Reducing the total area of impervious surface by limiting road widths and parking areas also reduces the volume of runoff that must be treated. Conservation designs benefit residents and their quality of life because of increased access and proximity to communal open space, a greater sense of community, and expanded recreational opportunities. Some literature notes more developer profit from conservation designed subdivisions compared to conventional subdivisions (Mohamad 2006), but others note that regulations requiring clustered-type designs might be needed where lot size alone appears to be a stronger driver of value to consumers (Kopits et al. 2007).

Examples of Conservation Design

- Cluster development
- Undeveloped land conservation
- Reduced pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)
- Site fingerprinting during construction

LID practices are engineered structures or landscape features designed to capture and infiltrate, store, convey, or filter runoff in a manner that attempts to replicate predevelopment hydrology.

Infiltration practices can also be used to achieve a goal of recharging groundwater while at the same time reducing runoff. Recharging groundwater is especially important in areas where maintaining drinking water supplies and stream baseflow is of special concern because of limited precipitation or high withdrawal demands. Infiltration of runoff can also help to maintain stream temperatures because the infiltrated water that moves laterally to replenish stream baseflow typically has a lower temperature than overland flows, which might be subject to solar radiation. Another advantage of infiltration practices is that they can be integrated into landscape features in a site-dispersed manner. This feature can result in aesthetic benefits and, in some cases, recreational opportunities; for example, some infiltration areas can be used as playing fields during dry periods.

Runoff storage practices reduce the volume and peak rate of runoff to protect streams from the erosive forces of high flows, and irrigate landscaping to providing aesthetic benefits such as more sustainable (i.e., more self-watering) landscape islands, tree boxes, and rain gardens. Designers can take advantage of the space beneath paved areas like parking lots and sidewalks to provide additional storage. For example, underground vaults can be used to store runoff in both urban and rural areas, and street tree designs have been developed to better enable use of that space for root growth to enable establishment of healthy urban tree canopy.

Runoff Storage Practices

- Parking lot, street, and sidewalk storage in underground infiltrating vaults
- Rain barrels and cisterns
- Depressional storage in landscape islands and in tree, shrub, or turf depressions
- Green roofs

Runoff conveyance practices can be used to slow flow velocities, lengthen the runoff time of concentration, and delay peak flows that are discharged off-site. LID conveyance practices can be used as an alternative to curb-and-gutter systems. LID conveyance practices often have rough vegetative surfaces that reduce runoff velocities and allow settling of solids. They promote infiltration, filtration, and some biological uptake of pollutants. LID conveyance practices also can perform functions similar to those of conventional

Runoff Conveyance Practices

- Eliminating curbs and gutters
- Creating grassed swales and grass-lined channels
- Roughening surfaces
- Creating long flow paths over landscaped areas
- Creating terraces and check dams

curbs, channels, and gutters. For example, they can be used to reduce flooding around structures by routing runoff to landscaped areas for treatment, infiltration, and evapotranspiration.

Filtration practices capture pollutants by physical filtration of solids or cation exchange of dissolved pollutants. They also reduce runoff volume, recharge groundwater, increase stream baseflow, and reduce thermal impacts. Pollutant buildup can be of concern, and pollutants are typically captured in the upper soil horizon. Captured pollutants can be removed by replacing the topsoil. The useful life of the media can be extended by selecting plants that also provide phytoremediation.

Filtration Practices

- Bioretention/rain gardens
- Vegetated swales
- Vegetated filter strips/buffers

Conservation landscaping reduces labor, watering, and chemical use. Properly preparing soils and selecting species adapted to the site increases the success of plant growth, stabilizing soils and allowing for biological uptake of pollutants. Pest resistance (reducing the need for pesticides) and improved soil infiltration from root growth are among the goals. Conservation landscaping is promoted by many entities in the Chesapeake Bay area and elsewhere.

Conservation Landscaping

- Planting native, drought-tolerant plants
- Converting turf areas to shrubs and trees
- Reforestation
- Encouraging longer grass length
- Planting wildflower meadows rather than turf along medians and in open space
- Amending soil to improve infiltration
- Integrated pest management

1.1.4.3 Benefits of Designing to Restore and Preserve Predevelopment Hydrology

Unlike traditional stormwater management, an approach to maintain or restore predevelopment hydrology meets multiple performance objectives and can offer additional benefits, including the following:

Pollution abatement. LID practices more reliably reduce pollutant loadings by reducing the runoff volume. LID practices, to a lesser degree, can reduce pollutants by settling, filtering, adsorption, and biological uptake.

Protect downstream water resources. LID practices help to prevent or reduce hydrologic effects on receiving waters, reduce stream channel degradation from erosion and sedimentation, improve water quality, increase water supply, and enhance the recreational and aesthetic value of our natural resources. Other potential benefits include reduced incidence of illness from swimming and wading, more robust and safer seafood supplies.

Protect integrity of streams and floodplains to preserve ecological functions. Costs of streambank restoration can be reduced or avoided altogether where appropriate protection techniques are used, in particular those techniques that maintain predevelopment hydrology during development, redevelopment, and in retrofitting. Excess deposition of sediment in rivers and in estuaries can be minimized by preventing upstream erosion caused by stresses resulting from excess stormwater volume. Using LID techniques such as stormwater wetlands also can help protect or restore floodplains, which can be used as park space or wildlife habitat (Trust for Public Lands 1999).

Conserve energy and reduce carbon emissions in landscape irrigation and other non-potable uses. U.S. water-related energy use—for pumping, treating and heating water—has been estimated to be at least 521 million MWh a year. That is equivalent to 13 percent of the nation's electricity consumption, with a CO_2 output equal to the emissions of more than 62 coal fired power plants. *The Carbon Footprint of Water* (Griffiths-Sattenspiel and Wilson 2009; http://www.rivernetwork.org/blog/7/2009/05/13/carbon-footprint-water) notes

> Water conservation, efficiency, reuse and [LID] strategies should be targeted to achieve energy and greenhouse gas emissions reductions. Research from the California Energy Commission suggests that programs focusing on these kinds of water management strategies can achieve energy savings comparable to traditional energy conservation measures at almost half the cost. Water management policies that promote water conservation, efficiency, reuse and LID can reduce energy demand and substantially decrease carbon emissions.
>
> If LID techniques were applied in Southern California and the San Francisco Bay area, between 40,400 [million gallons] and 72,700 [million gallons] per year in additional water supplies would become available by 2020. The creation of these local water supplies would result in electricity savings of up to 637 million kWh per year and annual carbon emissions reductions would amount to approximately 202,000 metric tons by offsetting the need for inter-basin transfers and desalinated seawater.
>
> As the [United States] struggles to reduce its carbon emissions in response to global warming, investments in water conservation, efficiency, reuse and LID are among the largest and most cost-effective energy and carbon reduction strategies available.

Help achieve sustainability in environmental, energy, and economic performance. The multiple benefits can help to achieve sustainability. For example as in the requirements for federal facilities contained in the Executive Order on Federal Leadership in Environmental, Energy, and Economic Performance (October 5, 2009). The Executive Order includes requirements for federal facilities to increase energy efficiency; conserve water and support sustainable communities (http://www.whitehouse.gov/the_press_office/President-Obama-signs-an-Executive-Order-Focused-on-Federal-Leadership-in-Environmental-Energy-and-Economic-Performance/).

Groundwater recharge and stream baseflow. Growing water shortages nationwide increasingly indicate the need for holistic water resource management strategies. Development increases impervious surfaces and runoff. Infiltration practices replenish groundwater and increase stream baseflow. Adequate groundwater recharge is important because low groundwater levels can lead to low baseflows in dry weather. Greater fluctuations in stream flows and temperatures occur when rainfall does not infiltrate, to the detriment of aquatic life.

Water quality improvements/reduced treatment costs. Keeping water clean can prevent the costs for cleaning it up. The Trust for Public Land (1999) notes that Atlanta's tree cover has saved more than $883 million by preventing the need for stormwater facilities. A study by the Trust for Public Land and the American Water Works Association (2004) of 27 water suppliers found that higher forest cover in a watershed reduced water treatment costs. According to the study, approximately 50 percent of the variation in treatment costs can be tied to the percentage of forest cover. It also found that for every 10 percent increase in forest cover, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover.

Reduced incidence of combined sewer overflow (CSOs). Many municipalities with older sewer systems have CSOs. When cities were developed before the mid-1900s, sanitary wastewater and stormwater were conveyed together to a receiving water. With the advent of treatment requirements for sanitary wastewater, those combined sewers were just connected to wastewater treatment plants. Therefore, the stormwater drainage in many older cities is conveyed to wastewater treatment plants, and during large storm events, it exceeds the plant capacity and overflows the raw sewage/stormwater mix into waterways. Solutions to CSOs have focused on sewer separation and detention in large tunnels—very expensive alternatives. LID techniques, by retaining and infiltrating runoff, reduce the frequency and amount of CSOs. For the past several years, communities such as Portland (Oregon), Chicago, and the District of Columbia have been piloting and implementing LID approaches aimed at reducing runoff generated and subsequently discharged into the combined system.

Habitat improvements. Innovative stormwater management techniques like LID or conservation design can be used to improve natural resources and wildlife habitat, or avoid expensive mitigation costs. For example, in 2008 the National Marine Fisheries Service (NMFS) determined that the National Flood Insurance Program (NFIP) administered by the Federal Emergency Management Agency (FEMA), jeopardized endangered salmon and killer whale populations by enabling development in environmentally sensitive floodplains. NMFS then proposed alternative measures FEMA could take to comply with the Endangered Species Act (ESA) and the goals of the NFIP. Such measures included additional protections for sensitive areas and requiring LID techniques in developments (National Wildlife Federation 2008; http://online.nwf.org/site/DocServer/Memo_to_Colleagues_re_NMFS_NFIP_Biop.pdf?docID=10562). The complete National Oceanic and Atmospheric Administration (NOAA) NMFS biological opinion is at http://www.nwr.noaa.gov/. Another example is the Etowah Habitat Conservation Plan (HCP) adopted by several local governments in Georgia's Etowah Basin, which includes adoption of LID techniques by participating local governments to streamline compliance with the ESA (www.etowahhcp.org/).

Reduced downstream flooding and property damage. LID practices, when applied throughout a watershed, can reduce flash flooding, and reduce property damage or risk during small storm events.

Reduce erosion and sediment loss. Designs that manage runoff on-site or as close as possible to its point of generation reduce erosion and sediment transport, as well as stream erosion.

Real estate value/property tax revenue. Property owners will pay a premium to be near amenities like water features, open space, trails, and clustered subdivisions. EPA's early *Economic Benefits of Runoff Controls* (USEPA 1995) described many examples. Indication of increased value of conservation subdivisions is observed by Rayman (2006), and for protected riparian corridors by Qui et al. (2006). The extent of willingness to pay for such an environment lies with the consumer because there have been observations where the added value was not observed (Kopits et al. 2007). As continuing urbanization makes natural areas more scarce and precious, and as more of the population moves into cities for reasons such as transportation, the characteristic of valuing green amenities should continue to be assessed to ensure that it is captured in cost/benefit analyses.

Lot yield. In cases where LID practices are incorporated on individual house lots and along roadsides as part of the landscaping, land that would normally be dedicated for a stormwater pond or other large structural control can be developed with additional housing lots.

Aesthetic value. LID designs can enhance a property's aesthetics using trees, shrubs, and flowering plants that complement other landscaping features, resulting in a perceived value of *extra* landscaping.

Quality of life, public health, and public participation. An increasing number of studies suggest that vegetation and green space—two key components of green infrastructure—can have a positive effect on human health. Recent research has linked the presence of trees, plants, and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performance, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders and other health aspects. More information on those types of studies is at the University of Illinois at Urbana-Champaign, Landscape and Human Health Laboratory, Human Health Benefits of Natural Landscapes Web site at http://lhhl.illinois.edu/all.scientific.articles.htm. Placing water quality practices on individual lots provides opportunities to enhance public awareness of their natural environment. Homeowners often consider natural open space to be important in planned communities.

Reduce air pollution through uptake by trees. Trees remove gaseous air pollution primarily by uptake via leaf stomata, though some gases are removed by the plant surface (Smith 1990). In 1994 the U.S. Forest Service estimated that trees in Baltimore removed an estimated 499 metric tons of air pollution at an estimated value to society of $2.7 million (Nowak and Crane 2000).

Reducing urban heat island effect through evapotranspiration. For trees in grass-covered areas, mid-day temperatures have been reported to be 0.7 degree Celsius (°C) to 1.3 °C cooler than in an open area. Reduced air temperature can improve air quality because the emission of many pollutants or ozone-forming chemicals are temperature dependent. Lower air temperature can reduce ozone formation (Souch and Souch 1993; Nowak at www.ufore.org)

Reduced energy costs for heating and cooling. Improved insulation against summer heat is provided with green roofs. Mature, shady, deciduous trees can reduce air conditioning costs up to 30 percent, while a wind break of evergreens can save 10–50 percent off heating costs in the winter (www.dnr.state.md.us/forests/publications/urban5.html). Green roofs are also cited to reduce urban heat island effect and provide winter insulation (Portland BES 2007).

Saving money on drainage infrastructure. Curb, gutter, storm drain pipes, and runoff detention practices can be reduced by reducing the volume of runoff to be conveyed (WERF 2008; USEPA 2007).

Example Green Infrastructure Benefits Analysis. An example of the wide array of benefits achievable is presented in Philadelphia's *Green City, Clean Water* report (2009) summarizing the vision of using LID to mitigate stormwater overflows. Philadelphia has, like many older cities, a legacy of combined sanitary and storm sewers, and recently compared the costs and benefits of using green infrastructure to help mitigate the CSOs to the costs of conventional stormwater retrofits such as tunnels. Table 3-1 presents an overview of the types of benefits the city envisions from a plan to implement green stormwater management.

The cost estimates for construction and maintenance can be found in the Long-Term Control Plan at http://www.phillywatersheds.org/ltcpu/. Additional information on valuing benefits and on the estimated capital and O&M costs of individual green infrastructure elements considered by Philadelphia are provided in Section 2 of this chapter.

A broad overview of the ancillary benefits that can be realized from LID is provided by the Center for Neighborhood Technology in its Green Values Calculator (www.cnt.org/natural-resources/green-values).

Table 3-1. Projected ancillary benefits of using LID and green infrastructure stormwater practices in Philadelphia to help achieve CSO mitigation

Economic Benefits	About 250 people would be employed in green jobs per year
Social Benefits	Increase of more than 1 million recreational user-days per year would be enjoyed
	Reduction of approximately 140 fatalities cause by excessive heat over the next 40 years
	Increase in property values of 2%–5% in greened neighborhoods
Environmental Benefits	1.5 billion pounds of carbon dioxide emissions avoided [partially through reduced heavy equipment requirements for alternative stormwater management] or absorbed
	Air quality benefits on average leading annually to 1-2 avoided premature deaths, 20 avoided asthma attacks, and 250 missed days of work or school
	Water quality and habitat improvements including 5-8 billion gallons of CSO avoided per year; 190 acres of wetlands restored or created, 11 miles of stream restored.
	Reduction in electricity and fuel use [partially through reduced construction of alternative stormwater management infrastructure].

Source: Green City, Clean Waters: Philadelphia's Program for Combined Sewer Overflow Control, A Long-Term Control Plan Update, Summary Report, 2009. http://planphilly.com/node/9842

1.2 Overview of the Urban Runoff Chapter

This chapter provides recommendations for restoring or maintaining predevelopment hydrology for urban runoff to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

Maintaining or restoring predevelopment hydrology is the stormwater management goal recommended in this document, as required by Congress in section 438 of EISA for federal development and redevelopment projects exceeding 5,000 square feet. A number of technical resources, guidance, and design manuals are available that review in detail the key techniques and topics pertinent to urban runoff control. The technical material that is available in the referenced existing sources will not be repeated here.

1.2.1 Management Practices and Management Practice Scales

The following presents an overview of the approach presented in this chapter to achieve this goal by implementing strategies at the regional and watershed scale down to the site scale:

- At the regional or watershed scale, planning techniques such as smart growth and policies to allow conservation development, as part of watershed planning, can be used to lay the groundwork for ensuring that development has minimum impacts on water resources, including no net increase in stormwater runoff. This is important for both developed areas and for yet undeveloped areas.
- At the site scale, using green infrastructure/LID practices, along with source control and pollution prevention, are necessary to achieve the goals of protecting and restoring the Chesapeake Bay.

Applying LID practices at the site scale is recommended for new development, redevelopment, and retrofit. LID practices are flexible in design, so are widely applicable. LID practices such as functional conservation landscaping, bioretention, and swales require only a minimum modification from traditional landscaping design, often at no additional cost, and potentially provide long-term reductions in cost because of the reduced structural components requiring maintenance. There might also be reduced watering costs (because runoff is infiltrated instead of directed to drains) and turf care costs. In highly impervious urban areas where infiltration into soils is not feasible, the traditional stormwater management approach might call for detention of certain storm depth in a tank for water quality volume settling or peak shaving; that might not be significantly different in capital cost from retention in a cistern for use in landscaping or toilet flushing, and both require O&M. Appropriate practices are site-specific, as are costs. The basis for cost comparison, i.e., the alternative management strategy, is important in determining the extent of additional costs incurred with LID practices.

LID practices such as minimizing impervious surfaces, permeable pavement, green alleys, green streets, cisterns and rain barrels, and green roofs have become widely accepted in cities that have needed to manage excess pollutant runoff, water shortages, or flash flooding. The technology is now well-proven and shown to be adaptable for implementation at new development, redevelopment, and retrofit sites. Relatively small-scale LID practices can be dispersed throughout a site, capturing runoff from small drainage areas for infiltration, evapotranspiration, or capture and use. A site can be designed based on a *rooftop-to-stream* treatment train approach that includes both source-control practices and runoff treatment practices. The treatment train approach allows site designers and stormwater managers to take advantage of every opportunity to prevent runoff pollution and reduce runoff volume close to its source, thereby protecting headwater streams, municipal drainage systems, and downstream receiving waters, as follows:

- Minimize runoff generation by limiting the amount of directly connected impervious surface
- Capture runoff for evaporation or reuse
- Naturally infiltrate and filter runoff through landscaped areas
- Direct surplus runoff to engineered practices such as bioretention and other infiltration devices
- Prevent contamination of runoff using pollution prevention techniques
- Manage off-site runoff using regional stormwater practices, if necessary

This guidance provides an overview of the implementation measures recommended for managing urban stormwater to protect and restore the Chesapeake Bay or other waters affected by development. The implementation measures are action-oriented and, when considered together, from watershed scale to site scale, form a step-wise approach to addressing runoff volume and pollutant concentrations and for selecting management practices.

Sections 2 and 3 of this chapter summarize key elements of this approach: volume reduction and pollutant reduction through source control and treatment. Section 2 also addresses sectors of development such as new development and transportation-related development and provides references for more detailed information.

Section 4 addresses the opportunities to achieve volume reduction and pollutant reduction in the context of redevelopments. Section 5 addresses turf management. Particularly with respect to nutrients, that constitutes one of the most widespread land uses in the Chesapeake Bay watershed.

Appendix 1 consists of a series of fact sheets that briefly describe some of the key practices for which new research and guidance are available and include applicability, unit processes, feasibility constraints and limitations, runoff volume and pollutant-load-removal estimates as applicable, design and maintenance considerations, costs and factors that affect cost, and key references and resources. Photos and diagrams of typical applications are also provided. The fact sheets are intended to highlight new research and seminal resources with the most up-to-date approach on each management practice. Those practices that are adequately covered by other publicly available resources have links to existing sources.

1.2.2 Implementation Measures for Urban Runoff in the Chesapeake Bay Watershed to Control Nonpoint Source Nutrient and Sediment Pollution

Development or redevelopment projects with a footprint that exceeds 5,000 square feet should use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the watershed and site with regard to the temperature, rate, volume, and duration of flow. (Note: That is based on the approach adopted by Congress for federal facilities in section 438 of the Energy Independence and Security Act, 2007)

Implementation Measures:

U-1. Maximize infiltration, evapotranspiration, and harvest and use practices on-site, to the maximum extent technically feasible. Examples of these practices include the following:

- Bioretention cells or raingardens
- Green streets, right-of-way and parking lot designs and retrofits
- Cisterns and interior and exterior use of runoff
- Green roofs
- Tree planting and urban forestry
- Soil amendments and turf management

U-2. Implement policies to preserve or restore predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection. Implement at the regional, watershed, and site scales, as appropriate. Consider the following factors: land use, hydrology, geomorphology, and climate. Use Options 1 or 2 or similar performance-based approaches to achieve the desired hydrological goals:

- Option 1: Retain the 95th Percentile Rainfall Event (simplified method)
- Option 2: Conduct site-specific hydrologic analysis

U-3. Use planning and development techniques to direct development to areas where development will

- Have fewer impacts on water quality
- Preserve the integrity of healthy watersheds
- Achieve local objectives for infrastructure management and sustainability

U-4. Use conservation design and LID techniques to

- Minimize the hydrologic impacts of the development and preserve natural drainage ways to the extent feasible
- Integrate green infrastructure (GI)/LID practices into the design and construction of the development, to the extent feasible and preferably at the neighborhood scale

U-5. Examine federal facilities planning guidance, design manuals, and policies (municipalities would examine codes and ordinance, and industry or other facilities would examine corporate policy directives and guidance) for opportunities to revise and update

- Street standards and road design guidelines
- Parking requirements
- Setbacks (requirements for long driveways, and the like)
- Height limitations (encourage density where appropriate)
- Open space or natural resource plans
- Comprehensive plans or facility master plans

U-6. Examine and revise transportation, right-of-way and parking lot policies, guidance, and standards to reduce impervious areas and water resource impacts.

U-7. Minimize directly connected impervious areas in new development, redevelopment, and in retrofits by

- Disconnection of downspouts
- Infiltration of runoff onsite (preferably through bioretention practices)
- Product substitution, e.g., use of permeable paving materials
- Harvest and use of runoff onsite
- Construction of green roofs

U-8. Restore streams, floodways, and riparian areas to mitigate channel erosion and sedimentation and enhance the pollutant removal capacity of these areas.

U-9. Reduce the impacts of existing impervious areas through redevelopment and infill policies and strategies and identify and implement incentives for redevelopment that encourage the use of GI/LID designs and practices

- Retrofit existing urban areas to achieve the desired performance goals
- Assess candidate sites, prioritize, and implement practices based on expected cumulative benefit to the subwatershed or watershed
- Assess retrofit potential of significant runoff sources such as streets, highways, parking lots, and rooftops.
- Develop and implement redevelopment programs that identify opportunities for a range of types and sizes of redevelopment projects to mitigate water resource impacts that
  - Establish appropriate redevelopment stormwater performance standards consistent with the goal of restoring predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection, as determined by the appropriate regulatory authority for the region or site
  - Include development of an inventory of appropriate mitigation practices (e.g., permeable pavement, infiltration practices, green roofs) that will be encouraged or required for implementation at redevelopment sites that are smaller than the applicability threshold
  - Include site assessment to determine appropriate GI/LID practices
  - Review facility planning documents and specifications (as well as any applicable codes and ordinances) and modify as appropriate to allow and encourage GI/LID practices
  - Implement GI/LID demonstration projects
  - Incentivize early adopters of GI/LID practices
  - Maximize urban forest canopy to reduce runoff
  - Conduct soil analyses and amend compacted urban soils to promote infiltration

Reduce Pollutant Concentrations by implementing source control measures and treatment practices as necessary to meet water quality goals

Source Control/Pollution Prevention

Implementation Measures:

U-10. Identify the pollutants of concern (POCs) to help target the selection of pollution prevention/source control that are most appropriate, for example, nutrients and sediment.

U-11. Implement pollution prevention/source control practices, i.e., nonstructural, programmatic efforts as basic, routine land management practices to target specific pollutants.

U-12. Require source controls on

- New and redevelopment site plans for commercial/industrial facilities
- Commercial/industrial facilities through development of a
  - Stormwater Pollution Prevention Plan (SWPPP) where required for regulated industrial categories
  - Similar stormwater pollution prevention plans that might be required by local authorities
- Municipal facilities or other designated Municipal Separate Storm Sewer System (MS4s) permittees through development of Pollution Prevention/Good Housekeeping programs such as the Stormwater Phase II Minimum Control Measures.

U-13. Develop and implement ongoing outreach programs aimed at behavior change to prevent pollution and control it at its source. Methods for impact and effectiveness evaluation should be incorporated into these outreach and education programs.

U-14. Implement programs for disconnection of directly connected impervious areas, such as residential downspout disconnection programs.

U-15. Conduct inspections of commercial/industrial facilities to provide compliance assistance or to ensure implementation of controls.

Runoff Treatment

Implementation Measures:

U-16. Identify the POCs to help target the type of treatment approaches that are most appropriate.

U-17. Select treatment practices based on applicability to the POCs

- Use practices to reduce runoff volume as the preferred and most reliable approach to reducing pollutant loading to receiving waters
- Use treatment practices as needed if reduction of runoff is not feasible
- Base the selection of treatment practice on
  - Treatment effectiveness for the POC to ensure discharge quality
  - Long-term maintenance considerations to ensure continued adequate maintenance and recognition of life-cycle costs
  - Site limitations to ensure appropriateness of practice to the site
  - Aesthetics and safety to ensure public acceptance

Turf Management Implementation Measures

Implementation Measures:

Turf Landscape Planning and Design

U-18. Where turf use is *essential* and appropriate, turf areas should be designed to maintain or restore the natural hydrologic functions of the site and promote sheet flow, disconnection of impervious areas, infiltration, and evapotranspiration.

Turf Management

U-19. Use management approaches and practices to reduce runoff of pollutant loadings into surface and ground waters.

U-20. Manage turf to reduce runoff by increasing the infiltrative and water retention capacity of the landscape to appropriate levels to prevent pollutant discharges and erosion.

U-21. Manage applications of nutrients to minimize runoff of nutrients into surface and ground waters and to promote healthy turf

- Where appropriate, consider modifications to operations, procedures, contract specifications and other relevant purchasing orders, and facility management guidance to reduce or eliminate the use of fertilizers containing P

U-22. Manage turf and other vegetated areas to maximize sediment and nutrient retention.

U-23. Reduce total turf area that is maintained under high input management programs that is not essential for heavy use situations, e.g., sports fields and heavily trafficked areas.

U-24. Convert *nonessential*, high-input turf to low-input or lower maintenance turf or vegetated areas that require little or no inputs and provide equal or improved protection of water quality.

U-25. Use turf species that reduce the need for chemical maintenance and watering, and encourage infiltration through deep root development.

U-26. Conduct a facility or municipal wide assessment of the landscaped area within the facility property or jurisdiction. This assessment should include

- A map of the jurisdiction or facility, including the identification of all turf and other landscape areas
- An inventory or calculation of the total turf and other landscape area in acres or hectares using GIS techniques or other methods
- An evaluation to determine essential and nonessential turf areas
- Identification and delineation of all high-input, low-input, and no-input turf areas
- An evaluation of turf management activities and inputs, preferably by turf category or significant turf area within the facility or jurisdiction
- An assessment of landscape cover type benefits such as pollution load reductions and resource savings, e.g., water and energy that are provided by each landscape cover type
- An assessment of landscape cover type health, infiltrative and pollutant loading capacity and opportunities to increase soil health to promote the infiltrative capacity of turf and landscape areas
- An assessment of surface water and groundwater loadings related to high-input, low-input, and no-input turf area

U-27. Develop a management plan that contains

- An analysis of options to reduce or eliminate *nonessential* turf or convert *essential* turf to low-input turf that performs optimally from a water resource protection perspective
- An analysis of turf areas to identify opportunities to maximize water quality benefits of landscapes in regard to runoff, in-stream flows, infiltration, groundwater recharge and sediment, nutrient and pathogen loadings
- A landscaping approach that integrates turf management within the context of natural resource and habitat plans
- Stated goals and objectives regarding the reduction of turf related inputs (water, fertilizers, pesticides, fossil fuels) and maximizing water resource benefits on a facility- or municipality-wide basis
- An analysis of options to reduce potable water use by using cultural practices, hardy cultivars, or recycled water or harvested runoff
- An identification of areas where soil amendments can be used to enhance soil health and the infiltration capacity of the soils
- Areas of turf that could be used to manage runoff
- Areas of turf that could be replaced by lower maintenance cultivars or other grasses such as switch grass
- A training program for landscaping personnel
- An implementation schedule
- An annual landscaping inventory and progress report

U-28. Develop and implement ongoing public education and outreach programs Bay-friendly lawn, landscape, and turf management. Programs should target behavior change and promote the adoption of water quality friendly practices by increasing awareness, promoting appropriate behaviors and actions, providing training and incentives. Impact and effectiveness evaluation should be incorporated into such outreach and education programs.

2 Implementation Measures for Reducing Urban Runoff Volume

The shortcomings of traditional, detention-based stormwater control efforts, and the need to use approaches to reduce runoff volume to protect water quality, have been well-documented (NRC 2008; USEPA 2009).

This section presents an approach of land use and growth management measures that guide development to areas that minimize effects on sensitive resources and open space, and ensure that new and redevelopment sites are designed to reduce runoff volume through on-site stormwater retention.

Development or redevelopment projects with a footprint that exceeds 5,000 square feet should use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the watershed and site with regard to the temperature, rate, volume, and duration of flow. (Note: Based on the approach adopted by Congress for federal facilities in Section 438 of the Energy Independence and Security Act, 2007)

Implementation Measures:

U-1. Maximize infiltration, evapotranspiration, and harvest and use practices on-site, to the maximum extent technically feasible. Examples of these practices include

- Bioretention cells or raingardens
- Green streets, right of way and parking lot designs and retrofits
- Cisterns and interior and exterior use of runoff
- Green roofs
- Tree planting and urban forestry
- Soil amendments and turf management

U-2. Implement policies to preserve or restore predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection. Implement at the regional, watershed, and site scales, as appropriate. Consider the following factors: land use, hydrology, geomorphology, and climate. Use

Options 1 or 2 or similar performance-based approaches to achieve the desired hydrological goals:

- Option 1: Retain the 95th Percentile Rainfall Event (simplified method)
- Option 2: Conduct site-specific hydrologic analysis

U-3. Use planning and development techniques to direct development to areas where development will

- Have fewer impacts on water quality
- Preserve the integrity of healthy watersheds
- Achieve local objectives for infrastructure management and sustainability

U-4. Use conservation design and LID techniques to

- Minimize the hydrologic impacts of the development and preserve natural drainageways to the extent feasible
- Integrate green infrastructure (GI) LID practices into the design and construction of the development, to the extent feasible and preferably at the neighborhood scale

U-5. Examine federal facilities planning guidance, design manuals, and policies (municipalities would examine codes and ordinance, and industry or other facilities would examine corporate policy directives and guidance) for opportunities to revise and update

- Street standards and road design guidelines
- Parking requirements
- Setbacks (requirements for long driveways, etc.)
- Height limitations (encourage density where appropriate)
- Open space or natural resource plans
- Comprehensive plans or facility master plans

U-6. Examine and revise transportation, right-of-way, and parking lot policies, guidance and standards to reduce impervious areas and water resource impacts.

U-7. Minimize directly connected impervious areas in new development, redevelopment, and retrofit by

- Disconnection of downspouts
- Infiltration of runoff onsite (preferably through bioretention practices)
- Product substitution, e.g., use of permeable paving materials
- Harvest and use of runoff onsite
- Construction of green roofs

U-8. Restore streams, floodways, and riparian areas to mitigate channel erosion and sedimentation and enhance the pollutant removal capacity of these areas.

U-9. Reduce the impacts of existing impervious areas through redevelopment and infill policies and strategies and identify and implement incentives for redevelopment that encourage the use of GI/LID designs and practices.

- Retrofit existing urban areas to achieve the desired performance goals
- Assess candidate sites, prioritize, and implement practices based on expected cumulative benefit to the subwatershed or watershed
- Assess retrofit potential of significant runoff sources such as streets, highways, parking lots, and rooftops
- Develop and implement redevelopment programs that identify opportunities for a range of types and sizes of redevelopment projects to mitigate water resource impacts that
  - Establish appropriate redevelopment stormwater performance standards consistent with the goal of restoring predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection, as determined by the appropriate regulatory authority for the region or site
  - Include development of an inventory of appropriate mitigation practices (e.g. permeable pavement, infiltration practices, green roofs) that will be encouraged or required for implementation at redevelopment sites that are smaller than the applicability threshold
  - Include site assessment to determine appropriate GI/LID practices
  - Review facility plans and specifications (as well as any applicable codes and ordinances) and modify as appropriate to allow and encourage GI/LID practices

- Implement GI/LID demonstration projects
- Incentivize early adopters of GI/LID practices
- Maximize urban forest canopy to reduce runoff
- Conduct soil analyses and amend compacted urban soils to promote infiltration

2.1 Maximize Infiltration, Evapotranspiration, and Harvest and Use

Restoring or maintaining predevelopment hydrology has emerged as the generally preferred approach for controlling urban runoff and protecting water quality for several reasons. Most importantly, this approach addresses the root cause of impairment. Traditional control approaches attempt to control the symptoms (e.g., peak flow, excess pollutants), but that is largely ineffectual in protecting streams and water quality because of the scale of the problem, the cumulative effects of multiple developments, and the need to manage both site- and watershed-level effects. The problems associated with traditional control approaches in protecting water quality are presented in the Introduction to this chapter. This section presents the approaches for obtaining the goal of restoring or maintaining predevelopment hydrology.

To maintain or restore site or watershed hydrology, the watershed should function hydrologically after development as it did before human induced land alterations. In the Chesapeake Bay, most areas before development were forested with mature trees, and the bulk of the rainfall was intercepted, infiltrated, or evapotranspired.

To mimic the natural behavior of the landscape, the stormwater management system should be designed to manage runoff through the following:

- Infiltration and groundwater recharge
- Evapotranspiration
- Harvest rainfall and use of captured rainfall on-site

On sites where inadequate area or the intended use of the development precludes managing the desired volume on-site, off-site mitigation should be considered within the same subwatershed.

2.2 Implement Policies to Preserve and Restore Predevelopment Hydrology

This guidance provides two options that site designers can use to establish appropriate performance goals to maintaining or restoring predevelopment hydrology; however, note that in many situations, it might be feasible and beneficial to have no runoff from a site. The discussion of the two options does not preclude the use of more protective performance goals. Option 1, the methodology based on retention of the 95th percentile rainfall event, is a simple way to establish the performance goal and does not require detailed analysis of the site conditions or a continuous simulation modeling approach. It is assumed that using that performance standard will generally result in designs that protect or restore site hydrology. However, there could be situations where Option 1 (retaining the 95th percentile rainfall event) is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams) or is overprotective (in the case of naturally impermeable surfaces). In such cases, Option 2 (site-specific hydrologic analysis) could be used to determine the performance design objective necessary to preserve predevelopment runoff conditions. The expectation is that Option 2 can be used in situations where the designer has the requisite data and resources to analyze site infiltration, evapotranspiration, interception, and potential harvest and use scenarios to establish these design objectives and to design the runoff management system to meet the goals of maintaining and restoring site hydrology. More detailed descriptions of the two options follow.

Option 1: Retain the 95th Percentile Rainfall Event

Under Option 1, managers design, construct, and maintain stormwater management practices that manage rainfall on-site, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the Maximum Extent Technically Feasible (METF). The 95th percentile rainfall event is the event whose precipitation total is greater than or equal to 95 percent of all storm events over a given period of record. For example, to determine what the 95th percentile storm event is in a specific location, all 24-hour storms that have recorded values over a 30-year period would be tabulated, and a 95th percentile storm would be determined from that record, i.e., 5 percent of the storms would be greater than the number determined to be the 95th percentile storm. Thus the 95th percentile storm would be represented by a number such as 1.5 inches, and that would be the design storm. The designer selects a system of practices, to the METF, that infiltrate, evapotranspire, or harvest and reuse that volume multiplied by the total area of the facility/project footprint. Methods and data used to estimate the 95th percentile event are discussed in Appendix 2 of this chapter.

For the purposes of this document, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the predevelopment hydrology with respect to the volume, flow rate, duration, and temperature of the runoff for most sites.

Where technically feasible, the goal of Option 1 is that 100 percent of the volume of water from storms less than or equal to the 95th percentile event over the footprint of the project should not be discharged to surface waters. In some cases, runoff can be harvested and used and ultimately can be discharged to surface waters or a sanitary treatment system; such direct or indirect discharges must be authorized. For example if runoff is captured for nonpotable uses such as toilet flushing or other uses that are not irrigation related, the waters could be discharged into the sanitary sewer system or other appropriate system depending on local requirements.

Runoff volumes that exceed the 95th percentile event can be managed by using overflow or diversion strategies and practices as well as the detention practices used for flood control.

Designers should also account for potential thermal effects of structures such as roofs and paved surfaces that can increase the temperature of stormwater runoff. Designers should select materials that minimize temperature increases (consider material such as concrete versus asphalt; vegetated roofs, and the like and use them as appropriate).

Rationale for Selecting Option 1. Retention of 100 percent of all rainfall events equal to or less than the 95th percentile rainfall event was estimated to be a representation of the natural hydrology on most sites as a default value. On most sites, little or no runoff occurs from small, frequently occurring storms, and such storms account for a large proportion of the annual precipitation volume. When development occurs, the hydrologic balance of the site is disturbed and as a result runoff occurs from both small and large storms. There is an increase in the number of runoff events, and an increase in the runoff volume, duration, rate, and temperature. Receiving water degradation and habitat loss occur from this changed hydrologic regime.

Table 3-2. Example 95th percentile storm events or select U.S. cities

City	95th percentile event rainfall total (in)
Baltimore, MD	1.6
Binghamton, NY	1.2
Charleston, WV	1.2
Elmira, NY	1.2
Harrisburg, PA	1.4
Lynchburg, VA	1.5
Norfolk, VA	1.7
Richmond, VA	1.7
Salisbury, MD	1.7
Washington, DC	1.5
Williamsburg, VA	1.4

Source: Adapted from Hirschman and Kosco 2008

Table 3-2 contains representative 95th percentile storm event volumes in inches from selected cities in the Chesapeake Bay watershed. Figure 3-10 contains a plot representing storm event frequency for Washington, DC. In Figure 3-10, the 95th percentile storm event has been identified and is approximately 1.5 inches.

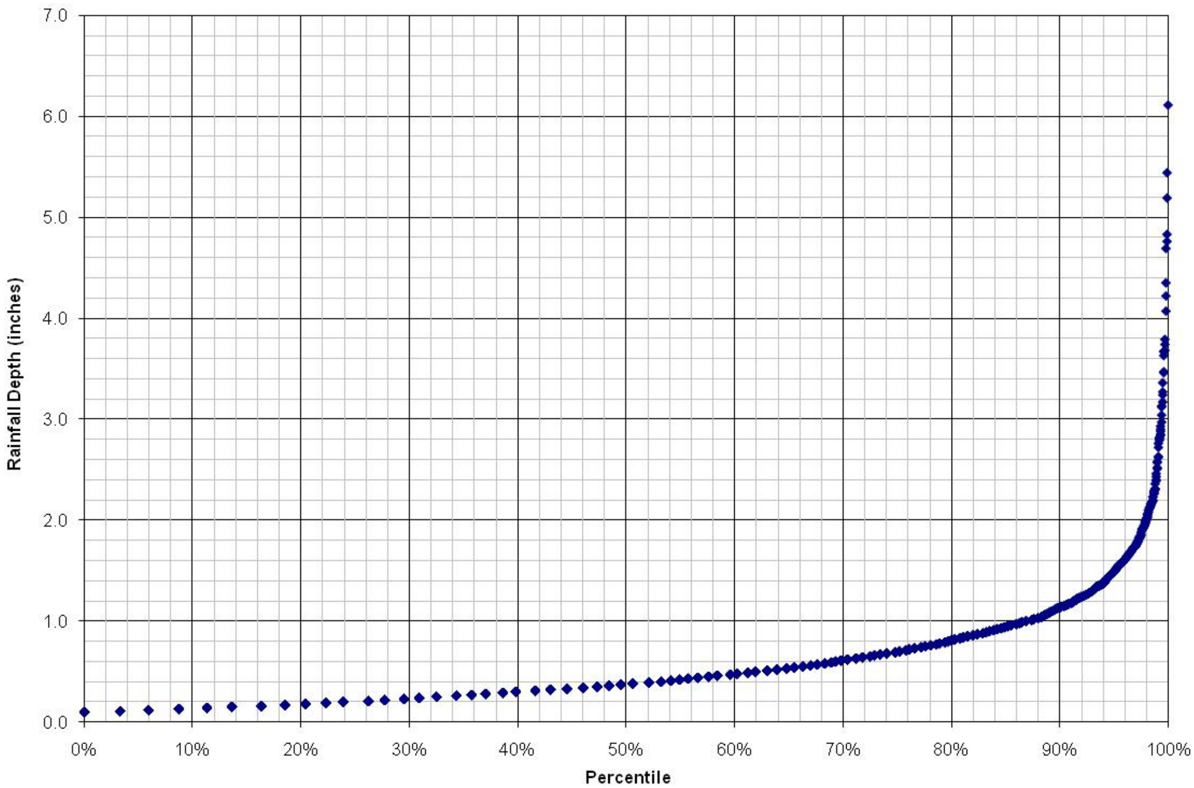


Figure 3-10. Rainfall frequency spectrum showing the 95th percentile rainfall event for Washington, DC (Reagan National Airport ~1.5 inches).

Calculating the 95th Percentile Rainfall Event

This chapter's Appendix 3 contains information on how to calculate the 95th percentile rainfall event for a specific area. A long-term record of daily rainfall amounts (such as 30 years) is needed to calculate long-term precipitation values (Chang 1977; Boughton 2005). When selecting the length of record to use, consider the potential effects of climate change in the region—for example, has the rainfall pattern changed over the past few decades, and if so, should a safety factor be included in case the trend continues?

Designers opting to use Option 1 would need to do the following:

1. Calculate or verify the precipitation amount from the 95th percentile storm event (that number would be typically expressed in inches, e.g., 1.5 inches)

2. Employ on-site stormwater management controls to the METF that infiltrate, evapotranspire, or harvest and use the appropriate design volume

- The 95^{th} percentile event can be calculated by using the following procedures below (summarized from Hirschman and Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program,* Center for Watershed Protection): Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at www.nesdis.noaa.gov

- Remove from the data set all data for small rainfall events that are 0.1 inch or less and snowfall events that do not immediately melt. Such events should be deleted because they do not typically cause runoff and could cause the analyses of the 95^{th} percentile storm runoff volume to be inaccurate.

- Use a spreadsheet or simple statistical package to sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number / total number of events). For example, if there were 1,000 rainfall events and the highest rainfall event was a 4-inch event, 999 events are less than the 4-inch rainfall event (or a percentile of 999 / 1,000, or 99.9 percent).

- Use the rainfall event at 95 percent as the 95^{th} percentile storm event.

Option 2: Site-Specific Hydrologic Analysis

Under Option 2, the predevelopment hydrology would be determined on the basis of site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools. The designer would then identify the predevelopment condition of the site and quantify that the post-development runoff volume and peak flow discharges are equivalent to predevelopment conditions. The post-construction rate, volume, duration and temperature of runoff should not exceed the predevelopment conditions, and the predevelopment hydrology should be replicated through site design and other appropriate practices to the METF. Additional discussions of appropriate methodologies to use in assessing site hydrology have been included in Appendix 3.

The predevelopment hydrologic condition of the site is the combination of runoff, infiltration, and evapotranspiration rates and volumes that typically existed on the facility site before *development* on a greenfields site (meaning any construction of infrastructure on undeveloped land such as meadows or forests). In practice, determining the predevelopment hydrology of a site can be difficult if no suitable reference site is available. As a result, reference conditions for typical land cover types in the locality often are used to approximate what fraction of the precipitation ran off, soaked into the ground, or was evaporated from the landscape. Using reference conditions can be problematic if suitable data are not available or unique site conditions exist that do not fit within a typical land use cover type for the area, e.g., meadow or forest. The intent is not to restore the site to pre-Columbian conditions but to develop or redevelop the site to ensure that a stable hydrologic regime is in place to protect groundwater, surface water, and receiving stream channel stability.

For redevelopment sites, existing site conditions and uses of the site can influence the amount of runoff that can be managed on-site through infiltration, evapotranspiration, and harvest and use and, thus, affect the achievement of the performance design objective. In the context of some redevelopment projects, fully restoring predevelopment hydrology can be difficult to achieve. In such cases, EPA recommends using a systematic analysis to determine what practices can be implemented. The *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act,* EPA 841-B-09-001 (USEPA 2009e), (http://www.epa.gov/owow/nps/lid/section438) provides methodology for federal facilities in determining METF. Examples of conditions that could prevent a fully restored predevelopment hydrology are a combination of the following:

- The presence of shallow bedrock; contaminated soils, near-surface groundwater; or other factors such as underground facilities or utilities.
- The design of the site precludes the use of soil amendments, plantings of vegetation or other designs that can be used to infiltrate and evapotranspirate runoff.
- Water harvesting and reuse are not practical or possible because the volume of water used for irrigation, toilet flushing, industrial make-up water, wash-waters, and the like, is not significant enough to warrant designing and using water harvesting and reuse systems.
- Modifications to an existing building to manage stormwater are not feasible because of structural or plumbing constraints or other factors as identified by the facility owner/operator.
- Small project sites where the lot is too small to accommodate infiltration practices adequately sized to infiltrate the volume of runoff from impervious surfaces.
- Soils that cannot be sufficiently amended to provide for the requisite infiltration rates.
- Situations where site use is inconsistent with the capture and reuse of stormwater or other physical conditions on-site that preclude the use of plants for evapotranspiration or bioinfiltration.

- Retention or use of stormwater on-site or discharge of stormwater on-site via infiltration has a significant adverse effect on the site or the downgradient water balance of surface waters, groundwaters or receiving watershed ecological processes.
- State and local requirements or permit requirements that prohibit water collection or make it technically infeasible to use certain green infrastructure/LID techniques.
- Retention or use of stormwater on the site would cause an adverse water balance to either or both the receiving surface waterbody or groundwater.

In cases where a technical infeasibility exists that precludes full implementation of the performance design goal, the facility should still use stormwater practices to infiltrate, evapotranspire, or harvest and use on-site the maximum amount of stormwater technically feasible.

2.3 Land Use Planning and Development Techniques to Direct Development

2.3.1 Impacts of Land Use on Hydrology and Geomorphology

An evaluation of the land use and hydrology/geomorphology of a watershed or site is an important first step in designing to maintain or restore predevelopment hydrology and mitigate pollutant loading.

One of the key strategies to reduce runoff is to change the pattern of land development to one that is less destructive to water quality. Land use is the largest driver of changes in stormwater runoff, and developed and urbanized lands contribute the largest volumes of increased runoff. The progression of development has led to the increased urbanization of the population. The urbanization of land, however, has outpaced the urbanization of the population, indicative of *sprawl*-type development. That trend has been witnessed nationally, and with the population of the Chesapeake Bay area expected to continue to increase it will place more development pressure on the watershed (National Research Council 2008; Beck et al. 2003).

Such urbanization patterns have significant effects on land use as the predeveloped conditions of forests, meadows, and agricultural lands are replaced by hardened landscapes. Impervious surfaces, such as roads and roofs are the main land cover in urban areas and have a significant impact on stormwater quality. For example,

- Roads and parking lots are as much as 70 percent of total impervious cover in ultra-urban areas (National Research Council 2008)

- Roads tend to capture and export more stormwater pollutants than other land covers in highly impervious areas, especially for small rainfall events (National Research Council 2008)

Even urban land cover that is not hardscape does not infiltrate rainfall as it would before development. Urban soils have much higher bulk density (the mass of dry soil divided by its volume, which serves as a predictor of porosity) than undisturbed soils because of soil compaction typical of construction practices and urban uses. As shown in Table 3-3, the bulk density of urban soils is closer to concrete than to undisturbed soils. The ability of soils with such levels of compaction to infiltrate and retain stormwater is greatly diminished and results in greater quantities of runoff. The lack of an absorptive humus layer, and active soil biota, can also play a role in reducing infiltration rates.

As a result of such compaction, the runoff from urban soils often resembles that of impervious surfaces, especially for larger storm events.

Table 3-3. Bulk density of urban soils is closer to concrete than to undisturbed soils

Material	Bulk density (grams per cubic centimeter)
Undisturbed Soil	1.1 to 1.4
Urban Lawn	1.5 to 1.9
Fill Soil	1.8 to 2.0
Soil Adjacent to Buildings and Roadways	1.5 to 2.1
Concrete	2.2

Source: Schueler and Holland 2000

An understanding of such effects is essential to effectively mitigate them. Watershed and site assessments enable a better understanding of the factors contributing to hydromodification, so that appropriate mitigation techniques can be selected. The site assessment process should evaluate the hydrology, topography, soils, vegetation, and water features (i.e., wetlands, riparian areas, and floodplains) to identify how stormwater moves through the site before development. Additional information on the site assessment process is provided in Section 3 of this chapter.

In addition, to protect stream channels from increased erosion, it is necessary to control the total time—the duration—stream channels are subject to geomorphically significant flows. The flows can result in channel erosion caused by the additional energy imparted to the stream channel by the increases in runoff velocities and volumes. The extended high flows typically lead to stream channel destabilization because the stream did not evolve under those conditions and lacks the capacity to dissipate this increased energy without scouring the stream bed. In response, both the channel and banks are incised, creating increased sediment transport. Those problems are aggravated as the flow travels downstream, with other altered watersheds contributing their increased volumes.

The traditional stormwater management approach was based primarily on flood protection and often focused on not exceeding a predevelopment flow rate, but it did not take into account additional volume. When there is greater volume to be discharged, the duration of the peak flow rate is longer than under predevelopment condition. When multiple discharges of this type enter a receiving stream, the flow peaks that once were sequential become additive, creating much higher peak flows in the stream than existed in predevelopment conditions. The relationships between hydrologic and geomorphic changes and biological parameters can be analyzed using protocols such as that laid out in WERF's *Protocols for Studying Wet Weather Impacts and Urbanization Patterns* (WERF 2008a).

2.3.2 Appropriate Designs as Part of a Comprehensive Watershed Plan

This section contains an overview of example strategies, policies, and practices that land managers on different scales (federal, state, local) have used to reduce the effects of development and redevelopment on receiving water hydrology. The strategies and approaches used to achieve a community's hydrologic stormwater goals will depend on the scale at which the approach is to be applied—regional, local jurisdiction, watershed, subdivision/facility campus, or building lot. Issues and potential tools for different scales of implementation are provided in Table 3-4.

Such strategies should be included as part of a comprehensive watershed plan to protect the resources in the watershed and downstream. Development approaches should be viewed across a watershed or region, down to the local scale, to help achieve communities' desired goals for water resources while avoiding unintended consequences, such as flooding or inadequate base stream flow. Comprehensive planning is an effective nonstructural tool to reduce the amount of impervious surface in a watershed and to guide future development in a manner that best protects water quality.

Water management planning is just one component of watershed planning for restoring ecosystem function. For example, the importance of maintaining natural daylight/nighttime conditions for the propagation of many species has recently become recognized and integrated into facility planning (General Services Administration 2005) (P-100-2005-2.12 Landscape Lighting, http://docs.darksky.org/Codes/SimpleGuidelines.pdf). Comprehensive watershed planning should ideally encompass a holistic approach to sustainability.

Table 3-4. Strategies and tools for implementing stormwater protection goals at different scales

Scale	Example strategies at different scales	Example programs and initiatives
National	Water Environment Research Foundation	*Using Rainwater to Grow Livable Communities Sustainable Stormwater Best Management Practices (BMPs),* Case studies of LID program development in cities nationwide, tools and resources targeted to specific user groups.
	National Association of Regional Councils	Promotes information exchange to help regional organizations achieve goals.
	EPA's *Green Infrastructure* and *LID* websites, U.S. Department of Defense LID Policy	Provide national-level guidance
	NFIP under the FEMA	*NFIP and the Endangered Species Act: Implementing a salmon friendly program by developing a reasonable and prudent alternative;* Program to prepare guidance for use in developing flood-risk areas <http://www.fema.gov/about/regions/regionx/nfipesa.shtm>
Regional	Regional Commissions facilitate cooperation (such as similar ordinances for development equity) and leverage funds for outreach, etc.	Northern Virginia Regional Commission: Example program www.onlyrain.org. Washington Metropolitan Council of Governments: Example Symposium—Innovative Stormwater Controls on Roads & Highways, November 2009
	Interstate, multijurisdictional partnerships	Chesapeake Bay Program: state, federal, academic and nonprofit partnership. www.chesapeakebay.net/partnerorganizations.aspx
	Public-Private Partnerships (any scale)	The Healthy Lawn and Clean Water Initiative, Chesapeake Bay Executive Council and the fertilizer industry agree on voluntary P reductions in fertilizer http://archive.chesapeakebay.net/pubs/Lawn_Care_MOU.pdf *The Growing Home Campaign.* Provides incentives for homeowners to increase urban canopy with cost shared by landscape industry. www.baltimorecountymd.gov/Agencies/environment/growinghome
	University-Public-Private Partnerships	Designing and monitoring pilot or demonstration facilities. Outreach with university and extension programs. Stormwater programs at Villanova, University of Maryland, and North Carolina State University working together in partnership Connecticut's NEMO (Nonpoint Education for Municipal Officials) Program and Center for Land Use Education and Research (CLEAR), http://nemo.uconn.edu

Table 3-4. Strategies and tools for implementing stormwater protection goals at different scales *(continued)*

Scale	Example strategies at different scales	Example programs and initiatives
Local Jurisdiction	Ordinances that allow LID, fees to enable programs, fines, technical assistance	D.C.'s Impervious Area Fee Spotsylvania, Virginia, Ordinance Lycoming County, Pennsylvania (Draft), prepared under PA Act 167
	Smart Growth policies	Baltimore County, Maryland, designates land management areas; www.baltimorecountymd.gov/Agencies/planning/masterplanning/smartgrowth.html%20 The *Philadelphia Green* program revitalizes and maintain abandoned land and public spaces by partnering with government, businesses, and the community
	Green Street policies	The Port Towns' (Maryland) 2010 Legislative Priorities include *Fund at least one Green Street in each of the Port Towns.* http://porttowns.org
Watershed	Pollutant trading[a,b]	Region states are evaluating programs.[c] EPA Region 3 is evaluating the use of urban stormwater trading for the Chesapeake Bay. Virginia Soil and Water Conservation Board Guidance Document on Stormwater Nonpoint Nutrient Offsets, Approved July 23, 2009. http://townhall.virginia.gov/L/GDocs.cfm
	Use watershed-scale hydraulic and pollutant models to optimize control type and location	Models such as BMP-DSS (BMP Decision Support System) have been used in Maryland as planning tools
	Inter-jurisdictional cooperation for purposes of load management and TMDL application	Chesapeake Bay Program
	Local Watershed Groups where Volunteers lead projects	EPA's *Watershed Central* provides blog and information: http://wiki.epa.gov/watershed/index.php Anne Arundel County, Maryland Master Watershed Stewards Academy
	Fee-in-lieu or off-site mitigation when compliance on-site is not feasible	Washington, DC, Proposed Off-Site Stormwater Mitigation Fee
	Total Maximum Daily Load (TMDL) provides framework for prioritizing efforts	Restoring the Legendary Lynnhaven Oysters: *Coordinated Actions Lower Bacteria Levels and Reopen Shellfish Areas in the Lynnhaven River Watershed,* www.epa.gov/owow/TMDL/tmdlsatwork/pdf/lynnhaven_river_sound_byte.pdf; and www.epa.gov/owow/nps/Success319/state/va_3bays.htm

Table 3-4. Strategies and tools for implementing stormwater protection goals at different scales *(continued)*

Scale	Example strategies at different scales	Example programs and initiatives
Facility campus or subdivision	Smart Growth, Conservation Development	Downtown Silver Spring, Maryland Sussex County, Delaware Arlington, Virginia's MetroRail Corridor Lancaster County, Pennsylvania
	General Service Administration P-100 Guidance	U.S. Navy Police and Security Operations Facility, Norfolk, VA. *High Performance Federal Building Database,* http://femp.buildinggreen.com/
Building Lot	LID Practices	Design guides for LID prepared by federal, state, and, local entities

Notes

a. Lal, H. 2008. *Nutrient Credit Trading: A Market-based Approach for Improving Water Quality* NTSC/NRCS/USDA; www.wsi.nrcs.usda.gov/products/w2q/mkt_based/docs/nitrogen_credit_trading.pdf

b. USEPA. 2003b. *Fact Sheet: Water Quality Trading Policy*. www.epa.gov/owow/watershed/trading/2003factsheet.pdf; and USEPA 2003b. *Water Quality Trading Policy*, www.epa.gov/owow/watershed/trading/finalpolicy2003.pdf

c. Chesapeake Bay Foundation. No Date. *Facts about Nutrient Trading from the Chesapeake Bay Foundation,* www.cbf.org/Document.Doc?id=141

A watershed approach is a flexible framework for managing water resource quality and quantity within specified drainage areas, or watersheds. A watershed plan is a strategy that provides assessment and management information for a geographically defined watershed, including the analyses, actions, participants, and resources related to developing and implementing the plan. Typical steps in watershed plan development include the following:

- Characterize existing conditions
- Identify and prioritize problems
- Define management objectives and procedures for documenting outcomes compared to objectives
- Develop protection or remediation strategies
- Implement and adapt selected actions as necessary
- Document activities a watershed

The watershed approach includes stakeholder involvement and management actions supported by sound science and appropriate technology. Resources for preparing watershed plans are provided in Table 3-5.

The strategy selected for protecting and restoring watershed hydrology depends on the existing condition of the landscape: new development strategies have a different focus than retrofit activities in an existing urban landscape. Where redevelopment or infill development occurs, measures and practices to restore the predevelopment hydrology should be used, although a different suite of approaches might be more suitable than those recommended for new development.

Table 3-5. Resources for preparing watershed plans

Reference	Information provided
National Management Measures to Control Nonpoint Source Pollution from Urban Areas. EPA-841-B-05-004. (USEPA 2005).	Provides overview of elements in developing and implementing watershed protection plans
Handbook for Developing Watershed Plans to Restore and Protect our Waters. EPA-841B-08-002. (USEPA 2008d).	Describes processes and tools used to quantify existing pollutant loads, develop estimates of load reductions needed, identify appropriate management measures, and track progress

2.3.3 New Development and Redevelopment Strategies to Minimize Impacts of Development

The objective in new development is preventing additional runoff, pollutant loading, and the corresponding degradation in the watershed. Control measures focus first on the larger scale concepts such as smart growth (for example for overall facility siting), conservation design (for facility campus), and the use of LID practices distributed throughout a site. Many municipal entities have adopted such practices, and the concepts are also appropriate for use in planning and designing federal facilities.

Development Planning Techniques such as Smart Growth

New development creates extensive areas of impervious cover and increased runoff volumes. The developments are necessarily supported by additional roads and other associated infrastructure, compounding the effects. Facilities planners, and communities, should consider the cumulative effect of large-scale development, including the loss of natural areas and degraded streams and rivers.

Decisions about where and how to develop affect water quality perhaps more than any other factor. Preserving and restoring natural landscape features (such as forests, floodplains, and wetlands) is an integral part of green infrastructure. Efficient land use such as redeveloping already degraded sites can also serve to protect ecologically sensitive areas from development. Underused shopping centers or excess parking lot area can be targeted for development cost-effectively when considering that the supporting infrastructure is likely already in place. An example is the Naval Facilities Engineering Command Building 33 (NAVFAC Building 33), where the project's reuse of a brownfield site and reuse of an existing building were its most prominent green features (High Performance Federal Buildings Database, http://femp.buildinggreen.com/overview.cfm?projectid=495).

Development planning techniques such as smart growth should be used to accomplish the multiple goals of sound development with minimum detrimental effects on water quality. Sound principles of both smart growth and water quality protection can be achieved by using these approaches for new development, redevelopment, and retrofit. To achieve the common goals of smart growth and water quality protection, new development should be within or adjacent to existing development when possible.

The increases in local government costs of sprawl development patterns include increased costs for water distribution, sewer collection networks and maintenance, and increased school bus transportation cost. Locating facilities away from core services, and drawing accompanying housing development with it, could contribute to those types of costs. Note that it is difficult to state which growth pattern is ultimately the most challenging financially to a community as population pressures increase (Stephenson et al. 2001).

Examples of guidance for planning development are provided in Table 3-6. While such documents are usually prepared with a focus on municipal planning, the concepts are also applicable in many cases to federal facilities. Those documents also contain information on the water quality benefits provided by the pollution-avoidance strategies.

The Smart Growth Network has established the 10 primary principles of Smart Growth, which are listed in Figure 3-11. Many of these principles indirectly mitigate the impacts of growth on water resources, but the three listed in bold font, in particular, can be used to reduce or avoid the stormwater related impacts of both new development and redevelopment.

While several of the principles of smart growth apply, ones that can be most readily used to reduce the hydrological impacts of development and redevelopment activities are as follows:

- **Conserve Undeveloped Land** to preserve critical environmental areas. This maintains natural riparian buffers, floodplains, natural drainage ways, predevelopment hydrology, and watershed functions. Protecting natural areas such as forests, grasslands, and wetlands, and other open spaces that serve to filter, infiltrate, and evapotranspirate rainfall and snowmelt help maintain the stability of the watershed.

Table 3-6. Existing guidance on municipal smart growth approaches that are also applicable to federal facilities planning

Document	Highlights
Using Smart Growth Techniques as Stormwater Best Management Practices, www.epa.gov/dced/stormwater.htm	Detail policies and techniques that are integral non-structural stormwater practices
Smart Growth for Clean Water: Helping Communities Address the Water Quality Impacts of Sprawl, National Association of Local Governmental Environmental Professionals, Trust for Public Land, ERG www.nalgep.org/publications/PublicationsDetail.cfm?LinkAdvID=42157	Identifies approaches that can improve water quality, profiles successful local partnerships, and identifies barriers and solutions to implement smart growth for clean water programs.
Protecting Water Resources with Higher-Density Development, www.epa.gov/dced/water_density.htm (USEPA 2010c)	Provides research and example scenarios of how higher densities might better protect water quality—especially at the lot and watershed levels.
Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales www.epa.gov/dced/water_scorecard.htm	Provides policy guidance and case studies for protecting open space, promoting infill, designing better streets and parking lots, and adopting site-level green infrastructure practices.
Developing A Sustainable Community: A Guide to Help Connecticut Communities Craft Plans and Regulations that Protect Water Quality http://nemo.uconn.edu/publications/LIDPub.pdf	A guide to help users focus on where LID these practices can be integrated into a development policies.

- **Direct Development to Existing Communities and Infrastructure** to reduce the development of greenfields. This makes use of existing transportation networks, and reduces sprawl and the addition of new impervious surfaces. Redevelopment of existing communities and Brownfields can result in positive water quality impacts and limits the changes in land cover in undeveloped areas that result in stormwater volume increases (for more detail, see the redevelopment section of this chapter).

- **Use Compact Site Design** to reduce the extent of land disturbance, minimize infrastructure requirements to service the community, and reduce the overall impervious footprint (also see Conservation Design below).

- ***Create Range of Housing Opportunities and Choices:*** Providing quality housing for people of all income levels is an integral component in any smart growth strategy.
- ***Create Walkable Neighborhoods:*** Walkable communities are desirable places to live, work, learn, worship, and play and, therefore, are a key component of smart growth.
- ***Encourage Community and Stakeholder Collaboration:*** Growth can create great places to live, work and play—if it responds to a community's own sense of how and where it wants to grow.
- ***Foster Distinctive, Attractive Communities with a Strong Sense of Place:*** Smart growth encourages communities to craft a vision and set standards for development and construction that respond to community values of architectural beauty and distinctiveness, as well as expanded choices in housing and transportation.
- ***Make Development Decisions Predictable, Fair and Cost Effective:*** For a community to be successful in implementing smart growth, the private sector must embrace it.
- ***Mix Land Uses:*** Smart growth supports the integration of mixed land uses into communities as a critical component of achieving better places to live.
- ***Preserve Open Space, Farmland, Natural Beauty and Critical Environmental Areas:*** Open space preservation supports smart growth goals by bolstering local economies, preserving critical environmental areas, improving our communities quality of life, and guiding new growth into existing communities.
- ***Provide a Variety of Transportation Choices:*** Providing people with more choices in housing, shopping, communities, and transportation is a key aim of smart growth.
- ***Strengthen and Direct Development Toward Existing Communities:*** Smart growth directs development toward existing communities already served by infrastructure, seeking to use the resources that existing neighborhoods offer, and conserve open space and irreplaceable natural resources on the urban fringe.
- ***Take Advantage of Compact Building Design:*** Smart growth provides a means for communities to incorporate more compact building design as an alternative to conventional, land-consumptive development.

Source: The Smart Growth Network: www.smartgrowth.org/about/principles/default.asp?res=1024#top

Figure 3-11. The 10 primary principles of smart growth.

2.4 Use Conservation Design and LID Techniques

While planning techniques such as smart growth focus on where to locate development and redevelopment, conservation design techniques promote the best practices to mitigate the impacts of properly sited development. The design goal is to minimize the overall hydrologic modifications by protection of natural areas and ecosystem functions. Whereas watershed planning and smart growth address the *landscape or regional* scale, conservation design and LID practices address the community and site scales. Conservation design methods include the following (City of Portland 2004):

- Fitting development to the terrain to minimize land disturbance
- Confining construction activities to the least area necessary and away from critical areas
- Preserving areas with natural vegetation (especially forested areas) as much as possible
- On sites with a mix of soil types, locating impervious areas over less permeable soil (e.g., till), and trying to restrict development over more porous soils (e.g., outwash)
- Clustering buildings together
- Minimizing impervious areas
- Maintaining and using the natural drainage patterns

Existing guidance on conservation design is provided in Table 3-7.

Table 3-7. Existing guidance on conservation design approaches for municipal planning that also apply to federal facilities

Document	Highlights
Conservation Design for Stormwater Management: A Design Approach To Reduce Stormwater Impacts from Land Development and Achieve Multiple Objectives, Delaware Department of Natural Resources and Environmental Control and The Environmental Management Center of the Brandywine Conservancy, 1997 www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/Delaware_CD_Manual.pdf	Approaches, design procedures, and case studies.
Randall Arendt, Growing Greener: Putting Conservation into Local Plans and Ordinances, National Lands Trust-American Planning Association-American Society of Landscape Architects, 1999.	Evaluates the regulatory and zoning issues for implementing conservation design strategies
Site Planning for Urban Stream Protection, Tom Schueler/ Metropolitan Washington Council of Governments, 1995, www.mwcog.org/store/item.asp?PUBLICATION_ID=56	Reduce pollutants and protect aquatic resources through improved construction site planning.
Center for Watershed Protection www.cwp.org/Resource_Library/Better_Site_Design/index.htm	Library of References

Implementing these methods often requires an evaluation of institutional issues that influence growth and development. Using policies requiring compacting development, conserving open space, and protecting environmental assets is often impeded by facility planning guidance, or for municipalities, zoning requirements (Arendt 1999). When considering using conservation design policies to protect water resources, the issues should be examined both to determine if existing policies are promoting excess impervious area, and to identify impediments that could preclude adoption or implementation of more environmentally sound designs.

GI/LID Practices and the Treatment Train Approach

Many types of LID practices exist, with many variations of each practice. Projects are most successful when practitioners integrate them into a site design and use them in a treatment train approach. In such an approach, the overflow from one practice flows into a second or third practice, such as a green roof followed by a cistern, with the overflow to a planter box with its own overflow and underdrain. Site conditions, applicable performance requirements, and cost typically influence the selection of appropriate LID practices. Table 3-8 lists some of the major types of practices, and a fact sheet or link for each is provided in Appendix 1.

Table 3-8. Typical LID practices

LID BMPs for site plans	
Alternative Turnarounds[a]	Conservation Easements[a]
Development Districts[a]	Eliminating Curbs and Gutters[a]
Green Design Strategies[a]	Infrastructure Planning[a]
Narrower Residential Streets[a]	Open Space Design[a]
Protection of Natural Features[a]	Riparian/Forested Buffer[a]
Street Design and Patterns[a]	Urban Forestry[a,b]
Site-scale LID practices	
Bioretention (Rain Gardens)[a,b]	Rainwater Harvesting[b]
Green Roofs (Eco roofs)[a,b]	Blue Roofs with Water Harvesting[b]
Green Parking[a]	Grassed Swales[a]
Infiltration Trench[a]	Infiltration Basin[a]
Permeable Interlocking Concrete Pavement[a]	Pervious Concrete Pavement[a]
Porous Asphalt Pavement [a]	Vegetated Filter Strip[a]
Soil restoration[b]	Constructed wetlands[b]
Compost Blankets[a]	Infiltration Practices[b]

Notes

a. Fact sheet provided at
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

b. Fact sheet provided in Appendix 1 of this chapter

The performance of LID practices in reducing the annual volume of runoff varies significantly according to the specific design of the practice and the regional climate. Depending on the site design and area rainfall patterns, runoff can be maintained at predevelopment conditions by careful site planning and design. Several design guides have been developed that detail the procedures for site analysis and LID practice sizing. Some of the best design guides for LID are provided in Table 3-9. Additional resources are listed in Appendix 2 and in the fact sheets in Appendix 1.

Table 3-9. Example nationally applicable LID design methods and manuals

Prince George's County, Maryland, *Low-Impact Development Design Strategies: An Integrated Design Approach,* EPA 841-B-00-003, 2000. Prince George's County, Maryland, *Low-Impact Development Hydrologic Analysis,* EPA 841-B-00-002, 2000. www.epa.gov/nps/lid/
USEPA, *Stormwater Best Management Practices Design Guide,* Office of Research and Development, EPA/600/R-04/121, Volumes 1-3 (121, 121A, 121B), September 2004. http://www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm
Center for Watershed Protection *Urban Subwatershed Restoration Manual Series* (http://www.cwp.org/Store/usrm.htm) Center for Watershed Protection *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (http://www.cwp.org/Resource_Library/Center_Docs/SW/pcguidance/Manual/PostConstructionManual.pdf)
U.S. Naval Facilities Engineering Command, *Low Impact Development, Draft, Unified Design Criteria,* UFC 3-210-10, October 2004. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf
U.S. Army Corps of Engineers. *Low Impact Development for Sustainable Installations: Stormwater Design and Planning Guidance for Development within Army Training Areas.* Public Works Technical Bulletin 200-1-62. October 2008.
Geosyntec Consultants and Wright Water Engineers. *Urban Stormwater BMP Performance Monitoring.* 2009. http://www.bmpdatabase.org/MonitoringEval.htm
The Low-Impact Development Center, http://www.lowimpactdevelopment.org/; several LID manuals

Specific to the Chesapeake Bay area, a literature review and assessment of the reported performance of many LID practices was recently conducted for the region to estimate the capability of the practices for volume control and pollutant reduction. The Mid-Atlantic Water Program housed at the University of Maryland reviewed and compiled effectiveness estimates for BMPs implemented and reported by the Chesapeake Bay watershed jurisdictions (*Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay* (Simpson and Weammert 2009) www.chesapeakebay.net/marylandBMP.aspx). The report estimates that the infiltration practices such as bioretention, as designed and with safety factor considerations, could reduce runoff from the first 1–1.5 inches of runoff up to 80 percent, for the purposes of conservatively estimating wide-scale effectiveness in the region. That depth is approximately the 85th to 95th percentile storm event in the region. The report was not meant to evaluate how currently designed practices would perform consistently in the 95th percentile storm event. Practices to achieve retention of the 95th percentile storm event would need to be designed for that specific target performance. Additional information on the findings are provided in Appendix 1 (1.1.1 *Performance Estimate Summaries for Infiltration Practices*) and in the Bioretention fact sheet in Appendix 1.

By using design procedures outlined in the LID manuals such as those in Table 3-9 and in Appendix 2 of this chapter, practices can achieve runoff reduction to restore or maintain predevelopment hydrology.

The effectiveness of conservation design using LID to reducing runoff is demonstrated in subdivision-wide results recently reported. Sources for information on existing LID subdivisions are provided in Table 3-10.

Table 3-10. Sources of information on existing LID subdivisions

Name, location, and reference	Performance summary
Meadow on the Hybelos, 8.27-acres Puget Sound area in Pierce County, Washington. www.sldtonline.com/content/view/344/75	2007 to 2008: LID subdivision designs performed better than design objectives, and exceeded the local requirement that post-development discharge volume not exceed predevelopment discharge volume. The researchers also reported that underdrains significantly impair hydrologic performance (WERF 2009).
Cross Plains, WI; Burnsville, MN; Somerset, MD: Jordon Cove, CT (ASCE/WERF/EPA International Stormwater BMP Database, *Urban Stormwater BMP Performance Monitoring*—Geosyntec Consultants and Wright Water Engineers 2009). www.bmpdatabase.org	Annual runoff reductions from 40% to 90% over the monitoring period were observed, with significantly reduced performance when rain events occurred under already saturated conditions.

2.5 Evaluate Planning Manuals and Guides

LID approaches and practices, smart growth and conservation development strategies can all be promoted by incorporating them into facility planning manuals and guides, similar to municipal codes and ordinances in some cases. Some aspects of existing planning manuals and guides can hinder LID development strategies because of the lack of understanding of the practices that in some cases differ from the traditional stormwater management approaches. For example, existing planning documents might require a curb and gutter that can serve to concentrate flows leading to increased volume of runoff to streams—one potential solution is to either drop the requirements for curb and gutter or state that curb cuts are encouraged to facilitate the use of roadside swale infiltration. Facility planning guides can also prevent naturalized landscaping, stormwater use in toilet flushing, and rain gardens that can have periodic short-term ponding. Resources that federal facility planners, municipal officials, and designers can use to evaluate codes and ordinances for revision to accommodate these approaches are provided in Table 3-11.

Table 3-11. Resources for evaluating codes and ordinances for municipalities that are applicable for use in reviewing federal facility planning manuals, guides, and specifications

Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales, USEPA 2010e, www.epa.gov/dced/water_scorecard.htm	Provides policy guidance and case studies for protecting open space, promoting infill development over Greenfield development, designing better streets and parking lots, and adopting site-level green infrastructure practices.
Out of the Gutter, National Resources Defense Council, July 2002 http://www.nrdc.org/water/pollution/gutter/gutter.pdf	NRDC recommends LID, for Washington, DC, including specific observation and recommendations for revisions to existing codes and ordinances.
A Catalyst for Community Land Use Change, National NEMO Network 2008 Progress Report: http://nemonet.uconn.edu/about_network/publications/2008_report.htm	Examples of local regulations for water quality protection.
Puget Sound Partnership Low Impact Development Local Regulation Assistance www.psp.wa.gov/downloads/LID/PSPSurveyLIDRegulAsistance_23April2010.pdf	Assistance to help local governments integrate LID into their development standards and regulations.
Better Site Design: A Handbook for Changing Development Rules in Your Community, Center for Watershed Protection, 1998 www.cwp.org/Store/bsd.htm	Examples and case studies for changing development regulations to promote better site design, also referred to as environmentally sensitive design or LID.
Plan Review checklist and flow chart, Office of Watersheds, Philadelphia Water Department: http://www.phillyriverinfo.org/WICLibrary/DevelopmentProcess_Final.pdf	Example of how to prioritize stormwater planning early in the overall plan review process for development projects.
Audit of Pavement Standards for the Saluda-Reedy Watershed, Mitigating the Impacts of Impervious Surfaces in Greenville and Pickens Counties, South Carolina, Saluda-Reedy Watershed Consortium c/o Upstate Forever, 2006. www.upstateforever.org	Identifies opportunities for flexibility in street width, parking ratios, sidewalk and driveway, and other aspects of paving.

The following list contains the most common elements of planning design requirements that can cause unnecessary construction of impervious surface areas that have applicability to federal facilities (CWP 1998 *Water Quality Scorecard*; USEPA 2009). Facility planners, similar to communities, should carefully review existing policy mechanisms to determine opportunities to revise to reduce water resource effects that can result from creating impervious surfaces:

- *Density patterns.* Dispersing low-density development across the watershed can negatively affect receiving waters by constructing significantly more impervious surfaces.

- *Street standards or road design guidelines* are used to dictate the width of the road, turning radius, street connectivity, and intersection design requirements. Facility planners should review street and road standards to determine if road designs can be changed to reduce impervious surface cover and still meet transportation and safety requirements.
- *Parking requirements* are generally set to the minimum, not the maximum, number of parking spaces required for retail and office parking.
- *Setbacks* are used to define the required distance between a building and the right-of-way or lot line. Many setback requirements specify the use of long driveways. Establishing maximum setback lines for buildings can reduce the creation of unnecessary impervious surface areas by bringing buildings closer to the street.
- *Height limitations* are used to limit the number of floors in a building. Limiting height can spread development out if square footage is unmet by vertical density.
- *Open space or natural resource plans* are used to identify land parcels that are or will be set aside for recreation, habitat corridors, or preservation. Such plans help communities prioritize their conservation, parks, and recreation goals and protect important areas from development.
- *Comprehensive plans* might be required by state law, and many cities, towns, and counties prepare comprehensive plans to support zoning codes. Federal facilities might have an opportunity to contribute to achieving the region's goals in the plan. Most comprehensive plans include elements that are intended to address land use, open space protection or creation, natural resource protection, transportation, economic development, and housing. These elements are important facets of a comprehensive watershed protection approach. Increasingly, local governments are identifying areas of existing green infrastructure and outlining opportunities to add new green infrastructure throughout the community to protect water resources.

2.6 Evaluate Transportation-Related Standards

Minimize/reduce impervious areas by using techniques such as reduced street widths and parking areas. Many urban and suburban streets are sized to meet code requirements for emergency service vehicles, on-street parking, and free flow of traffic. Such code requirements often result in streets being oversized for their typical everyday functions. The Uniform Fire Code requires that streets have a minimum 20 feet of unobstructed width; a street with parking on both sides would require a width of at least 34 feet. In practice, many suburban and urban streets can be much wider than that as local design practices have increased street widths to 40 and 50 feet. Those designs result in increased runoff and associated pollutant loadings. In sum, the two issues are often (1) planning documents often require excessively wide streets and do not specify a maximum width; and (2) the minimum requirement for widths is often exceeded.

Just decreasing the amount of impervious surface alone might not provide substantial stormwater benefits if the adjacent soils are highly compacted. Combining the reduced street width with the installation of swales or amended soil filter strips, or by using tree pits (even extending under paved sidewalks) to collect stormwater will provide enhanced performance.

Many communities have adopted narrower street width standards while also accommodating emergency vehicles by developing alternative street-parking configurations, designing adequate turnarounds, prohibiting parking near intersections, providing vehicle pullout space, and using smaller block lengths. Examples are provided in Table 3-12. A key to identifying and successfully codifying narrow street widths is coordination among departments, including fire, transportation, and public works.

Table 3-12. Examples of adopted narrow street widths

Jurisdiction	Street width (feet)	Parking condition
Phoenix, AZ	28	parking both sides
Orlando, FL	28 22	parking both sides, res. Lots < 55 feet wide parking both sides, res. Lots > 55 feet wide
Birmingham, MI	26 20	parking both sides parking one side
Howard County, MD	24	parking unregulated
Kirkland, WA	12 20 24 28	alley parking one side parking both sides—low-density only parking both sides
Madison, WI	27 28	parking both sides, <3DU/AC parking both sides, 3-10 DU/AC

ADT: Average Daily Traffic; DU/AC: dwelling units per acre

Source: Adapted from Cohen 2000; CWP 1998.
http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/narrow_streets.htm

The need to accommodate bike lanes and sidewalks adds to the pressure to increase width, making efficient design and incorporating permeable pavements where appropriate, even more important. Holistic design concepts such as *Complete Streets* (www.greenhighwayspartnership.org) describe broader function goals consistent with the focus of environment protection, such as lighting to prevent unnecessary glare and interference with off-road nighttime conditions.

Integrating green streets into overall development and redevelopment projects provides many opportunities for improving environmental and energy performance. For example, the small town of West Union, Iowa, evaluated combining its planned green street retrofit with a separately planned, energy-saving project to convert the central business district to sustainable geothermal energy. By adding pipes to convey excess geothermal energy underneath the planned permeable pavement in the green street, the town estimated it could save money in shoveling and plowing, reduce risk of ice patches, reduce salting costs, and, as a side-benefit, reduce salt runoff to the trout stream in the watershed. Such a project might not be achievable for capital cost reasons in many cases, but the long-term cost savings it provides demonstrates that it is well worth evaluation (http://www.iowalifechanging.com/community/downloads/West-Union-Iowa-Green-Streets-Pilot-Project-Summary.pdf).

Zoning requirements often require that parking be provided for the maximum business day, resulting in unused parking and impervious area for the majority of the year. Reassessing the actual needed parking area can minimize impervious area.

Green street and highway design is necessary to help mitigate the effects of stormwater runoff from those surfaces using roadside infiltration. A proven example of a green street is Seattle’s pilot Street Edge Alternatives Project (SEA Streets), Figure 3-12, completed in 2001. It is an LID design that provides drainage that more closely mimics the natural landscape before development. Seattle Public Utilities accomplished this by reducing impervious surfaces to 11 percent less than a traditional street, by providing surface detention in swales, and adding more than 100 evergreen trees and 1,100 shrubs. Monitoring shows that the design has successfully reduced the volume of stormwater runoff by 99 percent http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/StreetEdgeAlternatives/index.htm.

Resources for additional information on street and highway design for LID are provided in Table 3-13.

Source: from http://courses.washington.edu/gehlstud/Precedent%20Studies/SEA_Street.pdf

Figure 3-12. Seattle SEA Streets

Table 3-13. Resources for information on street and highway design for LID

Document	Highlights
Green Highway Partnership (GHP), with weekly electronic newsletter, http://greenhighwayspartnership.org/	Tracks practices for green highways and green infrastructure, including innovative stormwater management, LID and transportation legislation.
Project 25-20(01): Evaluation of Best Management Practices for Highway Runoff Control, Low Impact Development Highway Manual, National Cooperative Highway Research Program, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_565.pdf	Provides scientific and economic information for selection and design of BMPs to control highway runoff, including BMPs to treat: nutrients, TPH, PAH, metals, pathogens, pesticides, temperature, TSS, trash.
Anacostia Waterfront Transportation Architecture Design Guidelines http://ddot.washingtondc.gov/ddot/cwp/view,a,1249,q,627063,ddotNav_GID,1744,ddotNav,|33960|.asp DDOT. 2005.	Guidelines for transportation design to support the economic and environmental health of the region, incorporating LID design practices.
Portland Green Street Program, Portland, Oregon, Bureau of Environmental Services (BES) www.portlandonline.com/BES/index.cfm?c=44407	Design information, project reports, technical guides, newsletter.
Tabor to the River, Portland BES www.portlandonline.com/bes/index.cfm?c=47591	Comprehensive, 500-street, watershed retrofit program detailed.
Natural Drainage Projects, Seattle, Washington, Seattle Public Utilities (SPU), www.seattle.gov/util/naturalsystems	Design information and details on LID street design and elements, porous pavement specification, project reports.

2.7 Minimize Directly Connected Impervious Areas in New Development, Redevelopment, and Retrofit

Not all impervious areas are created equal. Impervious areas that are directly connected to the storm sewer system convey excess stormwater volumes more rapidly and with greater impact than impervious areas that do not have a direct connection (i.e., are disconnected). The term *effective impervious area* (EIA) is used to describe this concept. EIA is the measure of how much impervious surface is directly connected to the conveyance system. One of the first steps to mitigating the effects of imperviousness is evaluating the opportunities to disconnect it so the rain can be infiltrated, evapotranspired, or harvested and used.

- **Downspout Disconnection.** Downspout disconnection is the process of separating roof downspouts from the sewer system and redirecting roof runoff onto pervious surfaces, most commonly a lawn, or to a stormwater management practices such as a bioretention cell or cistern.

- **Substituting Permeable Pavements for Conventional Pavements.** Using permeable pavements can reduce directly connected impervious area because pervious materials are substituted for impervious materials while maintaining the intended function. Permeable pavements can be used to infiltrate stormwater, making areas that were once a source of stormwater a means of reducing the volume of runoff. Similarly, green roof retrofits reduce the imperviousness of rooftops by using engineered soil media and vegetation to lower the runoff potential.

- **Maximizing Opportunities to Infiltrate, Evapotranspirate, and Harvest and Use.** Disconnect flows using infiltration and evapotranspiration by incorporating bioretention into street designs. Bioretention features can be tree boxes that collect stormwater runoff from the street (similar to conventional tree boxes), planter boxes, curb extensions, or bioswales. To adapt to street configurations, grades, soil conditions, and space availability, a range of shapes, sizes, and layouts can be used. Using existing rights-of-way and using techniques such as curb cuts to facilitate stormwater movement away from directly connected drainageways and into infiltration features are common practices.

Rainwater harvesting has recently become recognized as a stormwater management tool because of its ability to reduce stormwater runoff volumes from impervious surfaces. It also serves as a source substitute for potable water and can enhance water supplies and decrease the cost and impacts of supplying water to urban areas. Collected rainwater is ideal for nonpotable applications, such as landscape irrigation, toilet and urinal flushing, cooling system make-up, and vehicle washing. Such collection and use is a key component of an integrated water resources management approach. Performance of rainwater harvesting systems depends on the volume of water stored and the demand for the stored water.

Rainwater harvesting has been practiced by civilizations for centuries and is now actively used in many countries that experience chronic or seasonal water shortages. In this country, though, rainwater harvesting has been primarily used for flash flooding control, or otherwise managing drainage problems. Now, in states such as Georgia, Virginia, and Texas, government-supported organizations have prepared manuals and guidelines for residential and commercial water harvesting for drought preparedness. For a listing of manuals and other resources, see the fact sheet in Appendix 1. In the Northwest, residential and commercial rainwater harvesting is used for stormwater management. In western cities, rainwater harvesting is becoming more common—Los Angeles County and Tucson, Arizona, for example—but water rights issues could restrict its use in some states.

Design and installation manuals relevant to the Chesapeake Bay area, references to example city ordinances, and other information on rainwater harvesting are provided in the fact sheet in Appendix 1.

2.8 Implement Restoration

2.8.1 Native Landscapes and Urban Tree Canopy

Restoring native landscapes in drainage pattern and in plant selection can be an important component of restoring predevelopment hydrology. Information on native landscaping is available from many state and local governments and sources listed in the Section 5 Turf Management, and in the fact sheets in Appendix 1.

In the Chesapeake Bay watershed, trees constitute a large part of the native landscape and play a major role in the water cycle. That is not the case with other, arid regions, where supporting nonnative forests could strain water resources. In the Chesapeake Bay region, however, significant potential exists to reduce runoff volumes on an annual basis using increased urban tree canopy. Interception in the tree canopy provides some capture in small events, but trees can evapotranspirate significant amounts—up to 200 to 800 gallons per day for some mature tree species (ITRC 2009). Each deciduous tree in the Baltimore area in the 2009 weather pattern evapotranspired approximately the following amounts (during leaf-on period)(personal communication, David Nowak, U.S. Forest Service):

- 2.6 gallons/day for a small tree (1-m radius crown)
- 260 gallons/day for a large tree (10-m radius crown)

For dense urban environments—and where utility conflicts can be managed—new technologies include the following:

- Structures or structural soils that allow root growth under sidewalks and vehicle areas.

- Permeable pavements that enable stormwater to flow to roots while supporting loads.
- Flexible sidewalk material (example: Belleview, Washington, http://www.ci.bellevue.wa.us/rubber_sidewalk.htm.
- Large-diameter soaking hoses or vaults built into tree pits that collect and infiltrate a first portion of runoff for evapotranspiration.

Using those technologies, little or no additional land is consumed in managing stormwater, and some street tree maintenance issues can be better managed.

To estimate the effectiveness of adding urban tree canopy and green roofs at reducing the stormwater runoff volumes in a dense urban environment, Casey Trees and LimnoTech developed the Green Build-out Model to quantify the stormwater benefits of trees and green roofs for different coverage scenarios in Washington, DC (Casey Trees 2007). The model was applied to an *intensive greening* scenario and a *moderate greening* scenario. Nearly all the waters in Washington, DC, are seriously polluted by urban stormwater runoff and the sewage overflows it causes. The Green Build-out Model demonstrates that trees and green roofs—just a portion of the types of infrastructure practices available—can be used to achieve substantial reductions in stormwater runoff and sewage discharges to the rivers. Key findings show for an average year:

- The intensive greening scenario eliminates more than 1.2 billion gallons of stormwater.
- Reductions in stormwater runoff volume of up to 10 percent across the city, with up to 27 percent reductions in individual sewersheds under the most intensive greening scenario.
- The DC Water and Sewer Authority could realize between $1.4 and $5.1 million per year in annual operational savings in the area because of reduced pumping and treatment costs.
- General hydrological relationships, including unit area planning factors, and modeling methodologies that are transferable to other municipalities.

Using trees to help manage stormwater and protect water quality is increasingly accepted by some engineers and land managers as sustainability becomes more important in land design. A statement by the Chesapeake Bay Executive Council in 2006 emphasizes the point:

> Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter, and retain water, as well as air pollution from the air. Forests are also essential to the provision of clean drinking water to over 10 million residents of the watershed and provide valuable ecological services and economic benefits including carbon sequestration, flood control, wildlife habitat, and forest products.

A summary of resources for estimating stormwater management benefits of tree canopy are provided in Table 3-14. Additional information is provided in the Reforestation/Urban Forestry and Bioretention Fact Sheets in Appendix 1.

Table 3-14. Resources for estimating stormwater benefits of tree canopy and vegetation

Citygreen software by American Forests (2010a) www.americanforests.org/productsandpubs/citygreen *Trees Reduce Stormwater* website by American Forests (2010b) www.americanforests.org/graytogreen/stormwater	Analyzes the ecological and economic benefits of tree canopy and other green space.
i-Tree suite of software Tools from USDA Forest Service www.itreetools.org	Tools enable quantification on a per tree basis or on a watershed scale.
Phytotechnology Technical and Regulatory Guidance, The Interstate Technology & Regulatory Council, 2009	Provides guidance on using vegetation for soil remediation, and estimates of transpiration rates.
Casey Trees, Washington, D.C. Green Build-out Model. 2007. www.caseytrees.org/planning/greener-development/gbo/index.php	The Green Build-out Model demonstrated that trees and green roofs can be used to achieve substantial reductions in stormwater runoff and sewage discharges to the rivers.

2.8.2 Streams, Floodways, and Riparian Areas

Using stream and floodplain restoration, managers attempt to restore the ecological and hydrological functions and processes of a stream and its floodplain. The stream corridor is typically considered to consist of the stream channel, riparian zone, and flood plains (level areas near the channel, formed by the stream and flooded during moderate-to-high flow events). Stream corridors are influenced by the cumulative effects of upland and upstream activities and practices, including agricultural production, forestry, recreation, other land uses, or urban development. Specific restoration goals can include flood control, sediment control, improving drainage, stabilizing banks, and improving habitat. Correcting stream damage using stream restoration techniques is a costly undertaking with uncertain rewards; preventing the damage by using the techniques described in this guidance is a more reliable approach.

Restoring impaired waterways—in particular restoring the connection to the stream's floodplain to enable the streambank to overtop and spread excess flows out along the land to reduce velocity and allow for off-channel ponding and infiltration the length of the stream—is important to restoring predevelopment hydrology and reducing loading from larger and scouring flows. Degraded streams can themselves become a source of downstream pollution, such as when P-laden sediments are mobilized during high-flow events. In such cases, stream restoration can be a useful strategy to improve downstream water quality. It is important that the elevated flows causing sediment mobilization must also be addressed. Stream stabilization requires restoration of the stream's energy signature. The predevelopment hydrology of the watershed should be restored to regain the predevelopment character of the stream; however, in existing urban areas, that might be a longer-term goal. In urban areas, restoration by successive steps in the watershed and the stream might be desired.

A summary of existing information of the effects of stream hydromodification on the quality of the Chesapeake Bay is provided in Table 3-15. The studies demonstrate the importance of stream restoration and protection in achieving pollutant reduction in the Chesapeake Bay, particularly for sediment and the P that accompanies sediment loading.

Table 3-15. Studies quantifying the impact of sediment loading stream hydromodification on Chesapeake Bay water quality

Study	Findings
A Summary Report of Sediment Processes in Chesapeake Bay and Watershed, U.S. Geological Survey, Water-Resources Investigations Report 03-4123, 2003	Summarizes the impacts and sources of sediment and notes that sediment yield from urbanized areas can remain high after active construction is complete because of increased stream corridor erosion from altered hydrology
Schueler, T. The Practice of Watershed Protection, Technical Note #119 from *Watershed Protection Techniques 3(3):729–734*, Center for Watershed Protection, 2000.	Stream enlargement, and the resulting transport of excess sediment, is caused by urban development
U.S. Environmental Protection Agency. 2001. *Protecting and Restoring America's Watersheds: Status, Trends, and Initiatives in Watershed Management,* EPA 840-R-00-001. www.epa.gov/owow/protecting/restore725.pdf.	Straightened and channelized streams carry more sediments and other pollutants to their receiving waters. Up to 75% of the transported sediment from the Pocomoke watershed on the Eastern Shore of Maryland was found to be erosion from within the stream corridor
Gellis et al. 2007. *Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management, Chapter 6: Sources and Transport of Sediment in the Watershed.* U.S. Geological Survey Circular 1316.	Sediment sources are throughout the Chesapeake Bay watershed, with more in developed and steep areas
Gellis et al. 2009. *Sources, transport, and storage of sediment in the Chesapeake Bay Watershed.* U.S. Geological Survey Scientific Investigations Report 2008–5186	In the Piedmont region, streambank erosion was a major source of sediment in developed Little Conestoga Creek; 30% of sediment from the Mattawoman Watershed on the Coastal Plain (flat land) is from streambanks
Devereux et al. *Suspended-sediment sources in an urban watershed,* Northeast Branch Anacostia River, Maryland. Hydrological Processes, Accepted 2009.	Streambank erosion was the primary source of sediment in the Northeast Branch Anacostia River

Stream restoration can help to restore the natural ecosystem function of N removal that occurs in streams. Studies that evaluate the N removal ability of restored streams are summarized in Table 3-16.

Table 3-16. Studies evaluating the N removal ability of restored streams in the Chesapeake Bay watershed

Study	Finding
Kaushal et al. *Effects of Stream Restoration on Denitrification in an Urbanizing Watershed.* Ecological Applications 18(3) 2008, pp. 789-804.	Streams with ecological functions intact remove N at a much higher rate than degraded urban streams, and stream restoration practices can restore this N removal function.
Klocker et al. *Nitrogen uptake and denitrification in restored and unrestored streams in urban Maryland,* USA. Aquatic Sciences, Accepted October 2009.	Degraded urban streams, deeply eroded and disconnected from their floodplain, have substantially lower rates of N removal that than streams hydraulically connected to their riparian banks via low slopes. Reconnecting the stream to the floodplain can increase N removal rate.

In addition to the water quality improvements that can be achieved through stream restoration, the flood management community has become increasingly aware of the benefits of restoration in preventing flood damages. The Association of State Floodplain Managers has prepared a white paper called *Natural and Beneficial Floodplain Functions: Floodplain Management—More than Flood Loss Reduction* (www.floods.org), which emphasizes the multiple benefits of protecting and restoring streams and their associated floodplains.

Techniques for stream and floodplain restoration are described in the *Hydromodification* chapter of this document. Example references for stream restoration, and for information on the effects of urban runoff on stream ecosystems, are provided in Table 3-17.

Table 3-17. References on urban stormwater effects on streams with emphasis on restoration and habitat

USDA Natural Resources Conservation Service, *Part 654 Stream Restoration Design National Engineering Handbook,* 210–VI–NEH, August 2007
Federal Interagency Stream Restoration Working Group (FISRWG) (1998*). Stream Corridor Restoration: Principles, Processes, and Practices,* ISBN-0-934213-60-7, Distributed by the National Technical Information Service at 1-800-533-6847.
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Foundation (WERF 2006) Appendix B. Assessment of Existing Watershed Conditions: Effects on Habitat.

2.9 Reduce Impacts of Existing Urban Areas

2.9.1 Retrofits

Many urban areas were developed without any or with few stormwater controls designed to protect water quality and prevent stream channel degradation. This section contains recommendations for practices that can be used in such areas to try to reverse degradation that has already occurred by reducing the volume, rates, and duration of runoff. Specifically, the recommended control measures on existing urban land focus on retrofits to roof downspouts, roads, parking lots, and areas of compacted soils. While the suggestions are focused on stormwater management effectiveness, consideration should also be given to aesthetics when designing, and using a multidisciplined design team (engineer, landscape architect, maintenance staff) can result in more successful retrofits.

An effective retrofit strategy for urbanized areas combines planning techniques such as smart growth and green infrastructure/LID techniques. A comprehensive guide on retrofits for existing urban areas is the Center for Watershed Protection's (CWP's) *Urban Stormwater Retrofit Practices* (CWP 2007).

The CWP's *Urban Stormwater Retrofit Practices* manual focuses on stormwater retrofit practices that can capture and treat stormwater runoff before it is delivered to the stream. The manual describes both off-site storage and on-site retrofit techniques that can be used to remove stormwater pollutants, minimize channel erosion, and help restore stream hydrology. Guidance on choosing the best locations in a subwatershed for retrofitting is provided in a series of 13 profile sheets. The manual then presents a method to assess retrofit potential at the subwatershed level, including methods to conduct a retrofit inventory, assess candidate sites, screen for priority projects, and evaluate their expected cumulative benefit. The manual concludes by offering tips on retrofit design, permitting, construction, and maintenance considerations.

Table 3-18 presents common locations where additional storage and infiltration for stormwater can be provided in a subwatershed and common locations for on-site retrofits.

Table 3-18. Common locations for additional stormwater storage and infiltration and on-site retrofits

Common on-site retrofit locations in a subwatershed	
Where	**How**
Road Rights-of-Way	Direct runoff to a depression or excavated stormwater bioretention/infiltration treatment area within the right-of-way of a road, highway, transport or power line corridor. Prominent examples include highway cloverleaf, median and wide right-of-way areas.
Near Large Parking Lots	Provide stormwater infiltration treatment in open spaces near the downgradient outfall of large parking lots (5 acres plus).
Conveyance Systems	Investigate the upper portions of the existing stormwater conveyance systems (such as ditches) to look for opportunities to improve the performance. That can be done either by creating in-line storage cells (small dams with overflows) that allow infiltration or by splitting flows to off-line infiltration/treatment areas in the drainage corridor.
Hotspot Operations	Install filtering or bioretention treatment to remove pollutants from confirmed or severe stormwater hotspots discovered during field investigation.
Small Parking Lots	Insert stormwater treatment, preferably depressed bioretention or expanded tree boxes, in or on the margins of small parking lots (less than 5 acres). In many cases, the parking lot is delineated into a series of smaller, on-site treatment units.
Individual Streets	Look for opportunities with the street, its right-of-way, cul-de-sacs and traffic calming devices to infiltrate and treat stormwater runoff before it gets into the street storm drain network.
Individual Rooftops	Disconnect downspouts from storm drains, store and use the rainwater, and infiltrate excess stormwater runoff close to the source.
Little Retrofits	Convert or disconnect isolated areas of impervious cover to infiltration and bioretention, and treat excess runoff in an adjacent pervious area using low tech approaches such as a filter strip.
Hardscapes Landscapes	Reconfigure the drainage of high-visibility urban landscapes, plazas, and public spaces to capture and use, infiltrate and evapotranspirate, and treat excess stormwater runoff with landscaping and other urban design features.
Underground	Provide stormwater infiltration or treatment in an underground location when no surface land is available for surface treatment. Use this as a last resort at dense, ultra-urban sites.

Examples of LID road retrofits in the Chesapeake Bay watershed are included in Table 3-19.

Table 3-19. Examples of Maryland LID road retrofits

Site	Reference
Knollbrook Drive and Talbert Lane median and the Ray Road stormdrain outfall in the Takoma Branch subwatershed	*Final Technical Report, Pilot Projects for LID Urban Retrofit Program, In the Anacostia River Watershed, Phase IV,* USEPA: Prince Georges County, Maryland, 2007
U.S. Route 1 and Maryland Route 201 at I-95 (Bioretention)	www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/pdf/Final Technical Report Phase III.pd
Decatur Street Improvement, Edmonston, MD (holistic green street—multiple LID retrofits)	www.lowimpactdevelopment.org/greenstreets/projects.htm; http://edmonston.us.com/GreenStreetGroundbreaking.html
Route 202 Median (Bioretention)	www.co.pg.md.us/Government/AgencyIndex/GoingGreen/pdf/2009-annual-green-report.pdf
Route 201 Median (Bioretention)	www.co.pg.md.us/Government/AgencyIndex/GoingGreen/pdf/2009-annual-green-report.pdf
Peace Cross Green Highway Project—NW Prince George's County, adjacent to the Anacostia River. Network: • Baltimore Avenue • Bladensburg Road • Annapolis Road	www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/pdf/Final%20Technical%20Report_Phase%20III.pdf www.springerlink.com/content/l682122767u41k7x/fulltext.pdf
Route 202/I-495 interchange (Bioretention)	www.co.pg.md.us/Government/AgencyIndex/GoingGreen/pdf/2009-annual-green-report.pdf

2.9.2 Redevelopment

Implementing an effective redevelopment program is essential to restoring water quality, as discussed previously in this document. Section 4 of this chapter provides information on important issues that should be addressed in redevelopment policies and example practices that are appropriate for redevelopment. Figure 3-13 lists the stormwater retrofit and redevelopment programs that several cities have adopted or are piloting using GI/LID approaches. Implementation measures for redevelopment programs include establishing appropriate redevelopment performance standards, creating an inventory of appropriate mitigation practices for a range of project sizes, conducting site assessments as part of practice selection, reviewing planning policies (similar to municipal codes and ordinances), implementing demonstration projects, maximizing forest canopy, and mitigating compacted soils.

Some Municipal Highlights for Retrofit and Redevelopment Approaches and Practices:

Portland, Oregon, Bureau of Environmental Services: *A Sustainable Approach to Stormwater Management,* http://www.portlandonline.com/bes/index.cfm?c=34598

Seattle, Washington, Seattle Public Utilities *Natural Drainage Systems: Green Stormwater Infrastructure*, http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/index.htm

Kansas City, Missouri, *10,000 Raingardens* Program, www/rainkc.com/

Philadelphia, Pennsylvania, *Greenworks Philadelphia,* www.phila.gov/green

EPA's Green Infrastructure Web site: Case Studies of Green Municipalities, http://cfpub.epa.gov/npdes/greeninfrastructure/gicasestudies.cfm#Municipal

Figure 3-13. Municipal stormwater retrofit/redevelopment programs can provide insight to federal facilities for retrofit opportunities.

2.10 Costs of Green Infrastructure/LID Practices

This cost section provides sources for estimates of capital and O&M costs for individual practices and provides information that a policymaker or designer can use to help ensure that the cost savings and other benefits from GI/LID practices are considered during the decision process. This section presents examples from across the country that show how GI/LID practices compare financially to conventional stormwater management approaches.

The examples highlight municipal programs, but the concepts are applicable to cost evaluations on federal facilities.

The information is presented in the following format:

- Key factors in evaluating costs of GI/LID (section 2.10.1)
  - Planning and development processes that have a focus on LID and pollution prevention can help minimize the cost of implementing LID at the site level.
  - Flexibility of LID allows for practices to be integrated cost-effectively.
  - Opportunities for cost savings have been demonstrated and should be incorporated where feasible.
  - Environmental impacts downstream are a real and significant cost to society that should be included in determinations of development costs.

  - Ancillary benefits such as vegetated urban spaces and habitat should be included when assessing the value of stormwater management alternatives.

- Types of cost analysis that can support decision making and examples (section 2.10.2)
  - Capital Cost assessment: Capitol Region Watershed District, Minnesota, and Lenexa, Kansas
  - Life-cycle cost analysis: Portland, Oregon, and Commonwealth of Virginia
  - Cost-effectiveness analysis: Mecklenburg, North Carolina, and New York City
  - Include ancillary benefits in life-cycle cost analysis
    - Local example: Philadelphia, Pennsylvania
    - Regional example: Sun Valley Watershed in Los Angeles
- Costs of individual practices (section 2.10.3)
  - Issues to be considered when evaluating reported costs
  - Sources of cost information

2.10.1 Key factors in evaluating costs of Green Infrastructure/LID

Planning and Development Processes

The most important practices to help ensure minimum cost for protecting water quality are the planning and development processes and their products, i.e., the master planning documents, specifications, municipal codes and ordinances, and other tools that promote development that minimize detrimental effects. Incorporating water quality protection into those processes does not cost more and provides multiple other benefits in addition to water quality. Implementing an LID approach, while site specific in application, can be more cost-effectively achieved when incorporated into an overall development policy. That can facilitate cost-effective designs and improved performance by

- Enabling developers and designers to understand that stormwater requirements are to be addressed in initial concept plans, and that the methods are acceptable to achieve a community's goal (i.e., Spotsylvania County, Virginia, Figure 3-14, and Middlesound, North Carolina, Figure 3-3), to reduce redesigns

The development community in Spotsylvania County has realized cost savings from LID, after initial skepticism. The county lists a few of the many successful LID projects:

- A historical church in a developed area needed to add-on but could not afford land for a basin, so instead used grass-pavers for the parking lot. An underground tank captures and infiltrates rainwater. Originally, a 42” diameter outlet was planned, now a 6” PVC pipe works, with minimal runoff. Used a rain garden before the drainage inlets. ***A 45% savings.***
- Patriot Park—This development had no outlet as a result of 1930’s development design. Evapotranspiration rates were used to establish a potential water uptake. By using the required buffer and landscaping features the traditional basin was eliminated and there would be no downstream impact because up to a 100 yr storm event is retained on-site.
- Fence Company—The owner found that the bio-retention with underground storage cost approximately 30% less than a traditional basin with riser and land needed. Positives noted: 1) more land for material storage; 2) lower installation costs for installation; 3) easier to access and maintain.

“Spotsylvania has standardized agreements for BMP installation, inspection, and maintenance.

When it comes to the economics of LID practices for the most part you will not get an accurate figure until you show your applicants how to do it right. I have had farmers, homeowners, developers and many others say that after going through proper training courses they have found LID to be much easier than they have seen in the books and have been led to believe.”

—Richard Street, Spotsylvania County, Virginia, Department of Code Compliance, January 2010

Figure 3-14. Developers realized LID cost savings in Spotsylvania County, Virginia.

- Ensuring that the type and scale of the practices implemented are appropriate to minimize maintenance costs and to provide amenity and habitat value for social acceptance (Seattle SEA Streets, Washington, Figure 3-12); Portland Tabor-to-the River, Oregon, Figure 3-2).
- Creating a market where such design and construction practices are routine to bring down costs associated with risk perception and limited materials. For example, when Chicago started the Green Alleys program in 2006, permeable concrete was about $145 per cubic yard; after one year, the cost dropped to $45 per cubic yard (*Managing Wet Weather with Green Infrastructure—Green Streets* (USEPA 2008)). Portland’s green roof program notes that while literature values for green roofs cite an additional $5 to $25 per square foot, a focus on the bare minimum for a functioning eco-roof has reduced the additional cost to $3.50 to $8.00 per square foot (Portland BES 2008).

- Promoting practices that will help minimize overdesign and excess cost. For example, the use of permeable pavement should enable reduction of other stormwater drainage infrastructure (USEPA 2007).
- For some watersheds, reducing the costs of managing the increased flash flooding accompanying build-out of previously pervious area (Capitol Region Watershed District, Minnesota, Figure 3-19).

Flexibility for Integrating into Existing Infrastructure

Flexibility inherent in these practices allows the capture of small rain events to be integrated into the existing developed urban environment in many cases (NRDC 2006), such as blue roofs (New York City schools, Figure 3-15) that can serve as a first step in a treatment train to shave peak flows or store rainwater for use; landscaping features such as traffic islands, in-ground planters; or under-sidewalk systems (Minneapolis, Minnesota downtown MARQ2 street redevelopment project, Figure 3-16).

Here, blue roofs save money over conventional stormwater management practices for New York City school system for stormwater storage.

In 2003, the New York City School Construction Authority (SCA) adopted a new design standard requiring blue roofs, or roofs structurally capable of detaining water, on all new schools built citywide. In the past five years since adopting the requirement, SCA has built 14 new schools featuring the blue roof system. Essentially a blue roof is a drainage system that slows the rate water enters the public sewer system. Four aspects of the blue roof system determine its function: the structural integrity of the roof, the amount of water allowed to flow into the sewer, waterproofing of the roof, and the drain itself.

In the SCA's blue roof design, the roof drain detains up to three inches of water on the roof behind an adjustable weir valve. Any water in excess of three inches flows over the open top of the valve and into the sewers, but the detained water remains on the roof while being slowly filtered down the drain pipe.

For SCA, the decision to incorporate blue roofs in its design standard was driven by economics. DEP sets standards on the allowable flow of water to enter the public sewers from buildings, based on the local drainage plan and sewer capacity. To meet these drainage plan standards, any excess water must be stored on-site for delayed release into the sewer. SCA eliminated the need to build costly underground storage tanks at newly-built schools and additions by using a resource that was basically free: the roof. Since the engineering and design are already budgeted for in a new construction project, an integrated design to accommodate a blue roof adds very little or no additional upfront cost. And the maintenance and upkeep is no different than with a standard-drain roof.

SCA has been very satisfied with the cost-savings blue roofs afford them in building new schools and will continue to follow the standard in future projects.

—The City of New York *PlaNYC–Sustainable Stormwater Management Plan 2008*, p. 53.

Blue roof drain installed by the SCA on PS 12 (Photo credit: Council on the Environment New York)

Source: Forester Media, Inc. www.Forester.net. Excerpted with permission.

Figure 3-15. Blue roofs can serve as the first step in a treatment train to retain and use.

To reduce traffic congestion and refurbish its downtown, Minneapolis, Minnesota, recently completed the Marquette Avenue and 2nd Avenue (MARQ2) project, the first such effort aimed at reshaping transportation in the Twin Cities. Stormwater mitigation was a challenge. “We have long had capacity problems with stormwater management downtown,” says Lois Eberhart, water resources administrator for the city of Minneapolis. “We needed to find a new way of dealing with stormwater.” For 48 linear blocks, Minneapolis installed under-sidewalk structural cell frames to enable root growth for 185 trees. The project replaced previously impervious sidewalks with pervious pavement, allowing for greater infiltration and filtration of stormwater within the system.

Each cell group contains bioretention mix soil and can store 116 cubic feet (3.2 cubic meters) of stormwater. Over the entire project site, that’s nearly 21,600 cubic feet (611 cubic meters) of stormwater storage capability. The system is able to capture and treat the Minneapolis 90th percentile rain event (up to 1.03 inches, in a 24-hour period).

“We’ve modeled a 10% reduction in peak flows to our stormwater system as a result of this installation,” says Bill Fellows, project manager for the city of Minneapolis.

—Adapted from *Stormwater Magazine*, March-April 2010
www.stormh20.com/march-april-2010/reshaping-minneapolis-project.aspx

Figure 3-16. Under-sidewalk bioretention provides robust street trees as stormwater management benefit in the Minneapolis MARQ2 project.

Potential for Cost Savings

The potential for cost savings using LID where infiltration or drainage swales can be substituted for piping, inlets, and other stormwater infrastructure has been well-documented. Understanding the potential cost savings that can be achieved can help ensure that the most cost-effective designs are prepared. EPA's report, *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (EPA 841-F-07-006) (USEPA 2010d) compares the projected or known costs of LID practices with those of conventional development approaches. In terms of costs, LID techniques can reduce the amount of materials needed for paving roads and driveways and for installing curbs and gutters. Note that in some circumstances, LID techniques might result in higher costs because of more expensive plant material, site preparation, soil amendments, and increased project management costs. Other considerations include land required to implement a management practice and differences in maintenance requirements. Total capital cost savings ranged from 15 to 80 percent when LID methods were used (Table 3-20). The full report is at www.epa.gov/nps/lid.

Table 3-20. Cost comparisons between conventional and LID approaches

Project[a]	Conventional development cost	LID cost	Cost difference[b]	Percent difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	–96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

Source: *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (USEPA 2010d).

Notes:

a. Some of the case study results do not lend themselves to display in the format of this table (Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs).

b. Negative values denote increased cost for the LID design over conventional development costs.

c. Mill Creek costs are reported on a per-lot basis.

Costs of Environmental Impacts

The environmental results of each alternative evaluated should also be considered when assessing true costs. Damages from water quality impairments are significant—even though they can be spatially distant from the widespread, incremental sources of excess runoff and pollutants. They are often not considered when determining the costs of stormwater management at the local level, but they are a true cost of stormwater management. For example, beach closures and shellfish bed contamination, and loss of fisheries represent significant social and economic costs to society. In addition literature available on the Chesapeake Bay, a national overview of some of these issues is provided in EPA's 2000 report *Liquid Assets* (http://www.epa.gov/water/liquidassets/execsumm.html).

Ancillary Benefits

The value of ancillary benefits that can be difficult to quantify should also be considered when establishing the costs or value of stormwater management practices that prevent excess volume of runoff. Examples of those types of benefits were provided in the introduction to this chapter. Examples of where such benefits have been realized are provided later in this section.

2.10.2 Types of Cost Analysis that Can Support Decision Making

Typical components of stormwater management costs include capital costs, O&M, and program administration. Stormwater management can also impose opportunity costs when selecting one alternative for implementation precludes another use, such as alternative use of a piece of land or funds.

Depending on the needs of the user, and assuming a similar level of risk and performance, alternatives are often selected on the basis of the following:

- Capital cost assessment
- Life-cycle cost analysis (net present value)
- Cost-effectiveness to achieve a specific goal, such as cost per pound of pollutant
- Including ancillary benefits in life-cycle cost analysis

The objective of these examples is to demonstrate how communities have found LID or green infrastructure to be an acceptable or superior alternative on a cost or cost-value basis. These examples will not be applicable to every federal facility or community, but are intended to illustrate the methods and factors being used by many communities to assess the cost of various stormwater management approaches.

Capital Cost Assessment.

Lenexa (Kansas) and the Capital Region Watershed District (Minnesota) are examples of communities that selected LID approaches to development and retrofit because of the lower capital costs compared to conventional stormwater management alternatives. Their case study examples are provided in Figures 3-17 and 3-18.

Lenexa, Kansas (population 47,000) was experiencing development pressures that led to adoption of LID-oriented development standards and a watershed-based systems approach to stormwater management. Program goals included reducing flooding, improving water quality, preserving the environment and open space, and providing recreational areas and trails.

A multi-stakeholder process to evaluate the cost impacts of the proposed standard included the Lenexa Economic Development Council and Homebuilders Association. The cost analysis evaluated different construction types, and compared the cost of construction under the LID standards to the costs of construction under the conventional standards. Each type of construction showed a capital cost decrease with LID standards:

Savings Associated with Different Development Types Using LID		
Development Type	EDUs	LID cost savings
Single Family	221	$118,420
Multi-Family	100	$89,043
Commercial/Retail	57	$168,898
Warehouse/Office	356	$317,483

Note: Savings includes additional developable land in addition to infrastructure. Equivalent Dwelling Unit: 2,750 sf.

The demonstrated savings not only helped gain developer support for the ordinance and the systems-based approach for stormwater management, but also helped ease the adoption of a development fee to help manage increasing stormwater infrastructure needs as the community grows. The ordinance was adopted in 2004, and 2009 polling data shows citizen satisfaction with the Public Works Department at 84%.

Sources: City of Lenexa Department of Public Works (personal communication), www.raintorecreation.org, Beezhold, M.T. et al (2006)

Figure 3-17. Lenexa, Kansas, demonstrates cost savings of implementing LID policies.

The Capitol Region Watershed District (CRWD) encompasses 41 square miles, including parts of St. Paul, Minnesota, and five smaller cities. The watershed is 42% impervious, almost completely developed, leading to impaired water quality and localized flooding.

In a 298 acre subwatershed of Como Lake, the initial solution to localized flooding was a second 60-inch storm sewer at a cost of $2.5 million, which would have continued the impairment of the lake from the additional urban runoff. In 2003, CRWD, in cooperation with local municipalities selected an alternative approach: retrofits consisting of an infiltration facility, eight under-street infiltration trenches, eight raingardens, and a regional pond.

The infiltration design performance was 100% for the infiltration facility, 100% for the rain gardens, and 93% for the infiltration trenches.

This approach has been a success. The following are the key benefits reported by CRWD on this project, called the Arlington Pascal Stormwater Improvement Project (APSIP):

- Capital cost savings of $0.5 million, on a project originally estimated at $2.5 million including water quality treatment not achieved with the original solution.
- Volume reduction (hence TP and TSS removal efficiencies) of 96% to 100%, in 2008 exceeding design projections
- Tracking of O&M activities and costs as well as actual and modeled performance enabled the estimation of the cost-effectiveness ($ per unit pollutant removed) of each practice (for amortized capital plus annual O&M as “cost”). In 2007, the APSIP BMPs infiltrated over 2 million cubic feet of runoff at a cost of $0.03/cf.

Source: Capitol Region Watershed District. 2010. CRWD Stormwater BMP Performance Assessment and Cost-Benefit Analysis. (www.capitolregionwd.org)

Figure 3-18. Midwest Water District achieves capital cost savings, solves localized flooding problems, and reduces lake impairment with LID retrofits.

Life-Cycle Cost Analysis

Portland, Oregon, conducted a life-cycle cost analysis of green roofs compared to conventional roofs. Green roofs are just one alternative being implemented in Portland to help manage the stormwater that causes flooding, erosion, destroys habitat, and contributes to CSOs. In the study, a hypothetical new five-story commercial building with a 40,000-square-foot roof in downtown Portland was evaluated. Key findings included the following:

- For the building owner (private interest), there was a net benefit over the 40-year life of the roof of $404,000 (2008 dollars)

- For the public, there was an immediate and long-term benefit. At year 5, the benefit is $101,660; at year 40, the benefit is $191,421. That does not include monetizing many environmental benefits that are recognized but difficult to quantify.

Benefits to the public were noted to include the following:

- Reduced public costs to manage stormwater
- Avoided public stormwater infrastructure needs and O&M costs
- Reduced carbon emissions
- Improved air quality
- Increased habitat areas

Benefits to private interests were noted to include the following:

- Reduced stormwater fees
- Reduced private infrastructure and O&M costs
- Reduced energy demand and costs
- Increased roof longevity

The report concludes that the lack of an immediate, short-term benefit to an owner accounts for the limited implementation of green roofs in Portland and beyond. The report recommends developing economic incentives to promote the use of green roofs (or *eco-roofs*) to encourage the construction in the city and to enable the city to benefit from the immediate, short-term benefits that they provide. For federal facilities that are long-term owners or have long-term leases, the opportunities for savings should be considered. The tabulated summary of benefits and costs is provided in Table 3-21 (Portland BES 2008).

Whether green infrastructure practices are more costly for a site than traditional stormwater management practices—or how much more they might cost—depends on many factors. They include the overall development's site drainage design, the land and groundwater characteristics, preference for site amenities, and, of primary importance, the design scenario selected for comparison. Administrative costs for implementing a program should also be considered.

Table 3-21. Private and public life-cycle cost and benefits evaluation of eco-roofs

Focus area	Cost		Benefits		Summary	
	One-time	Annual	One-time	Annual	5–year (in 2008 $s)	40-year (in 2008 $s)
Private Costs and Benefits						
Stormwater Management						
volume reduction				$1,330	$6,822	$45,866
peak flow reduction[a]				--	--	--
Energy						
cooling demand reduction				$680	$3,424	$19,983
heating demand reduction				$800	$4,028	$23,509
Amenity Value						
amenity value[a]				--	--	--
Building						
ecoroof construction cost	($230,000)				($230,000)	($230,000)
avoided stormwater facility cost			$69,000		$69,000	$69,000
increased ecoroof O&M cost		($600)			($3,077)	($20,677)
roof longevity (over a 40-year period)			$600,000		--	$474,951
HVAC equipment sizing			$21,000		$21,000	$21,000
Total Private Costs and Benefits	**($230,000)**	**($600)**	**$690,000**	**$2,810**	**$(128,803)**	**$403,632**
Public Costs and Benefits						
Stormwater Management						
reduced system improvements			$60,700		$60,700	$60,700
Climate						
carbon reduction				$29	$145	$845
carbon sequestration[a]				--	--	--
improved urban heat island[a]				--	--	--
improved air quality				$3,024	$15,515	$104,576
Habitat						
habitat creation			$25,300		$25,300	$25,300
Total Public Costs and Benefits	**$0**	**$0**	**$86,000**	**$3,053**	**$101,660**	**$191,421**
Total Costs and Benefits			**($27,143)**			**$595,053**

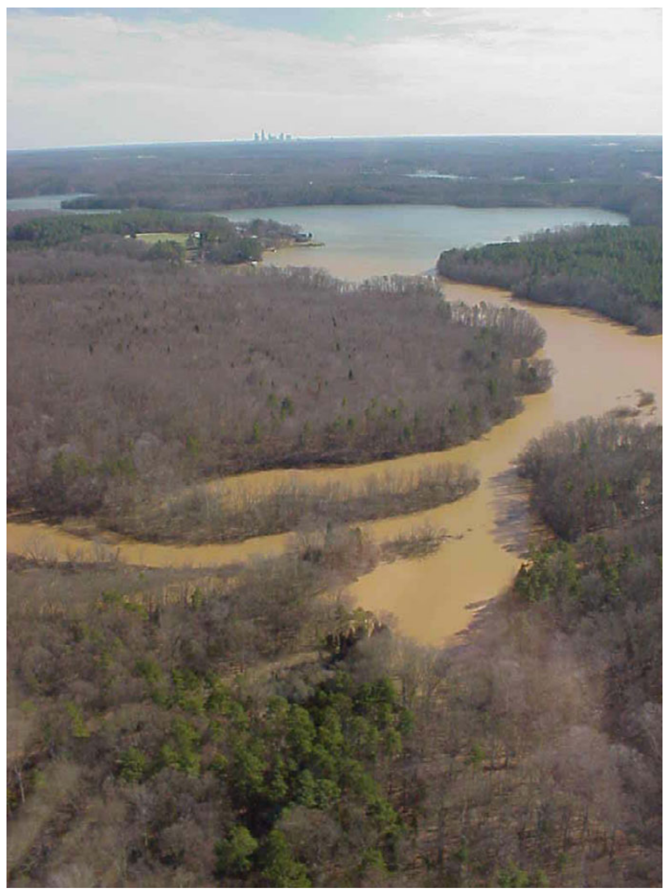
Source: City of Portland, Oregon, Cost Benefit Evaluation of Eco Roofs, 2008.

[a] The economic literature reports that an ecoroof can provide these economic benefits, however, data are unavailable at this time that would allow calculating a dollar amount for these benefits for an ecoroof in Portland.

In Virginia, a similar type of study was recently completed. To determine the financial impact of implementing new stormwater regulations, estimated additional costs were evaluated for a scenario of changing the stormwater management requirements to a proposed more stringent level (at the time, 0.28 lb/P/yr statewide; with a 10 percent reduction for redevelopment from previously developed site) with an emphasis on volume reduction. The report notes the environmental benefits of the proposed actions and the potential improvements in compliance options and effectiveness afforded by accounting for runoff reduction in loading reductions. The study concludes that while the incremental cost of the proposed regulations could not be estimated, new costs would be incurred on land development activities. Program administration costs were also noted as increasing, partially because of anticipated increases in tracking and in ensuring compliance with distributed infiltration systems, which, although smaller individually, would create a larger total number of practices requiring compliance tracking (Stephenson and Beamer 2008).

Cost-Effectiveness Analysis

Two cities that have conducted cost-effectiveness analyses on innovative and LID practices compared to traditional stormwater practices are Mecklenburg, North Carolina, and New York City. Each had significantly different situations to evaluate.



Source: McDowell Creek Watershed Masterplan, Charlotte-Meckenburg Stormwater Services 2006 <http://www.charmeck.org/Departments/StormWater/Projects/McDowell+Creek.htm>

Figure 3-19. Sediment entering Mountain Island Lake from McDowell Creek Cove.

Charlotte-Mecklenburg Stormwater Services is in a rapidly developing urban-suburban area. It has high sediment loads to the drinking water reservoir caused by the excess volume of urban runoff from development eroding local streams (Figure 3-19). Traditional stormwater management practices have not been adequate to prevent degradation. After a comprehensive watershed planning effort, the analyses demonstrated that LID policies should be implemented for development and that watershed retrofits were needed to protect the drinking water reservoir. The program focuses on in-stream restoration, upland BMP retrofits, and reforestation. Stream restoration was found to be the most cost-effective retrofit on *a dollar-per-pound-of-sediment-saved* basis, and extended detention was least the cost-effective means for sediment control retrofit in the watershed (Charlotte-Mecklenburg Water Services, McDowell Creek Retrofit and Restoration Master Plan at http://www.charmeck.org/Departments/StormWater/Projects/McDowell+Creek.htm).

New York City, like many older cities, has CSOs that routinely contaminate surface waters. Conventional solutions include constructing deep tunnels to store the excess stormwater-sewage mix. The high cost of the tunnels prompted the city to evaluate the cost-effectiveness of other solutions. The city determined that it was more cost-effective on a *dollar-per-gallon-saved* basis to implement new development standards, to require retrofits on building undergoing roof replacements to detain stormwater, and to implement LID retrofits such as green streets, than to rely on tunnel construction only. (PlaNYC, Sustainable Stormwater Management Plan, 2008 http://www.nyc.gov/html/planyc2030/html/stormwater/stormwater.shtml). The analysis does not consider the amenity benefits to the community, as was conducted in the Philadelphia analysis (Table 3-24).

One of the newer practices New York City found to be most promising is rooftop detention, or *blue roofs*. Rooftop detention can serve as a first step in a treatment train for peak shaving, or for storage for later use in irrigation, and so on. Cost observations were reported as follows:

> Rooftop detention, one of the measures most likely to be used to comply with the performance standard has low incremental costs. Compared to average costs of $18 per square foot for a typical four-ply roof, the costs of a blue roof are only $4 per square foot more. We assumed no additional maintenance costs above those incurred for a standard roof. When we consider lifecycle costs, the economics improve further, because the thicker membrane of blue roofs mean that they last longer than standard roofs; the warranty provided by manufacturers is 20 years, compared to 10 to 15 years for standard roofs. With approximate construction costs of $300 per square foot for new buildings, the cost of this strategy is little more than 1 percent of construction costs.

Source: The City of New York, PlaNYC, Sustainable Stormwater Management Plan 2008, p. 52.

The cost-effectiveness findings of these two communities are shown in Tables 3-22 and 3-23.

Table 3-22. Cost-effectiveness analysis of stormwater management practices is used to target the most cost-effective retrofit approach to reducing sediment loading to the drinking water reservoir in the McDowell Creek Watershed in Charlotte-Mecklenburg, North Carolina

Management practice	$ Per lb of sediment saved
Major system stream restoration/enhancement	$1.02
Minor system stream restoration/enhancement	$0.60
Sand filter	$24.43
Wet pond	$35.15
Wetland	$50.33
Rain garden	$19.55
Extended detention	$69.60
Vegetated swale	$3.89
Filter strip	$6.23
Pond retrofit	$1.88

Table 3-23. New York City's cost-effectiveness analysis demonstrates the cost-effectiveness of storage per gallon of runoff for new development standards, standards for existing building (during roof replacement), and LID retrofits compared to traditional CSO mitigation using tunnels. LID practices were among those with lower cost than traditional storage techniques.

Source control strategy	Cumulative runoff capture* (million gallons)	Cumulative PV cost (2010–2030) (millions)	Cumulative cost per gallon
Performance Standards for New Development	1,174	$105	$0.09
Performance Standards for Existing Buildings (plus preceding strategy)	2,838	$416	$0.15
Low- and Medium-Density Residential Controls (plus preceding strategies)	3,954	$625	$0.16
Greenstreets(plus preceding strategies)	4,178	$676	$0.16
Sidewalk standards (plus preceding strategies)	8,400	$1,704	$0.20
Road reconstruction standards (plus preceding strategies)	9,868	$2,123	$0.22
50% Right of way retrofits (plus preceding strategies)	24,092	$19,360	$0.80
Grey infrastructure reference case	Total CSO reduction	Total cost	Cost per gallon
Potential future CSO detention facilities	2,266	$2,337	$1.03

Notes:
* Cumulative runoff capture with the source control scenarios refers to gallons of stormwater runoff that can be retained or detained in those source controls. The city has not yet established the exact relationship between these quantities and the corresponding reduction in CSOs.
PV = Present Value

Source: PlaNYC – Sustainable Stormwater Management Plan, 2008, http://www.nyc.gov/html/planyc2030/html/stormwater/stormwater.shtml)

Locally evaluated benefits: Philadelphia. A broad range of societal benefits—and estimates of the monetary value associated with these benefits—are described in Philadelphia Water Department's (PWD's) *A Triple Bottom Line Assessment of Traditional and Green Infrastructure, Options for Controlling CSO Events in Philadelphia's Watersheds Final Report*, 2009. The categories of benefit accrual resulting from using green infrastructure stormwater management approaches are the following:

- Recreational use and values
- Property values, as enhanced by the LID options
- Heat stress and related premature fatalities avoided
- Water quality and aquatic habitat enhancements and values
- Wetland enhancement and creation
- Poverty reduction benefits of local green infrastructure jobs
- Energy usage and related changes in carbon and other emissions
- Air quality pollutant removal from added vegetation

Table 3-24 shows the benefits (and external costs) Philadelphia estimated for a 40-year period of two of the options compared for CSO solutions:

- A 50 percent LID and 50 percent conventional (tunnel) option
- An option consisting solely of conventional (tunnel) approaches

The 50 percent LID, or green infrastructure option, is a scenario in which 50 percent of the impervious surface in the CSO area is managed through green infrastructure and the remainder through conventional storage tunnels. The 30' Tunnel option represents a scenario where large tunnels would be used to manage the CSO. Philadelphia selected the options for analysis purposes, and they do not represent implementation decisions by the city. The table demonstrates the value of the ancillary benefits of using green infrastructure for CSO mitigation compared to the lack of ancillary benefits of traditional CSO management. Environmental performance of the two options is not estimated to be completely equivalent, which should be taken into consideration in fully comparing options.

Implementing those types of controls would be incremental over a development horizon time frame. Additional information on Philadelphia's program is provided in Section 4.

The cost estimates for construction and maintenance are in the Long-Term Control Plan at http://www.phillywatersheds.org/ltcpu/.

Table 3-24. Summary of Philadelphia's analysis of green infrastructure to help mitigate CSOs: Present value benefits of two options studied (Cumulative estimated through 2049 in 2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$524.5	
Improved aesthetics property value (50%)	$574.7	
Reduction in heat stress mortality	$1,057.6	
Water quality aquatic habitat enhancement	$336.4	$189.0
Wetland services	$1.6	
Social costs avoided by green collar jobs	$124.9	
Air quality improvement from trees	$131.0	
Energy savings usage	$33.7	$(2.5)
Reduced (increased) damage form SO_2 and NOx emissions	$46.3	$(45.2)
Reduced (increased) damage from CO_2 emissions	$21.2	$(5.9)
Disruption costs from construction and maintenance	$(5.6)	$(13.4)
Total	**$2,846.4**	**$122.0**

Source: Summary of Triple Bottom Line Analysis, City of Philadelphia Long-Term Control Plan, http://www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf

a. 28' tunnel option in Delaware River watershed

Regionally evaluated benefits: Sun Valley Watershed, Los Angeles County. The Sun Valley watershed area of Los Angeles County experienced frequent flash flooding and a conventional storm drain pipe solution was proposed. However, the community initiated a process that prompted Los Angeles County to review more environmentally sound alternatives, particularly in light of the areas (1) severe drought conditions; (2) decreasing groundwater supplies; (3) high cost of the current practice of importing most of the region's water from sources including out-of-state; and (4) impaired water resources from urban stormwater runoff. The underlying regional stormwater management issues of rainwater loss, high demand, and the resulting high-energy-use water supply infrastructure is described in *A Clear Blue Future: How Greening California Cities Can Address Water Resources and Climate Challenges in the 21st Century* (NRDC 2008).

To select the best-value alternative, categories of benefits were developed. Various methods were used to quantify the benefits including using avoided costs, willingness to pay values from the literature, and valuation pricing (e.g. increases in property values). Project benefits (and costs) were evaluated over a 50-year horizon. The benefits evaluated included the following:

- *Flood Control*—Avoided cost of facilities needed to provide comparable local and downstream flood protection

- *Water Quality Improvements*—Avoided costs associated with removal of bacteria and other listed pollutants from waters that contribute to the Los Angeles River
- *Water Conservation*—Cost savings associated with using stormwater for groundwater recharge and water supply augmentation compared to purchasing imported water
- *Energy*—Cost savings associated the reduced energy consumption from planting shade trees and the decreased amount of energy used to pump imported water into the Los Angeles Basin under each alternative
- *Air Quality Improvements*—Absorption of pollutants by the tree canopy and reduced emissions from power plants from decreased energy consumption
- *Ecosystem Restoration*—Increased habitat and open space
- *Recreation*—Value of increased parkland and recreation for the area
- *Property Values*—Impact of project components on nearby property values

The costs of each alternative were monetized, including capital facilities costs, land acquisition costs, and expected O&M costs. The results of the benefit-cost analysis are summarized in Table 3-25, which shows the benefit-cost ratio for each alternative. The ratios use the present value of total project costs and benefits over the 50-year evaluation period. As a result of the analysis, an LID and infiltration alternative was selected and successfully implemented instead of the piped solution. The Los Angeles County Department of Public Works is now widely using this type of project analysis (Los Angeles County Department of Public Works 2004: http://www.sunvalleywatershed.org/ceqa_docs/plan.asp).

Table 3-25. Benefit/Cost ratio analysis for Sun Valley stormwater management alternatives shows that the storm drain pipe alternative provided less long-term value than LID/green infrastructure alternatives in a 50-year net present value analysis

Alternative	Storm drain pipe alternative	Alternative 1 infiltration	Alternative 2 water conservation	Alternative 3 stormwater reuse	Alternative 4 urban storm protection
Present value of total benefits (millions $ 2002 USD)	$73.44	$270.47	$295.39	$274.93	$239.95
Present value of total costs (millions $ 2002)	$74.46	$230.40	$171.58	$297.90	$206.61
Benefit-cost ratio	0.99	1.17	1.72	0.92	1.16

Note: A Benefit-Cost ratio greater than one indicates more benefits than cost.

2.10.3 Costs of Individual Practices

Given the considerations described above, it is clear that comparing the costs of individual LID practices to each other, or just to other stormwater management practices, is not the best way to fully evaluate the costs of LID practices or to convey the information on the economies that can be realized by efficient development planning. In addition to not accounting for these benefits, just stating practice cost does not show how costs can be optimized by integrating LID features into the landscape, or by selecting rooftop-to-stream incremental features to filter, treat, retain, capture and use runoff. A green roof might appear a relatively high cost practice, but in a densely urbanized area, it could be the most economical solution for stormwater management, and given the potential benefits shown in the Portland BES, Oregon, study (Figure 3-2), could be a worthwhile investment in the long term depending on the ultimate use for the building.

Issues that should be considered when estimating capital costs include the following:

- Because LID practices are relatively new, few examples of comprehensive, full-scale project costs are readily available, and costs that are available often represent higher pilot-scale or demonstration project costs.
- Limited literature values for costs often do not provide complete information needed, such as design/construction/startup information, or level of water quality treatment to be provided.
- Costs are highly site specific and are influenced by contractors' familiarity with the practices, and therefore vary considerably.
- LID practices are constructed primarily by using conventional construction techniques that can be readily estimated using local contractor quotes and industry guides such as *Reed Construction Data* (R.S. Means), as is done for conventional construction.

Issues that should be considered when evaluating O&M costs include the following:

- O&M will account for much of the ownership cost, so managers should consider the expected reliability and ease of maintenance when selecting a practice, not just the capital cost.
- Utilities maintenance staff are trained in management of conventional drainage systems, and changes might be needed for institutional programs for O&M to result in more cost-effective O&M that has been reported for maintaining pilot facilities.
- O&M costs attributed to LID practices were found to primarily be for aesthetics (WERF 2005), although more information is needed to determine what role aesthetics play in O&M costs reported. Many of the activities that would have occurred in regular nonfunctional landscaping (weed control, litter removal) are reported as LID maintenance. That can make it difficult to determine how much of the reported cost is actually an additional cost incurred to ensure that the practice functions.

- O&M costs for maintaining bioretention might be similar to the current maintenance costs for nonfunctional landscaping, in fact, they could be lower because bioretention would receive more rainwater and require less watering with potable water.

A wide range of potential cost outcomes for both capital and O&M are reported, such as

- Cost savings using LID is widely reported from minimizing conventional piped infrastructure and ponds, and simply using land and landscaping functionally.
- Higher cost can occur in dense, urban environments where cistern systems or green roofs might be costly but necessary because of land limitations.
- Limited cost savings or additional costs could be incurred if the local codes require installing minimum-sized piped systems regardless of LID design. This could be for flood control or other site-specific issues.

Estimates of stormwater management practice costs have been prepared by several entities and reflect the variability that is inherent in site-specific design and construction.

The determination of the most cost-effective practice is site-specific, depending on the availability of land, the local costs of labor and materials, and level of treatment required. The costs of individual practices are provided in the practice Fact Sheets in Appendix 1. General cost ranges and cost estimating approaches for LID and other stormwater management practices have been documented in the literature and are repeated here. References are provided in Table 3-26.

Table 3-26. Sources of general cost ranges and cost estimating approaches for LID practices

USEPA. 2004a. Stormwater *Best Management Practices Design Guide*, Office of Research and Development, EPA/600/R-04/121, Volumes 1-3 (121, 121A, 121B).
USEPA. 2004b. *The Use of Best Management Practices (BMPs) in Urban Watersheds,* Office of Research and Development, EPA/600/R-04/184.
CWP. 2007. *Urban Subwatershed Restoration Manual Series* (http://www.cwp.org/Store/usrm.htm)
Water Environment Research Foundation. 2005b. *Performance and Whole-Life Costs of Sustainable Urban Drainage Systems,* 01-CTS-21T
Water Environment Research Foundation. 2009. *Decentralized Stormwater Controls for Urban Retrofit and Combined Sewer Overflow Reduction, Phase II*.
Wiess et al. 2005. *The Cost and Effectiveness of Stormwater Management Practices,* Minnesota Department of Transportation, MN/RC – 2005-23.

However, to supplement existing information sources, some recent examples are summarized in Table 3-27, and some specific recent cost information from those sources is provided here.

Table 3-27. Sources of recent cost information for LID practices—capital, O&M, life cycle

Source	Key items
USEPA. *Reducing Stormwater Costs through Low-Impact Development,* Publication Number EPA 841-F-07-006 USEPA 2010d.	Savings of 15% to 80% found for LID subdivisions compared to conventional subdivision drainage practices.
ECONorthwest. T*he Economics of Low-Impact Development: A Literature Review,* November 2007	Case studies of LID costs and economic benefits
Natural Resources Defense Council. *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*; NRDC 2006. www.nrdc.org/water/pollution/rooftops/contents.asp	Policy guide for decision makers for LID; nine case studies of successfully used green techniques.
Fact Sheets in Appendix 1	Cost considerations associated with each practice presented.
City of Portland, Oregon, Bureau of Environmental Services, Sustainable Stormwater Management Pages, www.portlandonline.com/bes/index.cfm?c=34598	Extensive examples of green roofs and green streets, as well as other sustainable stormwater practices.
Water Environment Research Foundation. *WERF Cost Tool*, 2009. Free spreadsheet tool developed as part of *Performance and Whole Life Cost of Best Management Practices and Sustainable Urban Drainage Systems* (2005). Water Environment Research Foundation. www.werf.org/AM/Template.cfm?Section=Stormwater3	Provides estimates based on literature values. Intended for modification as needed for user project data. Calculates life cycle cost. Contains literature review by practice.
City of Philadelphia. *Long Term Control Plan Update, Supplemental Documentation, Volume 3, Basis of Cost Opinions*, September 2009; www.phillywatersheds.org/ltcpu/Vol03_Cost.pdf	Full range of LID costs for new, redevelopment, and retrofit. O&M costs. Anticipated cost reduction as practices become more widely used. Retrofit focus.
North Carolina Coastal Federation. *Low Impact Development Pilot Study to Reduce Fecal Coliform into Core Sound, Final Report,* Sea Grant Project Number: 07-EP-03, November 2008	Detailed costs for rain gardens, cisterns, conservation landscaping and other LID practices. Six implemented and 9 planned.
North Carolina State University (NCSU). Bill Hunt et al. *Evaluating LID for a Engineering Development in the Lockwood Folly Watershed*, North Carolina. www.nhcgov.com/AgnAndDpt/PLNG/Documents/Brunswick LID.pdf	Demonstrates the cost savings achievable using LID in place of conventional stormwater treatment.
New York City, Plan NYC, Appendix C, 2008, www.nyc.gov/html/planyc2030/html/stormwater/stormwater.shtml	For controls that are high-priority for retrofit.
City of Portland, Bureau of Environmental Services. Cost Benefit Evaluation of Ecoroofs 2008. www.portlandonline.com/bes/index.cfm?c=50818&a=261053	Quantifies the benefits to owner and public of installing green roofs
PWD. A Triple Bottom Line Assessment of Traditional and Green Infrastructure. Options for Controlling CSO Events in Philadelphia's Watersheds Final Report, 2009. www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf	LID-based, green infrastructure approaches provide a wide array of important environmental and social benefits to the community, and that these benefits are not generally provided by the more traditional alternatives.

Sources of cost data for urban stormwater retrofits, especially roadway retrofits, include the following:

- Portland, Oregon's, Bureau of Environmental Services. For example, Portland notes in its description of its Tabor-to-the-River watershed green streets retrofit that resolves the drainage problems it faces using only pipe solutions would have cost an estimated $144 million, while adding sustainable, green stormwater management systems reduced the estimated cost to $86 million and enhanced water quality and watershed health (www.portlandonline.com/bes/index.cfm?c=50500&a=230066).

- Seattle, Washington's, utilities department, Seattle Public Utilities (SPU), has developed and adopted a green street design and retrofit approach it calls Natural Drainage Systems (NDS), started with the completion of the successful SEA Street project in 2001. (www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/index.htm). As part of the program's adoption, SPU conducted a benefit/cost comparison in 2003 between traditional designs and the NDS design. A summary is provided in Figure 3-20.

Local governments in the Mid-Atlantic area with cost data include the following:

- Philadelphia, Pennsylvania

- Montgomery County, Maryland

- North Carolina Division of Soil and Water's *Community Conservation Assistance Program* (CCAP)

Philadelphia Water Department (PWD). PWD conducted a cost analysis of wet-weather management approaches as part of its effort to screen and compare green-to-gray technologies in its Long-Term Control Plan Update (LTCPU). The costs for several of those technologies are provided here; for additional information and assumptions, see the LTCPU. In general, these are planning-level estimates, expected to fall in the range of –30 percent to +50 percent for the Philadelphia area.

Seattle Public Utilities—Natural Drainage System Program

Problem Statement: Seattle's receiving waters and aquatic life have been significantly impaired by the negative effects of urban stormwater runoff. Increasing volumes of runoff also cause flooding of roadways and property. Traditional methods of stormwater management and street design have proven to be ineffective at countering the effects of current and future development on receiving waters.

Natural Drainage Systems (NDS) is an alternative stormwater management approach that delivers higher levels of environmental protection for receiving waters at a lower cost than traditional street and drainage improvements.

- NDS targets areas of the city draining to creek watersheds that do not have formal drainage or street improvements.
- NDS design is based on technology that emphasizes infiltration and decentralized treatment of stormwater to reduce the total volume of runoff reaching creek systems.
- The goal of NDS is to more closely match the hydrologic function of natural forests that existed before development, thereby creating stable creek systems and clean water.
- NDS designs cost less than traditional drainage and street designs.

Cost analysis of natural vs. traditional drainage systems meeting NDS stormwater goals

Street type	***Local street*** **SEA Street**	***Local street*** **Traditional**	***Collector street*** **Cascade**	***Collector street*** **Traditional**	**Broadview Green Grid 15 block area**
Community Benefits	• One sidewalk per block • New street paving • Traffic calming • High neighborhood aesthetic	• Two sidewalks per block • New street paving • No traffic calming • No neighborhood aesthetic	• No street improvement • Moderate neighborhood aesthetic	• No street improvement • No neighborhood aesthetic	• Both SEA Street and Cascade types • One sidewalk per block • New paving • High neighborhood aesthetic
Ecological Benefits	• High protection for aquatic biota • Mimics natural process • Bio-remediate pollutants	• High protection flooding • Some water quality	• High water quality protection • Some flood protection	• High protection from flooding • Some water quality	• High water quality & aquatic biota protection • Some flood protection • Excellent monitoring opportunity
% impervious area	35%	35%	35%	35%	35%
Cost per block (330 linear feet)	$325,000	$425,000	$285,000	$520,400	Average per block: $280,000

Source: www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/index.htm

Figure 3-20. Comparison by SPU shows lower construction costs for NDS than traditional street design.

These costs were used as the basis for estimating the cost-to-benefits comparison of PWD's report *A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds*. The report indicates that the benefits from green infrastructure stormwater management are significant; those findings on benefit valuations are applicable even to non-CSO communities. To compare the costs of traditional versus green infrastructure, PWD assessed the capital, O&M, and life cycle costs for several stormwater management practices. It is important to note that the estimated costs were for facilities that would theoretically meet Philadelphia's stormwater ordinance, shown in Figure 3-21, to manage the first inch of runoff from directly connected impervious area, by infiltration possible, unless a waiver is obtained.

The Water Quality requirement stipulates management of the first one inch of runoff from all Directly Connected Impervious Areas (DCIA) within the limits of earth disturbance. The Water Quality requirement is established to (1) recharge the groundwater table and increase stream base flows; (2) restore more natural site hydrology; (3) reduce pollution in runoff; and (4) reduce combined sewer overflows (CSO) from the city's combined sewer systems. The requirement is similar to water quality requirements in surrounding states and in other major cities.

- The requirement must be met by infiltrating the water quality volume unless infiltration is determined to be infeasible (because of contamination, high groundwater table, shallow bed rock, poor infiltration rates, etc.) or where it can be demonstrated that infiltration would cause property or environmental damage.
- A waiver from the infiltration requirement must be submitted and approved if infiltration is not feasible... (continues)

Source: Philadelphia's *Stormwater Manual*; http://www.phillyriverinfo.org/WICLibrary/chapter%201.pdf

Figure 3-21. Philadelphia *Stormwater Manual* v2.0—Section 1.1.1 Stormwater Ordinance and Regulations

Cost estimate ranges for capital construction from PWD's Long-Term Control Plan for planning purposes are provided in Table 3-28 for redevelopment and for retrofit.

In addition to capital cost, PWD estimates the cost decrease that can occur as LID practices become more of a standard practice. In the LTCPU, PWD addresses many of the considerations in evaluating costs, including O&M schedules and costs and replacement costs. PWD LTCPU estimates that costs will decrease for the following reasons (PWD 2009):

- Improved site designs will result as designers learn to incorporate the new stormwater requirements into designs from the beginning. Now, such features are added to a site plan as an afterthought, resulting in higher design costs. Leaving more functional open space in the site design for stormwater management is assumed to occur over time, and designers will learn how to work with the expected site conditions.

Table 3-28. Summary of direct construction cost estimates from PWD's *Long-Term Control Plan Supplemental Documentation, Volume 3*

Control	Type	Minimum cost ($ / impervious acre)	Median cost ($ / impervious acre)	Mean cost ($ / impervious acre)	Max cost ($ / impervious acre)
Bioretention	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Subsurface Infiltration	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Green Roof	Retrofit	$430,000	$500,000	$500,000	$570,000
	Redevelopment	$200,000	$250,000	$250,000	$290,000
Porous Pavement	Retrofit	$65,000	$160,000	$160,000	$410,000
	Redevelopment	$44,000	$110,000	$110,000	$200,000
Street Trees	Retrofit	$18,000	$18,000	$18,000	$18,000
	Redevelopment	$15,000	$15,000	$15,000	$15,000

Source: Philadelphia LTCP; *Engineering News-Record* Construction Cost Index 7966; R.S. Mean 115.2

*From Philadelphia LTCP: Other cities have been experiencing costs in the range of $7–$16 per square foot ($305,000–$700,000 per impervious acre), with a typical range of $10–14 per square foot ($435,000–$610,000 per impervious acre). A recent green roof at Temple-Ambler campus was approximately $11 per square foot ($480,000 per impervious acre). The least expensive green roofs in Chicago, which has the largest-scale program in the U.S., are on the order of $6–7 per square foot ($285,000 per impervious acre), and this could be a reasonable estimate of what can be achieved in the future with a large-scale program in Philadelphia.

- Lower material costs are expected over time as the practices become more standard. The materials that are at a premium now because they are specialty items will become common. For example, PWD estimates that in the future, permeable pavement costs will be comparable to traditional pavement costs.
- Reduced design costs are expected as more designers become familiar with LID practices. PWD estimates that designs for LID projects will be on par with more standard designs.
- Reduced perception of risk will result in a lower contingency being applied to cost estimates.

The ranges of cost reduction expected by PWD over time from improved site design and lower material costs is approximately 20 percent up to about 25 percent.

Montgomery County, Maryland, LID Green Street Programs. Green street projects have been implemented for the past several years in Portland, Oregon; Seattle, Washington; and other locations. Montgomery County, Maryland, has undertaken several green streets projects, and recently compared the costs of its projects, both estimated and completed, with reported costs from other jurisdictions, as well as could be interpreted from the literature information provided. Limited data are available to date, and many factors contribute to the differences in costs reported, so the data might not be widely applicable. Table 3-29 presents a recent summary of the Montgomery County evaluation, with information added from Portland on its estimates.

Table 3-29. Summary of green streets cost evaluation

	Estimated level of WQ control	Total DA	Cost per acre DA (in $1,000s)		Cost per sf BMP SA (in $/sf)		Cost per impervious acre DA (in $1,000s)	
		(acres)	design	construction	design	construction	design	construction
Bioretention retrofit projects								
Montgomery County	100%	1.1[a]	$17	$112	$17	$113	$20	$131
Portland (Areas reported as impervious only)	100%	0.17[b]	$41	$214	$26	$136	$41	$214
	100%	0.21[c]	$10	$79	$8	$29	$10	$79
Prince George's County	66%	13.4[d]	$14	$104	$19	$139	$32	$233
	86%	1.5[e]	$72	$92	$99	$126	$217	$276
Swales and filter strip retrofit projects								
Montgomery County	16% to 50%	1.1 to 3.7[f]	$33 to $75	$26 to $84	$35 to $86	$39 to $44	$96 to $128	$40 to $143
Caltrans Swales	56%	0.20 to 2.4[g,i]	NR	$31 to $121	NR	$12 to $58	NR	$35 to $128
Caltrans Filter Strips	100%	0.49 to 2.42[h,j]	NR	$23 to $120	NR	$12 to $43	NR	$35 to $128
Burnsville, MN (less urbanized)	NR	5.3[j]	$12	$24	NR	NR	NR	NR

Source: Montgomery County, Maryland, and Portland, Oregon

Notes:

NR = Not Reported; DA = Drainage Area; SA = Surface Area; sf = square foot; Estimated Level of Control =
a. Dennis Ave. Health Center

b. 12th & Montgomery Ave.; Portland, OR, Report - only planter & pavers; http://asla.org/awards/2006/06winners/341.html

c. Green-Siskiyou, OR - curb planters, no subdrain, assume total DA (total impervious DA in report); http://www.asla.org/awards/2007/07winners/506_nna.html

d. Route 201 Gateway - roadway median retrofit

e. U.S. Rt. 1 at I-95 Interchange

f. Various projects, combination of completed costs and costs estimated for projects yet to be built

g. Various 2004 projects; include factors that increased the cost for dense urban retrofit (traffic control, etc.)

h. Various 2004 projects; include factors that increased the cost for dense urban retrofit (traffic control, etc.)

i. BMP Retrofit Pilot Program, Final Report, Report ID CTSW - RT - 01 – 050, California Department of Transportation, January 2004

j. Roadside swales and rain gardens; suburban community retrofits

Coastal North Carolina, Community Conservation Assistance Program (CCAP). Striving to protect its shellfish resources, North Carolina has encouraged LID since 1986. As a result, North Carolina has implemented a cost-share program to help start the adoption of new LID technologies. It developed cost information that it uses in the CCAP to estimate cost-sharing amounts. Table 3-30 provides a summary costs for coastal North Carolina for 2009.

Table 3-30. LID costs used by the North Carolina Division of Water Quality's *Community Cost Share Program*

BMP	Components	Unit type	All areas unit cost
Abandoned well closure		Each	
Backyard rain garden		SqFt	
	Bioretention excavation	SqFt	$5.00
	Bioretention soil amendment -sand	SqFt	$0.50
	Bioretention mulch	SqFt	$0.75
	Bioretention plants (installed)	SqFt	$1.50
Backyard wetland		SqFt	
	Wetland excavation	SqFt	$5.50
	Wetland plants (installed)	SqFt	$2.30
	Wetland outlet structure	Each	$50.00
Cisterns		Each	
	Cistern 250-1,000 gallons installed	Gallon	$1.75
	Cistern 1,000-3,000 galons installed	Gallon	$1.00
	Cistern 3,000 gallons installed	Gallon	
	Accessories package	Each	$700.00
	Cistern foundation	SqFt	$1.40
	Concrete pad for cistern	SqFt	$3.60
	Shipping charge	Each	
Critical area planting		SqFt	
	Grading - minimum	Job	$25.00
	Grading - light, 1" - 3" avg	100 SqFt	$3.90
	Grading - medium, 3" - 6" avg	100 SqFt	$4.82
	Grading - heavy, 6" - 9" avg	100 SqFt	$5.74
	Grading - extra heavy, 9" - 12" avg	100 SqFt	$6.66
	Grading - maximum heavy, more than 12" avg	100 SqFt	$7.58
	Vegetation (grass) - minimum	Job	$15.00
	Vegetation (grass)	100 SqFt	$0.75
	Vegetation (trees/shrubs)	SqFt	
	Vegetation - mulch, netting	100 SqFt	
	Vegetation - mulch, small grain straw	100 SqFt	$1.28
	Matting - excelsior, installed	SqYd	$0.95
Diversion		Feet	
	Excavation	SqFt	$5.00
	Vegetation (grass)	100 SqFt	$0.75
	Filter cloth-geotextile fabric	SqYd	$2.25
	Filter cloth-pins, metal anchor	Each	$2.00
	Vegetation - mulch, netting	100 SqFt	
	Vegetation - mulch, small grain straw	100 SqFt	$1.26
	Matting - excelsior, installed	SqYd	$0.95

Example Cost Comparison of LID Parking Lot and Conventional Parking Lot. When evaluating the costs of LID, it is important to compare to the costs of alternative stormwater management. The economies of subdivision development with LID practices have been documented (USEPA 2007). As an example, Table 3-31 presents a detailed breakdown of a cost comparison for two parking areas estimated for a project in Massachusetts, indicating that the LID construction cost was not higher than conventional costs. For this project, design costs were reported as higher because it was a relatively new type of design, but lower maintenance costs were anticipated.

Table 3-31. Comparison of conventional design vs. bioretention in two parking areas in Amesbury, Massachusetts

		Bioretention Area 1					Bioretention Area 2				
		Island = 51,155 SF (4,867 SF landscape)					Adjacent to clubhouse = 77,90 SF (19,584 SF landscape)				
		Quantity		Unit cost	Total cost		Quantity		Unit cost	Total cost	
	Item	LID	Standard		LID	Standard	LID	Standard		LID	Standard
Landscape	Loam (4" depth) (CY)	NA	59.6	$40	NA	$2,384	179	239.4	$40	$7,160	$9,576
	Bioretention soil mix (24" depth) (CY)	360.5	NA	$40	$14,421	NA	363	NA	$40	$14,520	NA
	Seed (SY)	240	541	$4	$960	$2,164	1360.8	1941	$4	$5,443	$7,764
	Composted, double shredded hardwood mulch (3" depth) (CY)	25	0	$28	$700	$0	68	20	$28	$1,904	$560
	Trees (EA)	18	18	$518	$9,315	$9,315	45	45	$518	$23,288	$23,288
	Shrubs (EA)	61	30	$32	$1,922	$945	216	108	$32	$6,804	$3,402
	Perennials and grasses (EA)	1450	0	$2	$2,900	$0	2068	0	$2	$4,136	$0
				total	$30,217	$14,808			*total*	$63,255	$44,590
Site work	HDPE Drain pipe (12" dia) (LF)	NA	55.4	$12	NA	$648	NA	148	$12	NA	$1,732
	Catch Basins (EA)	NA	2	$3,075	NA	$6,150	NA	4	$3,075	NA	$12,300
	Water Quality Units (Stormceptor STC 900) (EA)	NA	1	$8,000	NA	$8,000	NA	1	$8,000	NA	$8,000
	Curb (Extruded Concrete) Straight (LF)	NA	506.8	$6	NA	$2,914	NA	655.5	$6	NA	$3,769
	Curb (Extruded Concrete) Radius (LF)	NA	45.7	$8	NA	$356	NA	78.5	$8	NA	$612
	Wheel Stops (EA)	43	NA	$66	$2,838	NA	49	NA	$66	$3,234	NA
	Drain Manholes (EA)	NA	NA	$3,325	NA	NA	NA	1	$3,325	NA	$3,325
	Earthwork (CY)	NA	183	$5	NA	$860	NA	493	$5	NA	$2,317
	Pipe Bedding (CY)	NA	15.3	$2	NA	$36	NA	41.1	$2	NA	$96
				total	$2,838	$18,964			*total*	$3,234	$32,151
					Bioretention Area 1					***Bioretention Area 2***	
				total	$33,055	$33,772			*total*	$66,489	$76,740

Source: Eisenburg, Bethany, Design, Engineering, Installation, and O&M Considerations for Incorporating Stormwater Low Impact Development (LID) in Urban, Suburban, Rural, and Brownfields Sites, American Society of Civil Engineers (ASCE), Low Impact Development Conference Proceedings, 2008

3 Implementation Measures for Reducing Pollutant Concentrations with Source Controls and Treatment

Reduce pollutant concentrations by implementing source control measures and by treatment practices as necessary to meet water quality goals

Stormwater quantity control, along with source and pollution prevention controls, has been determined to be the most reliable means of achieving pollutant reduction and mitigating the many adverse environmental effects of excess urban stormwater runoff (National Research Council 2008). Many issues arise in the decision-making process of selecting stormwater controls. This section addresses some of those considerations related to source-control practice selection and stormwater treatment technologies.

This chapter does not address flood-control considerations. However, note that volume control practices can contribute to flood protection by infiltrating, evapotranspiring, and reusing precipitation that would otherwise contribute to floods. Although volume control is the most important tool to reduce the loadings of urban runoff pollutants to the Chesapeake Bay, some significant sources of pollutants are likely to require source control or treatment. They can include areas with vehicles or other urban/commercial/industrial activity.

A primary consideration in selecting stormwater management practices is the regulatory policy for the site and practice. Local, state, and federal regulations and policies apply, and managers should research these before site design and practice selection. Additional general information on how to choose among the many available stormwater runoff control practices is provided in *Decentralized Stormwater Controls for Urban Retrofit and Combined Sewer Overflow Reduction* (Weinstein et al. 2005).

Source Control/Pollution Prevention

Implementation Measures:

U-10. Identify the pollutants of concern (POCs) to help target the selection of pollution prevention/source control that are most appropriate, for example, nutrients and sediment.

U-11. Implement pollution prevention/source control policies, i.e., nonstructural, programmatic efforts as basic, routine land management practices to target specific pollutants.

U-12. Require source control practices on:

- New and redevelopment site plans for commercial/industrial facilities
- Commercial/industrial facilities through development of a
  - Stormwater Pollution Prevention Plan (SWPPP) where required for regulated industrial facilities.
  - Similar stormwater pollution prevention plans that may be required by local authorities or should be prepared for facility management.
- Municipal facilities or other designated Municipal Separate Storm Sewer System (MS4s) permittees through development of Pollution Prevention/Good Housekeeping programs such as the Stormwater Phase II Minimum Control Measures.

U-13. Develop and implement ongoing outreach programs aimed at behavior change to prevent pollution and control it at its source. Methods for impact and effectiveness evaluation should be incorporated into these outreach and education programs.

U-14. Implement programs for disconnection of directly connected impervious area, such as residential downspout disconnection programs.

U-15. Conduct inspections of commercial/industrial facilities to provide compliance assistance or to ensure implementation of controls.

Runoff Treatment

Implementation Measures:

U-16. Identify the POCs to help target the type of treatment approaches that are most appropriate

U-17. Select treatment practices based on applicability to the POCs

- Use practices to reduce runoff volume as the preferred and most reliable approach to reducing pollutant loading to receiving waters
- Use treatment practices as needed if reduction of runoff is not feasible
- Base the selection of treatment practice on
  - treatment effectiveness for the POC to ensure discharge quality
  - long-term maintenance considerations to ensure continued adequate maintenance and recognition of life-cycle costs
  - site limitations to ensure appropriateness of practice to the site
  - aesthetics and safety to ensure public acceptance

3.1 Source Control/Pollution Prevention

3.1.1 Identify Pollutants of Concern

Regulatory and Policy Drivers. POCs can be regulated by federal, state, or local requirements and policies. For the Chesapeake Bay, critical POCs are evident in the Chesapeake Bay Executive Order, which specifies that N, P, and sediment are POCs that must be controlled to successfully protect and restore the Bay.

Other examples of the types of regulations or issues that can result in specific types of pollutants being identified for reduction include the following:

- Narrative and numeric water quality standards at the federal, state, or local level.
- Specific National Pollutant Discharge Elimination System (NPDES) permit limitations.
- The Toxics Release Inventory makes available to the public annually collected data on the storage, release, and transfer of certain toxic chemicals from industrial facilities. Required under Emergency Planning and Community Right-to-Know Act, its primary purpose is to inform communities and citizens of chemical hazards in their areas.
- TMDL requirements under the Clean Water Act section 303(d) for water quality limited segments (www.epa.gov/owow/tmdl).
- States and local governments can develop watershed pollutant reduction goals, such as the Watershed Implementation Plans being prepared under the Bay TMDL (www.epa.gov/chesapeakebaytmdl/EnsuringResults.html?tab2=1).
- Other pollutants identified in studies evaluating urban runoff characteristics, such as metals from brake pad dust, toxic organics, petroleum hydrocarbons, pesticides and herbicides.

Predominant Land Uses. Specific land uses also contribute to the loading of certain pollutants. Land use type is one predictive indicator for the type of pollutants and typical pollutant loading that would be discharged during storm events. POCs and typical loadings from various land use types can be assumed using modeled data in the literature, such as from the 1983 Nationwide Urban Runoff Program (NURP) (see Table 3-32), or more recent sources. Models that can be used to estimate loading from land use types are provided in Appendix 2 of this chapter.

Table 3-32. Median stormwater pollutant concentrations from NURP study by land use

Pollutant	Units	Residential		Mixed		Commercial		Open space/ non-urban	
		Median	CV	Median	CV	Median	CV	Median	CV
BOD	mg/L	10	0.41	7.8	0.5	9.3	0.31	--	--
COD	mg/L	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/L	101	0.96	67	1.14	69	0.85	70	2.92
Total Pb	µg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total Cu	µg/L	33	0.99	27	1.32	29	0.81	--	--
Total Zn	µg/L	135	0.84	154	0.78	226	1.07	195	0.66
TKN	µg/L	1,900	0.73	1,288	0.5	1,179	0.43	965	1
Nitrate + Nitrite	µg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total P	µg/L	383	0.69	263	0.75	201	0.67	121	1.66
Soluble P	µg/L	143	0.46	56	0.75	80	0.71	26	2.11

Source: Nationwide Urban Runoff Program (USEPA 1983)
CV = Coefficient of variation = standard deviation/mean

More recent quantification of urban pollutants is summarized in the *National Stormwater Quality Database* (NSQD) (Pitt et al. 2004). Tables 3-33 and 3-34 include excerpts from the summary report to highlight pollutant concentrations from typical urban land uses. It is noted that the NURP data and the NSQD data were collected using different protocols, as the NSQD data was collected by MS4s under the NPDES program protocols, and NURP data was collected using U.S. Geological Survey (USGS) protocols.

Table 3-33. Median concentration of typical stormwater pollutants from urban land uses

Land use	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	NH_3 (mg/L)	$N0_2+NO_3$ (mg/L)	Total Kjeldahl nitrogen (mg/L)	TP (mg/L)
Residential	72	49	9	55	0.32	0.6	1.4	0.3
Mixed Residential	86	68	7.6	42	0.39	0.6	1.35	0.27
Commercial	74	42	11	60	0.5	0.6	1.6	0.22
Mixed Commercial	70	54	9.25	60	0.6	0.58	1.39	0.26
Industrial	92	78	9	60	0.5	0.73	1.4	0.26
Mixed Industrial	80	82	7.2	40.4	0.43	0.57	1	0.2
Institutional	52.5	17	8.5	50	0.31	0.6	1.35	0.18
Freeways	77.5	99	8	100	1.07	0.28	2	0.25
Mixed Freeways	174	81	7.4	48	--	0.6	1.6	0.26
Open Space	125	48.5	5.4	42.1	0.18	0.59	0.74	0.31
Mixed Open Space	109	83.5	6	34	0.51	0.7	1.12	0.27

Source: Pitt et al. 2004

Table 3-34. Median concentration of typical stormwater pollutants from urban land uses

Land use	Oil and grease (mg/L)	Fecal coliform (mpn/ 100 mL)	As, total (µg/L)	Cd, total (µg/L)	Cr, total (µg/L)	Cu, total (µg/L)	Pb, total (µg/L)	Ni, total (µg/L)	Zn, total (µg/L)
Residential	3.9	8,345	3	0.5	4.6	12	12	5.4	73
Mixed Residential	4.4	11,000	3	0.8	7	17	18	7.9	99.5
Commercial	4.7	4,300	2.4	0.89	6	17	18	7	150
Mixed Commercial	5	4,980	2	0.9	5	17	17	5	135
Industrial	5	2,500	4	2	14	22	25	16	210
Mixed Industrial	4.75	3,033	3	1.6	8	18	20	9	160
Institutional	--	--	--	--	--	--	5.75	--	305
Freeways	8	1,700	2.4	1	8.3	34.7	25	9	200
Mixed Freeways	4	730	3	0.5	6	8.5	10	--	90
Open Space	1.3	7,200	4	0.38	5.4	10	10	--	40
Mixed Open Space	6	2,600	3	2	6	10	10	8	88

Source: Pitt et al. 2004

Virginia-specific event mean concentrations were analyzed from the NSQD for the Virginia Stormwater program (Center for Watershed Protection and Chesapeake Stormwater Network 2008). The analysis showed significant differences in Virginia data compared to national averages, resulting in recommendation for use of Virginia-specific data for setting statewide or jurisdiction-wide evaluations. Table 3-35 presents the summary of that analysis.

Table 3-35. Result of evaluation of NSQD stormwater runoff quality data comparing national and Virginia-specific EMCs

Parameter	Median EMC (mg/L)
Total Nitrogen	
National	1.9
Virginia	1.86
Residential	2.67
Non-Residential	1.12
Virginia Coastal Plain	2.13
Residential	2.96
Non-Residential	1.08
Virginia Piedmont	1.70
Residential	1.87
Non-Residential	1.30
Total Phosphorus	
National	0.27
Virginia	0.26
Residential	0.28
Non-Residential	0.23
Virginia Coastal Plain	0.27
Virginia Piedmont	0.22
Total Suspended Solids	
National	62
Virginia	40

CWP & CSN. 2008. The Runoff Reduction Method, Virginia Department of Conservation and Recreation,
April 18, 2008, Appendix G

Other sources of information on the types and concentrations of pollutants associated with land use types are provided in Table 3-36.

Table 3-36. Sources of information on typical pollutants by land use type

Reference	Information provided
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Foundation (WERF 2006)	Appendix A. Assessment of Existing Watershed Conditions: Source of Stormwater Pollutants
Maestre, A., R. Pitt. *The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information.* Center for Watershed Protection, and EPA. 2005	Selected information from monitoring conducted for the NPDES Phase 1 stormwater program, from applications and subsequent monitoring, from 1992 to 2002. Approximately 3,765 events from 360 sites in 65 communities are included.

Watershed reconnaissance can be used to identify developed sites that might be hotspots of pollutants. Certain types of land uses, particularly industrial and commercial properties, can be significant sources of POCs that warrant source control and treatment control practices. Managers should evaluate such land use types to identify possible pollutant sources and determine their relative risk to water quality. Those reconnaissance efforts can help a municipality determine the following:

- Which land use(s) and activities are most common in the watershed
- What land uses(s) are expected to change in watershed
- The pollutants that would likely dominate in stormwater runoff, and the form of the pollutant (as total or dissolved, for example, or as organic nitrogen or ammonia) (can be more difficult to obtain)
- Any hotspot areas for the contamination

The identified pollutants are of concern regardless of whether they are impairing receiving streams.

Managers should review monitoring data from the watershed for the historical period of record to ascertain water quality characteristics and POCs. They should review water quality data for POCs to determine information regarding the form of the pollutant, such as

- Particle-size distribution
- Pollutant partitioning or fractionation
- Pollutant speciation, which affects bioavailability, toxicity, and treatability
- Whether the pollutant is exhibited during the first flush (WERF 2005)

That information should be used to determine which treatment unit processes or operations would be most appropriate if source controls are adequate.

Protecting existing uses, in addition to restoring impaired uses, is a critically important goal for restoring any waterbody. Areas of the watershed that are of high-quality and should be protected from degradation should also be identified. Table 3-37 provides resources for conducting watershed assessments to identify pollutant sources and to identify areas for additional protections.

Table 3-37. Sources of information on conducting watershed assessments

Reference	Information provided
National Management Measures to Control Non-point Source Pollution from Urban Areas, EPA-841-B-05-004. (USEPA 2005a)	Watershed assessment practices include examples of programs, methods to characterize watershed conditions and to establish indicators
Healthy Watersheds Initiative, www.epa.gov/healthywatersheds (USEPA 2010b)	Information on Healthy Watersheds, including - Approaches and benefits of conserving and protecting healthy watersheds - A systems approach to watershed assessment - Current assessment approaches being used by regions, states, and communities - Conservation Approaches & Tools - Outreach Tools - Links to projects at the national, regional, state, and local scales

A review of results of industrial/commercial facility inspections can indicate whether these types of properties are likely to become hotspots for pollutants. Additionally, managers can review reports of illicit discharges, illegal connections, and illegal dumping to determine if there are patterns in discharges that might not be predicted by land use alone, which would indicate a need for additional outreach and education or enforcement activity. Information from past inspections and investigations can also help to identify areas with legacy pollutants (spills, dumping, and so on) that need to be addressed before certain types of infiltration practices could be used. Also, managers can evaluate local planning documents to identify potential future land uses that might become sources of pollutants.

A generalized approach for a site assessment is to

1. Identify potential sources
   - By type—commercial, industrial, transportation
   - By risk—of spills, leaks, illicit discharges

- By using existing commercial/industrial databases, land use maps, field investigations, permit applications

2. Prioritize using
   - Pollutants of Concern (POCs)
   - Spill or discharge potential
   - Sensitivity of watershed
   - Past operation experience

3. Generate a list of potential hotspot areas prioritized according to the magnitude and severity of risk

4. Inspect and follow up for implementing corrective measures

References for conducting site assessments are provided in Table 3-38.

Table 3-38. Resources for conducting site assessments and implementing P2 BMPs

Reference	Information provided
Urban Subwatershed and Site Reconnaissance Users Guide. Manual 11 (Wright et al. 2005) www.cwp.org/Resource_Library/Center_Docs/USRM/USRM11_Appendix_C.doc	Includes a Hotspot Site Investigation (HSI) procedure, which quantifies a facility's impact and identifies possible BMPs needed. An inspection form is used to characterize the site, quantify impacts, and identify BMPs.
Urban Subwatershed Restoration Manual No. 9: Municipal Pollution Prevention/Good Housekeeping Practices (Novotney et al. 2008) www.cwp.org/Resource_Library/Center_Docs/municipal/USRM9.pdf	Guidance on how to improve ten key areas: municipal hotspots, municipal construction, road maintenance, street sweeping, storm drain cleanouts, stormwater hotlines, landscaping and park maintenance, residential stewardship, stormwater maintenance, and employee training
Urban Subwatershed Restoration Manual No. 8: Pollution Source Control Practices (Schueler et al. 2005) www.cwp.org/Resource_Library/Center_Docs/USRM/ELC_USRM8v2sls.pdf	Includes methods to assess subwatershed pollution sources, more than 100 regulatory and incentive options, 21 specific stewardship practices for residential neighborhoods, and 15 pollution prevention techniques for control of stormwater hotspots
California Stormwater Best Management Practice Handbooks (CASQA 2004) www.cabmphandbooks.com/industrial.asp	Guidance on preparing stormwater pollution prevention plans, fact sheets for a variety of source and treatment control BMPs, and information on monitoring, reporting, and evaluation
EPA's Menu of BMPs www.epa.gov/npdes/menuofbmps	Pollution Prevention/Good Housekeeping for Municipal Operations BMP Fact Sheets

Aesthetic Issues. Finally, water quality issues that are important to the community should help to determine POCs. For example, if a pond in a public park is being filled with sediment because of upstream construction or algae growth is excessive, sediment and nutrients are POCs for that pond's subwatershed.

3.1.2 Implement Pollution-Prevention and Source-Reduction Policies

Managers should review facility policy and specifications, state and local regulations, standards, and policies, as well as the ongoing pollution-prevention programs, to determine how they can be improved. Identify regulations, incentives or a combination of both that would be most appropriate to address the POC through source reduction or treatment. Evaluate the pollution prevention/source control program to ensure that it is using the most recent approaches and is being effectively implemented.

The following are examples of types of regulations and programs to be considered for POCs:

Excess pollutants from excess runoff

- Disconnection of directly connected impervious area, such as incentives for use of permeable pavement or for downspout disconnection

Nutrients (for additional information, see the Turf Management Section)

- Fertilizer limitations on use
- Phosphate ban (e.g., laundry detergent phosphate bans in Virginia (1988), Maryland (1985), District of Columbia (1986), and Pennsylvania (1990))
- Free yard care consultations/soil testing (e.g., services offered by cooperative extension agencies)

Pesticides

- Inspections of commercial/industrial storage and application procedures (e.g., as part of NPDES industrial facility inspections)
- Integrated Pest Management (IPM) incentives
- Example resources: Urban Pesticide Pollution Prevention (UP3) Project, www.up3project.org

Trash, Oil & Grease, Pathogens

- Stormwater ordinance that addresses trash, commercial loading areas, and such

- Fats, oils, grease program (e.g., JEA FOG program in Jacksonville, Florida)
- Pet waste ordinance (e.g., Virginia Beach Ordinance #1237, www.vbgov.com/file_source/dept/planning/Document/LynnhavenFecalReport2006.pdf)

Sediment

- Erosion and sediment control ordinance (EPA model erosion and sediment control ordinance)
- Disturbed area restoration ordinance
- Tree preservation ordinance (see the Reforestation Fact Sheet)
- Buffer ordinance (EPA model aquatic buffers ordinance)
- Erosion and sedimentation control certification requirements
- Runoff volume control ordinance

Hydrocarbons, Oil/Grease

- The Spill Prevention Control and Countermeasures (SPCC) rule includes requirements for oil spill prevention and response, including requirements for specific facilities to prepare and implement SPCC plans
- Requirements for covers and berms for fueling and fuel storage areas
- Green business certification to reward businesses that have taken tangible steps toward environmental sustainability (e.g., Bay Area Green Business Program)
- Metals
- Restrictions on the amount of copper and other metals contained in brake pads sold in Washington State in the future (State Senate Bill 6657, signed March 19, 2010) (http://www.washington.edu/admin/pb/billtracker/)

Resources for information on pollution prevention and source reduction practices and programs are provided in Table 3-39.

Table 3-39. Resources for information on stormwater pollution prevention practices

CZARA/6217 http://coastalmanagement.noaa.gov/nonpoint/welcome.html
EPA's National Management Measures to Control Nonpoint Source Pollution from Urban Areas, 2005 www.epa.gov/owow/nps/urbanmm/index.html
EPA's Education Resources for Non-Point Source Runoff (USEPA 2010a) www.epa.gov/owow/nps/eduinfo.html
EPA Menu of BMPs www.epa.gov/npdes/stormwater/menuofbmps
California Stormwater Quality Association (CASQA) Industrial and Commercial, Handbook www.cabmphandbooks.com/industrial.asp
2005 Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs www.ecy.wa.gov/biblio/0510032.html
Source Water Protection Practices Bulletin: Managing Stormwater Runoff to Prevent Contamination of Drinking Water, EPA 816-F-09-007 (USEPA 2009c) www.epa.gov/safewater
Source Water Protection Practices Bulletin: Managing Highway Deicing to Prevent Contamination of Drinking Water, EPA 816-F-09-008 (USEPA 2009d) www.epa.gov/safewater
Pollution Prevention Resource Exchange, a clearinghouse for pollution prevention information www.p2rx.org

3.1.3 Implement Source Control Practices

Source controls are the most cost-effective approach to reducing pollutant concentrations; however, to be effective, such controls must be adopted and properly maintained. Some source controls must be implemented as part of the design of the facility itself, such as ensuring that vehicle maintenance operations are conducted in an area where contaminated stormwater will not run off the site.

Table 3-40 shows some examples of source control implementation strategies targeted at specific pollutants. Those strategies are used in many municipal good housekeeping programs and might have applicability at federal facilities—most importantly those that are regulated as MS4s. The Stormwater Phase II Final Rule includes, in addition to local government jurisdictions, certain federal and state-operated small MS4s. Federal-operated small MS4s can include universities, prisons, hospitals, military bases (e.g., state Army National Guard barracks), and office buildings/complexes. The final rule requires the permittee to choose BMPs for each minimum control measure. (USEPA 2005b. *Stormwater Phase II Final Rule: Federal and State-Operated MS4s: Program Implementation* EPA 833-F-DD-D12 www.epa.gov/npdes/pubs/fact2-10.pdf)

Table 3-40. Pollution-prevention and source control practices used widely by municipal programs might have applicability to federal facilities

Strategy/BMP	Nutrients	Pesticides	Pathogens	Sediment	Metals, oil/grease
Require source controls on new and redevelopment site plans for commercial/industrial facilities					
• Require LID/infiltration practices where appropriate (not substitute for pollutant source control, and avoid hotspots)	•	•	•	•	•
• Mandatory storm drain marking for all inlets in maintenance yards, parking lots and along sidewalks	•	•	•	•	•
• Elimination of curb and gutter in favor of bioswales where feasible, particularly in residential or suburban areas	•	•	•	•	•
• Covered dumpster areas			•		•
• Covered outdoor loading/unloading areas that drain to sanitary sewer connections			•		•
• Covered fueling areas					•
• Native plant landscaping	•	•		•	
• Irrigation management	•	•		•	
• Develop leaf collection programs and composting/reuse programs	•	•		•	
• Disconnected roof gutters to minimize parking lot runoff			•	•	•
• Curb cuts to allow parking lot runoff to run into landscaping			•	•	•
Implement downspout disconnection program	•	•		•	
Provide pollution-prevention education					
• Native plant landscaping	•	•		•	
• Soil preparation, restoration, and amendments (composting)	•	•		•	
• Water conservation (e.g., irrigation management)	•	•		•	
• Integrated Pest Management	•	•			
• Household hazardous waste disposal and used oil recycling		•			•
• Car wash education				•	•
• Pet waste management	•		•		
Require source control activities					
• Cover materials/minimize exposure				•	•
• Fleet maintenance conducted inside or under cover					•
• Spill kits and response					•
• Spill training for all staff					•
• Parking lot maintenance			•	•	•

Table 3-40. Pollution-prevention and source control practices used widely by municipal programs might have applicability to federal facilities *(continued)*

Strategy/BMP	Nutrients	Pesticides	Pathogens	Sediment	Metals, oil/grease
Conduct inspections of commercial/industrial facilities to provide compliance assistance or require implementation of controls or both					
Implement source control measures					
• Cover materials/minimize exposure				•	•
• Fleet maintenance conducted inside or under cover					•
• Spill kits and response					•
• Spill training for all staff					•
• Street sweeping street sweeping at a monthly interval (or more frequently) along all curbed roads with speed limits of 35 MPH or less in urban/suburban areas; use regenerative air sweeper technology			•	•	•
• Parking lot maintenance			•	•	•
Establish dog walking areas with signage and locations to properly dispose of dog waste			•		
Inspection high-priority construction projects at high frequency				•	•

The types of pollutants controlled through this strategy will depend on the materials used/stored and the activities conducted at the facilities.

Federal facilities that often require industrial stormwater permit coverage that can contain SWPPP requirements include (www.fedcenter.gov) the following:

- General Services Administration (federal government construction)
- Naval Facilities Command (transportation vehicles)
- U.S. Army Corps of Engineers (DoD construction)
- Bureau of Reclamation (transportation vehicles)
- Other facilities that perform industrial activities, have vehicle fleets, and frequently undergo building construction

Some specific examples of leading municipal programs around the country that might provide information applicable to federal facilities include the following:

- New Jersey's Stormwater Program that includes a comprehensive storm drain marking requirements (http://www.state.nj.us/dep/watershedmgt/DOCS/StormDrainLabeling.pdf)

- San Mateo Countywide Water Pollution Prevention Program, which offers pollution prevention tips geared toward citizens, business owners, and municipalities (http://www.flowstobay.org)
- Seattle Public Utilities' Integrated Pest Management Program and ProIPM Fact Sheets (http://www.seattle.gov/UTIL/Services/Yard/For_Landscape_Professionals/Integrated_Pest_Management/index.asp)
- North Carolina Division of Pollution Prevention & Environmental Assistance's Web site, including the P2 infoHouse, a searchable database of pollution prevention resources (http://www.p2pays.org)

A recent source control program in the District of Columbia is the fee on the disposable bags from retail stores. Bags represent 47 percent of the trash in Anacostia River tributaries. The nickel-per-bag fee is an effort to reduce litter and generate funds to clean up the Anacostia River. The *Washington Post* reported that the fee was having a big effect within 3 weeks from the program's start, reports were that the fee had cut the use of plastic bags by half or more (*Washington Post*, Saturday, January 23, 2010). Reducing such nonessential waste at federal facilities should be considered, and federal facilities should consider supporting that type of initiative undertaken by the local governments.

3.1.4 Public Outreach

Many state and federal agencies require some form of outreach or public education and involvement as part of their water quality laws and regulations. That type of outreach is also applicable for federal facilities, particularly those with MS4 coverage. For example, Phase II of EPA's NPDES stormwater regulations, which requires MS4 operators to develop and implement stormwater management programs, state that localities are to provide opportunities for citizens to participate in developing the program and that they distribute educational materials on stormwater runoff. In all communities, whether regulated as MS4s or not, developing an effective outreach campaign will help gain the critical support and compliance that will lead to the ultimate success of a stormwater management program. Making the public aware of the issues, educating them on what needs to be done, and motivating them to take action will help managers meet both regulatory and water quality objectives.

Changing behavior through education and developing responsible attitudes among watershed citizens and communities is not a simple task. EPA has provided resources to help communities educate local citizens on how to protect local water quality through their own actions. EPA has published *Getting In Step: A Guide to Conducting Watershed Outreach Campaigns.* See http://www.epa.gov/watershed/outreach/documents/. *Getting In Step* approaches outreach using concepts from social marketing. Social marketing means looking at the target audience as consumers. Instead of selling products or services, social marketing sells ideas, attitudes, and behaviors. The goal of social marketing is not to make money, but to improve society and the environment. Social marketing campaign examples include the popular slogan “Only You Can Prevent Forest Fires.” Such campaigns persuade the public that a problem exists that only they can solve. For example, if the goal is to encourage people to test their soil before they apply lawn fertilizer, make it easier for them: sponsor a soil test day on which a local garden supply store hands out free soil test kits and demonstrates their use. This approach will go a lot further toward getting people to test their soil than merely sending out a flyer in the mail.

Getting In Step provides the overall framework for developing and implementing an outreach campaign in concert with an overall water quality improvement effort. It presents the outreach process as discrete steps, with each step building on the previous ones. The steps are as follows:

- Define the driving forces, goals, and objectives
- Identify and analyze the target audience
- Create the message
- Package the message
- Distribute the message
- Evaluate the outreach campaign

The *Getting in Step* guide includes worksheets to help develop an outreach plan, information on additional resources for outreach and education, publications, and other available outreach materials.

EPA also provides the Outreach Toolbox (http://www.epa.gov/nps/toolbox/) for organizations to use to educate the public on stormwater runoff. The toolbox contains a variety of resources to help develop an effective and targeted outreach campaign. Features of the nonpoint source Outreach Toolbox are

- *Featured Products*—Exemplary outreach examples culled from the catalog for increasing awareness and changing behaviors across each of the six targeted topics (general stormwater and storm drain awareness, lawn and garden care, pet care, septic system care, motor vehicle care, and household chemicals and waste) and organized by media type.
- *Searchable Catalog*—Contains more than 700 viewable or audible TV, radio, and print ads and other outreach products to increase awareness and/or change behaviors across six common topics (see Featured Products). Search by media type or topic. Permissions

for using the cataloged products are disclosed (and in most cases, granted) by the product owners, and contact information, campaign Web sites, and other pertinent details are provided.

- *Other Nonpoint Source Outreach Collections*—Links to collections of nonpoint source outreach and educational products compiled by states and other organizations.

3.1.5 Disconnecting Directly Connected Impervious Areas, Such as Downspout Disconnection

In many urban areas, roof downspouts are connected to the storm sewer system or, in some cities, to combined sewer systems. Disconnecting the downspouts allows the roof runoff to drain to the lawn or garden and infiltrate. Disconnection might not be applicable in all situations, depending on safety and property protection needs of each site. One example of a municipal downspout disconnection program is in Baltimore, Maryland (at http://baywatersheds.org/wp-content/uploads/2010/03/DownsputDisconnectionBrochure2010.pdf). The program, which targets sites in the Herring Run and Jones Falls watersheds, provides free surveys and disconnections for homeowners. The program also helps residents install rain barrels and rain gardens.

3.1.6 Inspections of Commercial/Industrial Facilities

A pollution-prevention program should include a component that tracks commercial/industrial activity and includes conducting routine and random inspections of commercial/industrial facilities. The program can be used to provide compliance assistance or to ensure implementation of controls, such as those required under a municipal ordinance. The activity is an integral component of the NPDES MS4 stormwater permit requirements, and technical guidance on approaches for inspection programs—for MS4 communities or for other entities—is provided in EPA's *MS4 Program Evaluation Guidance,* Chapter 4.6 Industrial/Commercial Facilities, January 2007, http://www.epa.gov/npdes/pubs/ms4guide_withappendixa.pdf. This guidance can provide useful information in implementing a program or survey of industrial/commercial operations at federal facilities.

In addition, the Chesapeake Stormwater Network has developed a *Stormwater Pollution Benchmarking Tool for existing industrial, federal and municipal facilities in the Chesapeake Bay Watershed* (http://csnetwork.squarespace.com/whatsnew/csn-releases-technical-bulletin-7.html). The tool guides facilities through a comprehensive assessment of its site to identify stormwater problems and retrofit opportunities, using 22 stormwater benchmarks. The tool also helps facilities develop an action plan to enhance stormwater pollution-prevention efforts at their individual facility.

Examples of stormwater inspection programs for commercial/industrial facilities that might be useful for federal facilities include the following:

- Contra Costa, California *Commercial & Industrial Business Inspection Plan,* 2005, http://www.ci.brentwood.ca.us/pdf/npdes/commerial_industrial_inspection_plan_05.pdf
- Sacramento County Stormwater Quality Program, http://www.sactostormwater.org/industrial/compliance.asp

Key technical components of an inspection program that might be applicable to federal facilities include the following (USEPA 2007):

- *Facility Inventory.* Characterize the facilities and prioritize them on the basis of their potential effect on stormwater quality, and the inspection program should be based on that prioritization approach.
- *Tracking.* A database facilitates program management. The database inventory should include facility type, past inspection or enforcement results, proximity to receiving waters, potential pollutant sources on-site, and other pertinent information to assist in inspection prioritization and management.
- *Standards, BMPs, and Outreach.* Many facilities have stormwater-specific stormwater management standards for industrial and commercial facilities to protect water quality and minimize stormwater pollution. Developing brochures, fact sheets, and posters to hand out to operators during inspections is useful for educating them about appropriate BMPs and inform them of what to expect from the inspection program.
- *Staff Training.* Routine training to ensure that inspectors are knowledgeable is essential to minimizing stormwater pollution from industrial/commercial facilities. It is important to cross-train any other staff used for stormwater inspections as well.
- *Inspections.* Most effective industrial/commercial inspection programs maintain a complete facility inventory and group them according to site-specific priorities. Inspection frequency is determined according to priority. An inspection standard operating procedure should be formalized and documented. It should include a checklist to be used during the inspection and possibly a report format. Inspectors should be aware of federal, state, and local stormwater regulations that might apply to industrial/ commercial facilities. Inspectors should be familiar with various types of BMPs commonly used at the types of facilities being inspected and should be able to educate facility operators about such BMPs. Inspections should be used to identify noncompliance issues and as an opportunity to educate facility operators about proper stormwater BMPs.
- *Program Support and Resources.* Inspection programs should be included in the operating budget.

3.2 Runoff Treatment

3.2.1 Identify Pollutants of Concern

Approaches for identifying POCs are discussed under section 3.1.1. For the Chesapeake Bay, POCs include N, P, and sediment. Source control and pollution prevention are the most effective means for reducing pollutant concentration, used with runoff minimization. Treatment should be used as needed, in addition to the measures of pollutant reduction and runoff minimization to mitigate the identified POCs.

3.2.2 Select Treatment Practices Appropriate to the POC

Treatment Practices and Design Guides. Treatment controls for stormwater, and estimates of their effectiveness, have been summarized in the literature. Example references are provided in Table 3-40. In general, the effectiveness for removing virtually all pollutants, with the exception of gross solids and heavy particulates, is highly variable because of the differences in practice design, nature of pollutants, changes in watershed conditions, and variability in storm characteristics (*Stormwater Best Management Practices (BMP) Performance Analysis,* December 2008, prepared for EPA by Tetra Tech).

Table 3-41 also includes references to sources of information on manufactured devices that might be useful as pretreatment before LID practices.

Table 3-41. References on general stormwater treatment BMP type, effectiveness, and design approaches

Reference	Information provided
Stormwater Treatment BMPs	
EPA's *Stormwater Best Management Practices Design Guide,* Volumes 1-3 (121, 121A, 121B), September 2004. U.S. Environmental Protection Agency, Office of Research and Development, EPA/600/R-04/121, www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm	Three volume series provides guidance when selecting BMPs (either through retrofitting of existing BMPs or applying newly constructed BMPs to new development) to prevent or mitigate the adverse effects of urbanization
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Foundation (WERF 2006)	Describes the performance of infiltration basins, bioretention, grass swales, porous pavement, as well as design and maintenance guidelines, and methods for modeling performance. Appendix D. Literature Review Supporting Design of Infiltration BMPs.
Maryland Stormwater Design Manual www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	Sizing and performance criteria for urban BMPs

Table 3-41. References on general stormwater treatment BMP type, effectiveness, and design approaches *(continued)*

Reference	Information provided
Stormwater Best Management Practices (BMP) Performance Analysis, December 2008, prepared for EPA by Tetra Tech	A procedure and results for estimating long-term performance for several types of LID BMPs designed and maintained in accordance with Massachusetts stormwater standards, but the procedure could be applied in other areas
Center for Watershed Protection Technical Memorandum: The Runoff Reduction Method www.cwp.org/Resource_Library/Center_Docs/SW/RRTechMemo.pdf	A framework for BMP designers to verify compliance with proposed stormwater regulations in Virginia
Water Environment Research Foundation. 2005b. *Performance and Whole-Life Costs of BMPs and SUDS* www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/ResearchProfile.cfm&ReportId=01-CTS-21-TA&CFID=2715758&CFTOKEN=75805127	Research on stormwater BMP effectiveness and cost
International Stormwater Database www.bmpdatabase.org	Compendium of results from studies of BMP effectiveness
Technology Acceptance & Reciprocity Partnership (TARP)	Testing protocols and performance reports for manufactured pretreatment devices
Washington State Department of Ecology, *Evaluation of Emerging Stormwater Treatment Technologies* www.ecy.wa.gov/programs/wq/stormwater/newtech/index.html	Program for evaluating stormwater technologies proposed by vendors, and a clearinghouse for information and decisions on their use
Center for Watershed Protection's National Pollutant Removal Performance Database, Version 3 *www.cwp.org/Resource_Library/Center_Docs/SW/bmpwriteup_092007_v3.pdf*	Compendium of results from 166 studies of BMP effectiveness
Determining Urban Stormwater BMP Effectiveness http://books.google.com/books?id=p5qMMwofaDwC&lpg=PA175&ots=Z_1Tyw56OG&lr=&pg=PA175#v=onepage&q=&f=false (Strecker et al. 2000)	Discussion of protocols for measuring and reporting BMP effectiveness.
Design Approaches	
Chesapeake Stormwater Network's *Baywide Design Specifications* www.chesapeakestormwater.net/baywide-design-specifications2	Detailed design specifications for rooftop disconnection, filter strips, grass channels, soil compost amendments, green roofs, rain tanks, permeable pavers, infiltration, bioretention, dry swales, urban bioretention, filtering practices, constructed wetlands, wet ponds, and extended detention ponds
U.S. Department of Defense. 2004. *Unified Facilities Criteria (UFC) Low Impact Development* http://www.wbdg.org/ccb/NAVFAC/INTCRIT/ufc_3_210_10n.pdf	Design criteria and examples for LID practices

Table 3-41. References on general stormwater treatment BMP type, effectiveness, and design approaches *(continued)*

Reference	Information provided
City of Portland *2008 Stormwater Management Manual* www.portlandonline.com/BES/index.cfm?c=47952	Typical design details for a number of LID BMPs for urban settings
Strecker, E., M.M. Quigley, and B.R. Urbonas. 2000. Determining urban stormwater BMP effectiveness. In *Proceedings of the National Conference on Tools for Urban Water Resources,* February 7-10, 2000, Chicago, IL.	Overview of BMP effectiveness

Table 3-42 lists some of the design manuals that have a specific focus on treatment of nutrients; it is not intended to be a comprehensive list, and updates are routinely made as technology advances.

Table 3-42. Stormwater treatment design manuals or specifications with focus on nutrient removal for urban stormwater

Reference	Information provided
Developing Nitrogen, Phosphorus and Sediment Reduction Efficiencies for Tributary Strategy Practices, BMP Assessment Final Report www.chesapeakebay.net/marylandBMP.aspx (Simpson and Weammert 2009)	Effectiveness estimates, focusing on nutrients and sediment, for a number of urban, agricultural, and forestry BMPs
New York State Stormwater Management Design Manual, Chapter 10: Enhanced Phosphorus Removal Standards www.dec.ny.gov/chemical/29072.html	Phosphorus removal section recently added
Chesapeake Stormwater Network Baywide Design Standards (CSN 2010) www.chesapeakestormwater.net/all-things-stormwater/category/baywide-design-specifications	Specifications for 15 stormwater BMPs
New Jersey Stormwater Best Management Practices Manual www.state.nj.us/dep/stormwater/bmp_manual2.htm	Chapter 4 includes information on meeting nutrient removal performance standards, and Chapter 9 includes design standards
Northern Virginia BMP Handbook www.novaregion.org/DocumentView.aspx?DID=1679	BMP manual with design calculations for phosphorus removal
Virginia Stormwater BMP Clearinghouse www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html	BMP design specifications

The potential for trees and other vegetation to remove pollutants from stormwater as a treatment practice has been evaluated in phytoremediation research but has not yet been widely studied for applicability in sequestering pollutants removed from stormwater or for extending the life of bioretention media. Plants provide nutrient uptake, toxin uptake such as heavy metals, and pollutant breakdown. This is an area for future research. Resources for information on phytoremediation is included in Table 3-43.

Table 3-43. Resources for information on phytoremediation

Reference	Type of information
Phytotechnology Technical and Regulatory Guidance, The Interstate Technology & Regulatory Council 2009 (http://www.itrcweb.org/Documents/PHYTO-3.pdf)	Provides guidance on using vegetation for soil remediation, and estimates of transpiration rates
EPA's Brownfields Technology Primer: Selecting and Using Phytoremediation for Site Cleanup (http://www.clu-in.org/download/remed/phytoremprimer.pdf)	Phytoremediation process, advantages and considerations, and additional resources
Phytotechnology Project Profiles (http://www.clu-in.org/products/phyto/)	Case studies demonstrating phytotechnology applications

Assessing Treatment Technologies. Understanding unit operations and processes is necessary for success of the treatment system design, as well as system O&M. This modern approach for stormwater treatment is based more on traditional industrial drinking water and wastewater treatment concepts, rather than on traditional stormwater approaches that generally addressed only the more basic goal of removing total suspended solids. This approach is presented in *Critical Assessment of Stormwater Treatment and Control Selection Issues* (WERF 2005a) and is applicable as treatment concerns become more focused on removal of P and N. The approach advises users to first select unit operations or processes applicable for POCs on the basis of the pollutant form (i.e., dissolved, colloidal, particulate), chemical speciation (e.g., ionic metal species, P species), and granulometric characteristics (e.g., particle size, specific gravity, surface area), and then individually select the components of a treatment system according to the unit operations or processes that are effective for treating the POCs (see Table 3-44). For example, this approach is presented in the *New York State Stormwater Management Design Manual,* Chapter 10: Enhanced Phosphorus Removal Standards.

A benefit to the LID-approach for stormwater management, both infiltration/evapotranspiration and harvest and use such as in irrigation or in toilets, is that reduction of the runoff volume often translates to a runoff in pollutant loading, as well as the benefit of reducing the excess volumes of scouring, flash-flooding runoff.

Table 3-44. Unit operation or processes and typical treatment system components for fundamental process categories

Fundamental process category (FPC)	**Unit operation or process (UOP)** ***Target Pollutants***	**Typical treatment system components (TSSC)**
Hydrologic Operations	Flow and Volume	Extended retention/detention ponds Wetlands Tanks/vaults Equalization basins
	Volume Reduction *All Pollutant loads*	Infiltration/exfiltration trenches and basins Permeable or porous pavement Bioretention cells Dry swales Dry well Extended detention basins
Physical Treatment Operations	Particle Size Alteration *Coarse sediment*	Comminutors (not common for stormwater) Mixers (not common for stormwater)
	Physical Sorption *Nutrients, metals, petroleum compounds*	Engineered media, granular activated carbon, and sand/gravel (at a lower capacity)
	Size Separation and Exclusion (screening and filtration) *Coarse sediment, trash, debris*	Screens/bars/trash racks Biofilters Permeable or porous pavement Infiltration/exfiltration trenches and basins Manufactured bioretention systems Engineered media/granular/sand/compost filters Hydrodynamic separators Catch basin inserts (i.e., surficial filters)
	Density, Gravity, Inertial Separation (grit separation, sedimentation, flotation and skimming, and clarification) *Sediment, trash, debris, oil and grease*	Extended detention basins Retention/detention ponds Wetlands Settling basins, tanks/vaults Swales with check dams Oil-water separators Hydrodynamic separators
	Aeration and Volatilization *Oxygen demand, PAHs, VOCs*	Sprinklers Aerators Mixers (not common for stormwater)
	Physical Agent Disinfection *Pathogens*	Shallow detention ponds Ultraviolet systems

Table 3-44. Unit operation or processes and typical treatment system components for fundamental process categories *(continued)*

Fundamental process category (FPC)	Unit operation or process (UOP) *Target Pollutants*	Typical treatment system components (TSSC)
Biological Processes	Microbially Mediated Transformation (can include oxidation, reduction, or facultative processes) *Metals, nutrients, organic pollutants*	Wetlands Bioretention systems Biofilters (and engineered bio-media filters) Retention ponds Media/sand/compost filters
	Uptake and Storage *Metals, nutrient, organic pollutants*	Wetlands/wetland channels Bioretention systems Biofilters Retention ponds
Chemical Processes	Chemical Sorption Processes *Metals, nutrients, organic pollutants*	Subsurface wetlands Engineered media/sand/compost filters Infiltration/exfiltration trenches and basins
	Coagulation/Flocculation *Fine sediment, nutrients*	Detention/retention ponds Coagulant/flocculant injection systems
	Ion Exchange *Metals, nutrients*	Engineered media, zeolites, peats, surface complexation media
	Chemical Disinfection *Pathogens*	Custom devices for mixing chlorine or aerating with ozone Advanced treatment systems

Source: WERF 2005a

Estimating Effectiveness of Stormwater Treatment Practices. As noted previously, estimates of the effectiveness of stormwater treatment practices vary for many reasons. The effectiveness of any stormwater BMP—for example, in annual pounds of pollutant removed or in percent of pollutant removed—will be a function of the rainfall pattern, the specific design of the BMP, the watershed and pollutant characteristics, and—for practices that include infiltration or filtration—the nature of the media. Media with high P or N content can export nutrients, while providing effective removals of trace metals. For more information on factors influencing the treatment effectiveness of bioretention and other LID practices, see the Fact Sheets.

A list of stormwater treatment BMPs, and their estimated effluent mean concentrations are provided in Table 3-45. The values are used in a WERF stormwater treatment model (the model name is SELECT) and provide an indication of the effluent quality that can be observed from the practices.

Table 3-45. Default effluent event mean concentration for BMPs used in WERF SELECT model

BMP	TSS (mg/L)		TP (mg/L)		TN (mg/L)	
	MED	STD	MED	STD	MED	STD
Extended Detention[a]	31	2	0.19	0.04	2.72	0.5
Wetland Basins[a]	18	1	0.14	0.02	1.15	0.2
Bioretention[a]	24	2	0.34	0.06	0.78	0.1
Swales[b]	13	1	0.22	0.05	2.72	0.4
Media Filters[a]	16	1	0.14	0.03	0.76	0.1
Permeable Pavement[a]	18	1	0.14	0.03	1.15	0.15

Source: Pomeroy and Rowney 2009

a. Geosyntec Consultants and Wright Water Engineers 2008.

b. Barrett et al. 1998

Estimates of potential pollutant-removal effectiveness were summarized on the basis of a literature review of data on the Chesapeake Bay watershed (*Recommendations for Endorsement by the Chesapeake Bay Program Nutrient Subcommittee and its Workgroups For use in Tributary Strategy Runs of Phase 5 of the Chesapeake Bay Program Watershed Model;* Collins et al. 2009, www.chesapeakebay.net/marylandbmp.aspx). The pollutant-removal estimates provided indicate that the majority of annual reduction in pollutant loading is derived from volume reduction, although some treatment can be achieved with appropriate media (low N and P content) and the conditions to enable denitrification to occur. Estimates of performance for LID practices, and other urban stormwater treatment practices, are provided for the following:

- Dry detention ponds and hydrodynamic structures BMPs
- Dry extended detention basins BMP
- Infiltration and filtration practices (includes bioretention, permeable pavement, infiltration trenches and basins, filters, and vegetated open channels)
- Urban wet ponds and wetlands

Infiltration and filtration practices have the best potential for addressing nutrient treatment of the because of the processes that can occur in the soils (if the soils are not nutrient-rich). LID technologies that do not provide *treatment* include green roofs, which provide volume reduction, and harvesting/blue roofs, which can provide volume reduction if flows are used for irrigation, other use, or can be evaporated. Note that infiltration through soils via applications such as bioretention are different from dry wells because a level of treatment is provided in the soil (see the 2008 EPA memorandum that clarifies that typical stormwater infiltration compared to dry wells, www.epa.gov/npdes/pubs/memo_gi_classvwells.pdf) (USEPA 2008a). The performance estimates for infiltration and filtration practices are provided in the Bioretention Fact Sheet in Appendix 1.

Actual pollutant-removal performance can vary significantly depending on many factors, including regional rainfall pattern, media specification, design features, and watershed characteristics that affect the pollutant concentration and speciation. To obtain more accurate estimates, approaches that combine pilot testing with continuous hydrologic modeling have been performed, for example in EPA Region 1. That type of approach could be successful in developing more accurate performance estimates for specific climate regions and practice designs (*Stormwater Best Management Practices (BMP) Performance Analysis,* prepared by Tetra Tech, Inc., for EPA Region 1 2008, www.epa.gov/region1/npdes/stormwater/assets/pdfs/BMP-Performance-Analysis-Report.pdf).

Long-Term Maintenance Considerations. Maintenance requirements should be evaluated as part of practice selection to help enable a more accurate comparison of the life-cycle costs of the practice. Maintenance considerations can include

- Necessary maintenance activities for the life of the control compared to alternatives
- How placement of the practice can affect maintenance (visibility, and such)
- Level of effort necessary to ensure adequate maintenance
- Frequency of maintenance necessary
- Responsible party to conduct maintenance or ensure continuing use of areas in drainage easements, and mechanisms for enforcement

Resources for information on maintenance considerations are provided in Table 3-46. Additional maintenance information is provided in the fact sheets in Appendix 1. Information on LID O&M costs is provided in Section 2 of this chapter.

Table 3-46. Resources for information on maintenance considerations

Stormwater Manager's Resource Center *Manual Builder* www.stormwatercenter.net	Information on maintenance tracking, frequencies, unit costs, easements, performance bonds, and checklists for maintenance inspections for common BMPs.
Virginia's *Maintaining Your BMP: A Guidebook for Private Owners and Operators in Northern Virginia* (VADCR 2009b) www.dcr.virginia.gov/chesapeake_bay_local_assistance/documents/bmpmaintfinal.pdf	Maintenance guidance for homeowners, homeowners associations, and other, nontechnical audiences.
Lake County, Illinois' *A Citizen's Guide to Maintaining Stormwater Best Management Practices for Homeowners Associations and Property Owners* www.northbarrington.org/files/newsletters/Guide_Final_110404.pdf	Step-by-step guide for planning for and conducting maintenance on common stormwater BMPs.
Pierce County, *Washington's Stormwater Maintenance Manual for Private Facilities* www.co.pierce.wa.us/xml/services/home/environ/water/wq/maintman/MaintManFinal2-22-05.pdf	Includes BMP-specific maintenance information and checklists as well as information on developing a maintenance program.

Physical Site Limitations. Physical site limitations can affect the appropriateness of a practice. These can include the following:

- Lack of adequate pervious area to infiltrate stormwater
- Presence of functionally impervious soils
- Steep slopes or a high groundwater table
- Presence of contaminated soils
- Potential for highly contaminated stormwater (from hotspots) infiltrating and contaminating groundwater source
- Proximity to building foundations, roadways, bridges, abutments, and retaining walls
- Lack of necessary vertical relief to transport stormwater flows
- Conflicts with underground utilities

Example resources for information on some of the site limitation issues are provided in Table 3-47.

Table 3-47. Example resources for information on some of the many site limitation issues to consider

Resource	Limitation addressed
CSN Technical Bulletin No. 1 *Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed Version 2.0,* Chesapeake Stormwater Network, Developed by Karst Working Group, Released June 2009	Infiltration practices in Karst areas
Groundwater Contamination Potential from Infiltration of Urban Stormwater Runoff. Shirley E. Clark, Robert Pitt, and Richard Field; To be published 2009 as Chapter 6 in *The Effects of Urbanization on Groundwater: An Engineering Case Based Approach for Sustainable Development.* Committee on Groundwater Hydrology, ASCE/EWRI.	Risk of groundwater contamination from infiltration practices
Center for Watershed Protection (CWP 2001) *Stormwater Practices for Cold Climates* www.stormwatercenter.net/Cold%20Climates/cold-climates.htm	Cold-climate considerations, including freezing temperatures and high runoff during snowmelt
Urban Small Sites Best Management Practice Manual, Chapter 2: Selecting BMPs (Metropolitan Council 2009) www.metrocouncil.org/environment/Water/BMP/manual.htm	Includes a matrix of physical feasibility factors to aid in selecting BMPs

Aesthetics and Safety. When selecting and designing BMPs, it is important to consider the surrounding land use type, the immediate context, and the proximity of the site to civic spaces to ensure that the site's aesthetics are preserved. Also, access to BMP areas should be limited to protect public safety. Finally, water should not be allowed to stand for longer than 72 hours to prevent mosquito breeding. More information about aesthetic and safety considerations is at the WERF *Using Rainwater to Grow Livable Communities* (WERF 2008b) site (www.werf.org/livablecommunities), particularly on the Green Infrastructure Design Considerations page (www.werf.org/livablecommunities/pdf/design.pdf).

4 Urban Runoff Management for the Redevelopment Sector

The implementation measures listed in Section 2 for reducing runoff volume are expanded in this section because of the importance of addressing redevelopment in the restoration of the Chesapeake Bay or other urban waterbodies.

The implementation measures specifically applicable to redevelopment (repeated from Section 2) are below.

Implementation Measure U-9 (in part):

Develop and implement redevelopment programs that identify opportunities for a range of types and sizes of redevelopment projects to mitigate water resource impacts that

- Establish appropriate redevelopment stormwater performance standards consistent with the goal of restoring predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection, as determined by the appropriate regulatory authority for the region or site.
- Include development of an inventory of appropriate mitigation practices (e.g., permeable pavement, infiltration practices, green roofs) that will be encouraged or required for implementation at redevelopment sites that are smaller than the applicability threshold
- Include site assessment to determine appropriate GI/LID practices
- Review facility planning documents and specifications (as well as any applicable codes and ordinances) and modify as appropriate to allow and encourage GI/LID practices
- Implement GI/LID demonstration projects
- Incentivize early adopters of GI/LID practices
- Maximize urban forest canopy to reduce runoff
- Conduct soil analyses and amend compacted urban soils to promote infiltration

About 50 percent of the residential, commercial, and industrial buildings present in the year 2030 will be constructed between 2000 and 2030 (Brookings Institute 2004), creating opportunities for water quality improvements that our cities must seize if we are to achieve the goals of restoring the Chesapeake Bay or other urban waters. As redevelopment projects occur over several decades, pollutant discharges from developed areas can be gradually reduced as practices are installed to incrementally improve the quality of runoff from existing, untreated developed land.

Sound redevelopment practices incorporate principles of smart growth and sustainable development (USEPA 2005c, 2006). LID practices installed at redevelopment projects in catchments that are served by combined sewer systems can help reduce the frequency and magnitude of CSOs to rivers and estuaries (Limnotech 2007).

Well-planned redevelopment is necessary for many reasons other than just water quality, prompting a growing number of redevelopment project designers and communities to develop holistic approaches for achieving water quality improvements in the redevelopment process in combination with other social, economic, and environmental factors. Water quality programs are an important component of a healthy, vibrant, livable, and environmentally sound community and are a key factor to consider in a redevelopment project.

Encouraging redevelopment, rather than greenfield development:

- Promotes land use efficiency
- Improves the quality of life in urban areas
- Optimizes use of existing public infrastructure
- Provides a tax base to enable maintenance of existing public infrastructure

LID and GI stormwater requirements create an excellent opportunity to facilitate mitigation of the effects of past development at the site or watershed scale, and to address other societal objectives.

Challenges and Opportunities in the Redevelopment Sector. Redevelopment projects require innovative, cost-effective, LID solutions to overcome challenges such as the following:

> *Site Constraints*. Most infill and redevelopment projects are small in area, highly impervious, and have existing utilities and infrastructure, all of which constrain the use of some traditional stormwater practices, particularly those that rely on infiltration through vegetative practices.

High Trash Loads. Runoff from highly urban watersheds is often severely polluted and contains a high load of trash, litter, debris and gross solids (City of Baltimore 2006), which can interfere with the performance of stormwater practices and creates the need for more frequent practice maintenance.

Compacted and Polluted Soils. Soils have been graded, eroded, and reworked by past development, often resulting in compaction such that runoff cannot be effectively infiltrated. In severe cases, legacy problems from past industrial and municipal activity have created *brownfields* that must be capped to prevent infiltration from leaching pollutants or contaminating soils (USEPA 2008b). For those sites with compacted or polluted soils, using infiltration practices might be limited. Example case studies are provided at EPA's Brownfields Program (http://www.epa.gov/brownfields/tools/swcs0408.pdf) (USEPA 2008c).

Natural Stream Network is Altered or Buried. Urbanization has severely altered, reduced or eliminated the natural stream network (National Research Council 2008). The urban stream system that remains is often highly degraded and altered in size and shape, and most development projects discharge to existing storm drain pipes or conveyance channels rather than streams.

Feasibility and Cost of Compliance. The cost of stormwater practices at redevelopment projects in highly urban settings is often more expensive than in new development projects in greenfield settings, where more surface land is available for the practices (Schueler 2007). The potential exists for other types of cost savings or amenity benefits, and they should be considered in addition to capital cost comparisons (Portland BES 2007).

Redevelopment Should Focus on Both Source Control (Pollution Prevention) and LID. Redevelopment sites in the Chesapeake Bay watershed and elsewhere in the nation often discharge to receiving waters that are listed as water quality impaired and require pollutant reductions through TMDLs for a range of pollutants, including bacteria, trash, nutrients, metals and hydrocarbons. All these varied sources should be addressed in redevelopment.

Smart Growth Considerations. Integrating LID practices into high-density land development is an essential element of creating desirable smart growth communities with green infrastructure, and sustainable cities, but it can be a challenge, especially for designers and developers unfamiliar with the practices. Therefore, it is important that managers select stormwater practices that will be consistent with those important redevelopment principles.

Because of those constraints, many urban communities in the Chesapeake Bay watershed (and elsewhere in the nation) have historically waived, relaxed, or otherwise reduced stormwater requirements for redevelopment projects. That has contributed to the continuing deterioration of urban waters. However, in recent years, stormwater managers have taken a more creative approach to treating stormwater from the redevelopment sector (see Figure 3-22 for example) that reflects the following opportunities:

> *New Redevelopment Practices*. In the past decade, considerable research has been conducted, demonstrations made, and experience gained—all of which demonstrate that a variety of LID practices can be used that are specifically adapted for highly urban areas. Those include practices such as expanded tree boxes with supporting structures to prevent soil compression under pavements, green roofs, permeable pavements, and flexible rubber sidewalk sections allowing for less destructive tree root growth). The new practices emphasize the sustainable use of stormwater as part of green buildings and green infrastructure. In addition, the new practices promote larger sustainability objectives such as increased energy efficiency and water conservation, greater building longevity, community greening, safer and more walkable communities, cleaner and cooler air in the summer, habitat for birds, and more creative architectural solutions.
>
> *Green Building and Sustainability Movement*. Designers are seeking *green* certifications for their buildings, and points are awarded for using innovative stormwater practices. Other certification systems reward effective stormwater solutions for the entire site and not just the building itself. Together, such certification systems provide powerful incentives to create innovative stormwater solutions for redevelopment projects.
>
> *Municipal Leadership on Green Infrastructure*. Federal facilities can look to cities that have found that a green approach to designing their streets, parking lots, and buildings can provide multiple benefits in the urban setting, and have retrofitted their infrastructure designs and building codes to allow for green streets and streetscapes, urban forestry, and landscaping areas to treat stormwater (City of Emeryville 2005; City of Philadelphia 2008; City of Portland 2008b; San Mateo County 2009).

With CSO abatement costs expected into the billions, in 1996 the Philadelphia Water Department (PWD), determined that after implementing conventional solutions, local waterways would still have eroded banks poor water quality and habitat. PWD decided to simultaneously address CSOs, the stormwater permit, Clean Drinking Water Act requirements, and repeated flooding, while preserving watershed health. Their strategy targets the sources of urban runoff and water quality problems rather than just symptoms. Philadelphia is focusing on

- A performance-based stormwater ordinance to create incentives for BMP use
- Pilot BMPs for research and education
- A stormwater rate reallocation study to migrate to an impervious-area-based formula

The ordinance encourages a return to predevelopment conditions requiring developers to manage the first inch of stormwater on-site. PWD partnered with other city departments to set up a new development review process. At one time PWD was the last to see development plans, now they are among the first, so they can request changes in designs to accommodate water quality goals before plans are finalized.

The building industry would have more requirements with the new regulations, but the city knew that these were not so different from what they face with greenfield development. The development community could be creative and use combinations of practices to meet the water quality, CSO abatement, and flood control requirements. So many requirements exist for development of green space, that infill development in Philadelphia is easier than in suburban areas.

Some chaos ensued in the first three months of the new ordinance, with pushback from developers and city agencies. Waivers were requested, none were granted. Only a small fraction resorted to in-kind trades implementing BMPs offsite but in the same sewershed. One year and approximately 500 development plans later, the city has seen a significant change in the regulated community. Developers learned which firms adapted to the requirements and can sail through review. There has been a substantial decrease in resubmissions.

The green development *buzz* spread. Developers realized that these BMPs offer benefits beyond stormwater control, and they are trying innovative approaches on their own as part of the trend to build more sustainable (e.g., LEED-certified) buildings. Recently, a public housing authority chose to install porous pavement because it was comparably priced and would allow for smaller drainage pipes. Infill developers garner support for a project by highlighting the potential to reduce neighborhood flooding, as the new requirements *turn back the clock* and improve on predevelopment conditions.

Demonstrating the Benefits of Green Infrastructure BMPs. How do these practices benefit rate payers? PWD showed quantitatively how the approaches help maintain streams and support more conventional infrastructure. They demonstrated cost benefits: each dollar spent on green practices resulted in a tangible improvement. Specifically, staff showed that the stormwater rate reallocation was estimated to alleviate the need for tanks that control 40 million gallons of stormwater, offering a direct financial benefit to the city. All of these efforts gradually changed the image of an institution that historically has been more comfortable with more engineered solutions. Now city officials come to PWD with green ideas of their own.

Future Expectations for the Successful Redevelopment Program. The city expects that charges to residential customers would remain the same or decrease, whereas charges to commercial customers would increase somewhat, as would be expected based on the relative amounts of impervious surface. The city provides other financial incentives, as well, such as a new tax credit for green roofs. Over the long term, the city expects that the stormwater fee will encourage more BMP implementation. They hope that businesses and institutions will consider the balance between initial capital costs for installing a BMP with the reduction over the long term in the rate charged for the stormwater utility.

PWD's staff enjoys the praise they receive from the community on individual projects and from other cities who want to learn from their successes. They are pleased that the development community has embraced the new stormwater regulations and have started to take the initiative in implementing green solutions.

Source: Adapted from the Water Environment Federation *Livable Communities*
http://www.werf.org/livablecommunities

Figure 3-22. Philadelphia: A successful redevelopment approach to restoring water quality, using a municipal example, shows how standards to manage stormwater on-site are accepted into facility planning approaches.

4.1 Establish Stormwater Performance Standards for the Redevelopment Sector Consistent with the Goal of Restoring Predevelopment Hydrology

For all redevelopment sites, establish the means of determining compliance with the performance standard for runoff volume reduction or pollutant reduction. The federal government is leading by example by requiring runoff volume reduction that would either be equivalent to that of predevelopment hydrology, or as a default depth, from the 95th percentile rainfall event. That requirement applies for redevelopment projects at federal facilities and lands nationwide, and is described in U.S. DoD (2009) and USEPA (2009e). It is derived from section 438 of the 2008 Energy Independence and Security Act. In the Chesapeake Bay watershed, that LID requirement would apply to about 1.5 to 1.9 inches of rainfall, depending on where the project is in the watershed.

4.2 Stormwater Management Practices for Redevelopment

A unique set of practices are commonly used to reduce runoff and pollutant loads from the redevelopment sector, as shown in Table 3-48. The practices can be applied to address untreated impervious or pervious areas in the redevelopment sector.

Table 3-48: Example practices for addressing the redevelopment sector

Treat impervious cover	Manage pervious areas
Green Roofs Rainwater Harvesting, including Blue Roofs Foundation Planters Permeable Pavers Expanded, Compaction-protected Tree Pits Flexible Rubber Sidewalk Sections for Tree Pits Urban Bioretention Bioretention	Conserve and Restore Natural area Remnants Soil Amendment and Restoration Reforestation Conservation Landscaping Turf Management Impervious Cover Reduction Create Functional Bioretention from Elevated Parking Lot Islands and Traffic Medians

Note: Where surface area is available, typical on-site LID stormwater practices from the new development sector can be used. In addition, when feasible on-site practices are not capable of achieving full attainment of predevelopment hydrology, restoration practices from the existing development areas may help in mitigation. For more detailed information on each practice, see the practice profile sheets in Appendix 1 of this chapter.

Key considerations in applying these practices are as follows:

- *Use a Roof to Street Design Approach*. Break the site into smaller drainage areas with a unique LID solution for each area (e.g., roofs, pedestrian areas, streets, open space and parking lots). In that manner, stormwater management is directly integrated into the design of buildings, parking lots, hardscapes, open spaces, landscaping, and streetscapes. That avoids the need for underground structures or consumption of costly surface real estate for stormwater practices. The basic approach includes

- Managing rooftop runoff through green roofs, water harvesting, disconnection, or storage and release from foundation planters
- Minimizing surface parking or designing surface parking to reduce, store, and treat stormwater using permeable pavements, bioretention, or biofiltration (see San Mateo County 2009)
- Designing urban hardscapes such as plazas, courtyards, and pedestrian areas to store, filter, and treat runoff using permeable pavers (with storage in the void space of underlying gravel), stormwater planters, and amenity bioretention areas
- Ensuring that all pervious and landscaping areas in the redevelopment project are designed for effective stormwater treatment using practices such as soil restoration, reforestation, and bioretention
- Designing the streetscape to maximize the capture and use of stormwater runoff by using expanded tree pits, street bioretention, curb cut extensions, and other *green street* methods (see City of Portland 2008b; City of Philadelphia 2008; and San Mateo County 2009)

An example of such a design approach is the redevelopment of an office building at 1050 K Street, NW, Washington, DC, in the downtown business district, shown in Figure 3-23. Figures 3-24 and 3-25 provide additional redevelopment examples.

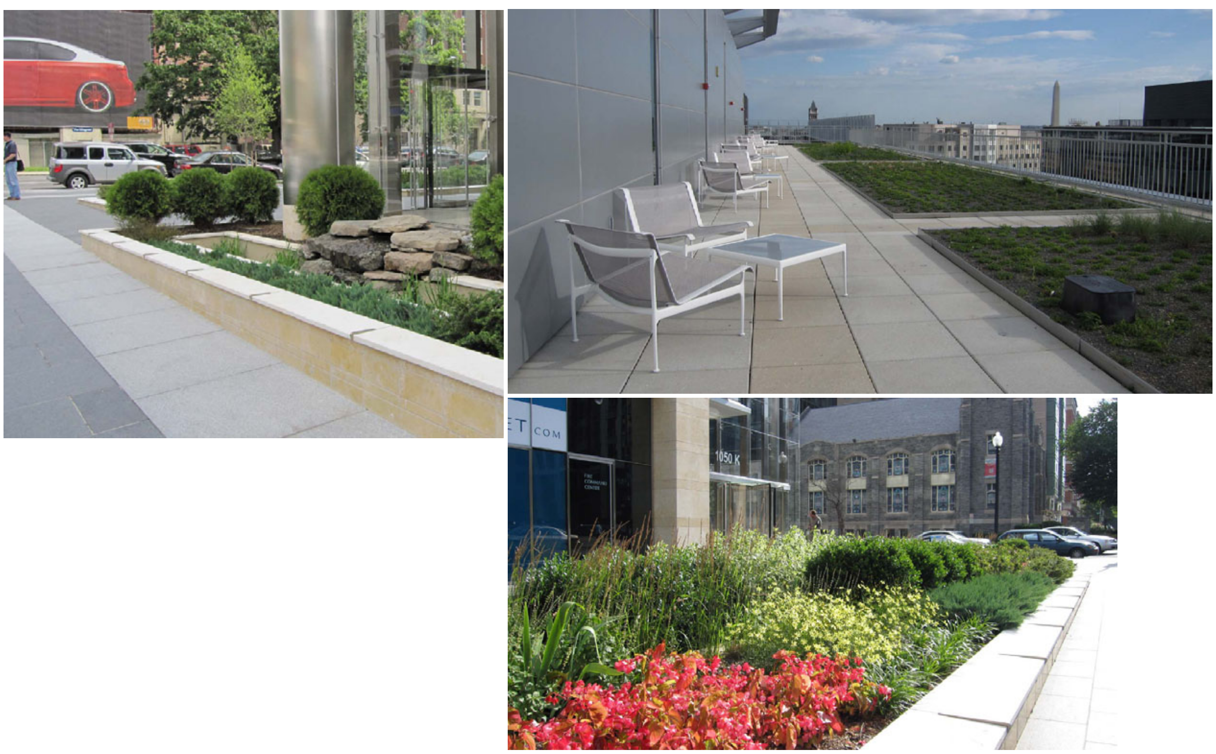
- *Reduce Real Impervious Cover*. Ensure that pervious cover performs hydrologically as if it were an undisturbed pervious area. Deep tilling and amending soils with compost and other materials can increase porosity and water holding capacity. In many cases, runoff from rooftops can be effectively disconnected and drained over such *improved* pervious areas.
- *Identify and Treat Hotspot-Generating Areas*. Require that contributing drainage areas from stormwater *hotspots* be isolated from the remainder of the site (usually by grading and drainage) so that the runoff can be fully treated to prevent toxic discharges to surface water or groundwater.
- *Adapt LID to Urban Design*. Adapt principles such as Better Site Design (CWP 1998) to urban environments. Examples include innovative urban parking management solutions (City of Emeryville 2005), municipal green street specifications (San Mateo County 2009), context-sensitive road design standards providing stormwater treatment in the right-of-way (MC 2008), and modifications to traditional streetscape standards to use

street trees as a stormwater filtering device (City of Portland 2008b; Cappiella et al. 2006; *Stormwater Magazine* March/April 2010).

The potential for green infrastructure to mimic natural systems even in the densest cities is demonstrated at 1050 K Street—a LEED Gold-certified office building in the heart of Washington, DC, on the site of a former parking lot. The site had been 97 percent impervious. The project design reduced impervious area to 67 percent. Runoff from the property occurs only in a major storm event because of the green infrastructure practices employed in the building design:

- Two tiers of green roofs retain rainwater falling on the rooftop
- Three bioretention cells in the building plaza retain and treat runoff from adjacent impervious areas
- A 5,000-gallon cistern beneath the building complements these features by storing any stormwater that cannot be retained.
- All irrigation water is from the cistern, reducing building water consumption and maintaining cistern storage capacity.

This suite of green infrastructure practices provides stormwater benefits, an urban oasis for the tenants and passers-by, and a competitive advantage for the building owners (Lanier 2007).



Photos, courtesy Lu Gay Lanier, The Timmons Group

Figure 3-23. Redevelopment stormwater retrofits at 1050 K Street, Washington, DC, illustrates practices applicable to federal facilities.

In 2009 Manassas Park, Virginia, expanded the elementary school, using an existing impervious parking lot as the site. The new school incorporates many natural educational features, a historic site, and functional stormwater features. Native plants and no-mow meadow grasses are used to enhance the educational experience. The post-development runoff is slightly lower than predevelopment conditions. See a video highlighting the features at http://vimeo.com/chesapeakebay.

A 75,000-gallon rainwater cistern, built to potable water standards, collects rainwater from the entire rooftop area and is used for toilet flushing and irrigation. It is estimated to conserve 1.3 million gallons of water per year. An outdoor classroom with semicircular, stepped seating doubles as a stormwater bioretention cell.

Figure 3-24. Manassas Park Elementary School.

The Yorktown retrofit project serves as a model for residential and business communities demonstrating how green roofs and other stormwater management designs can be implemented to improve water quality, decrease erosive stormwater, and conserve flora and wildlife resources in the Chesapeake Bay watershed.

In designing the green roof, structural concerns relative to the 30-year-old building were a major factor in the decision to use a lightweight building system incorporating waterproofing, root barrier, water retention, and drainage system in one layer. The 15 pound/square foot capacity had to include all weight associated with the waterproofing, growing media, water retention system, and mature vegetation (fully saturated and fully hydrated). The project, including membranes cost $12 per square foot (sf) (for a 4,700-sf green roof system).

It is estimated that the green roof provides a 20 percent reduction in cooling cost and should enjoy a life expectancy of more than 40 years. Initial reports confirm that 80 percent of the annual rainfall is retained on the roof, via a hydrogel technology along with the design of the porous growing media. Other storm water management features consist of rain gardens, a bioswale, and a federally protected biohabitat.

Source: www.greenroofs.org/washington/index.php?page=yorktown

Figure 3-25. Yorktown Square Condominiums, Falls Church, Virginia, successfully implemented a green roof retrofit.

4.2.1 Practice Integration and Assessment Tools

Effective application of the roof-to-street design approach in the redevelopment sector requires creative integration of stormwater practices in buildings, courtyards, streetscapes, and parking lots. Multiple practices are used to treat and reduce runoff from small and different urban surfaces, using a treatment train approach to help ensure the best performance. Redevelopment programs should identify opportunities for a range of types and sizes of redevelopment projects. Practices should be identified that can be encouraged or required for implementation at sites even below applicability area thresholds.

Integrating stormwater management practices into design requires overcoming some of the development *silos* that focus on a single-purpose objective. Landscaping can be designed as functional; parking lots can be designed with drainage features enabling placement of bioretention; opportunities have been identified in many formerly single-use designs.

Several tools have been developed to track progress in meeting the performance standards for the redevelopment sector, and to identify cost-effective combinations of practices at the site. Such tools include the following:

- A series of spreadsheets that allow the user to break the site into smaller drainage areas and size and optimize the most appropriate practices for them. For example Emeryville, California (City of Emeryville 2005), developed a spreadsheet-based calculator to determine the proper size of stormwater treatment devices for new development projects (see http://ca-emeryville.civicplus.com/DocumentView.aspx?DID=109). Virginia Department of Conservation and Recreation (VA DCR 2009a) developed a spreadsheet-based tool to estimate stormwater volume reduction and pollutant removal (see www.dcr.virginia.gov/lr2f.shtml).
- Philadelphia uses a series of checklists and worksheets to achieve the same purposes (City of Philadelphia 2008) (see www.phillyriverinfo.org/PWDDevelopmentReview/RequirementsLibrary.aspx#)

Urban communities in the Chesapeake Bay watershed and elsewhere should adapt and modify such integration tools to meet their unique redevelopment conditions.

Designers might also maximize stormwater *green* points to obtain green building certifications or use the performance benchmarks for sustainable stormwater initiatives (ASLA 2009). See the example in Figure 3-26.

The Eastern Village Condominiums structure is a redevelopment of a former office building that has been transformed into 56 condominium units in a thriving urban community. It is the first LEED-certified cohousing structure. Before construction, the site was more than 90 percent impervious while the new design decreased the imperviousness of the site to 54 percent. Practices installed at the site include a green roof, a vegetated courtyard, and rain barrels.

Roof area: 12,330 sf

Planted area: 8,000 sf

Cost: $36/sf (2006)

Source: www.greenroofs.org/boston/index.php?page=easternwin

Figure 3-26. Eastern Village Cohousing Condominiums HOA, Silver Spring, Maryland, are an example of redevelopment with stormwater management and amenity value from a green roof.

4.3 Site Evaluations

Site evaluations should be conducted to determine the appropriateness of infiltration practices. Soils should be evaluated to determine whether the site is subject to brownfield remediation. Stormwater designers can use the assessments to determine if stormwater runoff can be infiltrated, soils need to be capped, environmental and utility constraints exist, or natural area remnants can be protected or restored. The investigations are also useful to map the best locations for LID practices and how they can be connected as an effective system.

4.4 Planning Documents and Specification Review

Change or supplement planning documents and specifications as necessary to allow the use of certain redevelopment practices (e.g., rainwater harvesting/plumbing codes, green roofs/building codes; green streets/road codes). Some issues that federal facilities deal with are similar to codes and ordinances of local government, and those local government requirements could affect facility planning and design. Examples of municipal guides for codes review to help overcome barriers to LID implementation are EPA's *Water Quality Scorecard* (http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm) (USEPA 2009f), *Better Site Design: A Handbook for Changing Development Rules in Your Community* (CWP 1998) and NRDC's *Out of the Gutter: Reducing Polluted Runoff in the District of Columbia* (Woodworth 2002) (www.nrdc.org/water/pollution/gutter/gutter.pdf).

4.5 Demonstration Projects

Implement demonstration projects to promote and demonstrate green infrastructure techniques. That approach is proven to promote progress in implementing innovative practices.

4.6 Incentives for Early Adopters

EPA provides examples of program types and municipal case studies in the *Managing Wet Weather with Green Infrastructure Municipal Handbook Incentive Mechanisms* (USEPA 2009a). For municipalities, those can include a wide variety of financial and fee-reduction incentives.

For federal facilities, incentives include awards and recognition programs. In addition, when land is leased to private entities, requirements for on-site stormwater management should be included where technically feasible.

4.7 Maximize Urban Forest Canopy

Maximize vegetation and forest canopy across the site to gain incremental stormwater treatment using expanded tree pits, green roofs, foundation planters, and urban bioretention. Information on urban forestry practices is in section 2.8.1, and in the fact sheet on reforestation/urban forestry in Appendix 1.

4.8 Amend Compacted Urban Soils

Urban soils are often compacted resulting in poor infiltration rates. Amending the soil with compost or another soil mixture can significantly increase the infiltration rate for the soils. Information on soil amendment practices are in Section 5 on turf management, and in the fact sheet on soil amendment in Appendix 1. Soil amendments can export N and P, in particular just after installation, so take care to ensure use of low-P-containing soils, and to not offset the benefit of stormwater retention with nutrient export in larger storm events.

5 Turf Management

This section provides guidance on recommended turfgrass management practices that can be used to reduce the impacts of developed and developing areas on water quality. It provides recommendations that address both the initial design of landscapes and management practices that apply to the long-term management of areas planted with turf. Several overall principles guide the development of an effective turf management program.

Ideally, landscapes should be designed to achieve multiple goals, e.g., recreational use, aesthetics, wildlife habitat, water quality, and public health benefits. Designers should consider desired end uses, site conditions, maintenance needs, and potential benefits and other impacts that could result from a given design or set of landscape designs. The design and maintenance of a landscape, whether it is covered by turf or other vegetation, requires the use of an adaptive management approach that should be periodically adjusted according to the original vision for the landscape, changing site conditions, and other factors such as changes in use, local codes, and ordinances and other societal values that can dictate the desired use of the landscape.

For example, municipalities around the United States are implementing green infrastructure programs to modify both the built environment and the associated landscapes to reduce stormwater runoff, urban heat island impacts, air pollution, maintenance costs, and energy consumption. To simultaneously achieve those goals, many cities and private entities are actively trying to promote integrated designs that are more sustainable in the long term, less costly to maintain, more resilient to change, and provide higher levels of environmental protection and improved community livability.

The use of turf in landscapes has a longstanding history and is desirable in many situations for playing fields, access to facilities, safe transportation routes, urban open/green spaces, runoff filtration, and the like. However, all turf does not function equally in terms of use and performance, nor is turf the optimal vegetative cover for all landscape applications in terms of water quality protection. This section provides recommendations on how to manage different categories of turf on the basis of management prescription and environmental performance from a water quality and hydrologic perspective.

The following list of implementation measures provides an overview of the approaches and practices recommended in this section. For purposes of this section, *turf* refers primarily to grass grown on lawns and other landscaped areas in suburban and urban areas and not specifically to sod farms. (Although sod farms are not the focus of this guidance, the turf area cover and distribution numbers developed by the Chesapeake Stormwater Network include turf area cultivated by sod farms in the Chesapeake Bay watershed. For more detail, see Table 3-49.)

Implementation Measures:

Turf Landscape Planning and Design

U-18. Where turf use is *essential* and appropriate, turf areas should be designed to maintain or restore the natural hydrologic functions of the site and promote sheet flow, disconnection of impervious areas, infiltration, and evapotranspiration.

Turf Management

U-19. Use management approaches and practices to reduce runoff of pollutant loadings into surface and ground waters.

U-20. Manage turf to reduce runoff by increasing the infiltrative and water retention capacity of the landscape to appropriate levels to prevent pollutant discharges and erosion.

U-21. Manage applications of nutrients to minimize runoff of nutrients into surface and ground waters and to promote healthy turf

- Where appropriate, consider modifications to operations, procedures, contract specifications and other relevant purchasing orders, and facility management guidance to reduce or eliminate the use of fertilizers containing P

U-22. Manage turf and other vegetated areas to maximize sediment and nutrient retention.

U-23. Reduce total turf area that is maintained under high-input management programs that is not essential for heavy use situations, e.g., sports fields and heavily trafficked areas.

U-24. Convert *nonessential*, high-input turf to low-input or lower maintenance turf or vegetated areas that require little or no inputs and provide equal or improved protection of water quality.

U-25. Use turf species that reduce the need for chemical maintenance and watering, and encourage infiltration through deep root development.

U-26. Conduct a facility or municipal wide assessment of the landscaped area within the facility property or jurisdiction. This assessment should include

- A map of the jurisdiction or facility, including the identification of all turf and other landscape areas

- An inventory or calculation of the total turf and other landscape area in acres or hectares using GIS techniques or other methods
- An evaluation to determine essential and nonessential turf areas
- Identification and delineation of all high-input, low-input, and no-input turf areas
- An evaluation of turf management activities and inputs, preferably by turf category or significant turf area within the facility or jurisdiction
- An assessment of landscape cover type benefits such as pollution load reductions and resource savings, e.g., water and energy that are provided by each landscape cover type
- An assessment of landscape cover type health, infiltrative and pollutant loading capacity and opportunities to increase soil health to promote the infiltrative capacity of turf and landscape areas
- An assessment of surface water and groundwater loadings related to high-input, low-input, and no-input turf area

U-27. Develop a management plan that contains

- An analysis of options to reduce or eliminate *nonessential* turf or convert *essential* turf to low-input turf that performs optimally from a water resource protection perspective
- An analysis of turf areas to identify opportunities to maximize water quality benefits of landscapes in regard to runoff, in-stream flows, infiltration, groundwater recharge and sediment, nutrient and pathogen loadings
- A landscaping approach that integrates turf management within the context of natural resource and habitat plans
- Stated goals and objectives regarding the reduction of turf related inputs (water, fertilizers, pesticides, fossil fuels) and maximizing water resource benefits on a facility- or municipality-wide basis
- An analysis of options to reduce potable water use by using cultural practices, hardy cultivars, or recycled water or harvested runoff
- An identification of areas where soil amendments can be used to enhance soil health and the infiltration capacity of the soils
- Areas of turf that could be used to manage runoff
- Areas of turf that could be replaced by lower maintenance cultivars or other grasses such as switch grass

- A training program for landscaping personnel
- An implementation schedule
- An annual landscaping inventory and progress report

U-28. Develop and implement ongoing public education and outreach programs Bay-friendly lawn, landscape, and turf management. Programs should target behavior change and promote the adoption of water quality friendly practices by increasing awareness, promoting appropriate behaviors and actions, providing training and incentives. Impact and effectiveness evaluation should be incorporated into such outreach and education programs.

5.1 Background

In the Chesapeake Bay watershed, turf has been estimated to cover 3.8 million acres or 9.5 percent of the total land area. Turf, in terms of total area, is now the number one cultivated ground cover grown in the Chesapeake Bay watershed (Chesapeake Stormwater Network 2010). Tables 3-49, 3-50, and 3-51 adapted from the Chesapeake Stormwater Network (2010) reflect estimates of turf cover by state, distribution by landscape category or sector, and by county with the highest turf density. Figure 3-27 illustrates turf density by county in the Chesapeake Bay watershed that appears to show a positive relationship between degree of urbanization and turf cover density.

Table 3-49. Year 2001 turf cover estimate using a GIS and satellite data

State	Land acres in bay watershed	Urban[a] turf acres	Exurban[b] turf acres	Total turf acres	Percent land area with turf
MD	5,639,428	1,007,269	298,476	1,305,745	23.15%
VA	13,706,037	988,291	135,792	1,124,083	8.20%
PA	14,345,262	900,803	158,212	1,059,015	7.38%
DC	38,956	16,071	2,320	18,391	47.21%
DE	450,384	31,337	3,648	34,985	7.77%
NY	3,983,079	160,788	32,982	193,770	4.86%
WV	2,288,363	75,515	12,425	87,940	3.84%
Total	40,451,509	3,180,074	643,855	3,823,929	9.45%

Source: Chesapeake Stormwater Network 2010.

a. Urban area includes impervious and non-forested pervious surfaces in industrial, commercial, and residential areas with lot sizes generally less than 2 acres.

b. Exurban areas represent all non-urban lands. The *urban recreational grass* land cover class was solely used to identify turf grass in exurban areas.

Table 3-50. Distribution of turf grass by sector in Maryland, Virginia and New York (percent)

Turf sector	1989–1998[a]	MD 2005	VA 2004	NY 2005
Home lawns	70	82.6	61.6	82.1
Apartments	nd[b]	0.6	nd	0.8
Roadside Right-of-Way	10	4.3	17.5	nd
Municipal Open Space	7	3.5	6	nd
Parks	3.5	1.9	2.5	1.9
Commercial	nd	nd	5	0.3
Schools	3	3.4	2.9	1.6
Golf Course	2.5	1.4	2.2	3
Churches/Cemeteries	2	1.2	1.4	1.1
Airports/Sod farms)	1	1.1	0.9	0.6

Source: MDASS 2006, VADACS 2006, and NYASS 2004, as reported in Chesapeake Stormwater Network 2010.

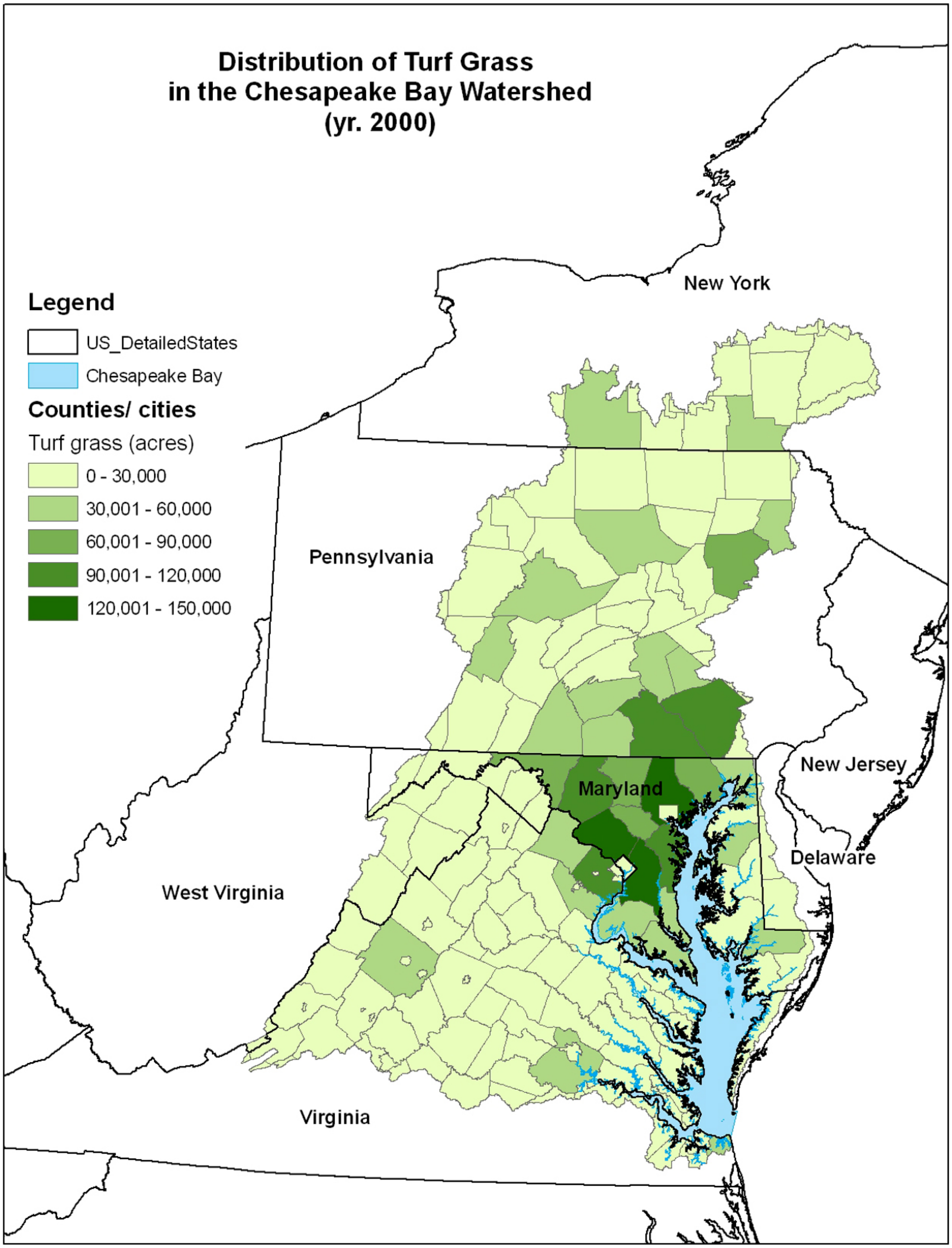
a. Average of three states: MDASS (1996), VAASS (1998) and PAASS (1989)

b. nd = no data because the indicated turf sector was not sampled or estimated

Table 3-51. Counties in the Bay watershed with the highest turf grass cover based on GIS

Jurisdiction/county	State	Turf acres	Total land acres	Percent turf
Montgomery	Maryland	140,272	317,420	44.20%
Baltimore	Maryland	136,456	379,708	35.90%
Prince George's	Maryland	121,008	306,846	39.40%
Lancaster	Pennsylvania	119,615	605,215	19.80%
Fairfax	Virginia	116,932	251,360	46.50%
York	Pennsylvania	110,564	577,749	19.10%
Frederick	Maryland	96,309	424,381	22.70%
Anne Arundel	Maryland	93,081	260,832	35.70%
Carroll	Maryland	85,114	286,896	29.70%
Harford	Maryland	77,084	272,524	28.30%
Howard	Maryland	66,239	160,906	41.20%
Luzerne	Pennsylvania	63,887	486,405	13.10%
Washington	Maryland	61,527	295,043	20.90%
Dauphin	Pennsylvania	56,347	337,650	16.70%
Henrico	Virginia	55,643	150,305	37.00%

Source: Chesapeake Stormwater Network 2010.



Source: Chesapeake Stormwater Network 2010

Figure 3-27. Distribution of counties with high turf cover in the Chesapeake Bay watershed.

The increase in turf area reflects a national trend according to Robbins and Birkenholt (2001) who examined turf in terms of land use/cover changes and the "expansion of high-input, monocultural, lawn landscapes," that "bring with them inputs of insecticides, herbicides and fertilizers...expanded use of lawn maintenance tools" such as mowers and "changes in soil profile, stormwater runoff, water consumption, micro-fauna diversity, energy use, air quality and habitat impacts." Fender (2008) reported that nationally, "There are an estimated 50 million acres of maintained turfgrass in the United States on home lawns, golf courses, sports fields, parks, playgrounds, cemeteries, and highway rights-of-way." Milesi et al. (2005) reported that nationally, 15.8 million acres (31.6 percent) of cultivated turf is in home lawns.

Turf that is properly located, selected, and maintained can provide water quality benefits, especially when used to reduce the effects of impervious surface cover (Beard and Green 1994; Carrow et al. 2008). As noted earlier in Sections 1–3 of this chapter, the use of practices that can reduce the effective impervious surface area of a developed area is encouraged. Landscapes planted with turf can effectively be used to treat runoff in grassed swales and filter strips and are commonly used along transportation systems and the borders of agricultural lands to reduce runoff pollutant loadings. Schueler (1987) described how such grassed systems can be designed for the catchment and filtration of runoff. For more information regarding the benefits of grass swales to manage runoff from agricultural fields, see Chapter 2. Grass swales also have proven to be effective in treating pollutants in highway runoff (Davis 2009).

The conversion of native landscape to turf, however, inevitably results in ecosystem-level changes regardless of how the turf is managed. For example, the conversion of native forest or native vegetation to turf or other cultivated landscapes can cause reductions in evapotranspiration; increases in runoff volumes, velocities and duration of flows; increases in runoff temperature; microclimate changes; decreased infiltration; changes in soil health and biota; and loss of species diversity and habitat. Infiltration tests conducted in a North Carolina watershed found that a medium-aged, pine-mixed hardwood forest has a mean final constant infiltration rate of 12.4 inches per hour; however, when the forest understory and leaf litter were removed, the resultant lawn had a mean infiltration rate of 4.4 inches per hour (Kays 1980). Dierks (2007) discussed the hydrologic benefits of native landscapes in his publication *Not all Green Space is Created Equal* and made the point that the heterogeneous nature of native landscapes typically results in stable ecological systems that do not require the level of inputs that managed turf typically requires. Dierks used Table 3-52 (adapted from Bharati 2002) and Figure 3-28 to emphasize the benefits of native landscapes and to compare the differences in hourly infiltration rates of different vegetative cover types such as silver maples and switch grasses and the differences in grass root depth and structure between native grasses and Kentucky bluegrass. Note, however, that changes in infiltration rate and soil health also can be due to land disturbances that occur during the development process. Typical land clearing practices often strip fragile topsoils from the site and compact the subsoils. In such situations, soil amendments can be used to restore soil health, and turf is often an appropriate cover to prevent erosion and reduce runoff related problems.

Table 3-52. Average hourly infiltration rates from multispecies buffer (adapted from Bharati et al. 2002)

Treatment	Jun	Aug	Oct/Nov	Avg
		(cm/hr)		
Silver Maple	38	46	30	38
Grass Filter	29	20	25	25
Switchgrass	27	8	21	19
Bean	8	9	13	10
Corn	3	5	3	4
Pasture	2	4	3	3
Sandy Loam				1.1*
Silty Clay Loam				0.3*

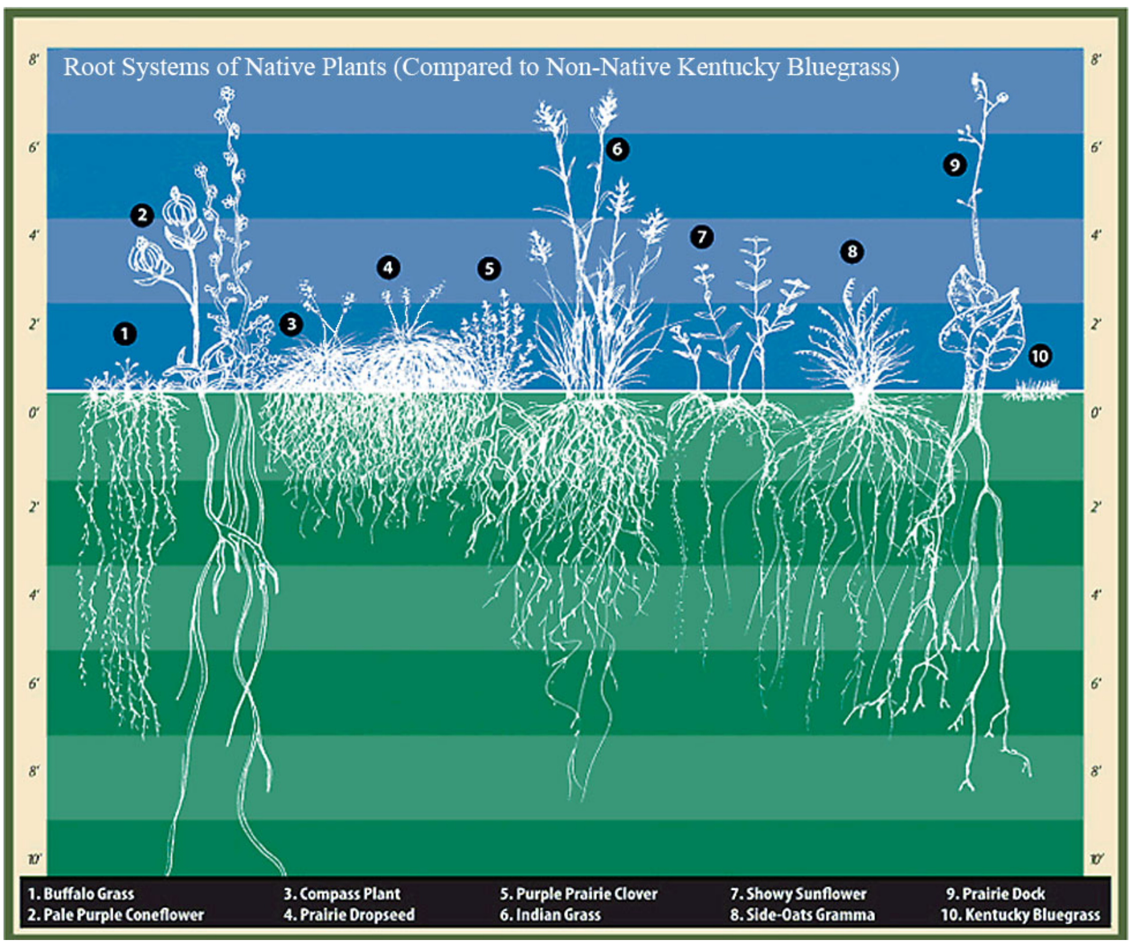


Figure 3-28. Comparison of native prairie and turf grass root and shoot growth.

Turf type and management practices also influence the behavior of turf in terms of changes in runoff hydrology and pollutant loadings. *High-input turf* is irrigated, frequently mowed, fertilized at rates of 3 to 5 lbs N/1,000 ft^2/year, and/or treated with pesticides as part of its regular maintenance regime. *Low-input turf* has little or no irrigation, is frequently mowed, fertilized at lower rates (1-2 lbs N/1,000 ft^2/year), and has low pesticide application. *No-input turf* is not irrigated, fertilized, or treated with pesticides and in some cases is mowed infrequently or not at all (Wilbe 2010).

5.2 Turf-Related Impacts

The following section contains descriptions of the main water quality related effect that can result from the cultivation and maintenance of turf.

5.2.1 Fertilizer Applications

The rate at which fertilizer is applied to home lawns and commercial and institutional landscaping varies depending on the level of maintenance (high or low input) and who is maintaining it (homeowners or lawn care companies), as shown in Table 3-53.

Table 3-53. Lawns managed by homeowners versus other lawn services

Comparative chemical application rates in pounds/acre/year in Maryland					
Chemical	**Cropland[a]**	**Golf fairway**	**Greens**	**Home lawn (do-it-yourself)**	**Home lawn (lawn service)**
N	184	150	213	44–261	194–258
P	80	88	44	15	no data
Pesticides	5.8	37.3	45.1	7.5	no data

Source: http://www.cwp.org/Resource_Library/Center_Docs/PWP/ELC_PWP129.pdf.
Note: a. Corn/soybean rotation

A residential lawn care survey, undertaken by Law et al. (2004) as part of the Baltimore Ecosystem Study, assessed fertilizer application rates and the factors that affect those rates to estimate N input from lawn care practices in urban watersheds. The results indicated a wide range in the rate of fertilizer N applied by homeowners and lawn care companies, averaging 1.99 lb/1000 ft2/year (about 88 pounds per acre) with a standard deviation of 1.81 lb/1000 ft2/year. Factors that affected fertilizer application rate include social economic factors (market value of the house, age of development) and soil characteristics (soil bulk density and soil N content). A 2010 inspection of information provided on lawn fertilizer products sold in gardening and appliance stores in the Chesapeake Bay watershed found that the manufacturers typically recommend four fertilizer applications annually. On the basis of the manufacturers' application recommendations, the typical user could apply the products at approximately 140 pounds per acre.

Schueler (2000d) estimates that home lawns account for 70 percent of total turf area in the Chesapeake Bay watershed, half of which is maintained as high-input turf. The remaining 30 percent of total turf area is public turf, including parks, golf courses, schools, churches, cemeteries, median strips, utility corridors, and office parks, of which one-third is estimated to be maintained as high-input turf. Applying those estimates to the estimated 3.8 million acres of turf in the Chesapeake Bay watershed yields 1.71 million acres maintained as high-input turf and 2.09 million acres maintained as low-input turf. Annual N applied to turf areas in the watershed, estimated using the definitions of high-input and low-input turf presented above, is approximately 389 million pounds of N per year.[1] Such a magnitude of N use in the watershed underscores the need for management practices that reduce risk, ranging from high-quality nutrient management planning and implementation by institutions to turf reduction actions, to prevent excess N from entering the Bay.

5.2.2 Irrigation

Irrigation of turf grass contribute to water shortages and overwatering can lead to poor turf health and runoff problems. Turfgrass-dominated landscapes can require the use of more water than landscapes consisting of a mix of groundcovers, shrubs, and trees. Grass generally consumes eight units of water compared to the same area of trees (five units), and shrubs and ground covers (four units) (Foster 1994).

5.2.3 Energy and Air Quality

Lawns that are mowed have energy costs and air quality impacts, depending on the type of mower used. According to Paul Tukey, founder of SafeLawns.org, a Maine-based nonprofit dedicated to minimizing the environmental effect of lawn care, gas-powered mowing, weed-whacking and edging a modest-sized lawn (625 square feet) for one month would use approximately 6 kilowatt hours or 0.2 gallon of gas (Mosko 2009).

Gas-powered lawn tools are also significant sources of smog and carbon monoxide. According to Clean Air Lawn Care's Clean Lawn Calculator (http://www.cleanairlawncare.com/calculator/), assuming conditions consistent with Maryland or Virginia with 36 mows per year for 1.7 million acres of high-input turf in the Chesapeake Bay watershed, gas-powered lawn equipment

[1] For this calculation, high-input turf is assumed to have an N application rate of 4 lb N/1000 ft^2/year, which is the midpoint of the high-input range defined previously. The N application for low-input turf is assumed to be 1 lb N/1000 ft^2/year, which is the low end of the 1 to 2 lb N/1000ft^2/year range to account for homeowners who do not apply any fertilizer.

produces 3,891,470,584 annual pounds of air pollution. That number can be reduced to 2,233,912,919 by using electric lawn equipment (powered by conventional energy) because electric mowers emit 3,300 times less hydrocarbons, 5,000 times less carbon monoxide, and one-fifth as much smog-forming N oxides as gas lawn mowers. Self-powered push mowers do not generate any air pollution, and they have the added benefit of mulching and depositing grass clippings on the lawn.

5.3 Turf Management Strategies, Practices, Resources and Examples

To ensure that turf performs optimally from a water-quality as well as a broader environmental perspective, the following turfgrass cultural practices should be promoted and encouraged.

5.3.1 Turf Landscape Planning and Design

The design of landscapes should be considered within the context of the site, facility and watershed. The use or degree of use of turf on a site will be dependent on a number of factors such as existing vegetative cover, soils, geology, intended use of the site and other environmental factors such as water quality and wildlife habitat protection. In areas where the natural vegetative cover, e.g., mature deciduous hardwood forest, will be initially developed, the designer should strive to retain as much natural vegetative cover as possible within the design context of the new development to preserve site hydrology, soils and existing wildlife habitat and reduce the need to restore, plant and manage disturbed soils. Lands regardless of vegetative cover type that are obviously degraded should be managed differently and can require restoration. For example, redevelopment and retrofit projects often present the designer with a much different set of factors and challenges to contend with given the existing site conditions. Soils in heavily urbanized areas and brownfields are often very poor, compacted, and not good media for growing and sustaining healthy plants; nor do they promote the level of infiltration necessary to reduce runoff, prevent erosion, filter pollutants maintain stream baseflow and aquifer recharge. Turf, in such conditions, might be a suitable choice for the designer to help restore the hydrologic function of the urban landscape, reduce pollutant loadings resulting from erosion of degraded soils, and provide urban open spaces. Designers also might want to consider laying vegetation using turf or other groundcovers and shrubbery and trees to increase the benefits of vegetation on runoff interception, evapotranspiration and nutrient uptake, and wildlife habitat.

Rating systems or metrics such as the Sustainable Sites Initiative (SSI) Guidelines and Performance Benchmarks 2009 might be useful in assessing designs to determine how well the designs meet multiple objectives for site sustainability in terms of site hydrology, vegetation, soils, human factors, and such. More information on SSI and similar rating systems is at the following sites:

- Sustainable Site Initiative Guidance and Performance Benchmarks 2009 (http://www.sustainablesites.org/report)
- Leadership for Energy and Environmental Design, LEED® for New Construction & Major Renovations (http://www.usgbc.org/ShowFile.aspx?DocumentID=1095)

5.3.2 General Turfgrass Best Cultural Practices

The following list of practices can be used to promote healthy turf that provides the desired use and environmental performance (Wilbe 2010). More details and examples of specific turf management practices are provided in subsequent sections.

Soil improvement

- Mulch clippings back into the grass. Recycling clippings onto lawns improves soil organic content and returns nutrients to the soil.
- Aerate compacted sites annually. Aeration loosens soil to improve water infiltration, air exchange, and plant rooting.
- Apply nutrients, as appropriate according to management goals, in spring, fall, or both, when roots are actively growing. Feeding stimulates root development, which in turn adds more organic matter to improve soil qualities.
- Mulch deciduous tree leaves into lawn areas. Directly mulch leaves into turfgrass where they will degrade into the turf canopy and add soil organic matter.

Preserve or enhance stand density

- Mow at heights of 3 inches and higher. Grass maintained at higher heights will support a larger root system to best sustain itself especially during times of stress. Taller grass can also help to naturally crowd out invasive weeds.
- Use soil and turf enhancement practices to increase turf density as appropriate for use, location, and environmental goals.

Water conservation

- Avoid watering during drought periods. Grass can go dormant in months when water is scarce and safely recover when rains return.

- Mow high to capture more water. Taller grass maintains denser roots to access more available soil moisture throughout the year.
- Feed in the spring and/or fall months. Feeding in the spring allows grass to grow deeper roots and develop reserves prior to summer stress periods. Fall feeding helps grass recover from any damage

Fertilizer care

- Feed only when grass is actively growing. Avoid feeding during periods of drought or when the ground is frozen (December–March).
- Apply fertilizer only to lawn areas. Sweep any material from paved impervious surfaces back onto lawns. Avoid fertilization runoff or deposition into waterbodies.
- Use proper fertilizer spreaders that have been calibrated. Use drop or rotary spreaders with side guards to keep fertilizers off of impervious surfaces
- Avoid fertilization before heavy rainfalls

Clippings management

- Sweep clippings off of impervious surfaces to avoid discharges into surface waters.

The Golf course industry provides a good example that illustrates the benefits of outreach and education efforts that promote the implementation of better practices. The industry—recognizing its role in promoting golf course designs and management practices that can be used to manage turf in an environmentally sound manner—developed golf course design and management principles and research and educational programs to promote that agenda.

The Golf and Environment Initiative was developed to further promote those goals. More information is at http://www.golfandenvironment.com/.

Numerous states and communities are also addressing the need to promote consistency and improved practice in terms of golf course management. The *Golf Course Water Resources Handbook of Best Management Practices*—recently produced by LandStudies, Inc., and the Pennsylvania Environmental Council, funded by the Pennsylvania Department of Environmental Protection (2009)—is one example of such a tool. The handbook pulls from the knowledge and experience of many golf course superintendants and provides a nice background on the importance of mapping, irrigation and water reuse practices, selecting and applying chemicals and fertilizers knowledgably, increasing the use and area of native plants and naturalized areas, as well as other topics. The document reviews 18 BMPs specific to golf courses. The document is at http://www.pecpa.org/files/downloads/Golf_BMP_Handbook_3.pdf.

Public education is also an important aspect of promoting better turf management practices. A good example of a program developed to change public behavior and promote better cultural practices to manage turf is Austin, Texas', *Grow Green* program. The city recognized the need to protect the Edwards aquifer and surface water quality from nutrient impairments and conducted a lawn fertilization and management study to reevaluate common fertilizer recommendations. As a result, the city recommended new residential lawn fertilization practices that change those promoted statewide for the last 20 years. Those recommendations were developed within the context of a comprehensive outreach program that educates the public about proper turf management practices. This program is a partnership among extension offices, retailers, nurseries, and government (state, municipal and federal). More information is at: http://www.ci.austin.tx.us/growgreen/.

5.3.3 Fertilizer Management

Soil tests are commonly used to manage fertilizer applications to optimize application rates and reduce runoff and leaching. Determining the nutrient N and P needs of lawns by the soil concentrations of P might not adequately predict proper application rates or potential for runoff or leaching of nutrients. Furthermore not all soil tests analyze for soil N content.

N should be applied on the basis of established requirements for grass species, season of growth, and intended use. Ideally fertilizers should be applied on the basis of the limiting nutrient and concentrations of nutrients determined by soil testing and local experience and research recommendations for the species being cultivated. Soldat et al. (2008) examined soil P concentrations in New York State and reported that their results suggest that "soil testing will not be an effective tool to predict runoff from turfgrass areas across the range of soil P levels common to New York State." Spreaders used to apply the fertilizer should be carefully calibrated to ensure even application at prescribed rates. The timing and methods of fertilizer application are also important. Lawn fertilizer should be applied in the early or middle spring and in the fall when turfgrass absorbs the most nutrients; fertilizer should never be applied when the ground is frozen (Wilbe 2010). Weather is also a consideration; fertilizer should not be applied during or before wind or rainstorms to prevent pollution of air and surface runoff. The type of spreader used can also reduce pollution; drop spreaders or rotary spreaders with a side guard help to keep fertilizers on the lawn and off impervious surfaces (Wilbe 2010). To determine application recommendations, refer to local guidance.

A number of researchers have demonstrated a connection between proper N fertilization, increased infiltration and reductions in runoff volume and P losses in runoff. (Easton and Petrovic 2004; Kussow 2008). Increasing plant density through fertilization can be a means to reduce runoff velocity and promote infiltration. Soldat and Petrovic (2008), however, also noted that, "Sediment losses from turf areas are negligible, generally limited to establishment, but runoff and leaching losses vary from inconsequential to severe depending on rate, source and timing of fertilizer application," and "Soil properties were found to have a larger effect on runoff volume than vegetative properties." Areas where turf is exists or is planned should be evaluated to determine whether fertilization and soil improvements can improve runoff management performance.

Some communities have implemented policies to restrict fertilizer application or prohibit P-containing fertilizers in watersheds that are sensitive to P enrichment. The following are examples of such types of policies.

- Chesapeake Bay Program Memorandum of Understanding (MOU): On September 22, 2006, the Chesapeake Executive Council, Headwater State Jurisdictions, and members of the lawn care product manufacturing industry signed an MOU that was intended to achieve a 50 percent reduction in the pounds of P in do-it-yourself lawn care products by 2009 (as compared to a 2006 base year). The MOU further committed the signatories to reduce N nutrient losses by recommending possible changes in product content, form, or application method, as well as develop outreach materials to educate the general public on the use of fertilizers. As a result, the industry achieved a 76 percent reduction in P before 2010, with elimination of P from all maintenance products scheduled for 2012; introduction of soil testing for homeowners; adoption of new applicators with a side guard that prevents application to hard surfaces as a standard feature; and education and outreach (radio public service announcements, print media, improved labeling, and point of purchase education). In addition, all lawn fertilizers now contain slow-release N and limited amounts of soluble N. Finally, a 32 percent reduction in N application rates and overall N pounds sold and used has been achieved compared to 2006.

- Annapolis, Maryland, recently became the first municipality in the Chesapeake Bay watershed to adopt an ordinance banning the use of fertilizer that contains P. Since January 1, 2009, residents have been required to use only P-free fertilizer, except in gardens, on newly established turf, and in cases where a soil test shows a P deficiency. For more information, see www.annapolis.gov/upload/images/government/council/Adopted/o1008.pdf.

- The New Jersey Department of Environmental Protection (NJDEP) is mandating that more than 100 New Jersey municipalities adopt local ordinances prohibiting the use of fertilizers containing P except under special circumstances (see ordinance details at www.state.nj.us/dep/watershedmgt/DOCS/TMDL/Fertilizer Application Model Ordinance.pdf). The state is also working to reduce fertilizer application statewide. In April 2008 NJDEP signed an MOU with two major fertilizer producers to reduce the amount of P in their lawn fertilizer products, distribute these products in garden centers statewide, and work with NJDEP to develop strategies to educate the public about proper selection and use of lawn fertilizer. For more information, see *Recent Partnership Limits Phosphorus in New Jersey Fertilizer*, on page 12 of *Nonpoint Source News-Notes* issue 86, at www.epa.gov/NewsNotes/pdf/86issue.pdf (USEPA 2009b). To date, a 50 percent reduction in pounds of P sold in the state has been achieved compared to 2006 levels, and a workgroup has been established to support the Healthy Lawns & Clean Water initiative. The Scotts Miracle-Gro Company received an Honorable Mention in the Governor's Environmental Excellence Awards in 2009 for achieving a 70 percent statewide reduction of P sold in the state and for execution of Healthy Lawns & Clean Water outreach materials.

- Township of Jefferson, New Jersey: Within the township, no person, firm, corporation, or franchise is to apply liquid or granular fertilizer containing P. No lawn fertilizer of any kind is to be applied on frozen ground or within 10 feet of a body of water, including wetlands. http://www.jeffersontownship.net/Cit-e-Access/news/index.cfm?NID=3762&TID=4&jump2=0

- Montville Township, New Jersey: Adopted July 2008, applying fertilizer is prohibited during a runoff-producing rainfall or before a runoff-producing rainfall is predicted to occur. Fertilizer application is also prohibited when soils are saturated and fertilizer can move off-site. Application is further prohibited on impervious surfaces, within 25 feet of a waterbody, and more than 15 days before the start or at any time after the March 15 to October 31 growing season. P-containing fertilizer is strictly prohibited anywhere outdoors at any time except where demonstrated to be necessary for the specific soils and target vegetation, as noted by Rutgers Cooperative Research and Extension's annual fertilizer recommendation. http://www.montvillenj.org/index.php?option=com_content&task=view&id=487

- Suffolk County, New York, Fertilizer Prohibition: A new law prohibits lawn fertilizer applications from November 1 to April 1 to prevent N runoff from frozen ground. The law, which also requires retailers to post signs near fertilizer displays advising customers of the date restrictions, took effect in January 2009. Violators, whether landscapers or homeowners, risk fines of $1,000. Licensed landscapers are required to participate in a 4-hour, county-sponsored session administered by the Cornell Cooperative Extension to renew their licenses. For more information, see http://www.nytimes.com/2009/03/15/nyregion/long-island/15fertilizerli.html?pagewanted=2&_r=1

- Highland Park, Illinois, Phosphorus-Based Fertilizer Ordinance: The Ordinance prohibits the application of fertilizer containing P to any area within city limits unless the user meets one of the three allowable circumstances contained in the ordinance. For example, the fertilizer containing P can be used in areas where the ambient P content is below the median P area for typical soils or the fertilizer is used under a tree canopy.

The ordinance further prevents the retail sale of fertilizer containing P within city limits. For more information, see http://www.cityhpil.com/pdf/Phosphorus-BasedFertilizerOrdinance.DOC

- Wisconsin Phosphorus Ban: In April 2009, Wisconsin Governor Doyle signed the Clean Lakes bill (2009 Wisconsin Act 9). The bill established a statewide law prohibiting the display, sale and use of lawn fertilizer containing P, with certain reasonable exceptions (e.g., when establishing grass or when a soil test shows that P is needed). The law takes effect in April 2010, which gives retailers time to prepare. Although retailers will not be permitted to display turf fertilizer that is labeled as containing P, they may post a sign advising customers that turf fertilizer containing P is available upon request for qualified uses. The prohibition does not apply to the following: the use of manure that is mechanically dried, ground, or pelletized, or to a finished sewage sludge product; the use of fertilizer that contains P to establish grass during the first growing season; the application of fertilizer where soils are deficient in P; and agricultural land. Violators can be required to forfeit not more than $50 for a first violation and not less than $200 nor more than $500 for a second or subsequent violation. For more information, see http://www.legis.state.wi.us/2009/data/AB-3.pdf.

- Dane County Wisconsin: As of January 2005, no person in Dane County could apply lawn fertilizer labeled as containing anything more than 0 percent P. Restrictions on lawn fertilizer application also include applying any type of fertilizer on frozen or impervious surfaces. http://www.danewaters.com/management/phosphorus.aspx

- Minnesota Fertilizer, Soil Amendment, and Plant Amendment Law: Minnesota enacted a statewide law in 2005 prohibiting the use of P lawn fertilizer unless new turf or lawn is being established, a soil test shows a need for P, or P is being applied to a golf course or sod growing area by trained staff. When such situations do not exist, state law requires P-free lawn fertilizer to be used. For more information about the law, see http://www.mda.state.mn.us/protecting/waterprotection/phoslaw.aspx.

- Buffalo, Minnesota: Effective in 2000, lawn fertilizers were not to be applied on frozen ground, specified as being between November 15 and April 15. And at no time can any person, firm, corporation, or franchise apply liquid or granular fertilizer within the city limits that contains phosphates. Fertilizer application is prohibited on impervious surfaces and on surfaces within drainage ditches or waterways or within 10 feet of a water resource. http://www.ci.buffalo.mn.us/Admin/CityCode/1056.htm

- Sanibel City, Florida: With respect to turf and landscape plants, fertilizers cannot contain more than 2 percent P or more than 20 percent N, with 70 percent of the N required to be slow release. Applications are maxed out at one pound of N per 1,000 square feet, for a total of 4 pounds of N per 1,000 square feet in any one year. Fertilizer can be applied up to six times in one year to a single area. Further, no fertilizer is to be applied on impervious surfaces or within 25 feet of a body of water. Retail businesses were required to post notices about the new regulation near the fertilizer to inform customers. http://www.sanibelh2omatters.com/documents/CITY%20APPROVES%20ENVIRONMENTALLY%20FRIENDLY%20REGULATIONS%20FOR%20FERTILIZER%20USE%20ON%20ISLAND.pdf

- Bellingham, Washington, Municipal Code: The city's municipal code contains restrictions pertaining to commercial P-based fertilizer. The municipal code prohibits the application of commercial fertilizer to residential lawns or public properties within the Bellingham city limits area of the Lake Whatcom watershed, either liquid or granular, that is labeled as containing more than 0 percent P or other compounds containing P, such as phosphate, except when applied to newly established turf or lawn areas in the first growing season. In addition, the municipal code prohibits applying fertilizer to frozen ground and impervious surfaces, and imposes requirements for cleanup of fertilizer that is applied, spilled, or deposited on impervious surfaces. Bellingham's Municipal Code is at http://www.cob.org/web/bmcode.nsf/srch/B5D4E84B824F05EB882561D600601973?OpenDocument.

- Whatcom County, Washington: As of April 2005 for Lake Whatcom and June 2007 for Lake Samish, using commercial fertilizers containing P on residential lawns or on public agency properties in the Lake Whatcom watershed is prohibited. Further, no commercial fertilizer of any kind is allowed to be applied on frozen or impervious surfaces. http://www.mrsc.org/mc/whatcom/Whatco16/Whatco1632.html

A few fertilizer restrictions have been in place for long enough to measure results. The following are two studies of the effectiveness of fertilizer ban policies in the Midwest.

- Reduced River Phosphorus Following Implementation of a Lawn Fertilizer Ordinance (Ann Arbor, Michigan): As part of its efforts to comply with a state-imposed P TMDL to reduce 50 percent of P discharges to the Huron River, the city of Ann Arbor enacted an ordinance that went into effect in 2007 to limit P application to lawns. The estimated effect of full compliance was a 22 percent reduction in P entering the river. The study indicates that after the first year of data collection and analysis, statistically significant reductions were documented for total P and, to a lesser degree, for dissolved P for every month from May to September. The research team states, "with a considerable degree of confidence that P concentrations were lower in 2008 at experimental sites compared with the reference period (2003 to 2005) and that the reductions were coincident with a city ordinance restricting use of lawn fertilizers containing phosphorus." However, the study does not conclude that those reductions were caused by enacting the ordinance, but shows that a correlation exists between reductions in P and the ordinance (Lehman et al. 2009). http://www.umich.edu/~hrstudy/Reports/LRM_08-40_web.pdf.

- Effectiveness of Minnesota Phosphorus Lawn Fertilizer Law: The Minnesota Phosphorus Lawn Fertilizer Law directed the Minnesota Commissioner of Agriculture to report in 2007 on the effectiveness of P lawn fertilizer restrictions. The report indicates that various forms of P-free fertilizers were being sold in stores across the state. For example, the state polled 87 stores and found that in 97 percent of those stores, P-free lawn fertilizer was being retailed. In addition, the report found that the law has reduced the amount of fertilizer containing P that was being used. The report showed a reduction of 141 tons of fertilizer used or 48 percent of use between 2003 and 2006. The law has not increased consumer cost for fertilizer and has generally gained consumer support.

  Additionally, since the law's inception, manufacturers have been able to adapt to the law and produce new P-free fertilizer products. Therefore, the change has also expanded the manufacturer's market for P-free lawn fertilizer in other areas concerned with water quality, including the Chesapeake Bay region, Florida, Michigan, Wisconsin, and other states. The report, however, documents only consumer use and manufacturer development and retail and does not look at the effects on water quality or turf management. It recommends further research to expand on those areas. For more information, see the Minnesota Phosphorus Lawn Fertilizer Law: http://www.mda.state.mn.us/protecting/waterprotection/phoslaw.aspx and the Minnesota Effectiveness Report of Phosphorus Lawn Fertilizer Law: http://www.mda.state.mn.us/en/sitecore/content/Global/MDADocs/protecting/waterprotection/07phoslawreport.aspx.

5.3.4 Pesticide Management

Pesticides in urban runoff have been well documented in monitoring studies conducted by the U.S. Geological Survey (USGS 2007). In addition, the Center for Watershed Protection summarized studies in two articles that indicated that urban land uses were sources of pesticides into surface waters (Schueler 2000b, 2000e).

Pesticide use should be managed to reduce applications via spot applications and the use of integrated pest management techniques (IPM). The use of combined fertilizer and pesticide (e.g., *weed and feed*) products should be avoided.

Barth (2000) found the following:

1. **Weed control and tolerance: Establish a realistic tolerance level for weeds and use least toxic control methods to maintain it.** For a low-input lawn, use least toxic

weed control methods such as cultivation, solarization, flaming, mowing, or herbicidal soap. For a lower input lawn, grow strong healthy grass and it will crowd out weeds. For the lowest input lawn, broaden your definition of *lawn* to include weeds that perform desirable functions. [Note: Increasing the mowing height can shade the soil surface and inhibit germination of weed seeds.]

2. **Integrated pest management: Establish a realistic tolerance level for pests and use least toxic control methods to maintain it.** For a low-input lawn, use least toxic control methods such as removing or trapping pests, introducing biological control agents, or apply least toxic chemical controls such as insecticidal soaps. For a lower input lawn, grow strong, healthy grass that can resist attack. For the lowest input lawn, use cultural controls to prevent infestation, protect natural predators, and add beneficial soil microbes.

As of January 1, 2010, products containing a combination of fertilizer and herbicide (commonly known as weed and feed) are no longer available for sale or use in the Canadian province of Alberta. That ban on the use of weed and feed fertilizers is because of potential health and environmental impacts. Because weed and feed is applied to an entire lawn, regardless of the size of the weed infestation, it results in an over-application of the herbicide 2, 4-D. Herbicide-only products will still be available for spot application, because they result in less surplus chemical draining from the lawn, running into storm sewers and entering waterways (Environment Alberta 2010).

5.3.5 Mowing

Lawn mowing practices can affect the amount of fertilizer, pesticide, and irrigation inputs needed. Mowing to a height of at least three inches shades out weeds, slows moisture loss, protects grass vigor, and encourages deeper root growth. When grass is mowed too low, the soil is exposed to light, which can stimulate weed seed germination (Barth 2000).

Mowing frequency is also an important factor. A general rule is to ensure that no more than one-third of the grass leaf be cut at one time to prevent plant damage. Actual mowing frequency will depend on the rate at which the grass is growing, which varies throughout the year (Barth 2000).

Recycling grass clippings by mulching them with a mulching mower and leaving them on the lawn provides nutrients, helps to build soils, and preserves landfill space. Also, mulching leaves into the grass adds organic matter and nutrients (Wilbe 2010). According to surveys, nearly 60 percent of Chesapeake Bay residents practice this form of grass recycling. Using a mulching mower can help meet at least one-fourth of the nutrient needs of a yard and saves time required to bag the clippings (Town of Culpeper 2009). A study by the University of Connecticut Agricultural Station, as reported by Barth (2000), found that most of the N from recycled clippings was incorporated into new grass growth within a week. The Rodale Institute Research Center found that an acre of clippings provides an average of 235 pounds of N and 77 pounds of P each year (Schultz 1989). Austin, Texas, having studied residential lawn fertilization practices, recommends that by leaving clippings on the lawn, 60 percent of the clippings' N and 100 percent of the P will be available to the grass within the growing season (Garrett no date). Grass clippings, leaves, fertilizer, and yard debris should be kept away from impervious areas, because if left in the gutter or streets, they will be washed into storm sewers and surface waters (Wilbe 2010).

5.3.6 Soil Amendments

Background—Soil Compaction

Urban soils have been shown to be more compacted than undisturbed soils (Schueler 2000c), generally as a result of construction activities, heavy equipment use, and intentional compaction. Foot and vehicular traffic can also compact soils. As measured by bulk density (defined as the mass of dry soil divided by its volume, expressed in units of grams per cubic centimeter (gms/cc)), undisturbed soils average 1.1 to 1.4 gms/cc, whereas urban lawns range from 1.5 to 1.9 gms/cc and athletic fields and fill soil typically range from 1.8 to 2.0 gms/cc. The bulk density of these disturbed soils can approach those of concrete (2.2 gms/cc).

An inverse relationship exists between soil bulk density and soil porosity, which indicates that compacted urban soils do not infiltrate stormwater as readily as undisturbed soils. The hydrologic consequence is higher runoff coefficients (Table 3-54), from 0.2 up to 0.5 (paved areas have runoff coefficients ranging from 0.5 to 0.99).

Soil compaction also has implications for plant growth and can restrict root growth, oxygen diffusion, nutrient retention, soil fauna, and inhibit beneficial fungi and other soil biota (Ocean County Soil Conservation District 2001).

A study in North Central Florida revealed that construction activities reduced lawn infiltration rates from 70 percent to 99 percent in comparison to untouched natural forest and pasture. "The compacted pervious area effectively approaches the infiltration behavior of an impervious surface," which increases stormwater runoff and the need for large stormwater conveyance networks (Gregory et al. 2006).

Table 3-54. Runoff Coefficients (C) for Rational Formula

Land use	C	Land Use	C
Business: Downtown areas Neighborhood areas	0.70–0.95 0.50–0.70	***Lawns:*** Sandy soil, flat, 2% Sandy soil, avg., 2-7% Sandy soil, steep, 7% Heavy soil, flat, 2% Heavy soil, avg., 2-7% Heavy soil, steep, 7%	0.05–0.10 0.10–0.15 0.15–0.20 0.13–0.17 0.18–0.22 0.25–0.35
Residential: Single-family areas Multi units, detached Munti units, attached Suburban	0.30–0.50 0.40–0.60 0.60–0.75 0.25–0.40	***Agricultural land:*** *Bare packed soil* *Smooth *Rough *Cultivated rows* *Heavy soil, no crop *Heavy soil, with crop *Sandy soil, no crop *Sandy soil, with crop *Pasture* *Heavy soil *Sandy soil Woodlands	0.30–0.60 0.20–0.50 0.30–0.60 0.20–0.50 0.20–0.40 0.10–0.25 0.15–0.45 0.05–0.25 0.05–0.25
Industrial: Light areas Heavy areas	0.50–0.80 0.60–0.90	*Streets:* Asphaltic Concrete Brick	0.70–0.95 0.80–0.95 0.70–0.85
Parks, cemeteries	0.10–0.25	Unimproved areas	0.10–0.30
Playgrounds	0.20–0.35	Drives and walks	0.75–0.85
Railroad yard areas	0.20–0.40	Roofs	0.75–0.95

Source: http://water.me.vccs.edu/courses/CIV246/table2_print.htm
* The designer must use her or his judgment to select the appropriate *C* value within the range. Generally, larger areas with permeable soils, flat slopes, and dense vegetation should have the lowest C values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should have the highest C values.

In examining 15 home lawns in central Pennsylvania, Hamilton and Waddington (1999) find excavation procedures and lawn establishment to be the most influential practices affecting lawn infiltration rates. Homes with minimal soil compaction had the highest infiltration rates. Reduced compaction was achieved by bringing in topsoil post-home construction and through core cultivation (aeration of the soil). The lawn with the highest infiltration rate (10cm/hr) was not excavated during construction, allowing "the macropore system to stay intact, preventing aggregate destruction during usual soil moving and handling, and preventing soil stratification when the soil was put back at the excavated sites." Other practices that can affect infiltration more than anything else are "the stripping of topsoil, traffic on exposed subsoil, the addition of debris to the soil, and stratification of soil upon replacement."

Solutions to Reduce Soil Compaction

Soil amendments can be used to enhance soil properties and increase the infiltrative and retentive capacity of soils. Soils can be amended by adding sand or other bulk materials, organic matter such as compost, inorganic or organic fertilizers. Some evidence exists that using compost teas and the inoculation of soils with soil microbes and mycorrhizal fungi can increase soil health and plant productivity. However, most research to date has been conducted on agricultural crops such as maize, wheat, and vegetables. The results of the studies demonstrate that using biological approaches for nutrient management can enhance plant nutrient use efficiency and improve soil water retention, aggregate stability, and the growth of specific crops (Adesomoye et al. 2008; Shaharoona et al. 2008; Ahmad et al. 2008; Dass et al. 2008). Given those results, it is likely that similar benefits will accrue from using biological approaches to turf management. Additional research, however, is needed to determine the benefits that can be achieved by using biological approaches as they relate to the optimization of turf grass performance, nutrient utilization, and soil health.

By mechanically treating, aerating, and amending disturbed soils, the physical structure of the soil can be improved, bulk density can be reduced, and the porosity and infiltrative capacity of the soils enhanced. In fine-textured (clay, clay loam) soils, the addition of compost/organic materials reduces bulk density, improves friability (workability) and porosity, and increases its gas and water permeability, thus reducing erosion. When used in sufficient quantities, adding compost/organic materials provides both immediate and long-term positive effects on soil structure so that fine-textured soils will resist compaction and increase their water-holding capacity. Soil aggregation in coarse-textured (sandy) soils will be improved. Those issues are discussed by Schueler (2000a) in an article that addresses reversal of soil compaction.

McDonald (2004) specifies 2 to 4 inches of compost tilled into the upper 8 to 12 inches of soil, depending on soil type, before planting. Balousek (2003) showed a marked decrease in surface runoff volume (36 to 53 percent) when compacted soils were chisel-plowed and deep-tilled, and when soils were also amended with compost, runoff was reduced by 74 percent to 91 percent. Additionally, compost is good source of N, P, and potassium and contains micronutrients essential for plant growth. Therefore, adding compost can also have a positive effect on fertilizer use and pH adjustment (lime/sulfur addition) and help reduce soil compaction. The benefits of compost are described in more detail in the Composting Council fact sheet, *Using Compost in Stormwater Management*, at www.compostingcouncil.org.

Redmond, Washington, has developed *Guidelines for Landscaping with Compost Amended Soils* (City of Redmond Public Works 1998). The document also contains data on the comparative costs of the use of soil amendments versus the use of other soil preparation methods, and describes the benefits in terms of payback and increased infiltration rates and reduced runoff. The city also quantified the reduced costs for detention facilities accrued from using compost-amended soils because of the increase in moisture-holding capacity of the amended soils. According to Hielema (1996), "the amended plots generated 53 percent to 74 percent of the runoff volume produced by unamended plots under saturated conditions." Thus, under such conditions, stormwater detention facilities could be reduced in size because of the holding capacity of the amended soils.

McCoy (2006) noted that soil amendments and soil treatments can be used to reduce compaction and increase infiltration. For example, additions of sand and gravel in the design of multiple layer soil profiles can reduce soil compaction and have the potential to decrease runoff and retain water for subsequent evapotranspiration.

For more information, see the manual, *Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13* in Washington Department of Ecology's *Stormwater Management Manual for Western Washington 2010 Edition* (http://www.buildingsoil.org/tools/Soil_BMP_Manual.pdf).

5.3.7 Water Management

Landscape irrigation uses up to 1.5 billion gallons of water every day across the country (EPA WaterSense). As reported by Mosko (2009), the Metropolitan Water District of Southern California determined that up to 70 percent of residential water use in Southern California is for outdoor irrigation, particularly lawns. Although the number of lawns in California is unknown, 84 percent of respondents in a 2000 statewide Air Resources Board survey described having a lawn area, and the *San Diego Union* recently reported an estimate that residential lawns cover 300,000 acres and annually soak up 1.5 million acre-feet of water.

According to Mosko (2009), the most popular grasses in Southern California are fescues, which generally require one inch of water per week during dry months and mowing about every other week. Assuming modest-sized lawn areas of 25 feet by 25 feet in both front and in back yards, the lawns could consume, in a single month, in excess of 3,000 gallons of water plus the 34 kilowatt hours of electricity required to deliver the water to Southern California homes.

Among other things, irrigation water waste is a product of inefficient system design, leaks, improper nozzle use, broken nozzles, improper system pressure and improper watering schedules. Excess water use can result in adverse environmental impacts, including over-drafting groundwater resources, reduced stream flows, water quality degradation, and disruptions to the ecosystems that depend on the water supplies (Vickers 2001).

Landscapes with automatic irrigation systems use more water than landscapes that water by hand. In-ground sprinkler systems, automatic timers for irrigation, and drip irrigation systems use 35 percent, 47 percent, and 16 percent more water than residences without these systems, respectively (Mayer and DeOreo 1998). Although, hand-watering or using drought-tolerant vegetation is most efficient, when irrigation systems are desired, reduced water consumption can result from using efficient equipment; proper design, installation, and maintenance of systems; and performing irrigation system audits regularly.

Efficient Irrigation Controllers

Weather-based irrigation controllers can produce water savings when replacing standard clock timer controllers. Weather-based controllers schedule irrigation according to landscape needs and local weather conditions. The technology eliminates the need for manual adjustments to the irrigation schedule. In a Las Vegas, Nevada-based study, researchers found that evapotranspiration-based controllers saved 20 percent more water than non-evapotranspiration-based controllers (Devitt et al. 2008). In a study in Irvine, California, researchers found the use of weather-based evapotranspiration controllers resulted in average water conservation savings of 41 gallons/day. Highest water savings were seen in the summer and fall when irrigation system use is highest. Researchers also found an average runoff reduction of 50 percent for those sites that employed use of weather-based irrigation controllers (IRWD 2004).

EPA's WaterSense program has released a draft specification for weather-based irrigation controllers and will label water-efficient controllers that meet its specification. Weather-based irrigation controllers that earn the label must demonstrate that they meet the watering needs of a typical landscape while not overwatering. For more information on the WaterSense label for irrigation controllers, see http://www.epa.gov/watersense/products/controltech.html.

Efficient Irrigation Practices

To distribute water evenly to an irrigated landscape, an irrigation system must be designed and installed with water efficiency in mind. Poorly designed irrigation systems result in water loss by overwatering certain landscape areas causing runoff while under-watering other areas. Landscape caretakers that use an irrigation system should ensure that the system is operating efficiently by understanding the distribution uniformity (DU) of the irrigation system. DU is a measure of the evenness of water applied to a landscape. An optimally performing irrigation system will have a DU of 80 percent for rotary sprinklers and 75 percent for spray sprinklers (The Irrigation Association 2007).

To test the DU of an irrigation system, a catch-can test is performed. A catch-can test involves several steps: (1) note location of sprinkler heads; (2) place identically sized containers near each sprinkler head and between heads; (3) run the sprinkler system until a minimum of 25 mm of water is collected in a container; (4) record the volume of water collected from each container; and (5) calculate the distribution uniformity:

$$DU = \frac{\text{Average catch-can volume in lower 25\% of catch-cans}}{\text{Average catch-can volume overall}}$$

If the DU of a system is below 50 percent, consider hiring an irrigation professional to adjust the system to obtain better performance and water savings. For more information on distribution uniformity and the catch can test, see http://www.ci.windsor.ca.us/DocumentView.aspx?DID=522.

EPA's WaterSense program partners with irrigation professionals trained in water-efficient design, installation and maintenance, and auditing irrigation systems. An irrigation system auditor will perform a catch can test on a property and provide customers with suggestions for improving irrigation system efficiency. Although, as mentioned, watering by hand is the most efficient means to irrigate a landscape, if an irrigation system is desired, use professionals trained to reduce water consumption. For a list of WaterSense irrigation professionals, see http://www.epa.gov/watersense/meet_our_partners.html.

Deficit irrigation, which is the practice of irrigating below the maximum water demand of the turfgrass to decrease soil moisture content and water use can also be used to reduce water consumption and irrigation. Shearman (2006) reported that water savings of 21 and 40 percent were feasible in a test plot in Nebraska when Kentucky bluegrass received deficit irrigation of 60 and 80 percent of potential evapotranspiration while maintaining an acceptable turfgrass quality.

5.3.8 Grass Species Selection

Some grass species perform better than others under low-input management. In a 5-year field trial in Rhode Island, hard fescue, tall fescue, colonial bentgrass, red fescue, and koeleria (prairie junegrass) were able to maintain 100 percent turf cover on poor soil with no irrigation or pesticides after establishment and only 1 to 2 pounds of N per 1,000 square feet per year applied as organic, granular fertilizer. Kentucky bluegrass and perennial ryegrass were not able to maintain cover under those conditions (Brown, R., personal communication 2010).

Another study in Rhode Island concluded that actively growing turfgrass used an average of 25 mm (1 inch) of water per week in July through September. Average rainfall for the same 12-week period is roughly 300 mm (12 inches). The water-holding ability of good soil and an ability to go dormant if needed allows the grasses survive despite interannual variations in rainfall patterns and timing. In fact, choosing grasses that can survive a dormancy period, and allowing the plants to go dormant during prolonged dry periods is a key strategy for reducing water use (Carrow et al. 2008).

According to Beard and Green (1994), “the proper strategy based on good science is the use of appropriate low-water-use turfgrasses, trees, and shrubs for moderate-to-low irrigated landscapes and similarly to select appropriate dehydration-avoidant and drought-resistant turfgrasses, trees, and shrubs for nonirrigated landscape areas.” It is also important when choosing grasses for low-input management to use improved varieties. The improved varieties have denser growth and better disease resistance than *common* types (Brown, R., personal communication, 2010).

Devitt and Morris (2006) note the need to consider the effects of landscape species selection including turf on water conservation and use, i.e., “Plant selection should be given serious consideration in the development of low water-using landscapes.” The authors also recommend that,

> [E]mphasis should be placed on the following factors:
>
> 1. Price water on the basis of its true societal value as a scarce resource.
> 2. Decrease irrigated landscape areas.
> 3. Track irrigations and adjust for changes in the seasonal demand of water. Irrigating based on seasonal demand will almost always use less water than irrigating based on guesswork.
> 4. Adjust landscape expectations down whenever possible and be more flexible in plant selection (especially with those plants know to be high water users). Low growth rates by decreasing fertilization and irrigations to achieve judicious size control.

If turfgrass is planted as ornamental vegetation in a landscape, choose native, drought-tolerant, or low-water-use turfgrass species that require less water and maintenance. To identify species appropriate for a site, consult lists of native species of vegetation. The Lady Bird Johnson Wildflower Center provides native plant lists for the United States: http://www.wildflower.org/. Local cooperative extension units can also provide information on planting regionally appropriate species.

For functional turf areas, traditional turf species might be desired. Traditional turfgrass is distinguished as warm-season or cool-season turfgrasses. Warm-season turfgrasses, such as Bermuda grasses, zoysia grasses, buffalo grass, little bluestem, and Pennsylvania sedge, are usually more drought tolerant and should be used in warmer climates. Some cool-season turfgrasses, such as fine fescues, are drought tolerant but are more appropriate for cold-weather climates. Other cool-season turfgrasses, such as Kentucky bluegrass, require high amounts of water (35 inches per year just for survival) and are inappropriate for many areas in the country (Vickers 2001).

One option when selecting grass species is to increase diversity by creating a mixed species lawn that incorporates clovers or legumes into the turf mixture. A uniform distribution of such plants can be achieved by evenly blending it with grass seed. Benefits include increased drought tolerance, lower N needs, increased pest resistance, and decreased weed infestations (Bellows 2010).

A combination of native grasses can provide a highly resistant, low-maintenance yard or turf. For example, a combination of little bluestem (*Schizachyrium scoparium*), common or Pennsylvania sedge (*Carex pensylvanica*), and tufted hairgrass (*Deschampsia flexuosa*) is well adapted to the Northeastern coastal areas (Bellows 2010).

No-mow lawn mixes are composed of slow-growing turf grasses like hard fescue and creeping red fescues, which require little maintenance because they have deep roots and are resistant to drought. Sedges and rushes can also be used as a low-maintenance ground cover suitable for moist climates (Bellows 2010).

Resources

The National Turfgrass Evaluation Program develops and coordinates uniform evaluation trials of turfgrass varieties and promising selections in the United States and Canada. The results can be used to determine the broad picture of the adaptation of a cultivar. Results can also be used to determine if a cultivar is well adapted to a local area or level of turf maintenance. http://www.ntep.org/contents2.shtml

The National Sustainable Agriculture Information Service (referred to as ATTRA) offers a *Sustainable Turf Care Guide* for lawn care professionals, golf course superintendents, or anyone with a lawn. The emphasis of the guide is on soil management and cultural practices that enhance turf growth and reduce pests and diseases by reducing turf stress. It also includes information about mixed species and wildflower lawns as low maintenance alternatives to pure grass lawns. http://attra.ncat.org/attra-pub/turfcare.html

5.3.9 Turf Assessments

Municipalities and facility owners should have a qualified landscape professional (e.g., a landscape architect, landscape designer, or other trained landscape professional) conduct an assessment of turf areas to identify essential versus nonessential turf and opportunities to reduce turf and decrease the inputs for turf areas that are retained as long as desired turf performance can be achieved.

In some cases, active management of landscapes through irrigation, mowing prescription and fertilization can enhance the environmental performance of the landscape. Easton and Petrovic (2008) evaluated P loading from an urban watershed in New York, measuring dissolved P, particulate P, and TP as well as site characteristic for three land uses: fertilized lawns, urban barren areas, and wooded areas. They found that applying P in excess of plant requirements can result in higher dissolved P in runoff, especially in areas that have been repeatedly over-fertilized, i.e., on lawns. However, particulate (sediment-bound) P was highest in runoff from land uses with the sparsest vegetation cover that have not been actively maintained (urban barren areas and wooded areas). The researchers suggested that these areas could benefit from judicious fertilization to improve groundcover and reduce erosion. Losses of dissolved P from these areas during wet weather can be minimized by properly timing fertilizer applications and matching the application rate to plant needs on the basis of soil tests.

Areas of essential turf should be determined by land owners/operators on the basis of factors they identify. For example, essential turf areas can include turf for transit paths, security, transportation visibility, historic preservation or dedicated recreational purposes such as picnic areas and ball fields, buffers for public health reasons, and water pollution control practices such as grassed swales. Nonessential turf areas are typically grassed areas that have not been planted for a specific use or environmental purpose and receive little or no use or maintenance except periodic mowing. Many of these grassed areas can be maintained only with turf cover because of ease of maintenance, habit or for aesthetic continuity and can be converted to less input-intensive ground covers that can provide increased habitat, improved aesthtics, and/or environmental performance.

All turf areas should be assessed by category and managed accordingly to maximize performance in terms of runoff reductions, erosion, nutrient discharges and infiltration. Areas with thin grass cover, bare soil, or other indications that the turf is not performing optimally from an environmental perspective should be identified and differentially managed by area or category to achieve the desired filtration, water retention, pollutant removal and infiltration objectives. In some cases, landscape managers might elect to convert turf to other landscape cover types, let the turf revert to native forest, or increase management prescription to optimize turf growth, thatch density, and nutrient and sediment retention

To reduce both the environmental effects of turf and management costs, communities and land managers across the country are identifying areas that are mow zones, low-mow zones and no-mow zones in an effort to reduce maintenance and provide increased ecological value from landscaped areas. Converting turf areas back to naturalized areas is also a strategy to eliminate the need to irrigate, fertilize, and apply pesticides except in cases where disease or invasive species are problematic.

For areas that will remain as turf, further evaluation can identify areas that will be actively managed (high-input) versus those that will be mowed and not treated with fertilizers and pesticides. Facilities, campuses and other managers of large tracts of land should develop landscape management plans, maps and operation and maintenance plans to properly manage each designated category of vegetative cover including high-input and low-input turf areas. Facility managers also might want to limit the creation or retention of high-input areas to the most visible and used landscaped areas (e.g., areas adjacent to building entrances, transit paths or areas where high quality turf is deemed essential). In contrast, lawns along the side and back of buildings or at the edges of parking lots might not require such intensive management and can be designated as low-input and low-mow areas. Examples of turf conversion or reduction strategies are provided below.

- The U.S. National Arboretum in Washington, D.C., has undertaken measures to reduce high-maintenance turf areas (U.S. Department of Agriculture, Agricultural Research Service, no date). The Arboretum occupies 446 acres of green space, about half of which is taken up by intensely managed gardens, collections, and research plots. Arboretum managers have drastically reduced the area devoted to turf and have changed the way the turf is managed. Large open spaces that were formerly devoted to turf are now managed as meadows and account for about 70 acres, and areas that are frequently mowed have been reduced to just 31 acres. Instead of mowing turf areas weekly, as is standard practice, they mow in response to height thresholds, so that the turf is mowed only 13 times on average during the growing season instead of 30 times (less if drought slows turf growth). The mowing height threshold is 5 inches, which is much higher than is commonly used on corporate campuses or on residential turf. They do not generally irrigate or fertilizer turf, do not use pesticides or herbicides, and leave clippings on the turf areas.

- Since 1995 the University of Nevada, Las Vegas has reduced turf on campus by 1,056,126 square feet, with an estimated water savings of more than 9 million gallons and more than $20,000 annually. Its efforts include computer-controlled watering of campus turf in compliance with water authority guidelines, enabling automatic shutdown with the use of flow sensors, decoders, and automatic irrigation adjustment through an evapotranspiration database, which is linked to the university's weather station for automatic irrigation adjustment because of changes in weather. All landscaping around new buildings is now xeriscaped, and more than 50,000 square feet of turf has been replaced with desert landscaping at the Shadow Lane Campus. A landscape design is in progress to reduce the heat-island effect of parking lots through tree planting in a project being planned in partnership with the U.S. Division of Forestry. More information is at http://barrickmuseum.unlv.edu/xeric/turf.html.

- Henderson, Nevada, Parks and Recreation Department has a turf reduction program that involves removing nonfunctional turf from targeted areas in the parks system and replacing it with more efficient xeriscaped areas. Since 2003 more than 85 turf conversion projects have been completed, removing more than 1.2 million square feet of turf, mostly from medians, parking lots, and areas where turf is primarily decorative. The turf removal has translated into an annual savings of more than 68 million gallons of water. The program was funded through a variety of grants and rebates rather than tax dollars. More information is at http://www.cityofhenderson.com/parks/parks/turf-conversion.php.

- A study was undertaken at the University of Waterloo in Ontario, Canada, to develop a methodology for assessing all campus areas to identify candidates for turf conversion (Hassan 2000). The study included an evaluation of stakeholder preferences, including turf users (students and faculty) and university staff who maintain turf areas. A set of criteria were established for evaluating existing turf areas according to current conditions, visibility and aesthetics, and feasibility and suitability for alternate plantings. More information is at http://www.adm.uwaterloo.ca/infowast/watgreen/projects/library/grass.pdf.

Another aspect that should be considered in turf management is irrigation. Areas planted in turf should be assessed to determine necessary irrigation regimes and periodically evaluated to identify opportunities to reduce water use on the basis of turf condition and other factors.

Carrow et al. (2008) provided an outline of the planning process and components of golf course BMPs for water use efficiency/conservation that includes a framework for managing golf courses and other landscapes to reduce water use. This assessment process, described below in modified form, could be used to plan, assess and implement programs to promote water use efficiency and conservation at most large, landscaped facilities or jurisdictions (adapted from Carrow et al. 2008):

A. Initial planning and site assessment
    1. Identification of water conservation measures and costs
    2. Purpose and scope of the site assessment
    3. Site assessment and information collection
        a. Current water use profile
        b. Irrigation/water system distribution audit

   c. Site assessment information, e.g., alternative water sources, golf course design modifications, and soil and climate conditions

B. Identify, evaluate and select *water conservation strategies*: and options and use the following 10 Core Water Conservation Strategies:

   1. Use nonpotable water sources for irrigation—alternative water sources; water harvesting/reuse
   2. Efficient irrigation system design and monitoring devices for implementing water conservation, e.g., remote sensing and real-time control devices
   3. Efficient irrigation system scheduling/operation
   4. Developing and selecting turfgrasses and other landscape plants with respect to water uptake and use requirements in terms of quantity and quality
   5. Landscape design for water conservation
   6. Altering practices to enhance water-use efficiency, e.g., soil amendments, cultivation, mowing, fertilization
   7. Indoor water conservation measures in buildings, air conditioning units, pools, and other facilities associated with a landscape site
   8. Educating management and staff in water conservation management practices and approaches
   9. Developing formal conservation and contingency plans
   10. Monitor and revise plans

C. Assess benefits and costs of water conservation measures on stakeholders

   1. Benefits—direct and indirect
   2. Costs
      a. Facility costs for past and planned implementation of water conservation strategies and practices
      b. Labor needs/costs
      c. Costs associated with changes in management practice, e.g., water and soil treatments, posting of signs, training

Resource

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5.3.10 Turf Restrictions

Limiting the amount of landscaped area for turfgrass and high water use plantings can reduce landscape irrigation demand. A number of municipalities limit turf areas. For example, the Marin Municipal Water District in California limits use of turfgrass and high water use plants to 35 percent of the total landscaped area (Marin Municipal Water District Ordinance 326, In Vickers 2001). Clark County, Nevada, set limits on turf areas for new properties according to drought conditions. Under non-drought conditions, the following limits apply:

- Single-family homes: 50 percent of a front yard can be grass, not including driveway or parking areas
- Multifamily (apartments, condos) and nonresidential developments: 30 percent of an area set aside for landscaping can be grass, excluding parking lots and driveways
- Golf courses: Limited to a maximum of 90 acres for 18 holes and 10 acres for driving ranges

For nonresidential landscapes, installing new turf is prohibited during drought conditions, with some exceptions for public spaces that have functional turf. For single-family and multifamily developments, installing new turf is prohibited in common areas of residential neighborhoods during a Drought Watch, and during a more severe Drought Alert, new turf is prohibited in residential front yards and cannot exceed 50 percent of the gross area of the side or rear yard or 100 square feet, whichever is greater. A maximum of 5,000 square feet of turf is permitted. The details of the Clark County Drought Restrictions are at http://library.municode.com/HTML/16214/level2/T30_30.64.html#T30_30.64_30.64.010.

5.3.11 Incentives for Landscape Conversion

Some communities use incentives to urge property owners to convert their lawns to less maintenance-intensive landscaping. Federal facilities planners will find such types of municipal incentive programs to be of interest because they provide documentation of the benefits achieved from lawn conversion. The following are examples of lawn conversion incentive programs:

- Cary, North Carolina, initiated a one-time, $500 per property payment to homeowners who convert at least 1,000 square feet of historically irrigated turf to natural area or warm-season grass. Homeowners must demonstrate past irrigation, submit a description of their conversion project, and provide receipts documenting the project. Customers are allowed a waiver of alternate-day watering restrictions to encourage establishment of new plantings, and thereafter are required to reduce their water budgets by 25 percent. A post-conversion site review is conducted to confirm successful establishment of the replacement landscape. During spring and summer months, the town anticipates a savings of about 675 gallons per month for each 1,000 square feet converted to natural landscape, and approximately 567 gallons saved per month for each 1,000 square feet of warm season grass conversion (Town of Cary 2009). http://www.townofcary.org/Departments/Public_Works_and_Utilities/Conservation/Water_Conservation/Incentive_Programs/Turf_Buy_Back_Program/Turf_Buy_Back_Program_Fact_Sheet.htm

- The Southern Nevada Water Authority's (SNWA's) Water Smart Landscapes rebate helps property owners convert water-thirsty grass to xeriscape. SNWA will rebate customers $1.50 per square foot of grass removed and replaced with desert landscaping up to the first 5,000 square feet converted per property, per year. Beyond the first 5,000 feet, SNWA will provide a rebate of $1 per square foot. The maximum award for any property in a fiscal year is $300,000. http://www.snwa.com/html/cons_wsl.html

Resources

EPA's WaterSense program has a specification for water-efficient, single-family new homes that includes landscape criteria. The specification requires use of a water budget tool to help calculate a regionally appropriate allotment of turfgrass for a residence or a turfgrass reduction to 40 percent of the landscaped area. Although the tool is designed for use by builders designing new homes, consumers can use it in existing landscapes to help understand whether their use of turfgrass and other high water using plants is appropriate for their region. To learn more about the water budget tool, see http://www.epa.gov/watersense/nhspecs/homes_final.html

The SSI provides guidance on sustainable landscaping. One of the criteria for which it has developed guidance is site design for water conservation. To participate in the program, landscapes are required to reduce potable water use for irrigation by 50 percent from a baseline. Reductions can be accomplished through using regionally appropriate plantings, irrigation efficiency (drip irrigation), using captured rainwater, and using recycled graywater to name a few. To track landscape water savings, SSI uses a water budget tool adapted from EPA's WaterSense program that has additional criteria, requiring a greater reduction in outdoor water use. For more information, see http://www.sustainablesites.org/.

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5.3.12 Environmentally Friendly Landscape Requirements

Plant selection and planning have a significant effect on the amount of maintenance and inputs needed to maintain attractive landscaping. Landscaping that is considered environmentally friendly requires few inputs and focuses on the use of native landscaping, the use of drought-tolerant or locally adapted plants, and other features such as rainwater harvesting, infiltration areas, and street trees. Several regional programs promote such landscaping principles, including the BayScapes program for the Chesapeake Bay region and Bay-Friendly Landscaping in the San Francisco Bay area. The following are examples of communities that have adopted environmentally friendly landscaping requirements for certain types of development projects:

- The Oro Loma Sanitary District in the San Francisco Bay area of California has adopted an ordinance requiring the integration of green building and Bay-Friendly landscaping strategies in district and public-private partnerships buildings and landscapes. Projects are required to meet the most recent minimum *Bay-Friendly Landscape Guidelines* and Bay-Friendly Landscape Scorecard points (http://www.stopwaste.org/docs/bay-friendly_landscape_guidelines_-_all_chapters.pdf). www.oroloma.org/asset/regulation/ordinance%2043.pdf

- Miami-Dade County, Florida, has established landscaping requirements for right-of-way landscapes that promote xeriscape and *Florida-Friendly* principles by setting minimum standards for irrigation and selection of plant material and mulch. The ordinance requires the use of drought-tolerant species and grouping of plants by water requirements, and it sets limits on irrigation systems. It also aims to promote trees for a variety of environmental benefits and to reduce exotic pest plants. http://www.miamidade.gov/govaction/matter.asp?matter=091097&file=true&yearFolder=Y2009

Resources

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5.3.13 Xeriscaping Requirements

Xeriscaping is a type of landscaping that conserves water through planting of native, water-efficient plants rather than water-intensive ones and using techniques that minimize the need for irrigation. Xeriscaping has water quality benefits in addition to water conservation benefits because it helps to prevent dry-weather runoff from over-irrigation.

Altbough xeriscaping is a common practice in arid areas, the concept can be applied in the Chesapeake Bay watershed. The National Institutes of Health in Bethesda, Maryland, has created ground level xeriscaped areas using green roof soil media and plants near their security entrance to reduce runoff and provide a low maintenance aesthetically pleasing landscape (Figure 3-29).

Figure 3-29. Xeriscape landscaping at NIH Campus (from Waring 2007).

Xeriscaping programs, typically, are voluntary and focus on education and outreach, although some communities have implemented xeriscaping requirements as part of their landscaping codes, and others have developed incentive programs. The following are examples of both regulatory and incentive approaches to xeriscaping.

- Rancho Cucamonga, California, has a xeriscape requirement for developments requiring landscaping plans (with some exemptions, including single-family homes and public spaces). Developments with model homes are required to use xeriscaping on half of the models, including low water use plants, water-saving irrigation systems, and signage indicating to buyers the water-saving landscape design features. http://search.municode.com/html/16570/level2/T19_C19.16.html

- Mesa, Arizona, offers a Grass-to-Xeriscape rebate to encourage single-family homeowners to replace their lawns with xeriscapes. When a customer removes 500 square feet or more of established grass and replaces it with a xeriscape, the Mesa provides a $500 rebate. http://www.mesaaz.gov/conservation/grass-to-xeriscape-rebate.aspx

- Gallup, New Mexico, has a Xeriscape Rebate Application Program in which customers are eligible to receive a rebate on their water bill for each square foot of irrigated turf grass, removed and replaced with an approved xeriscape landscape (the city provides a Xeriscape Plant List). Twenty-five percent of the qualifying total square footage of irrigated turf grass removed must be replaced with qualifying xeriscape plants, subject to inspection and approval. http://www.ci.gallup.nm.us/GJU/Gallup-Xeriscape%20Rebate%20Application.pdf

- In 2006 California passed the Water Conservation in Landscaping Act to require local municipalities to adopt landscape water conservation ordinances by 2010. To assist municipalities with compliance, the state issued a Model Water Efficient Landscape Ordinance and accompanying technical resources, including a compendium of existing local ordinances addressing water-efficient landscaping. The model ordinance and technical assistance information are at http://www.water.ca.gov/wateruseefficiency/landscapeordinance/.

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Appendix 1: BMP Fact Sheets

1.1 Introduction

The BMPs included in this document are not an exhaustive list but represent some examples of low-impact development (LID) practices that have been widely adopted and have proven to be effective in managing stormwater, and where there is new information on existing practices, such as street sweeping. The fact sheets contain technical information and references and are written to be applicable to federal facilities and nonfederal facilities.

Practices such as stormwater detention and hydrodynamic settling devices have an important role in stormwater management and are effectively described in many existing sources (for references, see Section 6). The practices presented in this appendix were selected because they represent newer approaches to stormwater management (such as green roofs or bioretention) or new technologies (such as blue roofs and cisterns) or where new information exists on existing technologies (such as bioretention).

The following BMP fact sheets were prepared for this document because new information is available that is relevant to application in the Chesapeake Bay watershed and potentially elsewhere. Each fact sheet includes a description of the practice, targeted pollutants, photos/diagrams, constraints/limitations, effectiveness, design, maintenance, and costs. Equally important practices that are already well-described on EPA's Web site are not repeated here; instead, links to them are provided below.

Practices with fact sheets in Appendix 1 consist of the following:

- 1.2 Rainwater harvesting
- 1.3 Green roofs
- 1.4 Blue roofs
- 1.5 Bioretention
- 1.6 Infiltration
- 1.7 Soil restoration
- 1.8 Reforestation/urban forestry
- 1.9 Street sweeping
- 1.10 Constructed wetlands

Practices with fact sheets on EPA's Web site consist of the following:

- Downspout disconnection
- Planter boxes
- Rain gardens
- Permeable pavements
- Vegetated swales
- Brownfield redevelopment
- Infill and redevelopment
- Green parking
- Pocket wetlands
- Compost Blanket

EPA's Green Infrastructure Web site:
http://cfpub.epa.gov/npdes/greeninfrastructure/technology.cfm

EPA's Menu of BMPs Web site:
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

1.1.1 Performance Estimate Summaries for Infiltration Practices

The performance of LID practices varies significantly by the design and the regional climate. In the Chesapeake Bay region, a large infiltration BMP relative to the drainage area could provide infiltration of the 95th percentile storm event or more. The slower infiltration rates of clay type soils results in the need for more storage, but they also have an ability to infiltrate. For additional discussion, see the bioretention fact sheet.

The performance of several of these infiltration practices was recently reviewed for the Chesapeake Bay region to estimate the capability for volume control and pollutant reduction based on the design criteria used in the region (which was not developed to manage the 95th percentile storm event). The Mid-Atlantic Water Program housed at the University of Maryland led a project during 2006–2009 to review and refine definition and effectiveness estimates for BMPs in the Chesapeake Bay watershed. It is called *Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay*, (BMP Effectiveness Report) and is at www.chesapeakebay.net/marylandBMP.aspx (Simpson and Weammert 2009). The urban stormwater BMPs reviewed by the Mid-Atlantic Water Program are at http://archive.chesapeakebay.net/pubs/BMP_ASSESSMENT_REPORT.pdf. The LID BMPs reviewed and their definition as reported in the BMP assessment are as follows:

Bioretention: An excavated pit backfilled with engineered media, topsoil, mulch, and vegetation. These are planting areas installed in shallow basins in which the stormwater is temporarily ponded and then treated by filtering through the bed components, and through biological and biochemical reactions within the soil matrix and around the root zones of the plants.

Permeable Pavement and Pavers: Pavement or pavers that reduce runoff volume and treat water quality through both infiltration and filtration mechanisms. Water filters through open voids in the pavement surface to a washed gravel subsurface storage reservoir, where it is then slowly infiltrated into the underlying soils or exists via an underdrain.

Infiltration Trenches and Basins: A depression to form an infiltration basin where sediment is trapped and water infiltrates the soil. No underdrains are associated with infiltration basins and trenches because, by definition, these systems provide complete infiltration.

Filters: Filters capture and treat runoff by filtering through a sand or organic media.

Vegetated Open Channels: Open channels are practices that convey stormwater runoff and provide treatment as the water is conveyed, includes bioswales. Runoff passes through either vegetation in the channel, subsoil matrix, and/or is infiltrated into the underlying soils.

The effectiveness summary from the BMP Assessment Report is provided in Table 3A1-1. The BMP Assessment Report provides a summary of assumptions, data sources, maintenance consideration, and other factors related to these LID practices in the Chesapeake Bay area. Among the assumptions used in preparation of the effectiveness estimates were

- That the estimates reflect performance that might actually be expected where persons less-specialized in bioretention prepare the design and install and operate the BMP, according the design criteria used in the region. This estimates *average* performance. This was intentionally not based on data from controlled research studies on practices designed, built, and maintained by bioretention experts. This does not reflect performance of systems designed to achieve retention of the 95^{th} percentile storm event.
- That the BMPs were designed for a 1-inch storm; at approximately 1 inch to 1.5 inches, the system would begin to overflow. (1.5 inches of rainfall is approximately the 95^{th} percentile rain event in the Chesapeake Bay area.)
- Lined bioretention cells were reported to have poorer performance; the presence of the liner reduces performance to approximately that of C/D soils with an underdrain.

In reviewing the effectiveness values in the table, it is important to note the variability in the estimates, that the estimates are intended to be conservative, and that the majority of the pollutant removal is associated with the volume reduction that occurs from either infiltration or evapotranspiration. For additional information on performance estimates, refer to the Bioretention/Biofiltration fact sheet.

Table 3A1-1. Effectiveness summary from the BMP assessment report

	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection areas (acres)		
	TP	TN*	TSS		TP	TN	TSS
Bioretention							
C/D soils, underdrain	37	10	50	**15**	45	25	55
A/B soils, underdrain	37	10	50	**65**	75	70	80
A/B soils, no underdrain	37	10	50	**80**	85	80	90
					± 20	± 15	± 15
Filter							
All (sand, organic, peat)	60	40	80	**0**	60	40	80
					± 10	± 15	± 10
Vegetated Open Channels							
C/D soils, no underdrain	10	10	50	**0**	10	10	50
A/B soil, no underdrain	10	10	50	**40**	45	45	70
					± 20	± 20	± 30
Bioswale	37	10	50	**65**	75	70	80
					± 20	± 15	± 15
Permeable Pavement (no sand/veg)							
C/D soils, underdrain	10	0	50	**10**	20	10	55
A/B soils, underdrain	10	0	50	**45**	50	45	70
A/B soils, no underdrain	10	0	50	**75**	80	75	85
					± 20	± 15	± 15
Permeable Pavement (with sand, veg)							
C/D soils, underdrain	10	10	50	**10**	20	20	55
A/B soils, underdrain	10	10	50	**45**	50	50	70
A/B soils, no underdrain	10	10	50	**75**	80	80	85
					± 20	± 15	± 15
Infiltration Practices (no sand/veg)							
A/B soils, no underdrain	25	0	95	**80**	85	80	95
					± 15	± 15	± 10

Table 3A1-1. Effectiveness summary from the BMP assessment report *(continued)*

	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection areas (acres)		
	TP	TN*	TSS		TP	TN*	TSS
Infiltration Practices (with sand/veg)							
A/B soils, no underdrain	25	15	95	**80**	85	85	95
					± 10	± 15	± 10

Source: Simpson and Weammert. 2009. *Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay*. Final Report.

Notes:

1. Soil classification (A, B, C, D) per U.S. Department of Agriculture (USDA) National Resource Conservation Service (NRCS)
2. EMC-based removal expressed as Percent Reduction (PR)
3. Mass-based removal expressed as percent removal of total load by mass (TR)
4. Nitrogen concentration reduction is low potentially because the solubility of nitrate, the potential for organic nitrogen and ammonia to mineralize in the bioretention media to the nitrate form, and the lack of conditions needed for denitrification contribute to nitrogen export.
5. Assumptions include (1) highly impervious urbanized land use; (2) generalized for design criteria typical of bay area jurisdictions; (3) designed, installed and maintained by persons who are not experts in bioretention; 3) low phosphorus soil media; (4) for systems designed for a 1-inch storm, rain events from 1 to 1.5-inch depth will begin to show overflow
6. Total removal estimated by the calculation TR = RR + {(100-RR) × PR)}, rounded to a factor of 5.
7. Authors caution that the estimates, based on limited data and generalized for simplicity, might not represent true long-term performance throughout the watershed. Performance is highly variable even under controlled conditions.

1.2 Rainwater Harvesting

Description of Practice

Rainwater harvesting can play an important role in managing stormwater runoff and can reduce both the costs and energy needed to convey and treat runoff offsite. Rain barrels and cisterns can be used to reduce runoff volume and mitigate peak runoff flow rates for small and medium storm events. Rainwater collected in harvesting systems is typically used only for nonpotable applications, such as irrigation, toilet flushing, and vehicle washing, but uses could expand as demand for water increases. In addition to reducing stormwater runoff, rainwater harvesting has the secondary benefit of reducing potable water demand because nonpotable uses represent up to 40 percent of overall household water demand. Rooftop runoff, because it typically contains low pollutant loads and is easily collected, is the source of most water collected in rainwater harvesting systems.

Harvested rainwater can be routed and stored in two main types of vessels called cisterns or rain barrels. Cisterns generally have a much larger capacity than rain barrels. Cisterns can be designed to hold hundreds or thousands of gallons. Rain barrels most often hold between 55–250 gallons with 55- to 75-gallon barrels being the most commonly used sizes. To capture the rainwater, roof downspouts are piped to the rain barrel or cistern. Most residential rain barrels are installed outside as are many cisterns. However, cisterns can be installed inside residential and nonresidential buildings, outside and above or below grade. Bypass drains or systems are used to divert excess volume when the rain barrel or cistern is full.

Some systems require the use of filtration or disinfection systems depending on the intended use and the size of the system. Rain barrels typically do not require such systems. Filtration and disinfection systems are used to reduce fouling, clogging, bacterial growth, slime formation and to treat the rainwater for its intended uses.

In most areas of the country, the use of rain barrels and cisterns is for water supply. They are also encouraged mainly to reduce the volume of runoff discharged from impervious surfaces, such as to help mitigate localized flooding or combined sewer overflows. In arid or semi-arid areas or areas of period drought rainwater harvesting systems can play an important role in the provision of supplemental irrigation or wash waters. Around the globe, rainwater collection systems are often used to provide potable water. In the United States the use of harvested rainwater for potable uses is restricted because of public health concerns.

Rainwater harvesting systems are most effectively used to reduce runoff volume when they are integrated into a treatment train or system of practices that can include green roofs, permeable pavements, or rain gardens/bioretention cells.

To optimize system performance, the system should be managed either manually or automatically to discharge the captured volume before the next significant storm event occurs. Such management strategies help to ensure that the maximum cistern/rain barrel capacity is available when a rain event occurs. For example, soaker hoses can be used with rain barrels to slowly drain the rain barrel in periods of non-irrigation use and automatic real-time control systems can be used for large nonresidential systems to control the timing of and the release rate of water from the cistern to ensure capacity is available to capture the next storm.

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
◉[1]	◉[a]	○[a]

Key: ● High effectiveness ◉ Medium effectiveness ○Low effectiveness

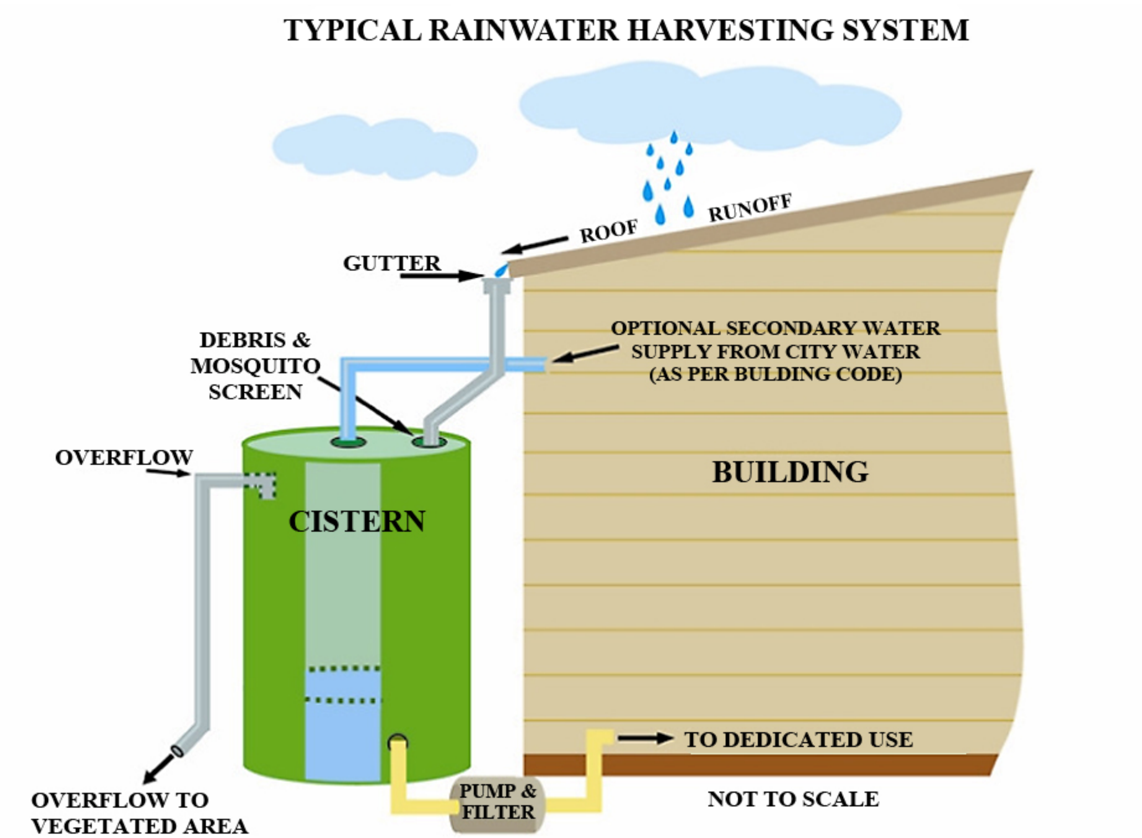
[a] The effectiveness depends on how the water is managed after capture, i.e., slowly released to a storm sewer, used for infiltrating irrigation, etc.

Targeted Pollutants

Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
○	○	○	○	○	○	○

Key: ● High effectiveness ◉ Medium effectiveness ○Low effectiveness

Photos and Diagrams



Source: NC Division of Water Quality. Technical Guidance: Stormwater Treatment Credit for Rainwater Harvesting Systems

Figure 3A1-1. Typical rainwater harvesting system

Common Feasibility Constraints and Limitations

- Requires a dedicated plumbing system for indoor use.
- Optimal performance requires active management to ensure that storage containers are emptied between storms.
- Local ordinances can restrict downspout disconnection or indoor use of harvested water.

Runoff Volume and Pollutant Load Removal Estimates

The volume retained in a storm event is determined by the size of the storage container and its available volume at the time of the storm. Careful operation of the system to ensure that cisterns and rain barrels drain completely before a rain event can help to maximize the available volume. The use of real-time control systems can increase performance significantly.

Pollutant removal by rainwater harvesting is minimal, and is generally limited to settling of suspended solids. Water quality can degrade in a cistern if bacteria are allowed to grow.

Practice Design

Sizing is based on rainfall patterns, drainage area, water demand, and space and/or budgetary constraints. Cisterns should be sized to store water from multiple events, or to empty between events, if capacity for back-to-back storms is needed.

Proper cistern capacity is calculated by balancing the expected rainfall volume with the anticipated water demand. Additional capacity could be incorporated to allow extended storage of rainwater for use during dry periods.

Design considerations include the following:

- Piping for harvested rainwater should be labeled to prevent accidental use for potable applications.
- Rain barrels and cisterns should be fitted with emergency overflows.
- Cisterns constructed belowground must be fitted with pumps to deliver collected water.
- Systems for indoor uses such as toilet flushing should be dual piped with potable water for back-up. A backflow prevention assembly should be used to prevent cross-contamination of the potable supply line. Local building codes should be consulted.
- Pretreatment might be desired before storage to prevent fouling of the storage tank. Screening, settling of suspended solids, and oil and grease separation (for parking lot runoff) might be beneficial. The first flush of runoff can be diverted from the storage tank to remove debris.
- Treatment requirements for stored rainwater vary by municipality and intended end use. Typically, no treatment is required for outdoor irrigation, while filtration and/or UV disinfection might be required for indoor nonpotable uses.
- Outdoor cisterns should be screened at each opening to prevent insects from entering.

American Rainwater Catchment Systems Association/American Society of Plumbing Engineers issued *Rainwater Catchment Design and Installation Standards* (August 2009) to assist in properly and safely implementing systems. Several localities have implemented or adopted standards as part of their building codes.

Maintenance Considerations and Resources

A typical maintenance schedule is provided in Table 3A1-2. Maintenance needs will vary by the type of system and location.

Table 3A1-2. Rainwater harvestor maintenance schedule

Activity	Minimum frequency
Inspect and clean filters and screens	Before the first storm event and every 2 months during the wet season
Inspect and clear debris from roof, gutters, downspouts, and roof washers, and other rainwater harvesting areas	Before the first storm event and every month during the wet season
Remove tree branches and vegetation overhanging roof or other above-ground rainwater harvesting areas	As needed
Inspect pumps, valves, and pressure tanks and verify operation	After initial installation and annually at the beginning of the wet season
Inspect cistern(s) and system labeling	After initial installation and annually at the beginning of the wet season
Inspect backflow prevention system	After initial installation and annually at the beginning of the wet season or as required by LACDPH
Cross-connection inspection and test	After initial installation and annually at the beginning of the wet season or as required by LACDPH

Source: Federico, et al. Geosyntec Consultants, *Technical Memorandum: Large-Scale Cistern Standards*, Report to Los Angeles County Department of Public Works, December 2009.

Costs and Factors Affecting Cost

Fifty-five-gallon rain barrels typically cost $50–$100 for prefabricated units, or $30 for do-it-yourself kits.

For cistern tanks, costs depend on the material used for construction, and costs are similar to other water storage tank systems (Table 3A1-3). A tool for estimating tank and pump costs is available from the Water Environment Research Foundation (WERF), the *User's Guide to the BMP and LID Whole Life Cost Model, Version 2.0*, and associated spreadsheet tool.

Table 3A1-3. Cistern tank costs

Cistern tank cost by type ($/gallon, installation not included), 2009			
Fiberglass	**Steel**	**Plastic**	**Concrete**
10,000 gal and up	500-15,000 gal	50-1,500 gal	2,000 gal and up
$ 1.33	$ 2.51	$ 1.43	$ 1.66

Source: WERF BMP and LID Whole Life Cost Model, Version 2.0

Costs for large cistern systems are dependent on many site-specific factors, such as whether excavation is required for underground units. Cost items applicable to systems used for irrigation can include

- Piping and pretreatment (screening)
- Tank, pumps, valves
- Site preparation
- Concrete pad for above ground; excavation for buried

Example system costs are provided in Table 3A1-4.

Table 3A1-4. Summary of cistern system costs with project characteristics

Site	Capacity (gallons)	Construction material	New/retrofit year installed	Location	Estimated cost
Landscape Architecture[a] Library, Tucson, AZ	11,600	Steel and Fiberglass	New 2007	Above-ground	$17,000 (total cost)
Fairmount Square[a] Grand Rapids, MI	30,000	Concrete	New	Buried	$40,000 (total cost)
Redbud Center[a] Austin, TX	31,000	Steel	New 2008	Above-ground	$250,000 (total cost)
Santa Monica Main[a] Library, CA	200,000	Concrete	New 2006	Buried	$700,000 (total cost)
Mark Miller Toyota[b] Salt Lake City, UT	1 @ 8,000 1 @ 2,000	Concrete	New 2008	Buried	$22,000 (total cost)
Hypothetical Office[b] Building, Arlington, VA	10,000	Fiberglass	New 2008	Buried	$179,000 (estimated total)
Open Charter Elementary, Westchester CA[b]	110,000	Modified RainStore3 Infiltration System	New 2004	Buried	$500,000 (not incl. design)
Hall House, Los Angeles, CA[a]	3,600	Polypropylene	Retrofit 1998	Partially Buried	$25,000 (installed)
Center for Community Forestry, Los Angeles, CA[a]	216,000	Concrete	New 2008	Buried	$400,000 (excludes soft costs, distribution system)

[a] Federico et al. 2009. Technical Memorandum: Large-Scale Cistern Standards. Prepared for Los Angeles County Department of Public Works, by Geosyntec Consultants.

[b] Water Environment Research Foundation. 2009. *User's Guide to the BMP and LID Whole Life Cost Model, Version 2.0*.

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1.3 Green Roofs

Description of Practice

Green roofs attenuate flow and provide storage and evapotranspiration of stormwater. They are typically designed with an impermeable membrane that is root resistant, an engineered soil medium, plants, and in many cases an underdrain system. Some green roofs also have leak detection systems. The design of green roof systems significantly affects performance. The two main categories of green roof designs are

- Extensive, which have a shallow planting media layer (typically 2–6 inches) and low-growing, drought tolerant plants.
- Intensive, which have a deeper media layer, and can be planted with a wider variety of plants, including trees and shrubs. Intensive green roofs can be fitted with walkways and used as recreational areas.

Rain falling onto green roofs is both detained and retained in the soil medium. When the soil medium becomes saturated, the excess water percolates through to the drainage layer and is discharged through the roof downspouts. Between storm events, water absorbed by the soil media is returned to the atmosphere by evapotranspiration. Depending on the design and climate pattern of the region, green roofs can provide significant stormwater volume reduction annually, decrease peak flow rates, and help to restore hydrologic function of the watershed by absorbing and attenuating runoff.

In addition to providing stormwater retention, green roofs can be designed to provide ancillary benefits, such as enhancing site aesthetics, urban habitat for birds and insects, reduction of urban heat island effects, insulation value for energy conservation, and increasing the longevity of roofing materials.

Green roofs are common in Europe but have only recently gained popularity in United States as a practice for mitigating stormwater runoff. The *International Green Roofs Projects Database* (www.greenroofs.com) lists more than 1,000 green roof projects, mainly in the United States.

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
●	⦿	○

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Targeted Pollutants

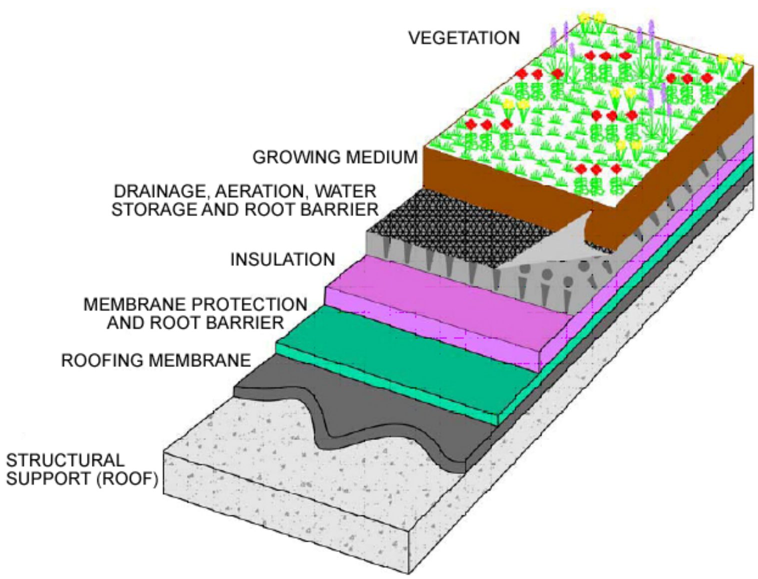
Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
○	○	○	⦿	○	○	⦿

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: The Low Impact Development Center

Figure 3A1-2. ASLA headquarters green roof.



Source: MDE Stormwater Design Manual

Figure 3A1-3. Green roof section.

Common Feasibility Constraints and Limitations

- Slopes when using the more typical construction practices are generally less than 30 percent. Installations on pitched roofs require stabilization structures to prevent migration of the soil medium. Specialized drains are typically required for slopes above 5 percent.

- Roofs must be able to bear the load of a fully saturated medium. Extensive green roof wet weight is approximately 6 to 7 pounds per square foot per inch of depth.
- Construction costs include transporting materials to a roof, which could require a crane.
- Costs of green roof construction are typically higher than other LID practices (such as bioinfiltration or blue roofs) for water-volume reduction. However, it has been shown to be cost-effective when other factors are considered, such as energy savings, and has other benefits to the public, including reduction of urban heat island effect, particularly in dense urban areas (Portland Bureau of Environmental Services 2008).

Runoff Volume and Pollutant Load Removal Estimates

Runoff volume removal is a function of the green roof area, the specifics of the green roof design, and the local climate and rainfall pattern. Green roofs can retain the full volume of small storms, and they are commonly designed to detain brief periods of high-intensity rainfall. Reported results for extensive roofs are summarized in Table 3A1-5.

Table 3A1-5. Performance estimates for annual flow retained, summer flow retained, and peak flow shaving for green roofs

Performance Measure	Performance[a] Estimate	Location	Depth of Media (not including submedia layers)	Source
Annual Flow Retained	50%	Philadelphia	3.5 to 4 inches	USEPA 2009
	75%	Washington, D.C.	3 to 18 inches	Glass 2007
	65%–70%	East Lansing, MI	1 to 2.4 inches	VanWoert 2005
	56%	Portland, OR	5 inches	Portland BES 2008
	26%–86%	National Range	Various	Portland BES 2008
Summer Runoff	95%	Philadelphia	3.5 to 4 inches	USEPA 2009
Peak Flow Shaving	30%–96%	National Range		Portland BES 2008
	60%	Portland, OR	5 inches	Portland BES 2008

[a] Performance as measured over the period as a whole, not for a specific event, for example, not for the 96th percentile storm event, but for that 96% of the total rainfall over the period was retained.

Pollutant removal in green roofs is strongly dependent on the specifics of the design and on rates of atmospheric deposition. Studies have shown that green roofs do not often provide pollutant reductions; however, it is noted that the concentration of pollutants in direct rainfall is very low (therefore, there is relatively little pollutant to remove). Temporary export of nutrient can occur during initial establishment of the media and plants. Poorly designed green roof soil media can lead to export of low concentrations of nutrients and solids from the media, fertilizer and plants. For this reason, it is preferable to discharge the runoff from green roofs into bioretention or other unit if pollutant reduction is needed in addition to the volume reduction (EPA 2009). Green roofs, however, have been shown to export lower levels of pollutants than conventional roofs. Material selection is an important consideration. Many roofing materials can export toxic chemicals used in their construction (Clark et al. 2008).

Practice Design

Green roofs are most often constructed on flat or shallow sloped roofs, but roofs with slopes up to 30 percent accommodate green roofs with the use of mesh, stabilization panels, or battens. The area covered by green roofs is typically limited to 50–80 percent of the total roof area because of the need to accommodate HVAC (heating, ventilation, and air conditioning) or other equipment (e.g., cell towers or solar panels) and roof access or other penetrations. Green roofs have also been designed to accommodate solar panels.

A typical green roof profile would include the following layers:

- Vegetation layer
- Engineered growth media
- Separation geotextile
- Semi-rigid plastic geocomposite drain or mat
- Root barrier
- Waterproofing membrane

Plant selection—Plant selection varies depending on the type of green roof installed. Extensive green roofs should be planted with low-growing, drought-tolerant plants, such as succulents. Sedums are frequently used. Intensive green roofs, which have deeper soil media, can accommodate a much wider variety of plants, including trees and shrubs. Intensive green roofs often require irrigation to support the larger plants.

Soil medium—To minimize the potential for nutrient export, the soil medium should have a high mineral content. Use of compost has been found to produce elevated levels of nitrogen and phosphorus in effluent, at least in the short term (Moran et al. 2004).

Maintenance Considerations and Resources

Maintenance requirements vary depending on design specifics, with extensive green roofs typically requiring less maintenance than intensive green roofs. Maintenance typically includes

- Periodic irrigation during plant establishment and dry periods.
- Periodic weeding, fertilization (if needed), and infill planting
- Periodic inspection of drainage outlets and waterproof membrane.

Costs and Factors Affecting Cost

Costs depend on the media depth, the number and type of additional structural components in the design, the vegetation selected, and the need for structural roof modifications. Costs for extensive green roofs typically range from $8–$14 per square foot (PADEP 2006). The installation cost of the green roof is partially offset by increasing the life of the underlying roof and reducing heating and cooling demand within the building.

Costs were reported to vary primarily by the installation type (WERF 2009; Portland BES 2008):

- Modular, tray-type installations: $19.50 per square foot
- Custom applications with media spread across the surface: $8.75 per square foot

Green roofs reduce energy costs and extend roof life. *Green Roofs for Healthy Cities* (www.greenroofs.org) provides a calculator to estimate the long-term savings.

A cost-benefit analysis of a hypothetical green roof concluded that green roofs had a higher net present value for the owner and the public, despite higher initial capital and O&M costs (Portland BES 2008). Not all benefits were examined, but areas where economic benefits accrued include

- For the public: (1) Reduced Stormwater Quantity; (2) Avoided Stormwater Infrastructure; (3) Improved Air Quality; (4) Enhanced Habitat
- For the owner or developer: (1) Reduced Stormwater Fees; (2) Extended Roof Life; (3) Increased floor-to-area (FAR) allowance allowing more floors and higher buildings; (4) Reduced energy costs

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1.4 Blue Roofs

Description of Practice

A blue roof is a roof design that is explicitly intended to provide temporary storage and slow release of stormwater runoff. In many locations, these approaches are also referred to as *rooftop detention*. They are most commonly used in dense urban areas where other methods of stormwater detention are impractical. Blue roofs are used to detain rooftop runoff on-site and reduce the rate of runoff from rooftops during rainfall events. A blue roof can be used as a standalone detention method. Or, because they do little to improve the water quality of runoff, they can be part of a treatment train that includes other LID and conventional BMPs such as bioretention, infiltration, or wetland systems to shave peak flows and provide temporary storage to enhance the function, improve the performance, and reduce the cost of those practices. Blue roofs are one of the least expensive means for temporarily detaining stormwater on-site and can be used where green roofs are not feasible, cost effective, or otherwise desired because of competing needs.

The four primary blue roof types are described below:

- *Roof-integrated Designs*—Roof-integrated designs are built during new construction or as modifications of existing roofs to intentionally store standing water over extended periods.

  These designs use a roofing membrane or waterproofing system as the primary water detention structure. Therefore, water is temporarily ponded directly on the roof surface. Roof integrated designs can be designed to store water as an open water surface or partially or completely within a porous media.

  In addition, structures such as walkways, decks, or plazas can be constructed on top of roof integrated designs to minimize the impact of ponded water on roof access. Alternatively, porous media such as flexible paving tiles or granular media can be used as a permeable walking surface on all or part of the roof to allow for access, while reducing the amount of standing open water.

  Roof-integrated designs can be constructed as a secondary roofing layer on top of an existing surface in the same manner as a physical root barrier in green roof designs.

- *Modular Tray Designs*—Modular tray systems use plastic trays to temporarily detain water during rainfall events and release this water over some period following a rainfall event. This approach provides flexibility in both the size and configuration of the detention system and is, therefore, well-suited for retrofit designs. Equipment and other roof penetrations can be avoided through selective placement of the trays. Loading issues can be addressed through optimal density and placement configurations. The trays can be physically attached to the roof or underlying supporting grid and/or held in place with ballast composed of coarse stone or other weighted materials. The depth of the ballast or media contained in the trays can be varied depending on the desire to reduce the presence of open water surfaces.

  Modular trays can have any number of different outlet designs according to the goals of the installation (e.g., reduce peak flows, achieve specific lag time for target events). When the water is released, the drainage system for the existing roof continues to function as it did before the retrofit (i.e., hydraulic head and flow depths on the roofing surface during rainfall are not increased).

Modular tray blue roof designs can be selectively mixed with green roof components to improve aesthetics and provide some of the additional benefits of green roofs. The most challenging component of blue roof tray designs is the robustness of the hydraulic outlet design. Consistent and reliable drainage of the trays with little maintenance is a key consideration. Some designs allow for trays to be interconnected to effectively act as a larger tank.

- *Roof-Dams/Roof-Checks*—Roof-dams or roof-checks are impermeable or semi-permeable interim breaks in the surface flow paths installed on existing or new roofs that allow water to pond behind them as temporary detention. The dams can incorporate specific overflow or outlet designs to slowly release the stored water. In the same manner as a roof-integrated design, the roof is used as the primary water detention structure with the flows being restricted by the roof-dams. If retrofit onto existing roofs, the ability of the roof to accept additional ponding should be assessed and addressed. In older roof installations, new roofing and additional water proofing might need to be installed in conjunction with the installation of the dams.
- *Actively Controlled Systems*—Blue roofs that are used for temporary rooftop storage can be classified as *active* or *passive* depending on the types of control devices used to regulate drainage of water from the roof. Passive designs use hydraulic structures such as weirs, orifice plates, or hydraulic regulators to control release rates from the roof. Active approaches allow for the use of a valve configuration and controller to regulate discharge of flows from rooftops.

  The simplest design for an actively controlled blue roof is the retrofit or installation of a pneumatically or hydraulically actuated pinch valve on the roof leader drain pipe. This valve can be connected to a low cost micro-controller, which monitors hydraulic head on the valve and timing of storage on the roof surface. The controller can be programmed to release the ponded water according to some predetermined optimal approach on the basis of analysis of the receiving storm sewer, downstream BMP, or receiving water. More complex designs can integrate communications with server-side and/or Internet-based data feeds, or telemetry to optimize release timing and quantities.

Blue roofs can be implemented effectively on shallowly sloped roofs in residential, manufacturing, commercial, or industrial settings. Rooftop detention is a particularly good storage option in densely developed areas where roofs make up a significant portion of the total site area.

Blue roofs are well-suited to applications on commercial and residential buildings, which typically have large, flat roofs and little or no area available for storage on site surrounding the building. Such large roofs generate significant runoff quantities. Rooftop detention using blue roofs represents a cost effective and convenient storage option that can be applied to new construction in the urban environment to provide adequate storage volume and runoff reduction to comply with stormwater regulations.

In addition to applications in densely developed areas, blue roof storage techniques also lend themselves well to implementation on sites with moderate to large flat roofs where flow from impervious non-roof area (e.g., parking lots, walkways) also contributes to the total runoff. In these situations, blue roofs are used to control rooftop runoff, while subsurface BMPs are used to control runoff from non-roof areas. The use of rooftop storage on such sites reduces the required volume for subsurface systems and allows these systems to be constructed over a smaller area.

Key advantages include

- Often the least expensive means for temporarily storing stormwater at a site particularly when compared to subsurface storage or green roof systems
- Can reduce the size and/or improve the performance of downstream BMPs, such as bioretention cells of infiltration systems
- Easy to install—no additional excavation is required, additional construction could be minimal depending on the depth of water to be stored
- Existing commercially available products for flow control
- Readily coupled with other storage techniques, such as subsurface or surface storage

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
○	●	○

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Targeted Pollutants

Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
○	○	○	○	○	○	○

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: with permission from the New York City Department of Environmental Protection

Figure 3A1-4. Rooftop detention being used to control runoff at a commercial property.

Common Feasibility Constraints and Limitations

- Storage using outlet controls limited to flat roofs or roofs with shallow slopes (e.g., < 1 percent) because of increased ratio of ponding depth to available volume for steeper slopes. This problem can be addressed through the use of modular tray designs or roof-dams.
- Limited benefit on sites where roof area makes up only a small portion of total impervious area.
- Regular maintenance varies by design, but is an important consideration. Verification of system performance might be necessary.
- Potential tampering must be considered in design.
- Pest problems must be avoided through proper design and maintenance, e.g., mosquitoes.
- Local building codes should be checked to ensure designs are compliant.

Because blue roof designs generally hold less than 4 inches of ponded water on the roof for times ranging from a few minutes to many hours, blue roofs typically do not impact the availability of roof space for other uses.

If such water ponding is incompatible with anticipated future uses of the roof, the blue roof can be designed to occupy a portion of the roof area, leaving additional roof space available for other purposes. If structures and equipment are mounted to the roof within the area intended for ponding water, it might be necessary to provide additional waterproofing around the structure or equipment or to elevate the equipment above the anticipated maximum water depth to prevent damage and provide access for maintenance. Where roofs are intended to be used as means of egress or points of rescue for fire safety, walkway pavers should be provided to allow for safe passage to fire escapes from the roof surface. The pavers provide a dry walking surface to allow for safe movement through ponded water. In addition, decks, walkways or pavers can be incorporated into the design of a rooftop detention system to provide space on the rooftop for passive recreational use.

The application of blue roof systems is most effective on roofs with a maximum slope of about 1/8 inch per foot (or 1 percent slope) or those with drainage configurations that can safely allow for the necessary volume detention.

To prevent clogging, the owner should inspect drains and clear snow and ice as necessary after winter precipitation events in accordance with established maintenance procedures. As with conventional flat roofs, maintenance procedures for blue roof systems include the removal of accumulated snow before an anticipated rain event to prevent possible overloading. Homeowners or building maintenance staff can remove snow from the blue roof using the same removal methods used for conventional flat roofs.

Runoff Volume and Pollutant Load Removal Estimates

Blue roofs primarily provide a means for temporarily detaining water. Little direct impact on water quality can be achieved through the use of blue roofs alone. Some evaporation will occur in systems that detain water for extended periods. Evaporation rates on blue roofs approach pan evaporation rates. Pan evaporation rates can be significant under certain climatic conditions (e.g., hot, windy, low humidity days).

Practice Design

Blue roofs are most often constructed on flat or shallowly sloped roofs, but tray and roof dam designs can be used on slopes in excess of 5 percent. On roof integrated designs where the roof is sloped, even very shallow slopes dramatically reduce detention capacity. Typically in retrofit situations, the roof is reconstructed as a part of blue roof installation. With tray designs, that might not be necessary. The designer must pay close attention to roof system manufacturer's requirements to ensure that the roofing system and design are compatible with manufacturer's warrantees and with the blue roof design.

Maintenance Considerations and Resources

Maintenance for most blue roof systems are similar to those required for typical flat roofing drainage systems and involve occasional snow and ice removal, regular inspection for debris clogging inlets, and inspection and repair of the roof.

Costs and Factors Affecting Cost

Blue roofs are one of the least expensive means for temporarily detaining stormwater on-site. The marginal cost of adding a blue roof to new construction is typically less than $2 per gallon of temporary storage where structural modifications to building design are not required (e.g., designs take into account snow loads). As new approaches (e.g., tray designs) gain wider acceptance in the marketplace, it is expected that blue roof detention can drop below $1 per gallon of temporary storage.

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1.5 Bioretention/Biofiltration

Description of Practice

Bioretention cells are small-scale, vegetated, shallow depressions that are used to reduce runoff volumes and pollutants through the process of soil filtration, interception, vegetative uptake, biological processes, infiltration, retention, and evapotranspiration. Bioretention cells can be used as stand alone systems or as part of a treatment train. Bioretention cells are typically designed with native soils and or/an engineered soil mix, and plants that are selected to be tolerant of a range of wet and dry conditions. In some cases site conditions or design goals might require the use of gravel for additional volume retention or the use of overflow devices. Where groundwater recharge is required, bioretention can help protect the quality of infiltrated stormwater. Bioretention typically has no underdrain or liner, both significantly reduce volume reduction performance.

Biofiltration allows for an underdrain, with only partial or no infiltration achieved, for applications such as where a discharge is desirable or infiltration is to be avoided.

The use of soil-based, vegetated systems have distinct advantages over the use of nonbiological infiltration trenches or similar designs for the following reasons (Davis et al. 2009):

- Roots promote media permeability.
- Surface vegetation can be used to slow stormwater flows and filter sediments.
- Roots support microbial populations needed for pollutant biodegradation.
- Phytoremediation uptakes and breaks down pollutants.

It is recommended that, where feasible, designs use a variety of hardy native plants that are adapted for both wet and dry soil conditions to ensure long-term plant survival and vigor. If native plants are not available, the use of nonnative, noninvasive species that typically do not require fertilizer, irrigation or pest control except at establishment is appropriate.

Bioretention cells can be used in a wide set of applications in the built environment to manage runoff from roofs, lawns, and streets and other impervious areas such as parking lots and sidewalks. Bioretention practice typically fall in to the following categories:

- Residential rain gardens
- Tree boxes (common and expanded) and shrub bioretention cells
- Sidewalk or right of way planter boxes
- Parking lot islands
- Street curbs extensions and bump-outs.
- Wooded bioretention areas
- Bioretention swales

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance For Design Storm Events

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
●	●	●

Key: ● High effectiveness ⦿ Medium effectiveness ○ Low effectiveness

Targeted Pollutants

Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
●	⦿	⦿	●	●	⦿	●

Key: ● High ⦿ Medium ○ Low

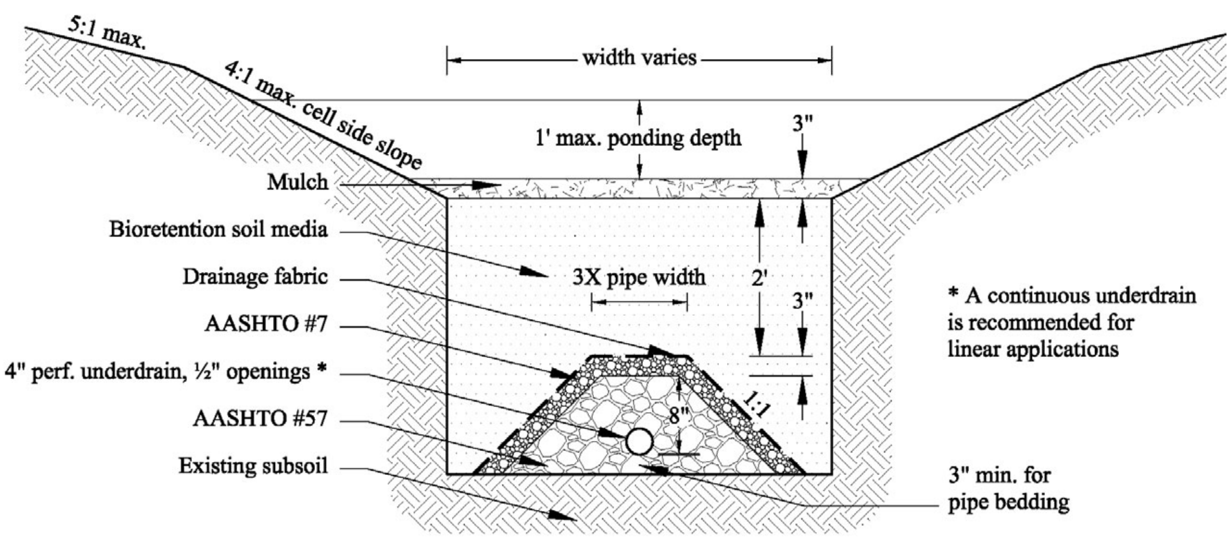
Photos and Diagrams

Source: Larry Coffman, Prince George's County, Somerset Subdivision

Figure 3A1-5. Bioretention cell for street and yard drainage.

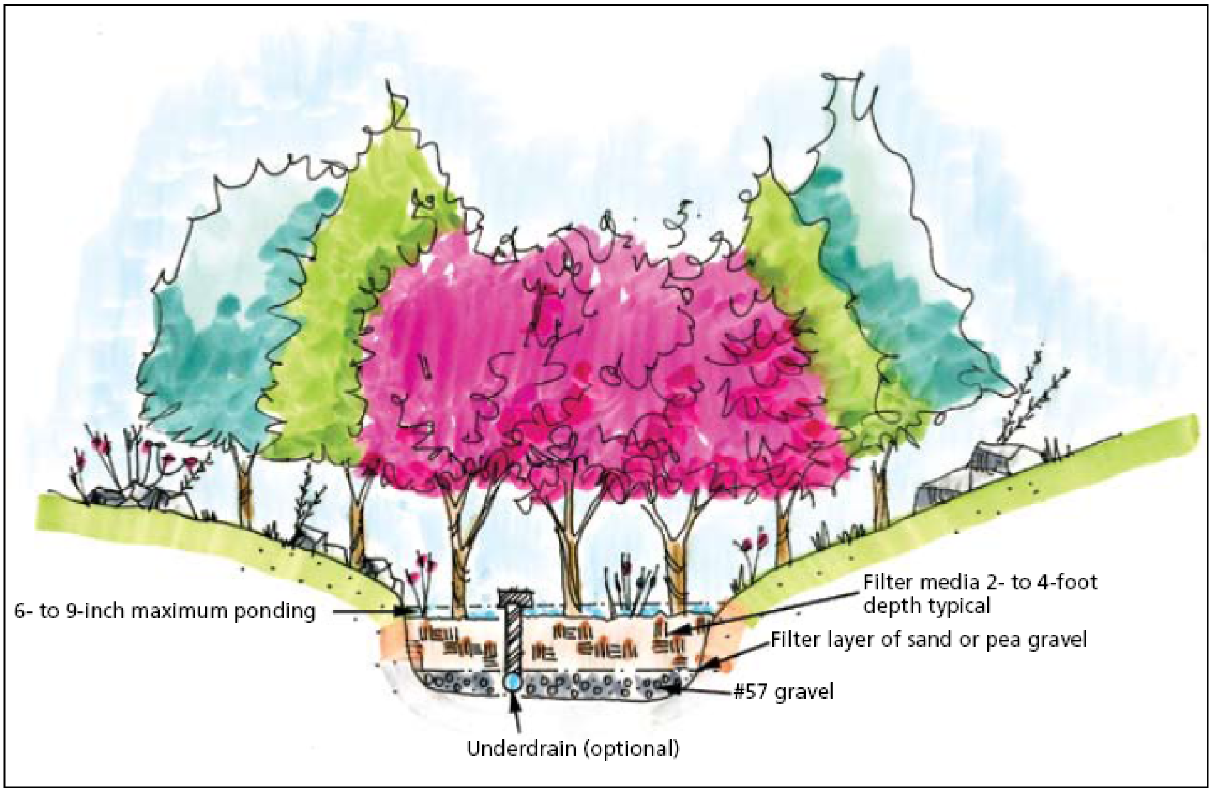
Source: Abby Hall, USEPA

Figure 3A1-6. An urban bioretention system treats sidewalk and road runoff.



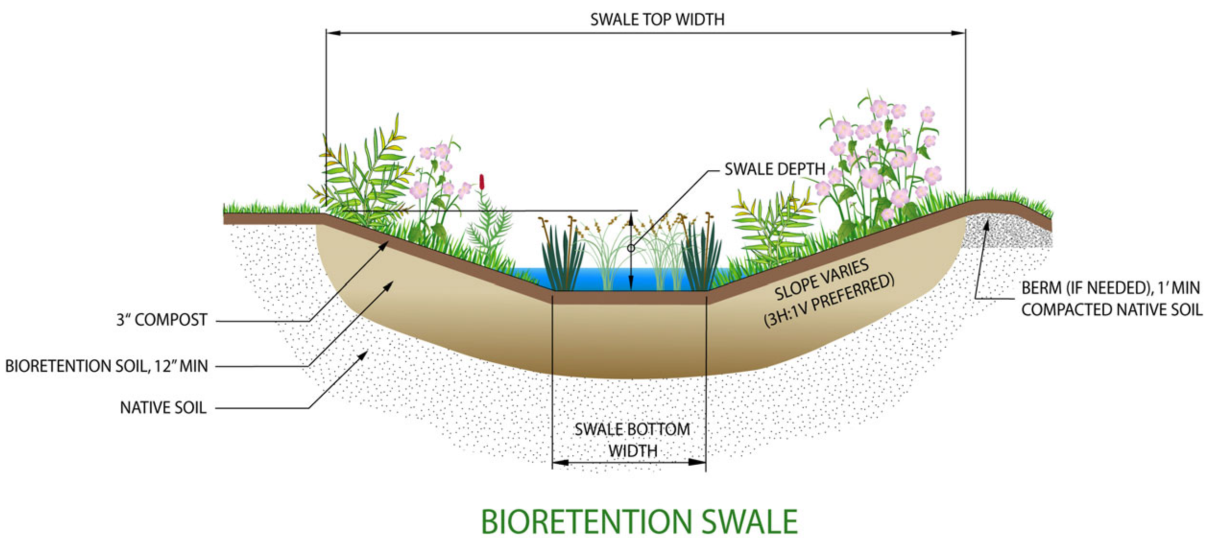
Source: LID Center

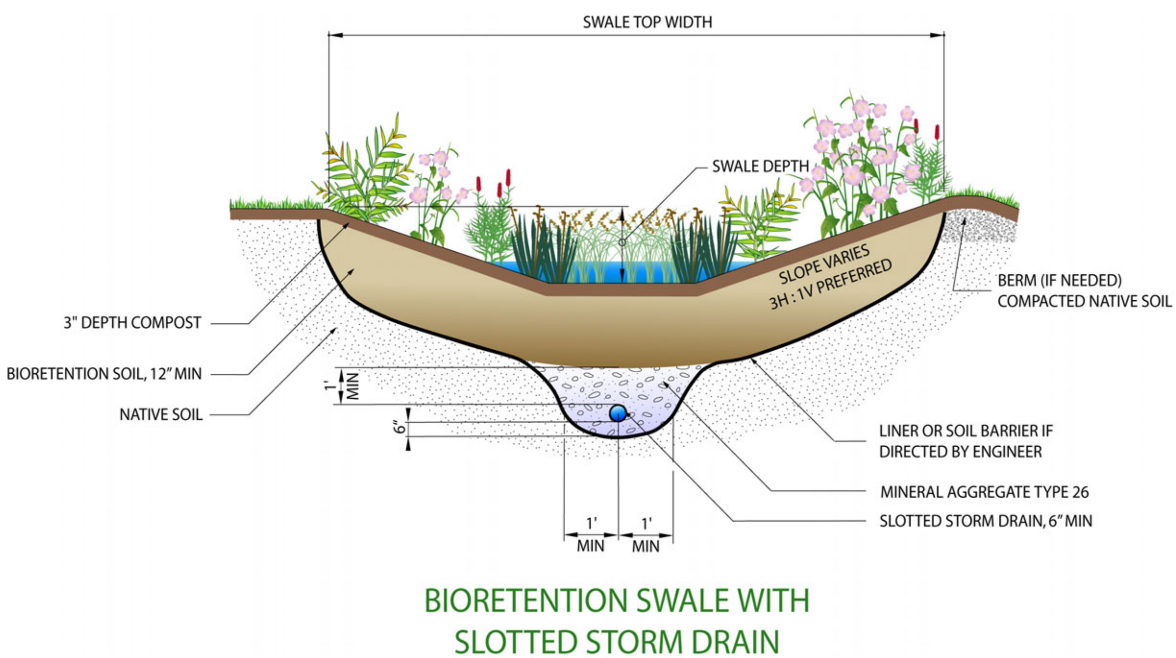
Figure 3A1-7. Typical bioretention cell cross-section. Not to scale.



Source: Urban Watershed Forestry Manual, Part 2, CWP and USDA, 2006

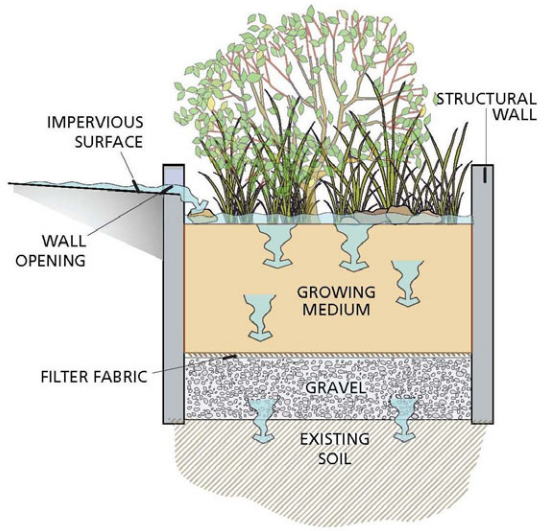
Figure 3A1-8. Wooded bioretention can increase pollutant uptake and requires specific design modifications for tree growth and avoiding engineering conflicts.





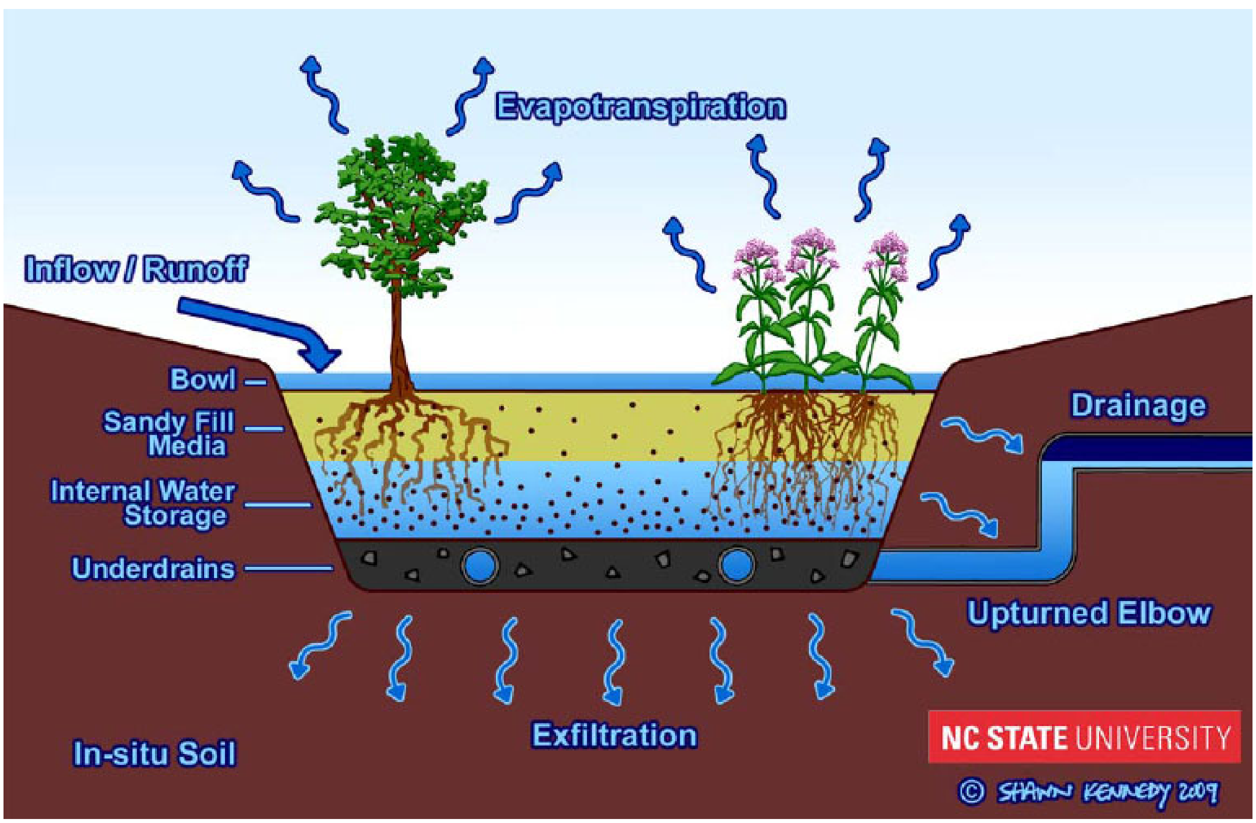
Source: Seattle Public Utilities

Figure 3A1-9. Bioretention swales with and without underdrain.



Source: Portland Bureau of Environmental Services

Figure 3A1-10. Infiltration planter box.



Source: Brown 2009

Figure 3A1-11. Bioretention with internal water storage volume.

Common Feasibility Constraints and Limitations

Bioretention practices should not be used in some applications, including

- Slopes are greater than 20 percent
- *Hot spots* that have a high potential for groundwater contamination, e.g., gas station runoff or areas where chemicals are stored or managed
- Large drainage areas from impervious areas greater than 15,000 square feet (unless a system of separate cells is used to manage the runoff)
- Areas of shallow bedrock or high water tables where infiltration is not feasible (note: design modification can be used to compensate for these conditions where surface retention is desired)
- Applications that have high sediment loadings unless use pretreatment systems and/or increase maintenance

Stormwater infiltration can affect groundwater quality; however, the incidence of groundwater contaminated to an unhealthy level from stormwater is low. Many factors contribute to the risk (Clark et al. 2009).

Estimated Effectiveness for Runoff Volume and Pollutant Load Reduction

Volume Reduction. The amount of volume reduction achievable is a function of design; for example, selecting a storm depth and designing the cell to capture this volume in the ponding area and upper soil void space. To determine the annual volume reduction achieved, the likelihood for back-to-back storm events and seasonal temperature variations should be considered, and continuous modeling is used for this analysis (USEPA 2008). Guidance manuals are referenced in this fact sheet, and by state and local jurisdictions, that provide instruction on methods for calculating volume reduction on the basis of infiltration rates and storage volumes. Evapotranspiration also provides some volume reduction. The following factors influence the annual stormwater volume reduction achievable:

- Local climate and rainfall patterns.
- Local soil characteristics, including the soils underlying the constructed bioretention cell.
- Local evapotranspiration rates driven by climate conditions, vegetation type, and length of growing season.
- Site conditions such as location in a sunny area or in deep shade.
- Ratio of cell media volume to drainage area. Increasing the volume of media relative to the drainage area has been demonstrated to reduce outflow.
- Use of underdrains or liners or both versus infiltration to underlying soil. The use of underdrains or liners can significantly reduce volume reduction performance. If an underdrain is used, adding an internal storage zone below the underdrain improves performance, allowing more time for infiltration, and potentially denitrification (see Figure 3A1-11).
- Care during construction to ensure construction site erosion does not clog the system.

Pollutant Reduction. Pollutant concentration reductions can be obtained through biofiltration to further reduce overall loading. Many factors associated with the pollutants, water, soil, plants, microbes, and system design affect pollutant removal performance.

For example, nutrient removal can be influenced by the following factors:

- The amount of organic material and the potential for the media to decay and leach nutrients
- The form of phosphorus or nitrogen as it enters the cell, and transforms in the cell
- Biological transformation of nutrients in microbial and plant processes
- Cation exchange capacity and ability to sorb nutrients
- The presence of an anaerobic/saturated zone which influences denitrification potential
- Soil media composition and volume
- Plant species, community composition, size, coverage and health

Phosphorus removal requires the use of a low phosphorus index soil mix with a high cation exchange capacity (Li et al. 2009). Layering of media targeted at specific pollutants can enhance water quality benefits (Li et al. 2009).

A summary of some pollutant specific removal information is provided below (Davis et al. 2009):

- *Suspended Solids*—Reductions can be as high as 99 percent. New facilities might initially export TSS from the washout of fines in the media.
- *Phosphorus*—Reduction is highly variable, typically from 50 to 80 percent. Effluent phosphorus at some locations has been higher than influent concentrations, largely because of high initial levels of soil phosphorus.
- *Nitrogen*—Because of the complex interactions of nitrogen species, total nitrogen removal is difficult to achieve. Nitrogen removal might be increased with the use of a higher percentage of organic matter in the soil mix (Hinman et al. 2005), provided the organic matter does not contain high nitrogen concentrations. Bioretention can remove organic nitrogen in the media's organic material. Nitrate, however, is very mobile, and only when the media remains saturated for an extended period denitrification possible.
- *Heavy Metals*—Dissolved and particulate-bound metals are removed by filtration of particulate metals and adsorption of dissolved species in the mulch and bioretention media. Metals have been shown to be primarily removed in the first 1 to 2 inches of the surface mulch layer (Hinman et al. 2005).
- *Oil & Grease*—Adsorption of low concentrations of motor oil to organic material in the soil mix have resulted in removal efficiencies of 96–99 percent. Native bacteria in the mulch can biodegrade the hydrocarbons over time.
- *Chlorides*—Bioretention does not treat chlorides and, where exposed to salting practices, has been found to leach chlorides year round.

- *Bacteria*—Removal of bacteria have been monitored to be between 70 percent (Hathaway and Hunt 2008) and 91 percent, through process that include filtration, drying, and exposure to sunlight.

The reductions in mass loading of nitrogen and phosphorus achievable with bioretention have been shown to be a result of the decrease in runoff volume, not necessarily decreases in concentration. Field tests have shown considerable mass reductions to be achieved even when increases in concentrations occur across the bioretention cell from nutrients contained in the media (Hunt et al. 2006). For this reason, a volume reduction performance goal is recommended. Understanding the ranges of effluent concentrations observed, though, is valuable to evaluate performance.

Typical influent and effluent concentration ranges. The range of observed concentrations of nutrients in stormwater runoff in the National Stormwater Quality Database is provided in Table 3A1-6 to give an indication of influent concentration ranges.

Table 3A1-6. Selected median concentration of nitrogen and phosphorus pollutants from urban land uses

	NH_3 (mg/L)	$N0_2$+NO_3 (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Phosphorus, total (mg/L)
Residential	0.32	0.6	1.4	0.3
Commercial	0.5	0.6	1.6	0.22
Industrial	0.5	0.73	1.4	0.26
Freeways	1.07	0.28	2	0.25
Open Space	0.18	0.59	0.74	0.31

Source: Pitt, R., A. Maestre, and R. Morquecho. 2004. The National Stormwater Quality Database (NSQD, version 1.1). University of Alabama, Department of Civil and Environmental Engineering, Tuscaloosa, AL. http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html. Updated February 16, 2004. Accessed February 3, 2010.

For effluent quality from bioretention, the following are noted:

- Effluent concentration goals of the *New York State Design Manual*, Chapter 10 Enhanced Phosphorus Removal (Quigley et al. 2008)
  - less than or equal to 0.1 mg/L TP
  - less than equal to 0.06 mg/L dissolved phosphorus
- Reported effluent concentration results from field studies in the mid-Atlantic (Davis et al. 2009)
  - from 0.06 to 0.56 mg/L TP
  - from 0.08 to 2.8 mg/L TN

Cold weather performance. Bioretention can provide effective infiltration in cold weather. Dietz and Clausen (2007) report that, despite measureable frost, 99 percent of runoff was either evapotranspirated or infiltrated for bioretention in Connecticut. The University of New Hampshire reports similar favorable performance in winter conditions (Roseen et al. 2009), and rapid thawing of bioretention media is reported when runoff enters.

Summaries of Volume and Pollutant Loading Reductions Achievable

The volume reduction achievable is based on the system design and local climate pattern. Systems can be design to retain and infiltrate a specific storm depth, with the excess volume either bypassing or overflowing the system. To determine the annual volume reduction achieved, continuous modeling can be used. For example, in *Stormwater Best Management Practices (BMP) Performance Analysis* (USEPA 2008), performance curves are generated on the basis of a given design specification, the soil infiltration rate, depth of runoff treated, and land use type for a specific climate area, in this case the New England region. Using that approach, it is possible to select a design storm to approximately achieve a desired annual volume reduction goal.

A wide range of performance results have been observed in field tests, and authors cite the difficulty of using such data to prepare general performance estimates (Dietz 2007; Li and Davis 2009; Davis et al. 2009). Volume reductions from 75 percent to greater than 90 percent on an annual average basis have been reported with bioretention (Geosyntec Consultants, *Urban Stormwater BMP Performance Monitoring,* International Stormwater BMP Database, WERF/ASCE/EPA 2009); these values typically reflect precipitation patterns of the study area where most of the annual rainfall occurs in small events of approximately an inch depth or less. For understanding and comparing performance results, estimates should be for an annual basis using long-term, region-specific weather data for a specific design scenario.

Performance estimates provided in Table 3A1-7 for hypothetical average bioretention installations in the Chesapeake Bay watershed lead to the following observations (Simpson et al. 2009):

- The majority of the load reduction is from runoff reduction, therefore reporting the runoff reduction component is essential for understanding system performance (Center for Watershed Protection and Chesapeake Stormwater Network 2008).
- Volume reduction can be a surrogate for, or approximate indicator of, the pollutant removal achieved.

Practice Design

Several design considerations influence the overall performance of bioretention, including

- The potential for clogging should be assessed and pretreatment, such as mulch, should be provided if necessary. If grass swales are used, care should be taken to ensure that sediment will not accumulate to the point where it overtakes the vegetation and becomes costly to remove.
- Well-draining soils allow for rapid infiltration, but if the infiltration rate is too rapid, nitrate can pass though without treatment.
- Soils with slow infiltration rates can decrease the overall stormwater volume retention. Infiltration tests at the site should be performed to better estimate expected performance. In these conditions, if a specified volume is to be retained, the designer should consider designing the subbase with gravel or other materials to retain the requisite volume.
- When conditions necessitate the use of underdrains the discharge rate should be as slow as feasible to maximize infiltration. Overflows are preferred to maintain maximum infiltration. Other options include positioning the discharge orifice above the bottom of the invert, with an upturned elbow outlet configuration (Brown 2009).

Table 3A1-7: Generalized bioretention performance estimates for the Chesapeake Bay Area demonstrate that the majority of the load reduction is from runoff reduction

Bioretention	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection area (acres)		
	TP	TN*	TSS		TP	TN	TSS
C/D soils, underdrain	37	10	50	15	45	25	55
A/B soils, underdrain	37	10	50	65	75	70	80
A/B soils, no underdrain	37	10	50	80	85	80	90
					±20	±15	±15

Source: Simpson and Weammert 2009.

Notes:

1. Soil classification (A, B, C, D) per USDA National Resource Conservation Service (NRCS)
2. Event Mean Concentration-based Removal expressed as Percent Reduction (PR)
3. Mass Based Removal expressed as percent removal of total load by mass (TR)
4. Nitrogen concentration reduction is low potentially because the solubility of nitrate, the potential for organic nitrogen and ammonia to mineralize in the bioretention media to the nitrate form, and the lack of conditions needed for denitrification contribute to nitrogen export.
5. Assumptions included: 1) highly impervious urbanized land use; 2) generalized for design criteria typical of Bay area jurisdictions; 3) designed, installed and maintained by persons who are not experts in bioretention; 3) low phosphorus soil media; 4) for systems designed for a 1” storm, rain events from 1” to 1.5” depth will begin to show overflow
6. Total removal estimated by the calculation TR = RR + {(100-RR) * PR)}, rounded to a factor of 5.
7. Authors caution that the estimates, based on limited data and generalized for simplicity, might not represent true long-term performance throughout the watershed. Performance is highly variable even under controlled conditions.

- An impermeable liner, with an underdrain, can be used to prevent infiltration of stormwater from the biofiltration cell, for example, if soil contamination is suspected. These systems provide water quality improvements because of the pollutant reductions available from the vegetated system and moderate volume reductions from evapotranspiration.

Maintenance Considerations and Resources

Typical maintenance activities are as follows:

- Supplemental irrigation might be needed during the first 2 to 3 years after planting. Drought-tolerant species might need little additional water after this period, except during prolonged drought, when supplemental irrigation can become necessary for plant survival.
- Weeds should be removed by hand until vegetation is established. Although plants might need pruning to maintain healthy growth, routine mowing should not be required. Dead or diseased plants should be removed and replaced. Mulch should be re-applied when erosion is evident to maintain a 2–3 inch depth.
- Inspect at least two times per year for sediment buildup, trash removal, erosion, and to evaluate the vegetation. Sediment should be removed in a manner that minimizes soil disturbance if

buildup reaches 25 percent of the ponding depth. Ensure pretreatment devices, if used, are maintained.

- Some manuals recommend replacing the top few inches of bioretention media every few years and/or when infiltration rates slow down too much.

Costs and Factors Affecting Cost

Costs vary according to many factors including soil depth, plant selections, slope conditions and the contractor's familiarity with the practice. Typically costs are (WERF 2009, *User's Guide to the BMP and LID Whole Life Cost Model, Version 2.0*, and associated spreadsheets)

- For residential rain gardens: Between $6 per square foot (installed by the owner) to $16 per square foot of rain garden surface area (professional installed).
- For urban curb-contained bioretention, $16–$29 per square foot, driven by the cost of curbing and other urban-related infrastructure that can be used for conventional landscaping.
- Bioretention cells often replace areas that would have been landscaped, so the life-cycle cost can be less than the landscaped alternative.

Some factors influencing costs are

- Material availability and transport
- Site conditions (e.g., traffic, utilities)
- Underdrains that might be selected if the subgrade soils infiltrate poorly; an overflow is typically less costly while providing better volume-removal performance
- Specific stormwater management requirements, such as enhanced nutrient removal
- The need for, and the type of, pretreatment
- Vegetation type and scale
- Soil medium specifications and availability
- Size of installation

The Prince George's County *Bioretention Manual* (2007) and WERF's *BMP and LID Whole Life Cost Model* (2009) provide reported costs and templates to facilitate project cost estimation.

Example Bioretention Design Manuals in the Chesapeake Bay Watershed Area

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Pennsylvania Stormwater Best Management Practices Manual, BMP 6.4.5 Rain Garden/Bioretention, 2006.

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1.6 Infiltration

Description of Practice

Infiltration practices use temporary surface or underground storage to allow incoming runoff to exfiltrate into underlying soils. By diverting runoff into the soil, infiltration practices not only reduce the volume of runoff discharged from the site, but also help to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Because of that, infiltration practices are limited to areas with porous soils (generally where measured soil permeability rates exceed one-half inch per hour) and where the water table or bedrock are well below the bottom of the practice.

Infiltration practices can be used at three scales: micro-infiltration, small-scale infiltration, and conventional infiltration (VA DCR 2010).

- Micro-infiltration practices (typically dry wells, French drains or paving blocks) treat runoff from impervious areas of 250 to 2,500 sq. ft.
- Small-scale infiltration practices (typically infiltration trenches or permeable paving) treat runoff from impervious areas of 2,500 to 20,000 sq. ft.
- Conventional infiltration practices (typically infiltration trenches or infiltration basins) treat runoff from impervious areas of 20,000 to 100,000 sq. ft.

Infiltration practices alone are not intended to trap sediment. At locations where sediment might be present, the practices should be designed with a sediment forebay and grass channel or filter strip, or other appropriate pretreatment measures to prevent clogging and failure. In addition, infiltration practices should not be used at sites with significant pollution potential (e.g., stormwater hotspots).

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
●	●	●

Key: ● High effectiveness ⦿ Medium effectiveness ○ Low effectiveness

Targeted Pollutants

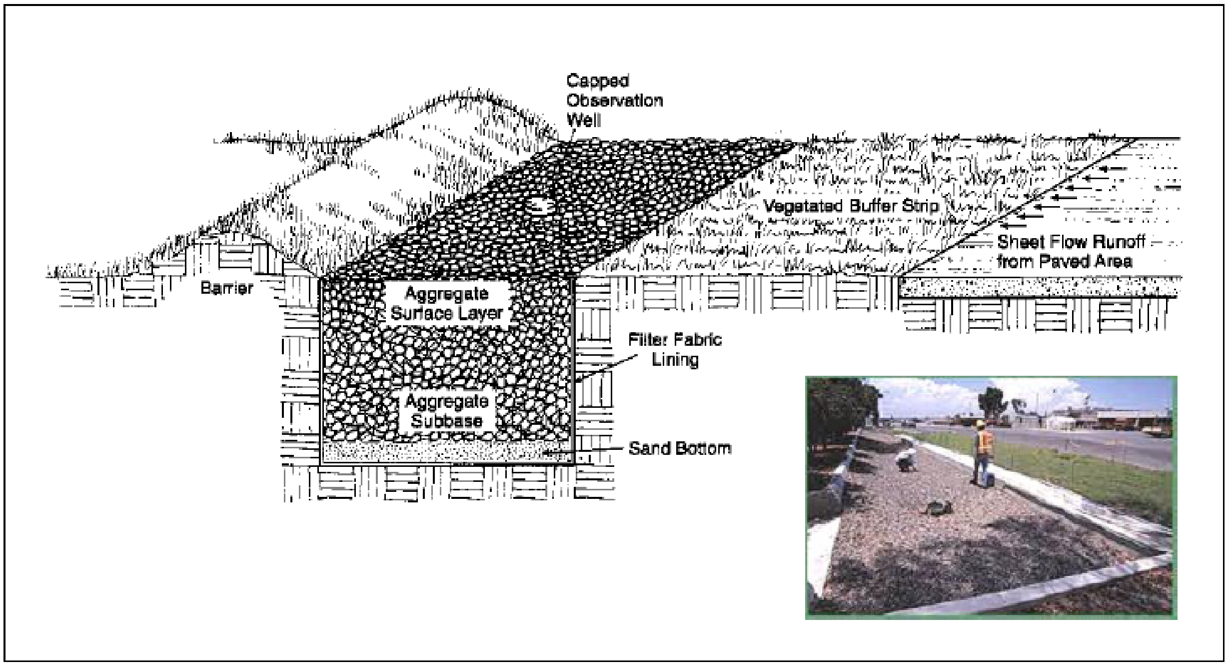
Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
●	⦿	⦿	⦿	○	○	⦿

Key: ● High effectiveness ⦿ Medium effectiveness ○ Low effectiveness

Photos and Diagrams

Source: Atlanta Regional Commission 2001

Figure 3A1-12. Infiltration trench.



Source: Atlanta Regional Commission 2001

Figure 3A1-13. Infiltration trench schematic.

Common Feasibility Constraints and Limitations

- Infiltration practices have a high runoff reduction capability and are suitable for use in residential and other urban areas where measured soil permeability rates exceed 0.5 inch per hour (VADCR 2010).

- Infiltration practices provide minimal benefits in terms of reducing concentrations of pollutants such as nitrate because they are below the root zone and surface soil profile.
- Total nitrogen removal is low for many infiltration and filtration practices, with the proportion of nitrate removal extremely low. Designers are using these practices to move water, not remove nutrients. Infiltration trenches can introduce dissolved pollutants such as nitrates and dissolved metals into groundwater (Lucas 2005).
- Infiltration is not recommended at sites designated as stormwater hotspots to prevent possible groundwater contamination. VADCR Design Specification No. 8 (VADCR 2010) provides a table of Potential Stormwater Hotspot and Site Design Responses.
- Excess sediments easily clog infiltration trenches. Hence, infiltration practices should be applied only in situations where pretreatment is provided.
- Sites that have been previously graded or disturbed do not retain their original soil permeability because of compaction; therefore, infiltration practices should not be situated above fill soils.
- Infiltration practices should be designed to minimize potential to create conditions favorable to mosquito breeding, which can occur if they clog and have standing water for extended periods.
- Designers should investigate whether a proposed infiltration practice is subject to a state or local groundwater injection permit.

Runoff Volume and Pollutant Load Removal Estimates

Volume reduction. The amount of volume reduction achieved for infiltration practices can vary based on the size of the infiltration practice and the soil infiltration rate. VADCR (2010) estimates an annual volume reduction from 50 percent (for a typical infiltration practice in soils with an infiltration rate of one-half to one inch/hour) to 90 percent (for an enhanced infiltration practice that is sized 10 percent larger than typical, with additional pretreatment and soils with an infiltration rate of 1.0 to 4.0 inches/hour). This annual volume reduction rate is a function of design and can be increased by modifying the design parameters.

Pitt et al. (2002) also found significant runoff reductions for infiltration practices. For example, sites employing rain gardens (one inch/hour amended soils, 60 sq. ft. per house) achieved annual roof runoff volume reductions of 87 to 100 percent.

Simpson and Weammert (2009) conservatively estimated the volume reduction of infiltration practices to be approximately 80 percent on an annual for the design criteria typically in use at the in Chesapeake Bay region at the time.

Pollutant reduction

Infiltration practices with appropriate pretreatment have been estimated to be able to remove 95 percent of the annual total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained appropriately. Undersized or poorly designed infiltration practices can reduce TSS removal performance. Pollutant reduction is a function of the volume removal achieved. A summary of pollutant reduction estimates for infiltration practices in the Chesapeake Bay area is provided in Table 3A1-1.

Practice Design

Several design considerations influence the overall performance of infiltration practices, including

- Areas of Hydrologic Soil Group A or B soils shown on NRCS soil surveys should be considered as primary locations for infiltration practices.
- The contributing drainage area to an individual infiltration practice should be less than 2 acres.
- Infiltration practices should not be hydraulically connected to structure foundations or pavement to avoid harmful seepage. Setbacks to structures and roads vary according to the scale of infiltration. Example specifications (VADCR 2010) state that, at a minimum, and subject to local requirements, conventional and small-scale infiltration practices should be a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines (VADCR 2010).

Brown and Hunt (2009) have identified innovative construction methods that can reduce soil compaction and enhance exfiltration from bioretention cells and permeable pavement. Those construction methods include using a rake method for excavating the bottom of the practice, avoiding excavation during or immediately after a rainfall event, and using boreholes, ripping or trenches to increase exfiltration rates.

Maintenance Considerations and Resources

Maintenance is critical to the success of infiltration practices. The most common maintenance problem is clogging of the stone by organic matter and sediment. The following considerations can minimize the risk of clogging:

- Small-scale and conventional infiltration practices should have an observation port installed at the low point. The observation ports should be inspected regularly and after major storms. A log should be kept of the water level remaining to track changes in the infiltration rate.
- In general, avoid use of geotextile liners because they can be prone to clogging.
- Sediment removal should take place when the basin is thoroughly dry.
- All use of fertilizers, mechanical treatments, pesticides, and other means to assure optimum vegetation health should not compromise the intended purpose of the infiltration basin. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.
- All vegetated areas should be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the remaining vegetation and basin subsoil.
- All structural components should be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

Detailed maintenance considerations are in the *New Jersey Stormwater Best Management Practices Manual* http://www.state.nj.us/dep/stormwater/bmp_manual2.htm) and VADCR Design Specification No. 8 (http://www.chesapeakestormwater.net/all-things-stormwater/infiltration-specification.html).

Costs and Factors Affecting Cost

Infiltration trenches are somewhat expensive, when compared to other stormwater practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about $5 per ft^3 of stormwater treated (SWRPC 1991; Brown and Schueler 1997).

Infiltration trenches typically consume about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about $2 per ft^3 (adjusted for inflation) of storage for a 0.25-acre basin (SWRPC 1991). Infiltration basins typically consume about 2 to 3 percent of the site draining to them, which is relatively small. Maintenance costs are estimated at 5 to 10 percent of construction costs.

Costs reported for infiltration practices in a 189-acre watershed included costs for infiltration trenches, and infiltration vault, raingardens, and a regional pond (CRWD 2010). The project included eight infiltration trenches, serving 16 acres of drainage area with a total storage volume of 19,354 ft^3. Averaged costs reported were $7.69/$ft^3$ for design and construction, not including bond interest; the construction cost component was $6.41/$ft^3$.

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1.7 Soil Restoration

Description of Practice

Soil restoration techniques can be used to improve compacted soils. The addition of compost can increase soil organic content, provide beneficial bacteria and fungi, and improve or restore soil water retention capacity and overall soil permeability. The addition of soil amendments can delay and often reduce the peak stormwater run-off flow rate and volume and decrease irrigation water requirements. Amending soils will also reduce fertilizer and pesticide requirements. Soil restoration techniques can also be used as part of a system to provide additional retention or infiltration capacity to manage runoff from disconnected gutters, grass channels, filter strips, and impervious areas.

Compost amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. Compost amendments can be applied to the entire pervious area of a development or be targeted in select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include

- Reduce runoff from compacted lawns and bare soils
- Increase volume of runoff infiltrated from rooftops or other areas
- Increase volume of runoff infiltrated within a grass channel or filter strip
- Increase volume of runoff reduced by a tree cluster or reforested area of the site (VADCR 2009)

Hydrologic Performance and Targeted Pollutants

The primary water quality improvements that result from restoring soil through tillage and compost amendments are increased infiltration and the resulting reduction in runoff volumes. Reducing runoff volume with compost generally reduces pollutant transport and loading off-site (Faucette et al. 2005, 2007).

Photos and Diagrams

Source: VADCR Specification No. 4

Figure 3A1-14. Soil amendments.

Common Feasibility Constraints and Limitations

Compost amendments are not recommended where

- Existing soils have high infiltration rates (e.g., HSG A and B soils), although compost amendments might be needed at mass-graded B soils to maintain runoff reduction rates
- The water table or bedrock is within 1.5 feet of the soil surface
- Slopes exceed 10 percent, unless surface applied as a compost blanket
- Existing soils are saturated or seasonally wet
- The use of tillage with soil amendments would harm roots of existing trees (stay outside the tree drip line)
- The downhill slope runs toward an existing or proposed building foundation
- The contributing impervious surface area exceeds the surface area of the amended soils (VADCR 2009)

Selecting the compost amendments should occur on the basis of the water quality objectives of the jurisdiction or the project. Compost amendments should be formulated to not adversely affect water quality. Properties such as nutrient content, soil moisture holding capacity, metals uptake capacity, shrink/swell, product maturity, pathogen, residual chemical content and weed seed content require a high level of scrutiny to ensure that the appropriate amendments are being used (Lenhart 2007).

Runoff Volume and Pollutant Load Removal Estimates

Balousek (2003) conducted research that demonstrated that compost-amended, chisel-plowed, and deep-tilled plot treatments showed runoff reductions from 74 to 91 percent, compared to the control. Chisel-plowed and deep-tilled treatment showed cumulative runoff reductions of 40 to 53 percent, compared to the control (Balousek 2003). The runoff reduction volume achieved by soil restoration depends on the site application and the pre-construction hydrologic soil group (VADCR 2009).

The use of compost amendments can reduce or eliminate the need for supplemental fertilization from inorganic fertilizer sources. Some studies, however, show that the concentrations of many pollutants can increase in the surface runoff after soils are amended with compost, hence the need for specification standards where nutrient runoff is to be limited. A study conducted by EPA's Office of Research and Development (Pitt et al. 1999) found that surface runoff from the compost-amended soils had greater concentrations of almost all constituents, compared to the surface runoff from the control sites. The concentration increases in the surface runoff and subsurface flows from the compost-amended soil test site were quite large, typically in the range of 5 to 10 times greater. Subsurface flow concentration increases for the compost-amended soil test sites were also common and about as large. When the decreased surface flow quantities were considered in conjunction with the increased surface runoff concentrations, it was found that all the surface runoff mass discharges were reduced by large amounts (to 2 to 50 percent of the unamended discharges). The large phosphorus and nitrogen compound concentrations found in surface runoff and subsurface flows at the compost-amended soil sites decreased significantly during the time of the tests (about 6 months). The older test sites also had lower nutrient concentrations than the new sites but still had elevated concentrations when compared to the soil-only test plots.

Use of compost and soil amendments with quality control specifications will help avoid potential issues such as excess nutrient runoff. Use of compost-amended soils can result in an overall nutrient loading increase, at least initially, so the trade-off between volume reduction enhancement and potential nutrient concentration increase should be considered.

The quality of compost being used (i.e., feed stock, maturity, presence of pesticides and herbicides) must be considered to minimize the adverse effects of water quality. One recent study concluded that because of its high nutrient content, but low leaching properties, mature compost made from deciduous leaves makes suitable compost for soil amendment in applications for water quality (Lenhart 2007). Two studies conducted at the University of Georgia found that when quality compost was used and compared to conventional seeding and mulching applications, runoff nitrogen loading was reduced by 58–92 percent, and runoff phosphorus loading was reduced by 83–97 percent (Faucette et al. 2005, 2007).

Practice Design

- The depth of compost amendment is based on the relationship between the surface area of the soil amendment to the contributing area of impervious cover that it receives. VADCR Stormwater Design Specification No. 4 (www.chesapeakestormwater.net/all-things-stormwater/soil-compost-amendments.html) includes a table (Table 3) that provides guidance as to the depth of compost, incorporation depth, and incorporation type based on the area to be amended and the contributing impervious area.

- EPA's Compost Blanket Factsheet includes guidelines and specifications for compost blankets for construction and post-construction use. (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=118).

- The compost material should be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost should have a moisture content that has no visible free water or dust produced when handling the material. VADCR Stormwater Design Specification No. 4 (www.chesapeakestormwater.net/all-things-stormwater/soil-compost-amendments.html) and the Low Impact Development Center (www.lowimpactdevelopment.org/epa03/saspec_print.htm) provide technical specifications for the compost material.

- Soil tests should be conducted during two stages of the compost-amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The second soil analysis is taken to determine whether any further nutritional requirements, pH, and organic matter adjustments are necessary for plant growth.

- VADCR Stormwater Design Specification No. 4 (www.chesapeakestormwater.net/all-things-stormwater/soil-compost-amendments.html) includes design criteria for soil amendments used to enhance downspout disconnections, grass channels, vegetated filter strips, in addition to several Bay-specific regional design variations.

- The City of Redmond, Washington Guidelines for Landscaping with Compost-Amended Soils (www.redmond.gov/insidecityhall/publicworks/environment/pdfs/compostamendedsoils.pdf) (Chollak and Rosenfeld 1998) provides design specifications and cost-benefit analysis of using compost-amended soils.

- The Composting Council and the Clean Washington Council developed guidance (Development of a Landscape Architect Specification for Compost Utilization, www.cwc.org/organics/org972rpt.pdf), which contains a series of short and long compost use specifications for various landscape applications. Both product specifications and end-use instructions are provided.

Maintenance Considerations and Resources

VADCR (2009) recommends that specific practices be used during the first year after amendment to help ensure success where turf is the appropriate groundcover. Establishing other landscape cover types, such as forest cover or native plantings, could require fewer or no follow-up chemical inputs after the site has been stabilized. VADCR recommendations for turf are

- Initial inspections: For the first 6 months following amendments, the site should be inspected at least once after each storm event that exceeds one-half inch.

- Spot Reseeding: Inspectors should look for bare or eroding areas in the contributing drainage area or around the soil restoration area, and make sure they are immediately stabilized with grass cover.

- Fertilization: Depending on the amended soils test, a one-time, spot fertilization might be needed in the fall after the first growing season to increase plant vigor.
- Watering: Water once every 3 days for first month, and then weekly during first year (Apr–Oct), depending on rainfall (VADCR 2009).

Item	Unit	Estimated unit cost (2005 dollars)
Soil and site preparation	S.Y.	$5–$8
Mechanical grading and tilling	S.Y.	$18–$27
Soil amendments	C.Y.	$15–$30
Blower application	S.Y.	$0.45–$1.00

Costs and Factors Affecting Cost

Costs include the amendment and the application into the existing soil. Typical costs are provided below (http://www.lowimpactdevelopment.org/ffxcty/5-1_soilamendments_draft.pdf).

Item	Unit	Estimated unit cost (2005 dollars)
Soil and site preparation	S.Y.	$5–$8
Mechanical grading and tilling	S.Y.	$18–$27
Soil amendments	C.Y.	$15–$30
Blower application	S.Y.	$0.45–$1.00

Cost calculations based on amending soils on one-quarter acre area to manage runoff for a one-half acre area were prepared by the Low Impact Development Center for Fairfax County, Virginia, in 2005, as follows:

Item	Required cost per year (2005 dollars)											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**…**	**25**
Installation	25,000												
Aerate			250		250		250		250		250		
Re-amend													25,000
Total cost	**25,000**		**250**		**250**		**250**		**250**		**250**		**25,000**
Annualized Cost	$1,125/year (includes re-amending in year 25)												

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1.8 Reforestation and Urban Forestry

Description of Practice

Forests are the most beneficial land use to protect the water quality of the Chesapeake Bay (USDA Forest Service*, Urban Tree Canopy Goal Setting*, 2006). Reforestation is the protection, enhancement and expansion of tree canopy in urban and suburban areas, in yards, parks, along streets, and public places. Urban forests provide significant environmental benefits through management of urban stormwater but also provide other benefits such as increasing property values, reducing energy costs for cooling in the summer, buffering wind and noise, improving air quality, providing habitat for wildlife, and beautifying the landscape. In urban areas, trees provide an important stormwater management function by intercepting rainfall that would otherwise run off of paved surfaces and be transported into local waters through the storm drainage system, picking up various pollutants along the way (CWP and USFS 2009). Trees also enhance stormwater management by evapotranspiring large quantities of stormwater, while the roots help to reduce soil compaction, enabling more infiltration of stormwater. In general, trees stabilize soils, reduce stormwater runoff, maintain the base flow of streams and filter nutrients and sediment (CWP 2007).

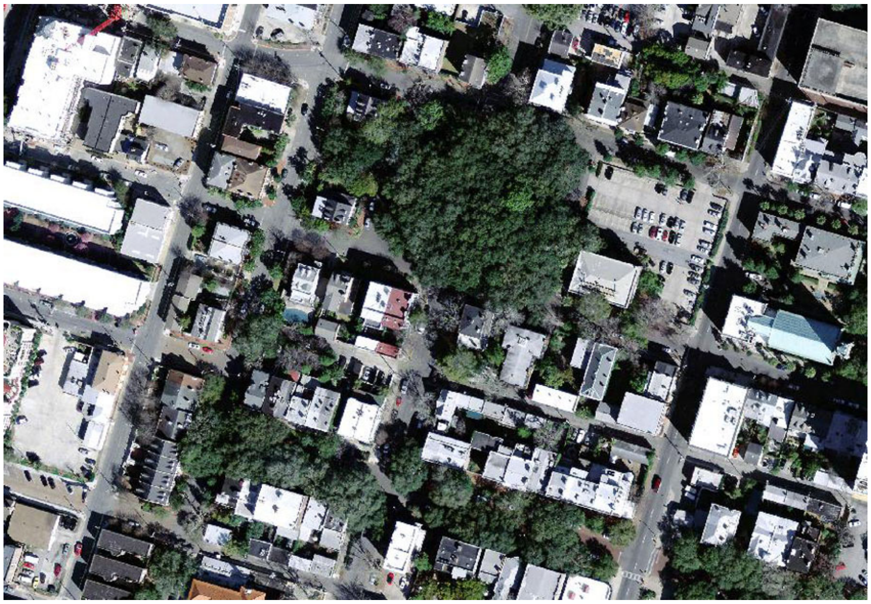
Reforestation can be achieved using many tools, such as developing an urban tree canopy goal for a site or community, and achieving that goal through the use of regulations, policies and/or incentives to plant trees and help ensure continued growth (Table 3A1-8).

Table 3A1-8. Urban watershed forestry objectives, by goal

Goal	Objective	Description
1. Protect	A. Protect priority forests	Select large tracts of currently unprotected and undeveloped forest to protect from futures development.
	B. Prevent forest loss during development and redevelopment	Directly or indirectly reduce forest clearing during construction
	C. Maintain existing forest canopy	Prevent clearing and encroachment on existing protected and unprotected forest fragments on developed land.
2. Enhance	D. Enhance forest fragments	Improve the structure and function of existing protected forests.
3. Reforest	E. Plant trees during development and redevelopment	Require on-site reforestation as a condition of development.
	F. Reforest public land	Systematically reforest feasible planting sites within public land, rights-of-way, or other priority sites.
	G. Reforest private land	Encourage tree planting on feasible locations within individual yards or property

Source: Cappiella et al. 2005. *Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed,* USDA Forest Service, Newtown Square, PA.

Photos and Diagrams



Source: CWP and USDA 2009

Figure 3A1-15. Urban tree canopy.

Common Feasibility Constraints and Limitations

- Developers have little incentive to leave or restore trees on development projects.
- Unless regulations or incentives are in place, property owners might not protect existing or plant additional trees.
- Utility corridor management needs lead to tree losses and damage.
- Human safety (fire response and transportation projects) often require tree removal.

Runoff Volume and Pollutant Load Removal Estimates

On average, forests contribute approximately one-tenth of the nitrogen to the Chesapeake Bay compared to developed lands (1.7 lbs acre compared to 14.8 lbs/acre). More specifically, riparian forests that buffer streams significantly reduce the amount of excess nutrients that enter the water, sometimes by as much as 30 to 90 percent (CBP 2007).

Forested areas have less runoff than developed areas, as indicated by the smaller runoff coefficient used when comparing to disturbed or impervious areas (Table 3A1-9).

Table 3A1-9: Site cover runoff coefficients[a]

Soil condition	Runoff coefficient
Forest Cover	0.02–0.05[b,c]
Disturbed Soils/Managed Turf	0.15–0.25[b,d]
Impervious Cover	0.95

Source: Hirschman et al. 2008

[a] Derived from research by Pitt et al. 2005; Lichter and Lindsey 1994; Schueler 2001a, 2001b; Legg et al. 1996; Pitt et al. 1999; Schueler 1987; and Cappiella et al. 2005.

[b] Range dependent on original Hydrologic Soil Group (HSG)

[c] Forest - A: 0.02 B: 0.03 C: 0.04 D: 0.05

[d] Disturbed Soils - A: 0.15 B: 0.20 C: 0.22 D: 0.25

Research has shown that trees are the most effective at reducing the runoff from small, more frequent storms (CWP and USDA 2009). Volume removal credit for trees has been adopted in stormwater programs, for example Washington State Department of Ecology has acknowledged one type of tree box structure (one that reduces soil compaction from load-bearing pavements by using a structural *vault*) as functionally equivalent to a rain garden. Allowing credit for the site-specific annual evapotranspiration should be considered, and research is being done, primarily by the U.S. Forest Service, to help make the tools available.

Practice Design

Many local, regional, and site-specific practices can be implemented to conserve existing urban forest and increase forest restoration. Local and state governments, and federal facilities, can develop policies operating procedures, contract specifications, or planning documents that incorporate urban forestry. They can encourage/require practices such as stream buffers and provide incentives for developers and property owners to conserve or restore urban forests. The following resources provide more information about those options:

- Guidelines for Developing and Evaluating Tree Ordinances (International Society of Arboriculture) - www.isa-arbor.com/publications/ordinance.aspx
- Protecting Water Resources with Higher Density Development (USEPA) www.epa.gov/dced/pdf/protect_water_higher_density.pdf
- Forest Friendly Development (Alliance for the Chesapeake Bay) www.alliancechesbay.org/pubs/projects/deliverables-145-8-2005.pdf

In addition, local governments lead by example and invest in urban forestry. Federal facilities can look to those programs for ideas on program implementation and for evidence of how trees are valued by the community at large, both for stormwater management benefits and other amenity value. For example, the Philadelphia Water Department Office of Watersheds (see www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=TreeVitalize) contends that “trees are one of the most effective, least costly methods of storing and controlling stormwater runoff.” The Office of Watersheds has already contributed to planting more than 500 trees in Philadelphia and hopes to increase this number through its involvement with the regional TreeVitalize Program (see www.treevitalize.net). As part of this program, Office of Watersheds will partner with the Fairmount Park

Commission to receive $300,000 over a 3-year period to plant up to 84 acres of forested riparian buffers throughout Philadelphia's park system (PWD 2009).

Federal Implementation of the Chesapeake Executive Council Directive on Forest Conservation provides specific actions to help achieve the goals of urban forest conservation and restorations. (www.chesapeakebay.net/press_ec2007forests.aspx?menuitem=20276)

- An example of local leadership in reforestation is Baltimore County's *Growing Home* Campaign. Benefit information is provided, including links to American Forests Personal Climate Change Calculator, and the National Tree Benefits calculator from Casey Trees, a local nonprofit. The tools help to educate the public on the multiple benefits of trees. The county provides financial incentives to plant trees through a public-private partnership with local nurseries and tree retailers.

The Center for Watershed Protection (www.cwp.org) and the USDA Forest Service have developed new designs for stormwater management practices for use in incorporating functional tree-based stormwater management systems into developments. The *stormwater forestry practices* address potential limitations through design modifications, species selection, and other methods. The designs listed below harness the benefits of trees to increase the effectiveness of stormwater practices, while providing other benefits to the community, such as cooling and shade, aesthetics, and wildlife habitat (CWP and USDA 2009). The fact sheets listed below are at www.forestsforwatersheds.org/reduce-stormwater.

- Wooded wetland
- Emergent pond/wetland system
- Bioretention and bioinfiltration facilities
- Alternating side slope plantings
- Tree check dams
- Forested filter strip
- Multi-zone filter strip
- Linear stormwater tree pit
- Stormwater treatment dry ponds

Trees design in dense urban environments presents many challenges with the infrastructure of streets, sidewalks, and utilities. Resources for addressing these issues include *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies* (Costello and Jones 2003). Other planning considerations such as neighborhood character in tree selection and placement are essential for a successful community street tree program (*The Road to a Thoughtful Street Tree Master Plan: A Practical Guide to Systematic Planning and Design,* Simons and Johnson 2008*).*

Practices to prevent root compaction and provide additional space under pavements for tree root growth are gaining acceptance. One example is Minnesota's MARQ2 project that used an elevated-pavement type structural support system for the planting of 179 trees along a redeveloped streetscape in the downtown area. The system was designed to manage stormwater as one of its functions to help prevent combined sewer overflows (http://www.stormh2o.com/march-april-2010/reshaping-minneapolis-project.aspx).

More information on using trees to manage stormwater is at

- Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites www.forestsforwatersheds.org/storage/part2forestrymanual.pdf
- Stormwater Management: Using Trees and Structural Soils to Improve Water Quality www.cnr.vt.edu/urbanforestry/stormwater
- Watershed Forestry Resource Guide—Reducing Stormwater Runoff www.forestsforwatersheds.org/reduce-stormwater

Maintenance Considerations and Resources

The benefits of urban trees can be extended with appropriate selection, planting design, and maintenance. American Forests estimates that the average life expectancy of a downtown urban street tree is just 13 years, while their rural counterparts can live up to 100 years or more. Symptoms of tree decline from urban stressors can take years to appear. Common causes of urban tree mortality include the following:

- Damage to roots or soils from nearby construction activities
- Air pollution
- Physical damage from lawnmowers, vehicles, or vandals
- Damage from disease and insects
- Trees planted in too small a space
- Improper planting and pruning techniques
- Tree stakes or grates left on too long
- Poor, compacted soils
- Lack of watering
- Removal or damage during maintenance of nearby utilities or sidewalks
- Competition from invasive plant species (CWP and USDA 2009)

The Urban Watershed Forestry Manual Part 3: Urban Tree Planting Guide (CWP 2006) (at www.forestsforwatersheds.org/storage/Part3ForestryManual.pdf) provides detailed guidance on urban tree planting, including site assessment, planting design, site preparation, and planting and maintenance techniques.

Costs and Factors Affecting Cost

The costs of reforestation will vary greatly by how and where the trees are incorporated into the urban/suburban landscape. A recent source of information on program cost is the American Public Works Association urban forestry handbook. This project was supported by the USDA Forest Service Urban and Community Forestry Program on the recommendation of the National Urban and Community

Forestry Advisory Council. The handbook series is titled *Urban Forestry Best Management Practices for Public Works Managers,* and the individual handbooks are the following:

- Volume 1 *Budgeting and Funding*
- Volume 2 *Staffing*
- Volume 3 *Ordinances, Regulations, & Public Policies*
- Volume 4 *Urban Forest Management Plan*

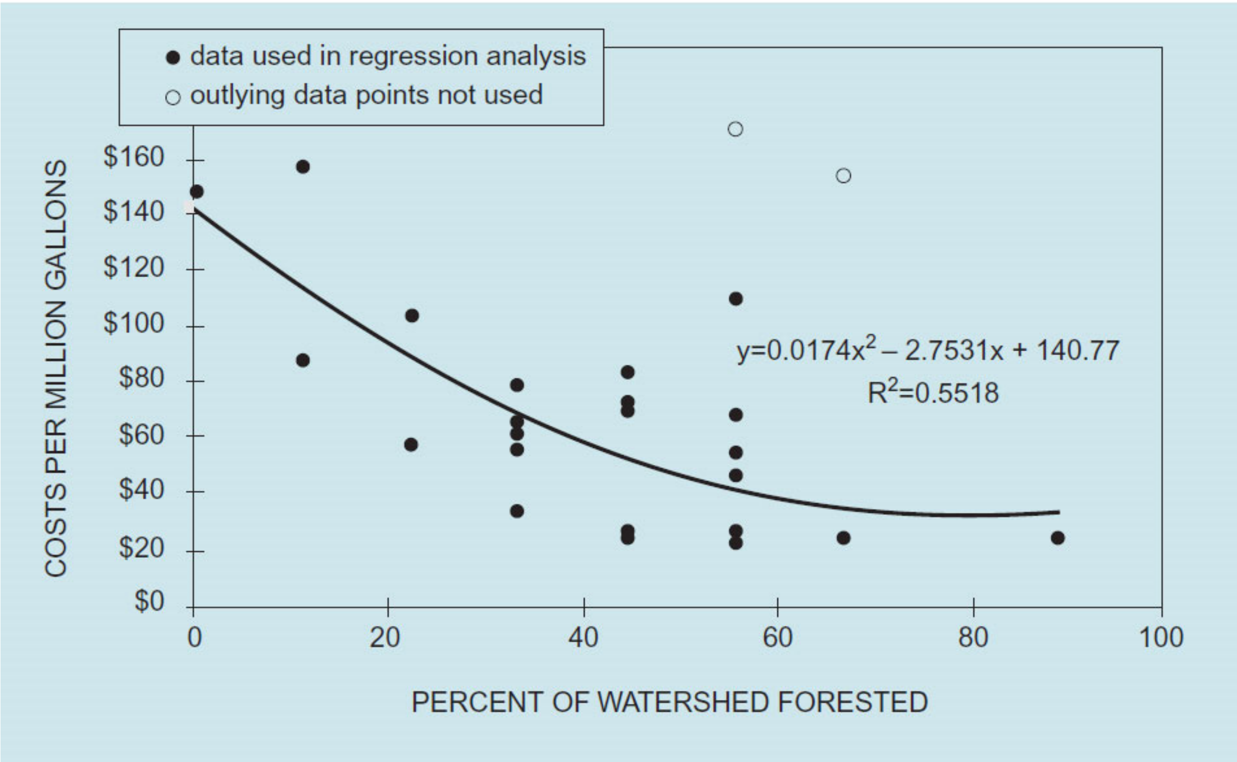
The series is available free for download at APWA Press, www.apwa.net/About/CoopAgreements/urbanforestry.

The value of the economic benefits of planting trees will also vary, however, and research is being done to attempt to quantify the value of urban tree canopy. American Forests (www.americanforests.org) has developed a tool to calculate the value of urban tree canopy in metropolitan areas, called CITYGreen. For example, American Forests determined that 34 percent of Montgomery, Alabama, was covered by tree canopy in 2002. The stormwater-retention capacity of Montgomery's urban forest is 227 million ft^3. The cost to manage that volume of runoff in traditional infrastructure is estimated at $454 million. In addition, Montgomery's urban forest is estimated to remove 3.2 million pounds of pollutants from the air annually, and that benefit is valued at $7.9 million (American Forests 2004). Even in arid locations, trees are important. In 2007 American Forests found that Albuquerque, New Mexico's tree canopy provided 20 million cubic feet in stormwater detention services, valued at $123 million (American Forests 2009).

Further, forests filter pollutants from runoff, therefore, allowing fewer contaminants to reach potable water sources. That results in less treatment costs for local governments.

An example of that is in a 2002 study by the Trust for Public Land and the American Water Works Association. For every 10 percent increase in forest cover in the source watersheds evaluated in the survey, treatment costs decreased by approximately 20 percent, up to about 60 percent forest cover (see Figure 3A1-16). No conclusion could be made for watersheds with more than 60 percent cover because of a lack of data. Treatment costs can level off when forest cover is between 70 and 100 percent, the study estimated. Other factors affecting treatment costs include the treatment practices used, the size of the facility, and the land use characteristics, including use of BMPs (*Watershed Forestry Guide,* Center for Watershed Protection and U.S. Forest Service. (www.forestsforwatersheds.org/forests-and-drinking-water/).

The USDA Forest Service provides a Guide for Chesapeake Bay Communities (see www.jmorgangrove.net/Morgan/UTC-FOS_files/UTC_Guide_Final_DRAFT.pdf) to assist them with the setting and evaluation of urban tree canopy goals. Setting tree canopy goals is essential to achieving program success. Principles of an effective urban forest program and several case studies across the United States are provided in the U.S. Forest Service-supported guide *Planning the Urban Forest: Ecology, Economy, and Community Development* (Schwab 2009).



Source: www.forestsforwatersheds.org/forests-and-drinking-water/

Figure 3A1-16. Relationship between forest cover and water treatment costs. Practice/program evaluation

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1.9 Street Sweeping

Description of Practice

Street sweeping is not a GI/LID practice, and reliance on this practice unfortunately requires repeating the investment continually. However, the current design and operational practices for roadways do present a need for street sweeping for water quality and for safety and aesthetics. This fact sheet is included to provide new information on street sweeping practices.

Street sweeping can provide significant pollutant removal, but many municipalities use sweepers that do not perform effectively or that can actually cause more water quality issues (Pitt et al. 2004). Aesthetics is the main reason most municipalities use sweepers, not water quality. For that use, *mechanical* broom sweepers can perform well. However, they do not provide the level of water quality benefit that can be obtained using improved sweepers.

Streets and roads compose up to 20 percent of total impervious cover in suburban subwatersheds and up to 40 percent in highly urban subwatersheds. Contaminated particulates or *street dirt* accumulates along curbed roads between rainfall events. During intense rainfall events, additional particulates can be washed on to these paved surfaces from adjoining land areas. This wet weather wash-on has been demonstrated to be quite important in understanding the pollutant removal benefits of street sweeping (Sutherland and Jelen 1996). Sources of pollutants include wash-on, atmospheric deposition, vehicle emissions, cargo spills, and wear and tear, breakup of street surface, road salts and deicers, litter, bird droppings, grass clippings, leaves and other organic material and sanding. That results in the accumulation of stormwater pollutants such as sediment, nutrients, metals, hydrocarbons, bacteria, pesticides, trash, and other toxic chemicals (CWP 2008).

Pollutants typically remain on streets until they are washed into the storm drain system during a rainfall event. However, some communities use street sweeping to remove some of the pollutants and prevent them from being conveyed into the storm drain system (CWP 2008).

Street sweeping and vacuuming includes the use of self-propelled and walk-behind equipment to remove sediment from streets and roadways and to clean paved surfaces in preparation for final paving. Sweeping and vacuuming prevents sediment from entering storm drains or receiving waters (CASQA 2003).

Targeted Pollutants (Highly Dependent on Equipment Type)

Targeted Pollutants

Sediment	Hydrocarbons	Trash	Nutrients
⦿	⦿	⦿	⦿

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: www.quincyma.gov/Living

Figure 3A1-17. The majority of pollutants on streets is closest to the curb.

Common Feasibility Constraints and Limitations

The following are common feasibility constraints and limitations of street sweeping:

- Sweeping and vacuuming might not be effective when sediment is wet or when tracked soil is caked (caked soil might need to be scraped loose) (CASQA 2003).
- Be careful not to sweep up any unknown substances or any object that could be hazardous (CASQA 2003).
- The use of kick brooms or some sweeper attachments tend to spread dirt rather than remove it (CASQA 2003). On the other hand, gutter brooms can be very effective at capturing street dirt.
- Access to the curb is paramount to street sweeping efficiency because the majority of pollutants on streets is closest to the curb. Parked cars can restrict access. Compliance with an appropriately enforced no-parking zone can provide access for street sweeping to the curb (CWP 2008).

Pollutant Load Removal Estimates

The ability of street sweepers to remove common stormwater pollutants varies depending on the sweeper technology being used, climate factors such as rainfall patterns, sweeper operation (including sweeper speed), sweeper maintenance (including broom wear), sweeping frequency, pavement conditions, the number of parked cars encountered, and the chemical and physical characteristics of the pollutants that have accumulated on the pavement. In addition, it can be difficult to estimate pollutant removal rates for street sweepers because of the difficulty in measuring particulate matter transported in runoff (APWA 2009).

Pros and cons of sweeper type on pollutant removal performance consist of the following:

- Mechanical street sweepers are more effective at removing larger-sized particles than fine-grained particles and nutrients. Newer high-efficiency sweepers pick up much smaller particles (Sutherland and Jelen 1997; Pitt et al. 2004).
- Mechanical sweepers are typically the least expensive and are better suited to pick up trash and coarse-grained sediment particles (CWP 2008). They provide less water quality benefits, but they

could be used as the first pass of tandem sweeping operations when followed by a sweeper that can remove the pollutant-heavy, fine-sized particles left behind by the mechanical sweeper.

- Regenerative-air and high-efficiency sweepers are better at removing fine-grained sediment particles but are less effective on wet surfaces (although they can still outperform mechanical sweepers) and are more expensive (CWP 2008).
- Street sweeping is presumed to be more effective at reducing stormwater pollutants in arid and semi-arid climates where pollutants can accumulate over longer intervals on street and curb surfaces (CWP 2008).

Practice Design

- Because they operate as a mobile BMP on-the-go, street sweeping can be of particular value in reducing pollutants from ultra-urban areas where few BMPs are feasible (Law et al. 2008).
- Street cleaning equipment can be most effective in areas where the surface to be cleaned is the major source of contaminants. Such areas include freeways, large commercial parking lots, and paved storage areas (Pitt et al. 2004).
- Improving or initiating street sweeping activities can reduce the amount of stormwater pollution that is conveyed into local aquatic resources. It requires examination of existing street sweeping technology and operations (if any) and identification of where improvements can be made to reduce the amount of pollution that has accumulated on public streets and roadways. (CWP 2008).
- Develop a list of areas where street sweeping activities could have the greatest influence on water quality. For example, an area with high accumulations of pollutants might suggest that more regularly scheduled street sweeping is needed. Also, street sweeping can be concentrated on the dirtiest streets in sensitive subwatersheds (CWP 2008).
- At a minimum, sweeping should occur during periods of heavy accumulation, such as early spring removal of deicing chemicals and sand in temperate climates (CWP 2008). During the fall, leaf removal should be conducted with specialized equipment, such as vactor trucks, because seasonal leaves can contribute 25 percent of nutrient loading in catch basins.
- Include municipal parking lots in the sweeping schedule.

Costs and Factors Affecting Cost

Several factors influence the overall cost of street sweeping:

- Street sweeping is major investment, and operators must be specially trained on how to properly drive and maintain them. Training should be held at least once a year for staff to provide them with a thorough understanding of the proper implementation of sweeping and other pollution prevention/good housekeeping practices and safety procedures (CWP 2008).
- Costs can vary significantly by the type of sweeper, operation and maintenance expenses, and sweeping frequency. The capital cost for a conventional street sweeper is between $60,000 and $120,000, with newer technologies approaching $180,000 (CASQA 2003).

Practice/Program Evaluation

It is important to evaluate the process and measurable performance goals and implementation milestones made for a street sweeping program (Table 3A1-10).

Table 3A1-10. Examples of measurable goals and implementation milestones for improving municipal street sweeping activities[a]

Example measurable goals	Time frame	Priority
Goals related to program startup		
Identify and collect basic information about municipal street sweeping activities	Complete shortly after program startup; updated regularly after that	Essential
Add the information about street sweeping activities to the simple database or binder that contains basic information about each municipal operation		Essential
Develop a digital GIS or hard copy map showing the location of all municipal street sweeping activities		Optional but recommended
Prioritize local pollution prevention/good housekeeping efforts	Year 1, repeat every 5 years	Essential
Goals related to preventing or reducing stormwater pollution		
Collect additional information about the way that street sweeping activities are conducted within your community. Include sweeper type; efficiency of fine sediment fraction removed, sweeping frequency, miles swept/coverage, and parking policies and enforcement along sweeping routes.	Year 1	Essential
Prescribe pollution prevention/good housekeeping practices to improve the way that municipal street sweeping activities are conducted within your community		Essential
Develop implementation plan for prescribed street sweeping program		Essential
Secure funding and resources to implement prescribed street sweeping program	Begin in Year 1	Essential
Implement prescribed street sweeping program	Begin in Year 2	Essential
Goals related to program evaluation		
Develop measurable performance goals and implementation milestones	Complete shortly after program startup; updated regularly after that	Essential
Evaluate progress in meeting measurable goals and implementation milestones, including pollution prevent/good housekeeping practices		Essential

Source: adapted from CWP 2008
a. These goals assume that street sweeping is at the top of your prioritized municipal operations list.

The methods used to evaluate success in meeting measurable goals and implementation milestones can be as simple as a semi-annual or annual inspections used to identify the improvements that have been put in place and the improvements that still need to be made (CWP 2008).

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1.10 Constructed Wetlands

Description of Practice

Wetland systems are designed for flood control and removal of pollutants from stormwater. Like natural wetlands, stormwater wetlands (a.k.a. constructed wetlands) temporarily store the water and have the capacity to improve water quality through microbial breakdown of pollutants, plant uptake, retention of stormwater, settling and adsorption (Barr 2001). Constructed wetlands, like wet ponds, incorporate wetland plants into the design and require relatively large contributing drainage areas. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake. Constructed wetlands have zones and plants similar to wet ponds but often with less fluctuation and the ability to maintain a higher diversity (Shaw 2003).

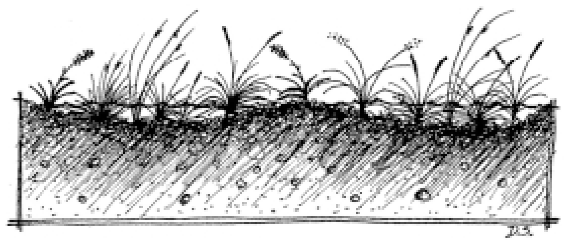
Wetlands are among the most effective stormwater practices in terms of pollutant removal and also offer aesthetic and habitat value. Although natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Constructed wetlands are designed specifically for treating stormwater runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life. Several design variations of the constructed wetland exist, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. Sediment forebays and micropools are often designed as part of constructed wetlands to prevent sediment from filling the wetland (Barr 2001).

A distinction should be made between using a constructed wetland for stormwater management and diverting stormwater into a natural wetland. The latter practice is not recommended because altering the hydrology of the existing wetland with additional stormwater can degrade the resource and result in plant die-off and the destruction of wildlife habitat. In all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased stormwater runoff. This is especially important because natural wetlands provide stormwater and flood control benefits on a regional scale (USEPA 2006).

Photos and Diagrams

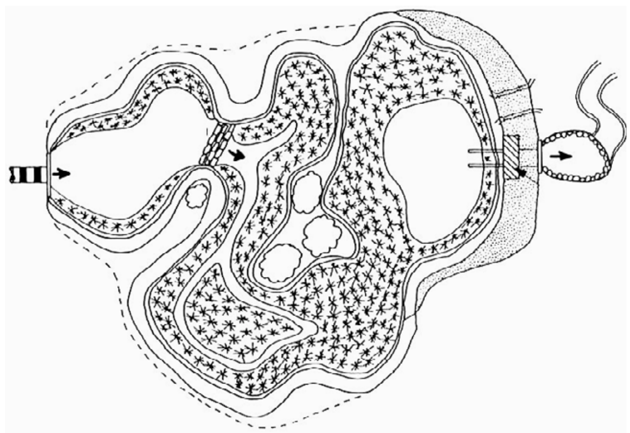
Source: USEPA 2006

Figure 3A1-18. Stormwater wetland.



Source: Shaw 2003

Figure 3A1-19. Drawing of a wetland.



Source: Barr 2001/Schueller 1992

Figure 3A1-20. Plan diagram of a shallow marsh constructed wetland.

Photo by A.H. Baldwin. Source: Simpson 2009

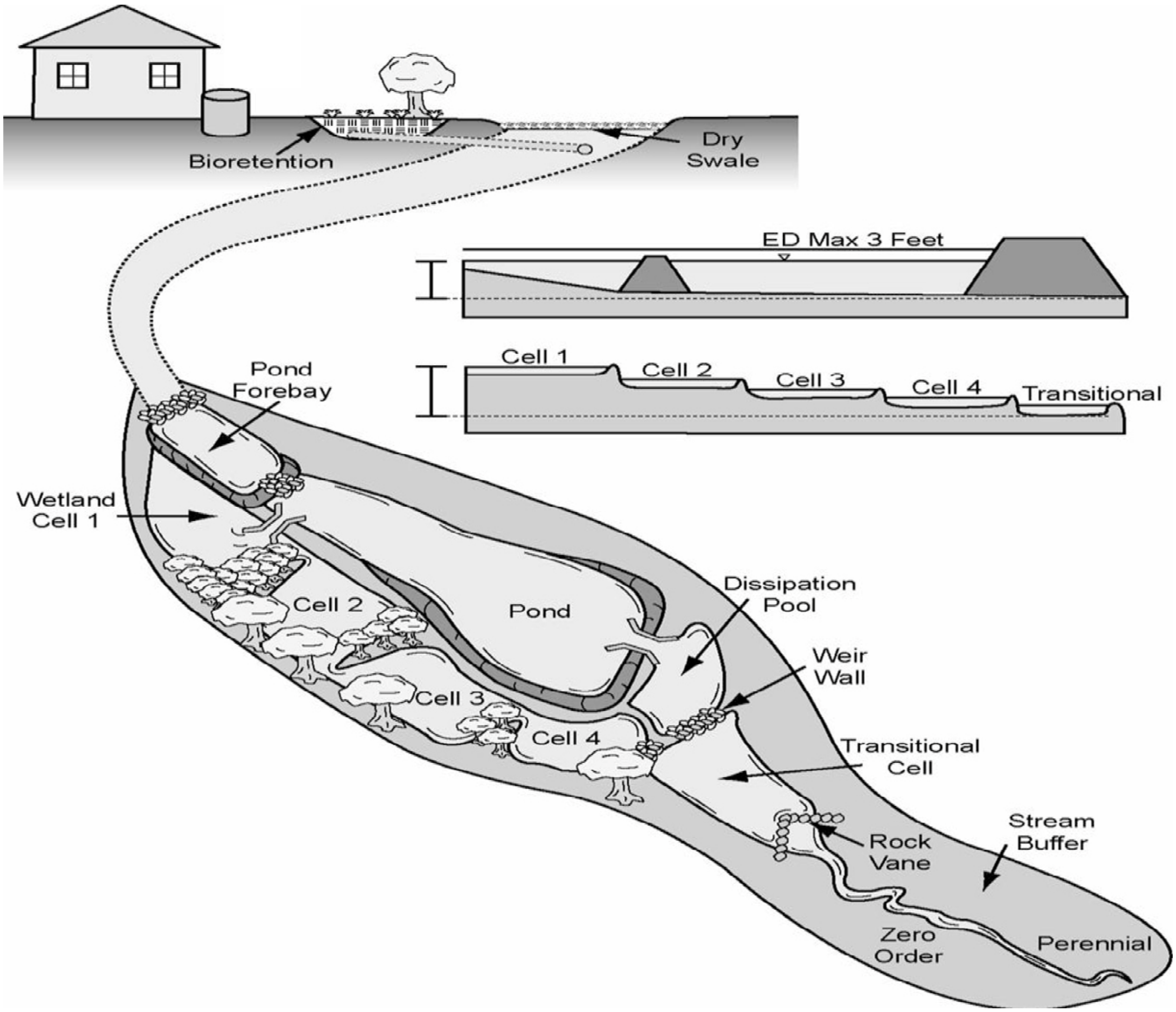
Figure 3A1-21. Stormwater wetland at the University of Maryland, College Park. Runoff from the parking lot enters the wetland from the left, flows in a roughly U-shaped counterclockwise pattern, and discharges via a riser at the top center of the wetland.

Source: VA DCR 2009

Figure 3A1-22. A constructed wetland basin.

Source: VA DCR 2009

Figure 3A1-23. Plan view constructed wetland basin.



Source: VA DCR 2009

Figure 3A1-24. Pond/wetland combination.

Common Feasibility Constraints and Limitations

Constructed wetlands are widely applicable and can be applied in most regions of the United States; however, there are limitations in specific climates and areas, including

- Arid and semi-arid climates where evaporation makes it difficult to retain water in a shallow pool
- Ultra-urban areas with little pervious surface available for the large land area required
- *Hot spots* that have a high potential for groundwater contamination, e.g., gas station runoff or areas where chemicals are stored or managed
- Retrofit or new construction in areas with minimal land

- Cold water trout streams because of thermal effects of heating a shallow pool, which can discharge warmer water
- Breeding ground for mosquitoes in improperly designed systems
- Careful selection of plants that will sustain life over the lifetime of the project
- Nutrient release can occur during the non-growing season
- Consideration of impact on natural wetlands and forests

(Adapted from USEPA 2006)

Pollutant reduction. Considerable variations exist in both methods of reporting treatment effectiveness, and a broad range of effectiveness is noted for individual sites. In a literature review conducted for these practices in the Chesapeake Bay region, effectiveness estimates for urban constructed wetlands were 60 percent for total suspended solids, 20 percent for total nitrogen and 45 percent for total phosphorus, and volume reduction was not noted as significant source of pollutant removal (Simpson et al. 2009). One study found that an experimental system had little potential for long-term, consistent mass removal of total nitrogen and total phosphorus, depending on the concentrations in the incoming runoff (Nietch et al. 2005).

Results from the studies show that some bacteria removal and inactivation can occur in constructed wetlands. The factors of light, time, temperature, and other factors (e.g., predation, sedimentation, sorption, filtration, pH, BOD, and DO) can also contribute to the inactivation of indicator bacteria in constructed wetland BMPs (USEPA 2006).

Cold weather performance. Cold temperatures can cause freezing of the permanent pool or freezing at inlets and outlets. Also in the winter, high salt concentrations in runoff from road salting, and high sediment loads from road sanding, can affect wetland vegetation. During the spring, snowmelt can carry a relatively high pollutant load with the high volume of runoff.

One of the greatest challenges of stormwater wetlands, particularly shallow marshes, is that much of the practice is very shallow. Therefore, much of the volume in the wetland can be lost as the surface of the practice freezes. One study found that the performance of a wetland system was diminished during the spring snowmelt because the outlet and surface of the wetland had frozen. Sediment and pollutants in snowmelt and rainfall events *skated* over the surface of the wetland, depositing at the outlet of the wetland. When the ice melted, this sediment was washed away by storm events (Oberts 1994). Several design features can help minimize this problem, including the following:

- *On-line* designs allowing flow to move continuously can help prevent outlets from freezing.
- Multiple cells, with a berm or weir separating each cell, can help retain storage for treatment above the ice layer during the winter season.
- Freeze-resistant outlets (i.e., weirs or pipes with large diameters).
- Planting salt-tolerant vegetation, such as pickle weed or cord grass when wetlands drain highway runoff or parking lots.

- Using a large forebay can help to capture the sediment from road sanding.

(Adapted from USEPA 2006)

Summaries of Volume and Pollutant Loading Reductions Achievable

Practice Design

Several design considerations influence the overall performance of stormwater wetlands:

- Sufficient drainage area to maintain water in the permanent pool, which is typically about 25 acres in humid area and more in drier regions.
- Upstream slopes of up to about 15 percent with shallow local slopes large enough to ensure hydraulic conveyance (generally about 3- to 5-foot drop minimum from inlet to outlet).
- Minor design adjustments for regions of karst (i.e., limestone) topography to include an impermeable liner.
- Wetlands can intersect the groundwater table, which might affect pollutant reduction capabilities.
- Incorporation of a sediment forebay, a small pool (typically about 10 percent of permanent pool volume), to trap coarse particles.
- Surface area of the stormwater wetland should be at least 1 percent of the drainage area.
- Length-to-width ratio of at least 1.5:1 to prevent short circuiting.
- Inclusion of both very shallow (<6 inches) and moderately shallow (<18 inches) to provide a longer flow path through the wetland and encourage plant diversity.

(Adapted from USEPA 2006)

Design Variations

There are three basic design variations of constructed wetlands:

- Shallow Marsh: Most of the wetland volume is in the relatively shallow high-marsh or low-marsh depths, with the only deep portions in the forebay at the inlet and the micropool at the outlet. Such systems are appropriate at the terminus of a storm pipe drain or open channel (usually after upland runoff reduction).
- Pond/Wetland System: Combining the wet pond and shallow-marsh designs requires less surface area than the shallow marsh alone because of the relatively deep volume of the wet pond. Such systems are appropriate in moderately to highly urbanized areas.
- Linear Wetland Cells: Systems installed within the conveyance system or zero-order stream channels.

(Adapted from VADCR 2009)

Maintenance Considerations and Resources

Typical maintenance activities are shown in Table 3A1-11 (USEPA 2009).

Table 3A1-11. Constructed wetland maintenance activities

Maintenance activity	Schedule
– Cleaning and removing debris after major storm events (> 2" rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repairing embankment and side slopes	Annual or as needed
– Removing accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
– Removing accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle

Costs and Factors Affecting Cost

The construction cost of urban constructed wetlands varies depending on the design, location, site-specific conditions, and the amount of earthwork and planting. (USEPA Wetlands Fact Sheet 1999). Construction cost estimates and references are provided by EPA in the Menu of BMPs *Stormwater Wetland Fact Sheet:* (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=74&minmeasure=5).

Table 3A1-12 provides an example of costs taken from North Carolina case studies provided in (Urban Waterways, North Carolina State University Cooperative Extension 2000, www.neuse.ncsu.edu/SWwetlands.pdf).

Unit costs for typical wetlands maintenance items are in Appendix A of EPA's 2009 *Stormwater Wet Pond and Wetland Management Guidebook* (www.epa.gov/npdes/pubs/pondmgmtguide.pdf)

Example Constructed Wetland Design Manuals in the Chesapeake Bay Watershed Area

Virginia Department of Conservation and Recreation *Stormwater Design Specification No. 13 Constructed Wetlands*, Version 1.6, September 30, 2009.
www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Table 3A1-12. Sample land and construction costs of a stormwater wetland (taken from North Carolina case studies).

Cost type	Description	Unit cost	Total cost	Cost per acre of watershed treated
Land	Land values can vary from $10,000 to $400,000 per acre in North Carolina. Assume $40,000 at this site.	$40,000/ac	$40,000	$800
Excavation and grading	A total of 4,800 cubic yards (1 acre x 1 yard depth).	$8/cy	$38,400	$770
Hauling	Area adjacent to site used to spread excess earth—costs included excavation costs	Part of above costs	Included in excavation and grading costs	Included in excavation and grading costs
Vegetation	Some local transplants, some natural establishment, and a few ornamental plants from local nursery.	$0.30/sf	$13,000	$260
Spillway and drawdown	Treated lumber used for aesthetic purposes. Drawdown holes drilled through principal spillway.	$0.25/sf	$11,000	$220
Total Land and Construction Costs			**$102,400**	**$2,050**

Note: The table is based on a 1-acre wetland treating a 50-acre watershed.

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VADCR (Virginia Department of Conservation and Recreation). 2009. *Draft VA DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.5*, July 2, 2009

Appendix 2: Methods and Tools for Controlling Stormwater Runoff (Quantity and Quality)

This appendix describes various methods, including guidance manuals, and tools for controlling stormwater runoff. This appendix includes

2.1 Methods and Manuals

2.2 Complex Models

2.3 Simpler Models (largely spreadsheet-based or online)

2.1 Methods and Manuals

Nationally Applicable LID Design Methods and Manuals
Prince George's County, Maryland, *Low-Impact Development Design Strategies: An Integrated Design Approach*, EPA-841-B-00-003, 2000. Prince George's County, Maryland, *Low-Impact Development Hydrologic Analysis*, EPA-841-B-00-002, 2000. www.epa.gov/nps/lid
EPA, *Stormwater Best Management Practices Design Guide*, Office of Research and Development, EPA/600/R-04/121, Volumes 1-3 (121, 121A, 121B), September 2004. www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm
Center for Watershed Protection *Urban Subwatershed Restoration Manual Series* (www.cwp.org/Store/usrm.htm) Center for Watershed Protection *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (www.cwp.org/Resource_Library/Center_Docs/SW/pcguidance/Manual/PostConstructionManual.pdf)
Water Environment Research Foundation (WERF). *Decentralized Stormwater Controls For Urban Retrofit And Combined Sewer Overflow Reduction* www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/ResearchProfile.cfm&ReportId=03-SW-3&CFID=2715758&CFTOKEN=75805127
WERF. *Critical Assessment of Stormwater Treatment and Control Selection Issues*. In Publication.
Geosyntec Consultants and Wright Water Engineers. *Urban Stormwater BMP Performance Monitoring*. 2009. www.bmpdatabase.org/MonitoringEval.htm
The Low-Impact Development Center, www.lowimpactdevelopment.org; several LID manuals

Federal Facility Design Manuals
EPA Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act, 2009, EPA-841-B-09-001, December 2009, www.epa.gov/owow/nps/lid/section438
U.S. Naval Facilities Engineering Command, *Low Impact Development, Draft, Unified Design Criteria*, UFC 3-210-10, October 2004. www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf
U.S. Department of Housing and Urban Development, *The Practice of Low Impact Development*, 2003, www.huduser.org/portal/publications/destech/lowImpactDevl.html
U.S. Army Corps of Engineers. *Low Impact Development for Sustainable Installations: Stormwater Design and Planning Guidance for Development within Army Training Areas*. Public Works Technical Bulletin 200-1-62. October 2008.

Transportation-focused LID Design Methods and Manuals
Low Impact Development Center, Inc., 2006, GeoSyntech Consultants, University of Florida, Oregon State University, *Evaluation of Best Management Practices for Highway Runoff Control, Report N. 565 for National Cooperative Highway Research Program (NCHRP), Project 25-20 (1).* http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_565.pdf

Example State/Local Design Manuals and Resources **(also refer to individual practice fact sheet references)**
The Chesapeake Stormwater Network. *Baywide BMP Design Specifications*. www.chesapeakestormwater.net/baywide-design-specifications2
Pennsylvania. *Stormwater BMP Manual*. 2006. www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305
Delaware. *Standards & Specifications for Green Technology BMPs*. 2005. www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf
District of Columbia. Stormwater Guidebook. http://ddoe.dc.gov/ddoe/frames.asp?doc=/ddoe/lib/ddoe/stormwaterdiv/2009.05.07_SWM_Table_of_Contents.pdf
North Carolina Coastal Federation, www.nccoast.org, resources on implementing LID to protect shellfish beds and coastal beaches.
U.S Fish and Wildlife Service, *Bayscapes*, www.fws.gov/ChesapeakeBay/Bayscapes.htm

BMP Performance Information
WERF. International Stormwater BMP Database. www.bmpdatabase.org
EPA. *Urban BMP Performance Tool*. www.epa.gov/npdes/urbanbmp
Center for Watershed Protection. National Pollutant Removal Performance Database. www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm

Source Control and Pollution Prevention Manuals
EPA *National Management Measures to Control Nonpoint Source Pollution from Urban Areas Office of Oceans, Wetlands and Watersheds*, EPA-841B-05-004, December 2005 (www.epa.gov/owow/nps/urbanmm/)
EPA *The Use of Best Management Practices (BMPs) in Urban Watersheds,* Office of Research and Development, EPA/600/R-04/184, September 2004.
Center for Watershed Protection *Urban Subwatershed Restoration Manual Series, Volume 8, Pollution Source Control Practices,* February 2007 (www.cwp.org/Store/usrm.htm)
Managing Storm Water Runoff to Prevent Contamination of Drinking Water and Managing Highway Deicing to Prevent Contamination of Drinking Water. Steve Ainsworth, USEPA

2.2 Complex, LID-capable Models

Publicly available models appropriate for evaluating LID practices include

- EPA's Storm Water Management Model, version 5 (SWMM5)
- EPA's Hydrologic Simulation Program—FORTRAN model (HSPF)
- U.S. Army Corps of Engineers, Hydrologic Engineering Center—Hydrologic Modeling System (HEC-HMS)
- Western Washington's Hydrology Model, version 3 (WWHM3)
- University of Wisconsin, Civil & Environmental Engineering Department, Water Resources Group—RECARGA

The following summarizes these complex, LID-capable models.

EPA's Storm Water Management Model, version 5 (SWMM5)

EPA's Storm Water Management Model (SWMM) is a dynamic, rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. SWMM5 divides the water balance process into four compartments:

(1) atmosphere (precipitation); (2) land surface (divides precipitation into infiltration, storage, or runoff; (3) groundwater; and (4) transport (pipe and channel flow, as well as storage). It can perform both single event and long-term continuous simulation using precipitation data recorded at hourly or less frequent intervals. The inputs can be supplemented with monthly evaporation data and daily temperature readings. Different hydraulic routing techniques are available to manage from simple to complex routing conditions. Infiltration can be simulated using Horton, Green-Ampt, or Curve Number techniques. These techniques vary in complexity and the availability of the parameters used for their estimation. They can take into account initial soil moisture conditions, hydraulic conductivity, soil moisture capacity, and its regeneration. Separate accounting is provided for runoff from pervious areas and impervious areas, and routing of runoff from one area over another is possible. SWMM5 can simulate pollutant buildup, washoff, and treatment, although those capabilities are not needed to determine predevelopment hydrology comparisons.

SWMM5's advantages are that it uses physically based process models and input parameters wherever possible, it can model any number of storage- or infiltration-based BMPs, it contains robust procedures for routing runoff flow, and it allows models to be built to any level of spatial detail needed to provide the most accurate water balance for a site. A disadvantage is that it does not have the capability to model some BMPs the employ infiltration, storage, and/or flow routing in combination with one another (such as infiltration ponds and vegetated swales).

This model has been in use since 1971 and has undergone several major upgrades since its inception, including expansion of LID applications in 2009. The following applications are discussed in the 2009 manual:

1. Post-Development Runoff
2. Surface Drainage Hydraulics
3. Detention Pond Design
4. Low Impact Development
5. Runoff Water Quality
6. Runoff Treatment
7. Dual Drainage Systems
8. Combined Sewer Systems
9. Continuous Simulation

The model and supporting documentation are at
www.epa.gov/ednnrmrl/models/swmm/index.htm.

EPA's Hydrological Simulation Program Fortran (HSPF), and WinHSPF

WinHSPF has broad capabilities for hydraulic, hydrologic, and water quality modeling. BMPs are modeled as either *reaches* that can represent channels or areas of storage, or as *pervious land*. WinHSPF can be used for a single rain event or continuous simulation. In WinHSPF, only the pervious land module can be used for infiltration. Infiltration can vary with time as soil moisture conditions change, and spatial variability in infiltration rates can be addressed. The advantages of WinHSPF include the very broad capabilities for simulating infiltration, surface runoff, groundwater movement, evaporation and evapotranspiration, snowmelt, and for water quality parameters, including temperature (a requirement of Section 438). Another advantage is that it has been incorporated into BASINS, an EPA model that takes advantage of the capabilities of GIS and other systems.

Disadvantages of WinHSPF are its complexity and its limited routing capability compared to SWMM5.

It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The user must input continuous rainfall records to drive the runoff model. Additional records of evapotranspiration, temperature, and solar intensity can be imported for more accurate results. A large number of model parameters can be specified, although default values are provided where reasonable values are available. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed.

The model and supporting documentation are available for download at
www.epa.gov/ceampubl/swater/hspf.

HEC-HMS

HEC-HMS replaces HEC-1 by building on the original capability of simulating precipitation-runoff and routing processes. HEC-HMS added capabilities for distributed modeling and continuous simulation. HEC-HMS includes a broad selection of models for representing rainfall distributions, computing runoff volume (i.e., different selections of infiltration and losses algorithms), for modeling direct runoff (overland flow and interflow); baseflow in a stream; and channel flow. It is capable of modeling either event-based or continuous simulations.

HEC-HMS uses three major components in analyzing a hydrologic system:

1. Basin model—user-entered data on basin data, including losses characteristics and connectivity

2. Meteorological model—user-entered data on rainfall, snowmelt, and evapotranspiration rate

3. Control specifications—user-entered calculation intervals

Precipitation considerations include areal and temporal distribution, and use of radar data. Evapotranspiration and precipitation are represented in the soil-moisture accounting (SMA) model and enables modeling of the drying of the watershed, or otherwise movement of water, between rainfall events for continuous modeling. A five-layer model is used: canopy, surface, soil, upper groundwater, and lower groundwater. Alternatively, there is a deficit-constant method that simplifies to a one-layer model for soil. HEC-HMS divides surfaces into either directly connected impervious areas or pervious surfaces. Losses on the pervious surfaces include interception, infiltration, storage (consisting of canopy, surface, soil-profile, and groundwater), evaporation and transpiration.

HEC-HMS is widely used for simulating distributed infiltration controls, particularly when interactions with streams (with potentially varying baseflows or flash-flows) or input into subsequent river analysis is desired, via HEC-RAS. HEC-HMS also includes extensive elements for modeling engineered structures in management systems for reservoirs, dams, pumps, and other structures.

This model is available for download at
www.hec.usace.army.mil/publications/pub_download.html

WWHM3

WWHM3 is the third edition of the Western Washington Hydrology model developed for Washington State Department of Ecology, with input parameters unique for that region. The model is built on a continuous simulation HSPF platform and can model the entire hydrological cycle for multiple years. The purpose of the WWHM3 is to size stormwater control facilities to mitigate the effects of increased runoff (peak discharge, duration, and volume) from proposed land use changes that affect natural streams, wetlands, and other water courses. WWHM3 also uses an *LID Scenario Generator* to show the mean annual distribution of stormwater into surface runoff, interflow, groundwater, and evapotranspiration. Using the LID Scenario Generator, the user can change land use combinations to optimize performance. The user can also explicitly model various LID practices, including green roofs.

The software has been used to develop stormwater systems for the 19 counties in western Washington State and is designed to comply with the Clean Water Act (NPDES Phase I and II), the Endangered Species Act and state and local stormwater regulations. More information is at www.ecy.wa.gov/Programs/wq/stormwater/wwhmtraining/wwhm/wwhm_v3/index.html.

RECARGA

The RECARGA model was developed by the University of Wisconsin Civil & Environmental Engineering Department Water Resources Group to provide a design tool for evaluating the performance of bioretention facilities, rain garden facilities, and infiltration basins. Individual facilities with surface ponding, up to three distinct soil layers and optional underdrains can be modeled under user-specified precipitation and evaporation conditions. The model continuously simulates the movement of water throughout the facility (ponding zone, soil layers and underdrains), records the soil moisture and volume of water in each water budget term (infiltration, recharge, overflow, underdrain flow, evapotranspiration, and the like) at each time step and summarizes the results. The results of this model can be used to size facilities to meet specific performance objectives, such as reducing runoff volume or increasing recharge, and for analyzing the potential impacts of varying the design parameters. Information is at http://dnr.wi.gov/runoff/stormwater/technote.htm.

2.3 Simpler Models

The following summarizes several simpler, spreadsheet-based or online, models:

Virginia Runoff Reduction Method Spreadsheets

The *Runoff Reduction Method* is a system that incorporates site design, stormwater management planning, and BMP selection to develop the most effective stormwater approach for a given site. The method relies on a three-step compliance procedure that includes (1) applying site design practices to minimize impervious cover, grading, and loss of forest cover, (2) apply runoff reduction practices, and (3) computer pollutant removal by selected BMPs. Two spreadsheets have been developed—one for new development and one for redevelopment projects—that allow the designer to see whether the phosphorus load reduction has been achieved by applying runoff reduction practices. www.dcr.virginia.gov/lr2f.shtml

LID Quicksheet 1.2

Developed by the Milwaukee Metropolitan Sewerage District (MMSD), LID Quicksheet 1.2 is a spreadsheet that has been developed to provide a practical way to calculate how the use of LID practices affect the stormwater detention volume required under Chapter 13. The LID practices included in the Quicksheet are rain gardens, rain barrels, green roofs, cisterns, and permeable pavement. The Quicksheet is intended to allow the designer to evaluate the effect of LID practices on reducing the volume of traditional stormwater detention. Information on LID Quicksheet 1.2 is in Appendix L at http://v3.mmsd.com/manuals.aspx.

Emeryville Stormwater Sizing Calculator

The City of Emeryville, California developed this spreadsheet-based calculator to determine the proper size of stormwater treatment devices for new development projects. The spreadsheet includes seven tables, each targeted to a specific type of stormwater treatment information. The tool uses user-defined drainage area and types to calculate the required facility size for the area. It also calculates the amount of shortfall in metered detention areas, bioretention basins, lowered planter strips, flow-through planter boxes, and bioretention swales. The tool can help track treatment capacity excess and shortages so that parcel areas can be redistributed if there is a shortfall. This tool and others are at http://cfpub.epa.gov/npdes/greeninfrastructure/modelsandcalculators.cfm.

Capitol Region Watershed District (Twin Cities, Minnesota), Volume Reduction Worksheet

This spreadsheet includes formulas for volume reduction practices. Volume credits are provided for seven different types of practices. www.capitolregionwd.org/permit_forms.html

The Center for Neighborhood Technology Green Values Calculator (GVC)

The GVC compares green infrastructure performance, costs, and benefits to conventional stormwater practices at both development-site and neighborhood scales. The tool provides a quantified analysis of green infrastructure environmental benefits including reduced runoff volume and groundwater recharge. Users can specify site data in a custom run or use several templates for typical urban and suburban scenarios. A number of *green interventions* can be selected and used to calculate financial and hydrologic reduction data. Hydrologic reductions include lot-level goals for peak and total discharge, desired total site peak discharge, total detention required, and average annual discharge. The GVC is maintained by The Center for Neighborhood Technology and is at http://greenvalues.cnt.org.

SELECT

The System Effectiveness and Life-cycle Evaluation of Costs Tool (SELECT) is a simple planning-level tool that enables a stormwater manager to examine the effectiveness of alternative scenarios for controlling stormwater pollution and the whole-life cost associated with each scenario. SELECT uses a long-term record of hourly rainfall, which it translates into runoff using a runoff coefficient that is related to the effective imperviousness of the catchment. The runoff is introduced to the BMP (which includes a number of common BMPs, including permeable pavement, wetlands, and swales). If there is capacity in the BMP, the runoff is captured; if the BMP is full, the runoff is discharged untreated to the receiving waters. The model calculates total outflow as the sum of what is treated and what is not.

This tool was developed for the Water Environment Research Foundation (WERF) by a team including ACR, LLC; the University of Utah; and Colorado State University and uses Microsoft Excel as an interface. SELECT is available only to WERF subscribers. More information, including how to become a WERF subscriber and download the tool, is at www.werf.org/select.

Upper Neuse Site Evaluation Tool (SET)

The Upper Neuse Site Evaluation Tool (SET) is a spreadsheet-based tool developed by Tetra Tech, Inc., for the Upper Neuse River Basin Association. It was designed to aid in the assessment of development plans and available BMPs to achieve regional water quality objectives. The SET can also be used to compare the costs of stormwater BMP systems and estimate the cost savings for reducing impervious surfaces within a site design. The most recent version of the SET is at www.unrba.org/set.

The SET has two functioning components—the Hydrology/Pollutant Component for assessing water quality impacts of development, and the Cost Component for assessing the costs of BMPs and other infrastructure. The Hydrology/Pollutant Component requires user-controlled targets for nutrient loading, an optional target for sediment loading, and targets for peak flow for storage of runoff during the type of storm events most likely to cause downstream channel erosion. Data entry includes general site data, land use, drainage areas and BMP information. Various BMPs can be tested to find a combination that meets the targets. The Cost Component allows a user to compare the costs of stormwater BMP systems and estimate the cost savings for reducing impervious surfaces within a site design.

Rainwater Harvester Computer Model

North Carolina State University developed a computer model to assist in determining the appropriate cistern size for a given situation. The model uses rainfall data and anticipated usage to establish cistern inputs and outputs and provides a cost summary and usage statistics in a report form. Version 2.0 includes an improved interface, reduced calculation times, an interactive graph of cistern levels, and the ability to save and load model inputs. Also, the Web site includes a quick online calculator that provides an overview of the benefits of a water harvesting system for homeowners. www.bae.ncsu.edu/topic/waterharvesting/model.html

Appendix 3: Procedures and Case Studies from the Section 438 Guidance

The following information is from the *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act* available at www.epa.gov/owow/NPS/lid/section438.

This appendix includes procedures for calculating the 95th percentile rainfall event, case studies of stormwater designs to retain the 95th percentile rainfall event, and assumptions related to the runoff methodology calculations.

Calculating the 95th Percentile Rainfall Event

A long period of precipitation records, i.e., a minimum of 10 years of data, is needed to determine the 95th percentile rainfall event for a location. Thirty years or more of monitoring data are desirable to conduct an unbiased statistical analysis. The National Climatic Data Center (NCDC) provides long-term precipitation data for many locations of the United States. You can download climate data from its Web site (www.ncdc.noaa.gov) or by ordering compact discs (NOTE: The NCDC charges a fee for access to their precipitation data). Local airports, universities, water treatment plants, or other facilities might also maintain long-term precipitation records. Data reporting formats can vary depending on the data sources. In general, each record should include the following basic information:

- Location (monitoring station)
- Recording time (usually the starting time of a time-step)
- Total precipitation depth during the time-step

In addition to the above information, a status flag is sometimes included to indicate data monitoring errors or anomalies. Typical NCDC flags include A (end accumulation), M (missing data), D (deleted data), or I (incomplete data). If there are no flags, the record has passed the quality control as prescribed by the NCDC and has been determined to be a valid data point.

Several data processing steps are used to determine the 95th percentile rainfall event using a spreadsheet. These steps are summarized below:

1. Obtain a long-term 24-hour precipitation data set for a location of interest (i.e., from the NCDC Web site).

2. Import the data into a spreadsheet. In MS Excel [Data / Import External Data / Import Data]

3. Rearrange all the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.

	A	B	C	D
1	Date	Prcp		
2	1/2/1921	0.05		
3	1/3/1921	0		
4	1/4/1921	0		
5	1/5/1921	0.33		
6	1/6/1921	0.08		
7	1/7/1921	0.08		
8	1/8/1921	0.19		
9	1/9/1921	0		

4. Review the records to identify if there are early periods with a large number of flagged data points (e.g., erroneous data points). Select a long period of good recording data that represents, ideally, 30 years or more of data. Remove all the extra data (if not using the entire dataset).

5. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.

6. Remove small rainfall events (typically less than 0.1 inch), which might not contribute to rainfall runoff. Such small events are categorized as depressional storage, which, in general, does not produce runoff from most sites.

	A	B	C	D
1	Date	Prcp		
2	1/5/1921	0.33		
3	1/8/1921	0.19		
4	1/14/1921	1.04		
5	2/6/1921	0.12		
6	2/11/1921	0.63		
7	2/20/1921	1.33		
8	2/28/1921	0.43		
9	3/3/1921	0.13		

Note: Steps 4 through 6 can be processed by applying data sort, delete and re-sort spreadsheet functions. In MS Excel [Data / Sort]

7. Calculate the 95th percentile rainfall amount by applying the PERCENTILE spreadsheet function at a cell. In MS Excel [=PERCENTILE(precipitation data range,95%)]

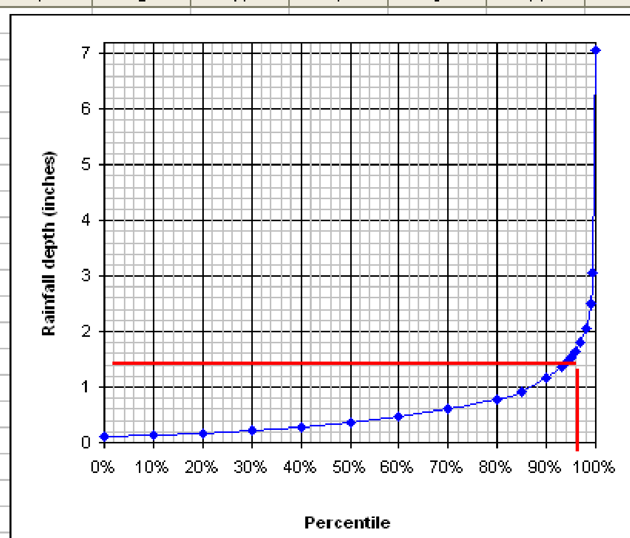
	A	B	C	D	E	F
1	Date	Prcp				
2	1/5/1921	0.33		=PERCENTILE(B:B,95%)		
3	1/8/1921	0.19		1.52		
4	1/14/1921	1.04				
5	2/6/1921	0.12				
6	2/11/1921	0.63				
7	2/20/1921	1.33				
8	2/28/1921	0.43				

Note: The PERCENTILE function returns the nth percentile of value in the entire precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5 percent of storms.

8. The 95th percentile was calculated in the previous step. However, if the user would like to see this information represented graphically and get a relative sense of where individual storm percentiles fall in terms of rainfall depths, the following methodology can be used. Derive a table showing percentile versus rainfall depth to draw a curve as shown below. The PERCENTILE spreadsheet function can be used for each selected percent. It is recommended to include at least 6 points between 0 and 100 percent (several points should be between 80 and 100 percent to draw an accurate curve).

	A	B	C	D	E	F	G
1	Date	Prcp		Percentile	Rainfall		
2	1/5/1921	0.33		0%	=PERCENTILE(B:B,D2)		
3	1/8/1921	0.19		10%	=PERCENTILE(B:B,D3)		
4	1/14/1921	1.04		20%	=PERCENTILE(B:B,D4)		
5	2/6/1921	0.12		30%	=PERCENTILE(B:B,D5)		
6	2/11/1921	0.63		40%	=PERCENTILE(B:B,D6)		

	A	B	C	D	E
1	Date	Prcp		Percentile	Rainfall
2	1/5/1921	0.33		0%	0.1
3	1/8/1921	0.19		10%	0.13
4	1/14/1921	1.04		20%	0.17
5	2/6/1921	0.12		30%	0.22
6	2/11/1921	0.63		40%	0.28
7	2/20/1921	1.33		50%	0.36
8	2/28/1921	0.43		60%	0.46
9	3/3/1921	0.13		70%	0.6
10	3/9/1921	0.31		80%	0.79
11	3/13/1921	0.46		85%	0.93
12	3/25/1921	0.47		90%	1.16
13	3/28/1921	0.12		93%	1.35
14	4/1/1921	0.36		94%	1.44
15	4/9/1921	0.69		95%	1.52
16	4/15/1921	0.24		96%	1.65
17	4/17/1921	0.32		97%	1.82
18	4/18/1921	0.55		98%	2.068
19	4/23/1921	0.69		99%	2.508
20	4/24/1921	0.19		99.5%	3.049
21	4/30/1921	1.44		100%	7.06



Use the spreadsheet software to create of plot of rainfall depth versus percentile, as shown above. The 95th percentile storm event should correlate to the rainfall depth calculated in step 7, however the graph can be used to calculate rainfall depths at other percentiles (e.g., 50 percent, 90 percent).

Case Studies on Capturing the 95th Percentile Storm Using On-site Management Practices

Introduction

This section contains nine case studies that are intended to be representative of the range of projects that are subject to the requirements legislated in section 438 of the Energy Independence and Security Act. The facility examples in the case studies were selected to illustrate project scenarios for differing geographic locations, site conditions, and project sizes and types. As noted in Part I, all projects with a footprint greater than 5,000 square feet must comply with the provisions of section 438. What that means is that both new development and redevelopment projects should be designed to infiltrate, evapotranspirate, and/or harvest and use runoff to the maximum extent technically feasible (METF) to maintain or restore the predevelopment hydrology of the site. Scenarios 1–8 are examples of sites where it was technically feasible to design the stormwater management system to retain the 95th percentile storm on-site. Scenario 9, however, was provided as an example of an METF analysis where site constraints allowed the designers to retain only 75 percent of the 95th percentile storm.

Given the site-specific nature of individual projects, the case study scenarios described here do not include site-specific design features such as runoff routing, specific site infiltration rates, the structural loading capacity of buildings and such, in terms of stormwater practice selection.

It should be noted that an example of Option 2, which requires a site-specific hydrologic analysis, has not been provided in this document because of the complexity of factors and the lack of general applicability such an analysis would have.

Background

Numerous approaches exist for determining the volume of runoff to be treated through stormwater management. Retaining stormwater runoff from all events up to and including the 95th percentile rainfall event was identified as Option 1 because small, frequently occurring storms account for a large proportion of the annual precipitation volume. Using GI/LID practices to retain both the runoff produced by small storms and the first part of larger storms can reduce the cumulative impacts of altered flow regimes on receiving water hydrology, e.g., channel degradation and diminished baseflow. For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the predevelopment hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites.

Determination of the 95th Percentile Rainfall Event

The 95th percentile rainfall event was determined using the long-term daily precipitation records from the National Climatic Data Center (NCDC 2007). By analyzing the frequency and rainfall depths from daily rainfall records over 24-hour periods, the 95th percentile storm event can be determined. From a frequency analysis viewpoint, the 95th percentile event is the storm event that is greater than or equal to 95 percent of all storms that occur within a given period. Regional climate conditions and precipitation vary across the United States. Because of local values, it is essential that the implementing agency or department establish the 95th percentile storm event for the project site because the control volume could vary depending on local weather patterns and conditions.

On-site Stormwater Management Practice Determinations

For the purposes of the case study scenarios, the following four categories of practices were selected as the most appropriate practices for implementing section 438 requirements: bioretention, permeable pavements and pavers, cisterns, and green roofs. Those practices were selected on the basis of known performance data and cost. For each case study, the same hierarchy of selection criteria was used, i.e., the most cost-effective practices were considered before other practices were considered. Bioretention practices were considered first because those systems generally have the lowest cost per unit of stormwater treated (Hathaway and Hunt 2007). Thus, if the bioretention system could not be designed to adequately capture the desired runoff volume, permeable pavement and pavers, cisterns, and green roofs were considered in that order according to relative cost. In most cases, a combination of practices was selected as part of an integrated treatment system. It should be noted that all treatment systems were designed to accomplish the goal of capturing the 95th percentile rainfall event on-site. Examples of on-site stormwater management practices selected for each site are presented in the results section. For the Boston, Massachusetts, site, it was assumed that bioretention was not feasible to simulate a situation where space was severely limited; as a result, interlocking modular pavers were selected as the most cost-effective stormwater management to capture the requisite design volume. To further illustrate the range of site conditions designers might encounter and how site conditions affect the selection of appropriate control options, Scenario #3 (Cincinnati, Ohio) was re-analyzed as Scenario #8. In Scenario #8, it was assumed that the site had clay soils and low infiltrative capacity. Given those site conditions, the range of potential control options was more limited and a combination of modular paving blocks, a green roof, and cisterns was ultimately selected because of cost and site suitability factors.

For purposes of these modeling exercises, a number of assumptions were associated with each category of practice. The assumptions are not necessarily an endorsement of a particular design paradigm, but rather were used to keep a somewhat conservative cap on the scenarios to demonstrate the feasibility of the approach. For example, bioretention retrofits can and should often be located in prior impervious locations; however, in all modeled scenarios bioretention was restricted to currently landscaped areas. The assumptions are as follows:

- **Bioretention areas**: On-lot retention of stormwater through the use of vegetation, soils, and microbes to capture, treat and infiltrate runoff.

  It is assumed bioretention practices would be installed within landscaped pervious areas or that pervious areas would be created for bioretention cells. While termed bioretention, these systems are designed to provide infiltration and temporary storage. Bioretention areas would be designed to accept up to a depth of 10 inches of water across the surface of the bioretention cell (see Resources at end of this Appendix). The conceptual design of this storage depth would occur within the media and/or could be included as ponded storage. Further design storage beyond the 10 inches would be acceptable (and encouraged) above the media on a site-by-site basis with ponded depth generally not to exceed 12 inches.

  Uniform infiltration was assumed across the entire base of the bioretention cell. No additional media underneath the amended soils were included in the designs with infiltration rates in this layer governed by the in situ soils. Underdrains were not modeled directly but could be applied at the point of storage overflow such that no overflow occurs until the design depth of 10 inches is saturated. This approach was selected to maximize the storage and infiltration benefits of these systems. Designs using underdrains at the base of the bioretention cell do not store the requisite volumes because the media is permeable and the underdrain conveys the runoff off-site through the underdrain before it can be infiltrated. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95^{th} percentile event volume.

  The bioretention footprint for modeling purposes was calculated as one uniform area that did not include side slopes. There is an expectation that actual bioretention cell construction would be distributed throughout the site with targeted locations based on hydrology (natural flow paths) and soils with greater infiltrative capacity. Side slopes can increase the surface excavation area required to accommodate the footprint and freeboard of these systems depending on the design or the bioretention system.

- **Porous/permeable pavement**: Transportation surfaces constructed of asphalt, concrete or permeable pavers that are designed to infiltrate runoff.

  Infiltration was modeled for the entire porous pavement area with drainage pipes used only as overflow outlets. This design was chosen to maximize infiltration capabilities of the system. While many types of porous pavement systems can be used, modular block type pavers were generally applied in this design category under the assumption that they typically include sufficient volumetric storage in the media layer. [Note: Other types of porous pavement applications are available that support heavy loads and can be designed to temporarily store and infiltrate runoff beneath the surface of the pavement.]

For these systems, an equivalent of 2 inches of design storage depth was assumed. This design depth could be achieved by specifying 10 inches of media depth that had 20 percent void space. Similarly, this could be achieved by designing 6 inches of media depth above the bottom surface, with specified media containing 33 percent void space. This alternative would have the overflow outlet at the 6-inch depth providing an equivalent water storage depth of 2 inches.

The soils under the paver blocks could require or be subjected to some compaction for engineering stability. As a result, infiltration into underlying soils was modeled conservatively by applying the minimum infiltration rate for each soil type (see Resources at end of this Appendix).

Generally, porous pavement is not recommended for high traffic areas or loading bays Because of that, the scenarios assume that only a percentage of total parking and road areas on a site can be converted to porous pavement. The assumed maximum percentage applied in the scenarios was set at 60 percent of the total paved area. Guidance on porous pavements is at: http://cfpub.epa.gov/npdes/greeninfrastructure/technology.cfm#permpavements

- **Cistern**: Containers or vessels that are used to store runoff for future use.

  Cisterns were modeled in cases where green roofs were not feasible or where it was necessary to include additional storage volume to meet the goal of on-site rainfall runoff capture. The sizes of cisterns would be calculated on the basis of site-specific rainfall, site-specific spatial and structural conditions, use opportunities and rates, and consideration of cost per volume of storage. For simplicity, cistern volume was reported as a total volume. This total volume could be subdivided into any number of cisterns to provide the total necessary storage but should be based on the impervious area and runoff quantities which will flow to the cistern. The most efficient cost per volume storage would need to be considered on a site-by-site basis (see Resources at end of this Appendix).

- **Green roof**: Roof designed with lightweight soil media and planted with vegetation.

  Frequently, green rooftop area is limited by structural capacity. In addition, other rooftop equipment might need to be accommodated in this space including HVAC systems and air handlers. For that reason, and to provide a somewhat conservative rate of application, it was assumed for these modeling analyses that up to 30 percent of a roof's impervious area could be converted into a green roof. Green roof area was assumed to have one inch of total effective stormwater storage, i.e., a 2.5-inch media depth with 40 percent void space (see the Resources at end of this Appendix).

General Approach

Using site aerial photos, spatial analysis should be conducted to estimate the land cover types and areas for each site. The surface conditions of each site can be digitized using geographic information systems (GIS) techniques. Alternatively, computer-aided design (CAD) drawings can be used to estimate the surface area of each land cover type. The schematic in Figure 3A3-1 illustrates the processes used for selecting and determining the overall size of stormwater management practices for each site.

The following steps provide more detailed information on acquiring and calculating the necessary data to complete the processes indicated in Figure 3A3-1. This methodology was used in the scenario analyses that follow.

Collecting spatial data for a site

1. Collect an aerial orthophotograph for the desired site.
2. Digitize land use/land cover conditions using GIS techniques. If CAD drawings of the site exist, they can be used to estimate land cover area (pervious, impervious).
3. Categorize the digitized or planned land use/land cover according to surface hydrologic conditions, e.g., rooftop, pavement, and pervious/landscaped area.
4. Estimate the size of each land use/land cover category (by polygon).

Determining the 95th percentile, 24-hour rainfall event

1. Obtain a long-term, 24-hour precipitation data set for the location of interest (i.e., from the NCDC Web site or other source).
2. Import the data into a spreadsheet. In MS Excel [Data / Import External Data / Import Data]
3. Rearrange all the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.
4. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.
5. Remove small rainfall events (typically less than 0.1 inch) that might not contribute to rainfall runoff. These small storms often produce little if any appreciable runoff from most sites and for modeling purposes are typically considered as volume captured in surface depression storage.

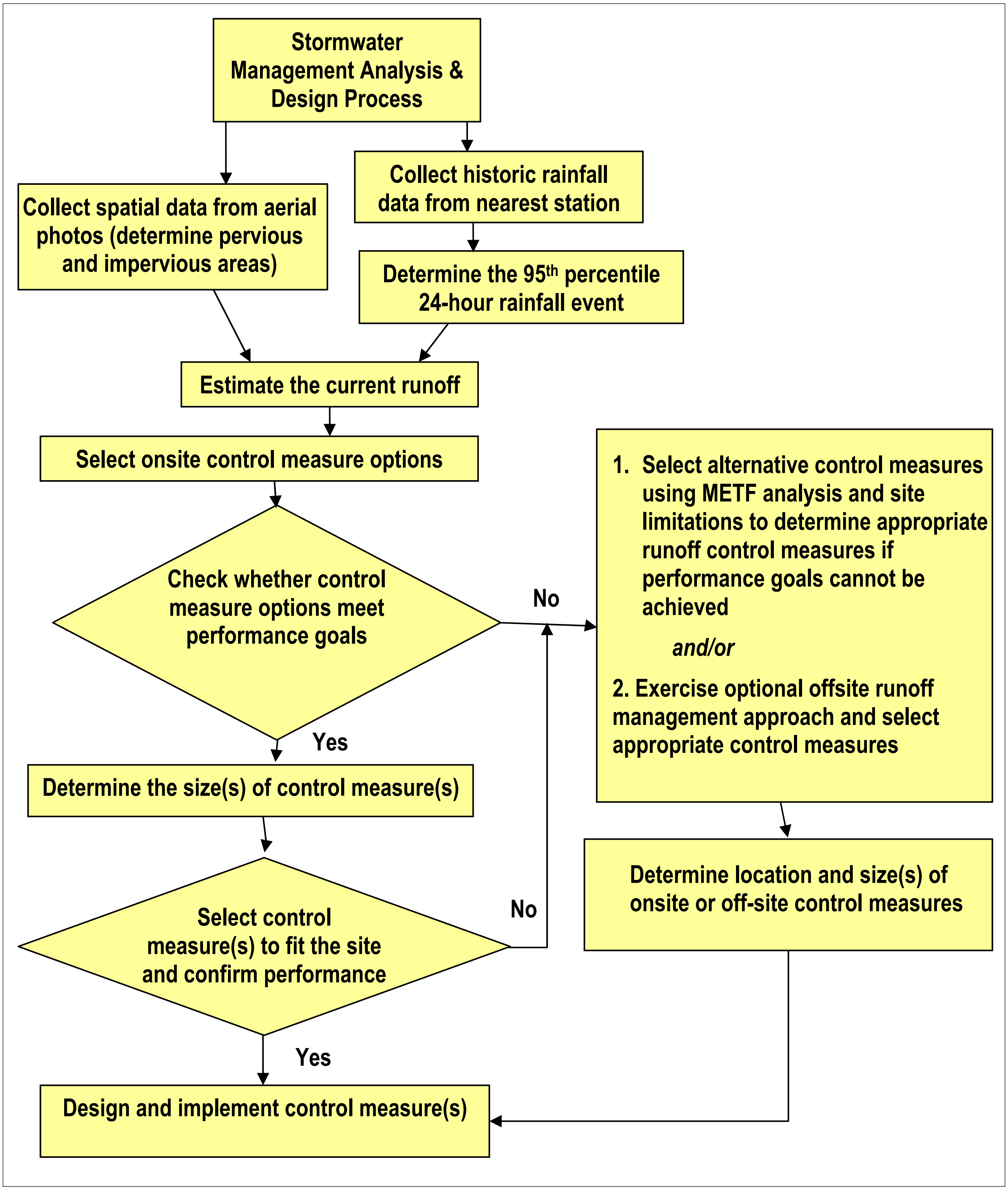


Figure 3A3-1. Flow chart depicting the process for determining control measures using the 95th percentile, 24-hour annual rainfall event.

6. Calculate the 95th percentile rainfall volume by applying the PERCENTILE spreadsheet function to a range of data cells. The PERCENTILE function returns the nth percentile value in the specified precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5 percent of storms. In MS Excel [PERCENTILE(precipitation data range, 95%)]

Estimating current runoff and placing on-site control measures to capture the 95th percentile rainfall event

1. Collect spatial data for a site, e.g., rooftop, pavement, and pervious areas as above.

2. Check soil type (USDA mapping, borings, or on-site testing) for the site to determine infiltration parameters. For this modeling, many of the assumptions that pertain to generalized soils groups and their infiltration properties come from the EPA Stormwater Management Model (SWMM 4.x) manual (see Resources at end of this Appendix).

3. Determine the current runoff volume that would occur during a 24-hour period by applying the 95th percentile rainfall to the existing site conditions (land use and soil properties) as above using a hydrologic model (such as TR-55 or SWMM). For this analysis, it is assumed that the rainfall amount is distributed over a 24-hour period. Actual rainfall event duration (and intensity) was not considered for determining rainfall runoff (however, timing was considered when modeling infiltration).

4. Determine flow paths so that management practice placements are in locations where flows can be intercepted and routed to practices. Because this is a site-specific effort and might require detailed topographic information or further surveys, this would be a task to be completed on-site and therefore is not included as a part of the modeling scenario exercise.

5. Select on-site control practices to capture the current 95th percentile runoff event; base the selection of appropriate options on site conditions, areas available for treatment options, and other factors such as site use and other constraints.

Note: The steps above have been generalized for the purposes of this guidance. It is recommended that a qualified professional engineer determine or verify that stormwater management practices are sized, placed, and designed correctly. Note also that the methodology to determine rainfall amount used a 24-hour period from daily records. Actual rainfall events might have occurred over shorter or longer periods. Similarly, for modeling purposes, the 24-hour rainfall amount was distributed to pervious and impervious areas (and management practices) as a uniform event occurring during a 24-hour period. A large data set (greater than 50 years) was used to reasonably represent rainfall depth on a daily basis. It stands to reason that more frequent, shorter duration precipitation events are better represented than less frequent, longer duration precipitation events.

Scenarios

Eight locations were selected for the 9 case studies as shown in Figure 3A3-2 and Table 3A3-1. Case study numbers 3 and 8 were both developed using the Cincinnati, Ohio, facility; although the site parameters were altered to represent differing site conditions and design constraints. Annual average rainfall depths for those locations range from 7.5 inches to 48.9 inches. Analyses of the 95th percentile rainfall events for the locations produced rainfall depths that range from 1.00 inch to 1.77 inches (Table 3A3-1).

Figure 3A3-2. Locations for analyzing on-site control measures.

The government facilities in the 8 case study locations were selected because they represent generic sites from the major climatic regions of the United States. The facilities also were selected because the sites have a range of site characteristics that can be used to illustrate different site designs and stormwater management options, e.g., pervious, roof, and pavement areas (Table 3A3-2). Site sizes range from 0.7 to 27 acres, with percent site imperviousness area ranging from 47 to 95 percent of the site. Aerial photos of the sites are included along with site-specific rainfall runoff and soil results.

Table 3A3-1. Summary of rainfall data for the seven locations

No	Location	NCDC daily precipitation data		Rainfall depth (inches)	
		Period of record	Coverage	Annual average	95th percentile rainfall event
1	Charleston, WV	1/1/1948–12/31/2006 (59 yrs)	99%	43.0	1.23
2	Denver, CO	1/1/1948–12/31/2006 (59 yrs)	96%	15.2	1.07
3	Cincinnati, OH	1/1/1948–12/31/2006 (59 yrs)	96%	36.5	1.45
4	Portland, OR	1/1/1941–12/31/2006 (66 yrs)	98%	35.8	1.00
5	Phoenix, AZ	1/1/1948–12/31/2006 (59 yrs)	99%	7.5	1.00
6	Boston, MA	1/1/1920–12/31/2006 (87 yrs)	99%	41.9	1.52
7	Atlanta, GA	1/1/1930–12/31/2006 (77 yrs)	100%	48.9	1.77
8	Norfolk, VA	1/1/1957–12/31/2006 (50 yrs)	99%	45.4	1.68

The results of the spatial analyses were summarized and divided into three land cover categories; rooftop, pavement, and pervious area, as shown in Table 3A3-2.

Table 3A3-2. Summary of land-use determinations of the study sites

No	Location	Facility spatial info (acres)				Site imperviousness
		Rooftop	Pavement	Pervious	Total	
1	Charleston, WV	0.1	0.4	0.2	0.7	73%
2	Denver, CO	0.5	1.9	2.0	4.5	55%
3	Cincinnati, OH	1.6	8.0	9.4	19	51%
4	Portland, OR	8.8	16.9	1.3	27	95%
5	Phoenix, AZ	0.2	0.7	1.1	2	47%
6	Boston, MA	0.9	1.5	1.1	3.5	69%
7	Atlanta, GA	3.9	10.8	6.2	21	70%
8	Norfolk, VA	0.9	0.55	0.15	1.6	91%

Methods for Determining Runoff Volume

Direct Determination of Runoff Volume

Runoff from each land cover was estimated using a simplified volumetric approach using the following equation:

Runoff = Rainfall – Depression Storage – Infiltration Loss

Again, this methodology does not consider routing of runoff; therefore, slope is not considered when calculating on a volumetric basis.

Infiltration loss is calculated only in pervious areas (e.g., there is no infiltration in impervious areas). In this analysis, infiltration was estimated using Horton's equation:

$$Ft = f_{min} + (f_{max} - f_{min})\ e - k\ t$$

where

Ft = infiltration rate at time t (in/hr)
f_{min} = minimum or saturated infiltration rate (in/hr)
f_{max} = maximum or initial infiltration rate (in/hr)
k = infiltration rate decay factor (/hr) and
t = time (hr) measured from time runoff first discharged into infiltration area

Infiltration loss for the 24-hour rainfall duration was estimated by the following equation with assumptions of a half hour Δt and uniform rainfall distribution in time:

$$Infiltration\ Loss = \sum (f \cdot \Delta t)$$

To more accurately describe the dynamic process of infiltration associated with Horton's equation, infiltration loss was integrated over a 24-hour period using a half hour time step while applying the maximum and minimum infiltration rates (in/hr) with time using the appropriate soil decay factor. The results of this process are further illustrated in the Resources section at the end of this Appendix.

Once runoff from each land cover was estimated, the total runoff from a site can be obtained using an area-weighted calculation as shown below:

$$Runoff_{site} = \{(Runoff_{roof} \times A_{roof}) + (Runoff_{pavement} \times A_{pavement}) + (Runoff_{pervious} \times A_{pervious})\} / A_{site}$$

Where $Runoff_{site}$ = total runoff from the site (inches); A_{site} = site area (acres); $Runoff_{roof}$ = runoff from rooftop (inches); A_{roof} = rooftop area (acres); $Runoff_{pavement}$ = runoff from pavement area (inches); $A_{pavement}$ = pavement area (acres); $Runoff_{pervious}$ = runoff from pervious area (inches); and $A_{pervious}$ = pervious area (acres).

An example demonstrating how to calculate runoff by applying the Direct Determination method is presented below using the Charleston, WV (Scenario #1) site condition presented in Tables 3A3-1 and 3A3-2.

$Runoff_{roof}$ = *95th Rainfall – Depression Storage*
= 1.23 – 0.1 = 1.13 inches
$Runoff_{pavement}$ = *95th Rainfall – Depression Storage*
= 1.23 – 0.1 = 1.13 inches
$Runoff_{pervious}$ = *95th Rainfall – Depression Storage – Infiltration Loss*
= 1.23 – 0.1 – 9.73 = 0 inches (i.e., no runoff because the result is a negative number)

$$Runoff_{site} = \{(Runoff_{roof} \times A_{roof}) + (Runoff_{pavement} \times A_{pavement}) + (Runoff_{pervious} \times A_{pervious})\} / A_{site}$$
$$= \{(1.13 \times 0.10) + (1.13 \times 0.41) + (0 \times 0.19)\} / 0.7 = 0.82 \text{ inches}$$

Infiltration loss was estimated on the basis of soil type B by applying the Horton equation as described above. Because the volume removed from surface runoff through infiltration was substantial, no runoff occurred from the pervious area.

In cases where sites had limited physical space available for stormwater management, a series of practices was used (e.g., treatment train) to simulate the runoff and infiltrative behavior of the system. For example, if there was inadequate area and infiltrative capacity to infiltrate 100 percent of the 95th percentile storm event within a bioretention system, another on-site management practice was selected to manage the runoff that could provide the necessary capacity. In such a manner, excess runoff was routed to another management practice in the series of treatment cells where possible.

Two types of soils were considered for every site: hydrologic soil groups B and C (except for scenario 8 in which hydrologic soil group D was used). Group B soils typically have between 10 and 20 percent clay and 50 to 90 percent sand and either loamy sand or sandy loam textures with some loam, silt loam, silt, or sandy clay loam soil textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. Group C soils typically have between 20 and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam soil textures with some clay, silty clay, or sandy clay textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (USDA-NRCS 2007). The application of these hydrologic soil groups was intended to give reasonable and somewhat conservative estimates of infiltration capacity.

General hydrologic parameters in this analysis were assumed as follows (see Resources at the end of this Appendix for citations of assumptions):

- Depression storage (or initial abstraction)
  - Rooftop: 0.1 inches
  - Pavement: 0.1 inches

- Pervious area: 0.2 inches

- Horton Infiltration parameters
  - Hydrologic Soil Group B
  - Maximum infiltration rate: 5 in/hr
  - Minimum infiltration rate: 0.3 in/hr
  - Decay factor: 2 /hr
  - Hydrologic Soil Group C
  - Maximum infiltration rate: 3 in/hr
  - Minimum infiltration rate: 0.1 in/hr
  - Decay factor: 3.5 /hr

- Design storage assumptions of control measures
  - Bioretention: up to 10 inches (but variable based on balancing necessary storage volume, media depth for plant survivorship, and surface area limitations)
  - Green roof: 1 inch (2.5 inches deep media with 40 percent void space)
  - Porous pavement: 4 inches (10 inches deep media with 40 percent void space)

Other Methods for Estimating Runoff Volume

Runoff from a site after applying the 95th percentile storm can be estimated by using a number of empirical, statistical, or mathematical methods. Several methods were considered in this analysis. The Rational Method can be used to estimate peak discharge rates and the Modified Rational Method can be used to develop a runoff hydrograph. The NRCS TR-55 model can be used to predict runoff volume and peak discharge. TR-55 can also be used to develop a runoff hydrograph. The EPA Stormwater Management Model (SWMM) can be used to simulate rainfall-runoff, pollutant buildup and wash-off, transport-storage-treatment of stormwater flow and pollutants, backwater effects, and such for a wide range of temporal and spatial scales. The SWMM model can be fit to model a small site with a distributed system. Hydrologic Simulation Program – Fortran (HSPF, USDA) is a watershed and land use based lumped model that can be used to compute the movement of water and pollutants when evaluating the effects of land use change, reservoir operations, water quality control options, flow diversions, and such. In general, regionally calibrated modeling parameters are incorporated into HSPF. QUALHYMO is a complete hydrologic and water quality model that can be used to factor in snowmelt or soil moisture conditions or to simulate system behavior on the basis of infiltration and ET, groundwater storage tracking, baseflow and deep volumetric losses, and other variables.

Many of the existing tools for analyzing distributed systems use some part or all of the principles or formulae of the modeling approaches highlighted above. For example, the Emoryville spreadsheet control measure model (Emoryville, California) uses a runoff coefficient (i.e., Rational Method) for analyzing lot-level to neighborhood-scale control measure sizing. The Green Calculator (Center for Neighborhood Technologies) estimates the benefit of on-site GI/LID options on a neighborhood-scale by applying the curve numbers (i.e., TR-55) and the Modified Rational Method. The Northern Kentucky Spreadsheet Tool uses a TR-55-based approach for control measure sizing on neighborhood or site level spatial scales. The WWHM (Western Washington Hydrology Model) is a regionally calibrated HSPF model intended for use in sizing stormwater detention and water quality facilities to meet the Washington State Department of Ecology standards. WBM-QUALHYMO is a Canadian model used in conjunction with the Water Balance Model (WBM). This model can be used to continuously simulate stormwater storage routing, stream erosion, drainage area flow routing, and snowmelt runoff (and ultimately freeze-thaw). Table 3A3-3 contains a summary of these different methods based on generic modeling features.

Table 3A3-3. Potential methods for analyzing control measures

Model considerations		Rational method	TR-55	SWMM	Direct determination	HSPF	QUALHYMO
Temporal scale	Single Event	Yes	Yes	Yes	Yes	Yes	Yes
	Continuous Simulation	No	No	Yes	Possible	Yes	Yes
Spatial scale	Lot-level	Yes	Yes[b]	Yes	Yes	No	No
	Neighborhood	Yes	Yes	Yes	Yes	Possible	Possible
	Regional	Yes	Yes[c]	Yes	No	Yes	Yes
Outputs	Peak Discharge	Yes	Yes	Yes	No	Yes	Yes
	Runoff Volume	Yes	Yes	Yes	Yes	Yes	Yes
	Hydrograph	Yes[a]	Yes	Yes	No	Yes	Yes
	Water Quality	No	No	Yes	Possible	Yes	Yes

[a] Modified Rational Method

[b] No less than 1 acre.

[c] No more than 25 square miles (up to 10 subareas).

From the viewpoint of modeling both lot-level and neighborhood scale projects, the Rational Method, NRCS TR-55, SWMM, and Direct Determination approaches were selected for use in scenario analyses. The strengths and weaknesses of the methods are presented in Table 3A3-4.

Table 3A3-4. Comparison of approaches for determining runoff volume

Method	Strengths	Weaknesses
Direct determination	• Methodology for runoff determination is same as SWMM • Models basic hydrologic processes directly (explicit) • Simple spreadsheet can be used	• Direct application of Horton's method can estimate higher infiltration loss, especially at the beginning of a storm • Does not consider flow routing
Rational method	• Method is widely used • Simple to use and understand	• Cannot directly model storage-oriented on-site control measures
TR-55	• Method is widely used • Simple to use and understand	• Might not be appropriate for estimating runoff from small storm events because depression storage is not well accounted for
SWMM	• Method is widely used • Can provide complete hydrologic and water quality process dynamics in stormwater analysis	• Needs a number of site-specific modeling parameters • Generally requires more extensive experience and modeling skills

Each method requires specific parameters for estimating runoff from a site. Runoff coefficients for the Rational Method are assumed to be 0.9 for rooftop and pavement areas, and 0.1 and 0.135 for Group B and C soil pervious areas, respectively (Caltrans 2003). The slope of the pervious area was assumed to be an average of 2 percent. Applying those runoff coefficients for each surface, the overall area-weighted runoff coefficient can be determined.

When applying the NRCS TR-55 method, Curve Numbers (CNs) should be determined for each drainage area. For rooftop and pavement areas the CN was assumed to be 98, and pervious area CN was determined on the basis of the hydrologic soil group and the status of grass cover condition. Curve numbers for pervious areas were assumed to be 61 and 74 for Group B and C soils, respectively, with an assumption of over 75 percent grass cover. The overall CN can be estimated by using an area-weighted calculation (USDA-SCS 1986).

In SWMM modeling, infiltration was modeled using Horton's equation. The same infiltration parameters and depression storage values used in the direct determination method of runoff treatment volume described earlier were applied to the SWMM analyses. The average slope of the pervious area was again assumed to be 2 percent. The same uniform rainfall distribution and time step was applied for the SWMM model runs.

Runoff Methodology Results

Stormwater management practice sizes (and depth) were determined using the Direct Determination approach to capture the volume of runoff generated in a 95th percentile rainfall event at each location. Total acreage, impervious area, the 95th percentile rainfall event, the current expected runoff for the 95th percentile rainfall event, and the future runoff with stormwater management controls were reported for each site. Results were summarized for the two soil types (three soil types for Scenarios #3 and #8 in Cincinnati). The spatial location of on-site control measures was also illustrated in the site aerial photo figures. Note that site practices were placed only on undeveloped or landscaped areas without regard for true flow paths or technical feasibility. It might be preferrable to place practices in existing impervious areas, if possible. For the purposes of this modeling exercise, the least cost and most practical solutions were used, i.e., locating bioretention systems on undeveloped or landscaped areas. On an actual site, flow paths would be determined and berms and swales might be used to route runoff to areas that are most suitable for infiltration. In other cases, areas that are impervious could be modified to accept runoff, e.g., impermeable pavements removed and replaced by permeable, sidewalks could be redesigned to include sidewalk bioretention cells, and streets could be designed with flow through or infiltration curb bumpouts/raingardens.

To compare other approaches of runoff estimation, alternate methodologies were also employed for three scenarios. TR-55 was used for Scenario #1 (Atlanta), the Rational Method was applied to Scenario #2 (Denver), and the SWMM was run for Scenario #7 (Charleston).

Although flood control is not the focus of this guidance, most localities have flood control requirements that will need to be considered in designing control measures to comply with section 438. For flood control purposes, TR-55 was used to model the 10-year frequency design storm for each site under the assumption that all stormwater management practices were in place. The 10-year design storms were selected from the NRCS TR-55 Manual (USDA 1986) for both the Eastern U.S. and the Western U.S. Precipitation Frequency Maps (www.wrcc.dri.edu/pcpnfreq.html). The 10-year frequency design storm was selected because it represents a common design standard used by state and local governments to manage peak rates of runoff and prevent flooding.

Cost Estimates for Selected Scenarios

Scenario numbers 2 and 7 include cost estimates comparing the capital costs for a design to comply with section 438 (retention of the 95th percentile rainfall event) and capital costs for a traditional stormwater management design (e.g., typical curb and gutter, off-site pond for stormwater management). These costs are based on average unit costs to construct both traditional and GI/LID controls.

Scenario #1 – Charleston, West Virginia

A 0.7-acre site with 73 percent impervious area was selected from Charleston, West Virginia (Figure 3A3-3). If the 95th percentile rainfall event (1.23 inches) occurred on the existing site (i.e., with no control measures), 0.82 inch of runoff using the Direct Determination method would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.03 acre if hydrologic soil group B is present, or 0.06 acre if hydrologic soil group C (Table 3A3-5) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 0.2 acre of pervious area would be available for placing bioretention systems. The effective design storage depth within the designated bioretention area was 8 inches.

Figure 3A3-3. Actual site and on-site control measures (Charleston, WV).

Table 3A3-5. Estimated sizes of on-site control measures for Scenario #1 (Charleston, WV)

Total Area (acres)		0.7	
Estimated Imperviousness (%)		73%	
95th Percentile Rainfall Event (inches)		1.23	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.82	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by Direct Determination method (acres)		0.03	0.06
Bioretention estimated by SWMM (acres)		0.03	0.05
Off-site storage necessary to control the 10-yr event of 3.9 inches (acre-ft)	With on-site controls	0.10	0.12
	Without on-site controls	0.16	0.17

Note: The two hydrologic methods used (direct determination and SWMM) estimated similar bioretention sizes.

Scenario #2 – Denver, Colorado

A 4.5-acre site with 55 percent impervious area was selected from Denver, Colorado (Figure 3A3-4). If the 95th percentile rainfall event (1.07 inches) occurred on the existing site (i.e., with no control measures), 0.53 inch of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.16 acre if the hydrologic soil group B is present or 0.3 acre if hydrologic soil group C (Table 3A3-6) is the predominant soil type on the site. Assuming that bioretention practices are placed only in areas that are currently pervious or landscaped, a total of 2 acres of pervious area is available for placing bioretention systems. The design storage depth of media within the designated bioretention area was 6 inches.

Figure 3A3-4. Actual site and on-site control measures (Denver, CO).

Table 3A3-6. Estimated sizes of on-site control measures for Scenario #2 (Denver, CO)

Total Area (acres)		4.5	
Estimated Imperviousness (%)		55%	
95th Percentile Rainfall Event (inches)		1.07	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.53	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination method (acres)		0.16	0.3
Bioretention estimated by Rational Method (acres)		0.16	0.28
Off-site storage necessary to control the 10-yr event of 3.2 inches (acre-ft)	With on-site controls	0.35	0.52
	Without on-site controls	0.64	0.64

Cost estimates were also developed for this scenario (Table 3A3-7) to compare the costs of installing on-site control measures to retain the 95th percentile rainfall event versus the costs to install traditional stormwater management controls (e.g., curbs and gutters combined with off-site retention such as extended detention wet ponds). In a GI/LID scenario, the bioretention cell would occupy a specified area. This same area in a traditional design would be covered in turf because the pond would typically be off-site and not occupy the area planted in turf. Table 3A3-7 includes this cost under the traditional column. Note: typical land development practices involve mass clearing and grading so little or no preexisting vegetation is typically retained. It is also assumed that the use of GI/LID practices would require less underground infrastructure because the traditional design typically routes stormwater underground to an off-site pond via pipes or culverts while GI/LID practices are designed to manage runoff on-site and as close to its source as possible. They are also dispersed across the site and routing occurs through surface drainage via bioswales and overland flow. As a result GI/LID practices do not require as much or any hard or grey infrastructure. The cost estimates were developed for Hydrologic Soil Group B.

Table 3A3-7. Estimated costs for Scenario #2 (Denver, CO)

Sizes of on-site control practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.07	
Bioretention (acres)		0.1	
Paver blocks (acres)		0	
Green roof (acres)		0	
Off-site Pond	WQV (ac-ft)	--	0.18
	10-Yr Fld Cntr (ac-ft)	0.15	0.14
Total Off-Site Requirement (ac-ft)		0.15	0.32
Land Area (assumes avg 3 ft depth)		0.05	0.11
% of the site		2.8%	
Costs of on-site control practices			
Biorention/alternative		$32,495	$4,187
Off-site Pond	WQV (ac-ft)		$14,833
	10-Yr Fld Cntr (ac-ft)	$10,073	$9,527
Infrastructure	Pipe	$8,990	$16,982
	Inlet	$9,920	$14,880
Land Area (assumes $300K/acre)		$14,500	$31,500
Sum		**$75,978**	**$91,909**
% difference from Traditional		**-17.3%**	

Scenario #3 – Cincinnati, Ohio

A 19-acre site with 51 percent impervious area was selected in Cincinnati, Ohio (Figure 3A3-5). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., no control measures were in place), 0.68 inch of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.8 acre if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 3A3-8) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Figure 3A3-5. Actual site and on-site control measures (Cincinnati, OH).

Table 3A3-8. Estimated sizes of on-site control measures for Scenario #3 (Cincinnati, OH)

Total Area (acres)		19	
Estimated Imperviousness (%)		51%	
95th Percentile Rainfall Event (inches)		1.45	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.68	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.8	1.3
Off-site storage necessary to control the 10-yr event of 4.2 inches (acre-ft)	With on-site controls	2.42	3.24
	Without on-site controls	3.29	3.73

Scenario #4 – Portland, Oregon

A 27-acre site with 95 percent impervious area was selected in Portland, Oregon (Figure 3A3-6). If the 95th percentile rainfall event (1.0 inch) occurred on the existing site (i.e., no control measures), 0.86 inch of runoff would be generated and require management. The site has the greatest imperviousness among the seven sites.

Given the site conditions, there is not enough pervious area to manage the entire runoff volume discharged by the 95th percentile rainfall event with bioretention. As a result, other practices were evaluated and selected. The practices integrated into the design included a green roof, cisterns, and porous pavement. On the basis of the technical considerations of constructing and maintaining control measures at the site, it was assumed that approximately 30 percent of the available pervious area could be converted into bioretention cells; 20 percent of total rooftop area could be converted into green roofs; 40 percent of paved area could be converted into paver blocks; and 50,000 gallons of total volume could be captured in cisterns for use on this urbanized site. Using this system of four different practices, all runoff for the 95th percentile rainfall event would be retained (Table 3A3-9).

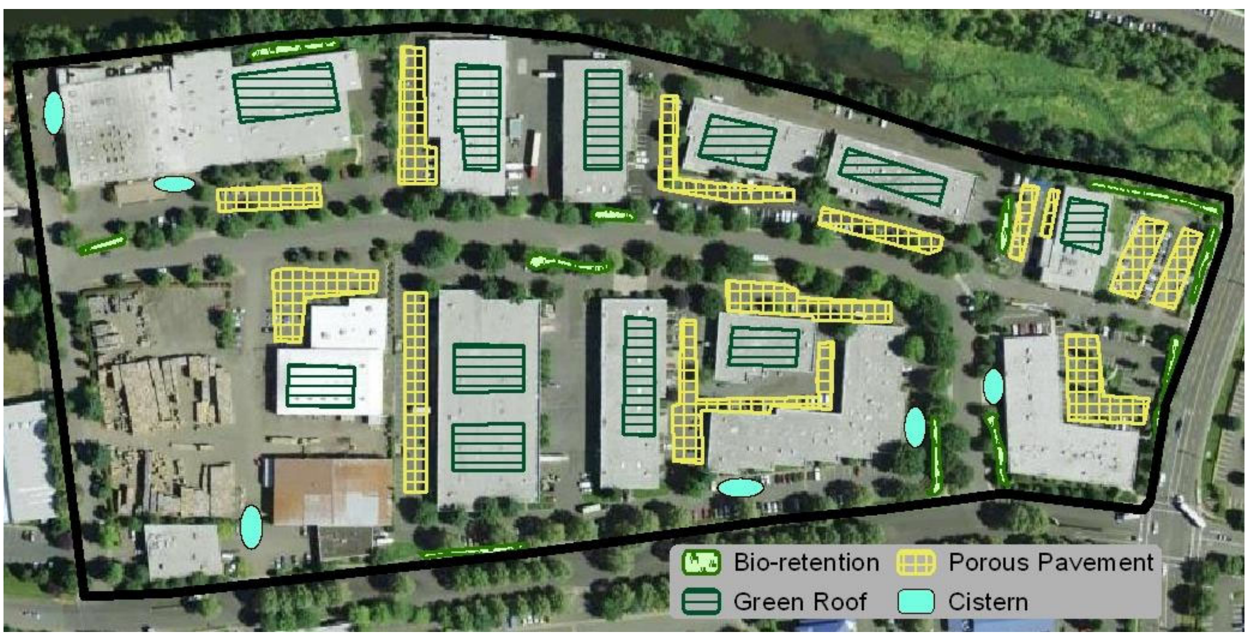


Figure 3A3-6. Actual site and onsite control measures (Portland, OR).

Table 3A3-9. Estimated sizes of on-site control measures for Scenario #4 (Portland, OR)

Total Area (acres)		27	
Estimated Imperviousness (%)		95%	
95th percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.86	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		1.4	3.5*
Bioretention estimated by Direct Determination (acres)		0.4	
Green Roof estimated by Direct Determination (acres)		1.7	
Cistern volume estimated by Direct Determination (gallons)		50,000	
Off-site storage necessary to control the 10-yr event of 3.7 inches (acre-ft)	With on-site controls	5.37	5.62
	Without on-site controls	7.70	7.71

*The size of porous pavement area was increased because the other control options were maximized based on the site-specific design assumptions.

A total of 1.3 acres of the site is pervious area or landscaped of which, 0.4 acres (30 percent of the pervious area) could be converted to bioretention cells that have a storage depth of 10 inches. Of the 8.8 acres of current rooftop area, 1.7 acres (20 percent of the rooftop area) could be retrofitted into green roof areas. Of the 16.9 acres of paved area, 1.4 acres (8 percent of the paved area) for hydrologic soil group B, or 3.5 acres (20 percent of the paved area) for hydrologic soil group C, of paver block systems could be implemented. One or more cisterns (as indicated in Figure 3A3-6) could be used to capture up to 50,000 gallons of runoff from rooftop areas. Note: The high percentage of imperviousness of the site (95 percent) requires that all infiltration designs be based on resident soil type and design volumes, or with adequate sub-bases or amended soils.

Scenario #5 – Near Phoenix, Arizona

A 2-acre site with 47 percent impervious area was selected near Phoenix, Arizona (Figure 3A3-7). If the 95th percentile rainfall event (1.0 inch) occurred on the existing site (i.e., with no control measures), 0.42 inch of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.06 acre if the hydrologic soil group B is present or 0.1 acre if hydrologic soil group C (Table 3A3-10) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 1.1 acres of pervious area is available for the placement of these practices. The design storage depth of media within the designated bioretention area was 6 inches. Note: If the design storage depth were increased to 10 inches, the off-site storage necessary for the 10-year event could be reduced to 0.03 acre-ft for type B soils and 0.08 acre-ft for type C soils.

Figure 3A3-7. Actual site and on-site control measures (Phoenix, AZ).

Table 3A3-10. Estimated sizes of on-site control measures for Scenario #5 (Phoenix, AZ)

Total Area (acres)		2	
Estimated Imperviousness (%)		47%	
95th Percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.42	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.06	0.1
Off-site storage necessary to control the 10-yr event of 2.4 inches (acre-ft)	With on-site controls	0.05	0.12
	Without on-site controls	0.18	0.18

Scenario #6 – Boston, Massachusetts

A 3.5-acre site with 69 percent impervious area was selected in Boston, Massachusetts (Figure 3A3-8). If the 95th percentile rainfall event (1.52 inches) occurred on the existing site (i.e., with no control measures), 0.98 inch of runoff would be generated and require management. Given these site characteristics, there is adequate area to place appropriately sized bioretention cells to capture the 95th percentile storm event. However, for the purposes of this analysis, unspecified conditions preclude the use of bioretention. As a result, a paver block system was selected as the best on-site control measure, and the system was designed such that the necessary design parameters could be achieved by storing some of the volume in the paver media and by infiltrating the remainder of the volume. The runoff from the 95th percentile rainfall event could be retained by installing a paver block area totaling 0.4 and 0.8 acre assuming soil types B and C, respectively (Table 3A3-11). For the purposes of this case study, a total of 1.5 acres of parking lot was made available to accommodate the paver block system. The area retrofitted with paver blocks would primarily be dedicated for use as parking stalls.

Figure 3A3-8. Actual site and on-site control measures (Boston, MA).

Table 3A3-11. Estimated sizes of on-site control measures for Scenario #6 (Boston, MA)

Total Area (acres)		3.5	
Estimated Imperviousness (%)		69%	
95th Percentile Rainfall Event (inches)		1.52	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.98	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		0.4	0.8
Off-site storage necessary to control 10-yr event of 4.5 inches (acre-ft)	With on-site controls	0.59	0.71
	Without on-site controls	0.89	0.96

Scenario #7 – Atlanta, Georgia

A 21-acre site with 70 percent impervious area was selected in Atlanta, Georgia (Figure 3A3-9). If the 95th percentile rainfall event (1.77 inches) occurred on the existing site (i.e., with no control measures), 1.17 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could not be adequately retained solely with bioretention systems. Because of the technical considerations of constructing and maintaining control measures at the site, it was assumed that up to 15 percent of the pervious area could be converted into bioretention cells, and up to 40 percent of paved area could be converted into a paver block system. If the stormwater management techniques used on the site include both bioretention and paver blocks as presented in Table 3A3-12, all runoff for the 95th percentile rainfall event would be controlled.

Figure 3A3-9. Actual site and on-site control measures (Atlanta, GA).

Table 3A3-12. Estimated sizes of on-site control measures for Scenario #7 (Atlanta, GA)

Total Area (acres)		21	
Estimated Imperviousness (%)		70%	
95th Percentile Rainfall Event (inches)		1.77	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		1.17	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
	Bioretention estimated by the Direct Determination (acres)	0.9	
	Paver block area estimated by the Direct Determination (acres)	0.9	3.2*
	Bioretention estimated by TR-55	0.8**	0.9
	Paver block area estimated by TR-55	0**	1.84
Off-site storage necessary to control 10-yr event of 6.0 inches (acre-ft)	With on-site controls	5.85	6.62
	Without on-site controls	7.25	8.49

*The size of porous pavement was increased because the bioretention already reached its maximum size based on the site-specific design assumptions.

**Because TR-55 estimated smaller runoff in this scenario, bioretention can retain all of the 95th percentile runoff if the site has soil group B.

For the example site in Atlanta, Georgia, areas of 1.8 acres for hydrologic soil group B, and 4.1 acres for hydrologic soil group C, would be required to manage the runoff discharged from a 95th percentile rainfall event. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 6.2 acres of pervious area is available for placing bioretention systems. The design storage depth of media within the designated bioretention area was 10 inches. Permeable pavement systems could be used to treat the remaining volume on the 10.8 acres of existing paved area.

In applying the TR-55 model, the overall curve numbers for the site were 87 and 91 for Group B and C soils, respectively. TR-55 was used to estimate 0.73 inch of runoff for soil group B and 0.97 inch for soil group C, which are smaller numbers than the 1.17 inches of runoff estimated by the Direct Determination method. As a result, the sizes of the on-site control measures designed using the TR-55 model were smaller than those designed using the Direct Determination method. Note: It is recommended that caution be exercised when using TR-55 to model storms less than 0.5 inch per event. See application of TR-55 in Table 3A3-4.

Cost estimates were also developed for this scenario (Table 3A3-13) to compare the costs to install on-site control measures to retain the 95th percentile rainfall event, and costs to install traditional stormwater management controls (e.g., primarily curb and gutter with off-site retention). The cost estimates were developed for Hydrologic Soil Group B.

Table 3A3-13. Estimated costs for Scenario #7 (Atlanta, GA)

Sizes of on-site control practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.77	
Bioretention (acres)		0.94	
Paver blocks (acres)		0.86	
Off-site Pond	WQV (ac-ft)	--	1.75
	10-Yr Fld Cntr (ac-ft)	0.84	0.0
Total Off-Site Requirement (ac-ft)		0.84	1.75
Land Area (assumes avg 3 ft depth)		0.28	0.58
% of the site		8.5%	
Costs of on-site control practices			
Biorention/alternative		$232,923	$30,617
Paver block/alternative		$236,878	$88,409
Off-site Pond	WQV (ac-ft)	$0	$72,888
	10-Yr Fld Cntr (ac-ft)	$39,648	$0
Infrastructure	Pipe	$54,827	$191,095
	Inlet	$52,080	$79,360
Land Area (assumes $300K/acre)		$84,000	$175,000
Sum		**$700,356**	**$637,368**
% difference from Traditional		**9.9%**	

Scenario #8 – Cincinnati, Ohio

A 19-acre site with 51 percent impervious area was selected in Cincinnati, Ohio (Figure 3A3-10). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., with no control measures), 0.68 inch of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.8 acre if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 3A3-8) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Scenario #8 represents an alternative to the Cincinnati, scenario in #3 (Figure 3A3-5). In this case, hydrologic soil group D was selected to represent the soil characteristics present for the entire site. Alternatively, simulations could have been run under the assumption that using infiltration practices were precluded by contaminated soils or high groundwater tables. Under those site conditions, bioretention options are severely limited and cannot be used to adequately capture the entire 95th percentile storm event. As a result, options such as cisterns and green roofs were considered. Without management practices, the 95th percentile rainfall event discharges 1.45 inches of stormwater, and 0.53 inch of this runoff is captured by on-site depression storage. The difference, 0.92 inch of runoff, would then require capture and management. Because of the technical considerations of constructing and maintaining controls at the site, it was assumed that up to 20 percent of pervious area can be converted into bioretention areas; up to 30 percent of paved area can be converted into porous pavement; and up to 30 percent of the rooftop area can be converted into green roofs. Cisterns can be added to the system if additional storage volume is required. Note that green roofs were selected lowest in the hierarchy of practices evaluated because of cost and potential structural issues associated with design and placement on existing buildings. By using the four on-site control options as presented in Table 3A3-14, all runoff for the 95th percentile rainfall event would be retained. From a management perspective, it was assumed that the design storage depth within the designated bioretention area was 6 inches because of the low infiltration rates adopted for this scenario.

This site contains a total of 9.4 acres of pervious area, 8.0 acres of paved area, and 1.6 acres of rooftop area. If 1.9 acres (20 percent) of the pervious area were converted to bioretention cells; 2.4 acres (30 percent) of parking lot converted to paver blocks; and 0.5 acre (30 percent) of rooftop area were retrofitted to green roof areas for this site, 97 percent of stormwater runoff from the 95th percentile storm would be captured on-site. By also adding one or more cisterns (as indicated in Figure 3A3-10), an additional 13,000 gallons could be captured, thus illustrating that 100 percent of the rainfall from the 95th percentile event can be managed on-site with GI/LID practices.

Figure 3A3-10. Actual site and on-site control measures (Cincinnati, OH).

Table 3A3-14. Estimated sizes of on-site control measures for Scenario #8 (Cincinnati, OH)

Total Area (acres)	19
Estimated Imperviousness (%)	51%
95th Percentile Rainfall Event (inches)	1.45
Expected Runoff for the 95th Percentile Rainfall Event (inches)	0.92
Stormwater Management Applied	Hydrologic Soil Group D
Bioretention estimated by Direct Determination (acres)	1.9
Paver block area estimated by Direct Determination (acres)	2.4
Green Roof estimated by Direct Determination (acres)	0.5
Cisterns estimated by Direct Determination (gallons)	13,000

Scenario #9 – Norfolk, Virginia

A 1.6-acre site with 91 percent impervious area was selected from Norfolk, Virginia. Table 3A3-15 contains the land use categories for the site. Figures 3A3-11 and 3A3-12 depicts the site and associated facilities. Site-specific factors based on an METF analysis allow management of 75 percent of the 95th percentile storm on-site (1.27 inches). The remaining portion of the 95th percentile rainfall event (0.41 inch would be discharged off of the site.

Table 3A3-15. Land use determination after redevelopment

Land use	Acres	Site coverage percent
Building	0.90	56.3
Parking	0.35	21.9
Streets/Sidewalks	0.20	12.5
Undeveloped	0.15	9.3
Total	**1.60**	**100%**

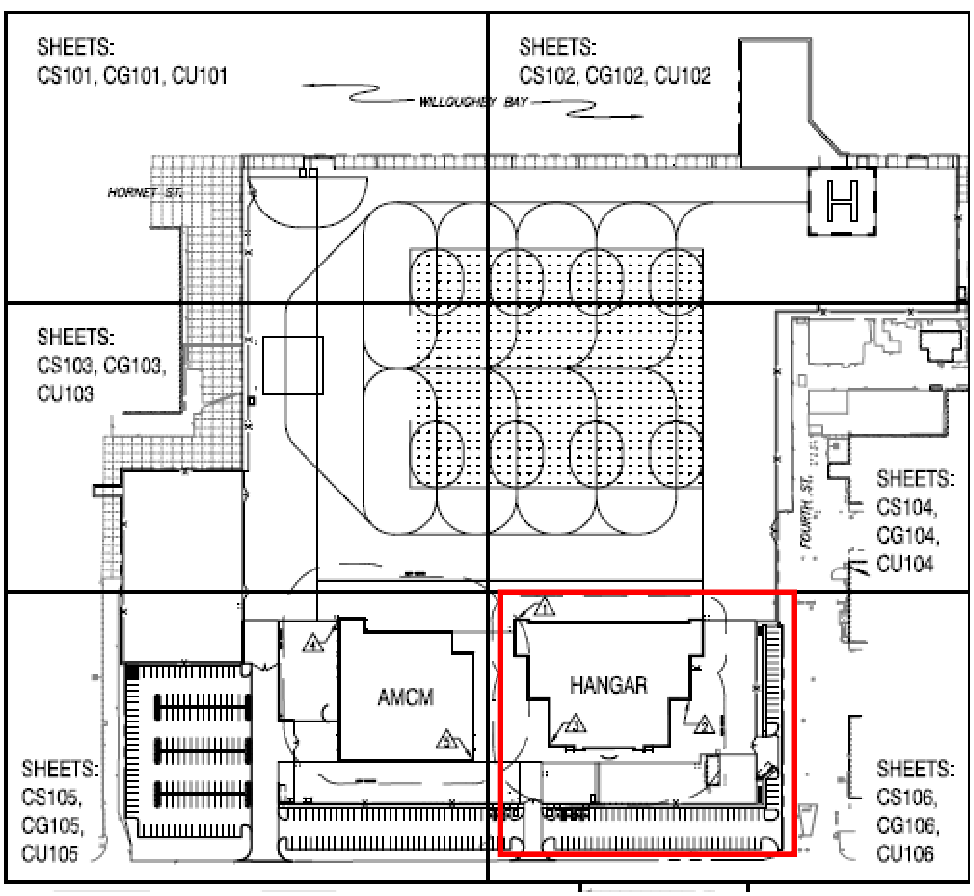


Figure 3A3-11. Proposed redevelopment scenario.

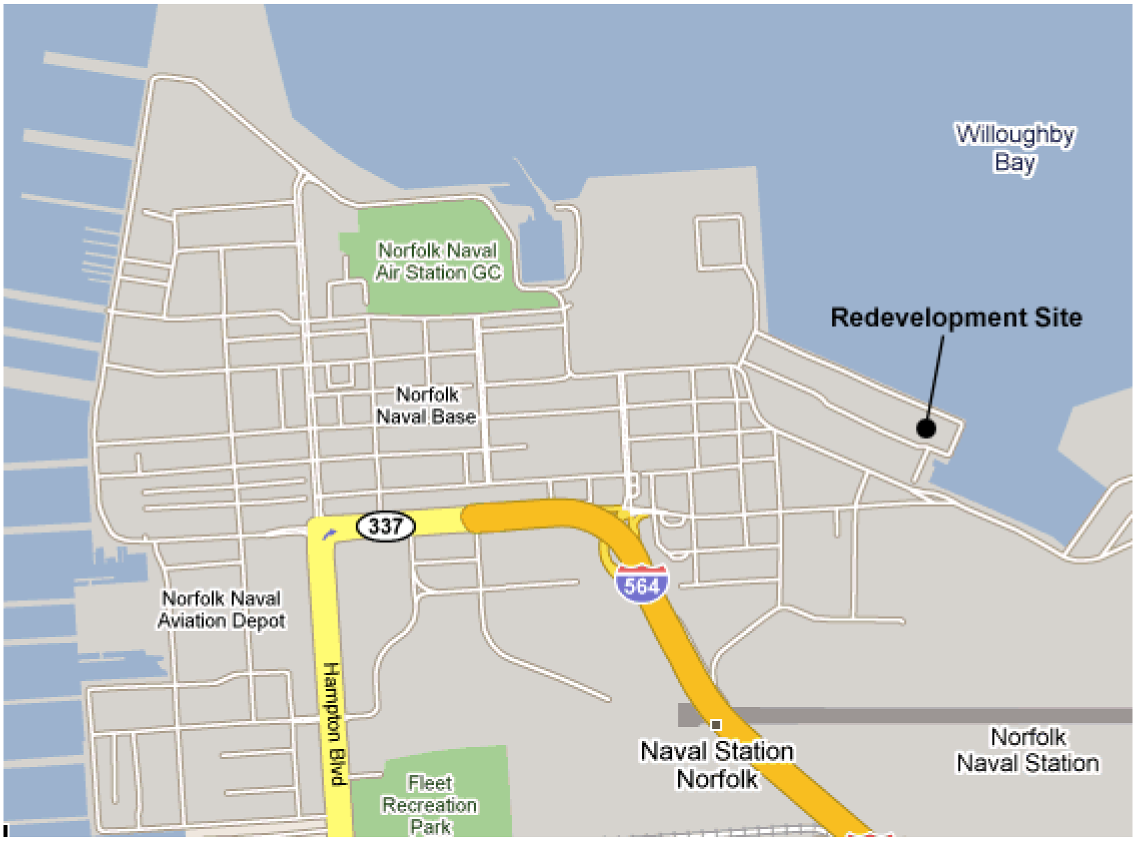


Figure 3A3-12. Location of facility (Norfolk, VA).

Site conditions and intended uses limited the number of practices that were technically feasible to use on-site to manage runoff. For example, a green roof was not feasible because the project includes the construction of an airplane hanger that lacks the structural strength to support a green roof. Cisterns were also not included in the set of suitable practices analyzed, which considered the number of people and amount of daily water use at the site, i.e., 40 people x 3.5 toilet flushes per day would use only 280 gallons of runoff per day or 2,000 gallons per week. Stormwater use for HVAC make-up would also be negligible according to the typical cooling system design. To put things in perspective, if the hanger rooftop covers the entire building footprint, 41,000 gallons of runoff would be generated from a 1.68-inch rainfall. Assuming a drawdown of 2,000 gallons per week from toilet flushing, the users would use only 5 percent of the 95th percentile event. Because of the relatively large volume of water that would need to be collected and used, cisterns were not considered a feasible option to manage a significant volume of runoff at the site.

However, site conditions did allow for both permeable pavement and bioretention practices (Figure 3A3-13 and Table 3A3-16). Approximately 0.15 acre (6,500 sf) of the proposed site is undeveloped and available for bioretention. On the basis of Department of Defense facility requirements, 10 percent of the parking area is designed with landscaping, usually around the perimeter and in landscaped islands. If the 10 percent were designed as bioretention cells, 0.035 acre of bioretention would be achieved. If bioretention cells were also placed in about 30 percent of the undeveloped area of the project, an additional 0.045 acre of bioretention could be implemented. Note: not all undeveloped land was assumed to be available for bioretention because of conflicts with site utilities, security and antiterrorism requirements and slopes that limited the use of infiltration practices directly adjacent to the hanger.

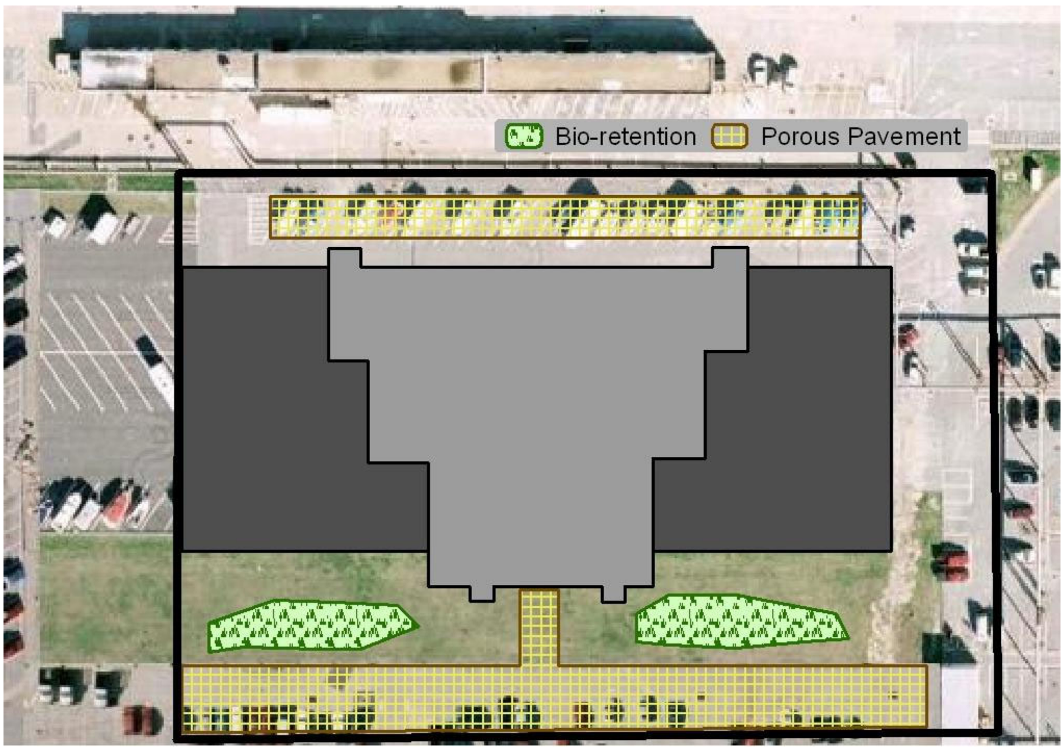


Figure 3A3-13. Actual site and on-site control measures (Norfolk, VA).

Table 3A3-16. Estimated sizes of on-site control measures for Scenario #9 (Norfolk, VA)

Total Area (acres)	1.6
Estimated Imperviousness (%)	91%
95th Percentile Rainfall Event (inches)	1.68
Expected Runoff for the 95th Percentile Rainfall Event (inches)	1.50
Stormwater Management Area Required	Hydrologic Soil Group D
Porous Pavement estimated by Direct Determination method (acres)	0.21
Bioretention estimated by Direct Determination method (acres)	0.08

The bioretention cells were designed with an effective storage depth of 10 inches, which includes a depth from media surface to outlet of 10 inches. In this case study, state regulations precluded the project from taking credit for the storage potential provided by the void space within the bioretention cell media. Similarly, approximately 0.55 acre of the proposed site is impervious because of parking lots, streets, and sidewalks. Because of the manufacturer's recommendation that permeable pavement materials not be used in applications subject to heavy loads and potential pollutant exposure, the access roads and parking lot access isles were assumed to be constructed from conventional impervious concrete or asphalt. Thus, 60 percent of the parking area (primarily parking stalls and sidewalks), which is about 38 percent of the entire paved area, is assumed to be suitable for paver blocks. A high water table at the site limited the modeled net storage depth under paver blocks in the parking areas and sidewalks to 4 inches. This storage was calculated using the assumption that the pavement sub-base of 12 inches would have a minimum void space of approximately 30 percent.

Comparison of the Runoff Estimation Methods

As illustrated in each of the case studies above, runoff of the 95th percentile storm was estimated to size on-site control measures. The estimates were produced by applying four different methods: the Direct Determination method, the Rational Method, the NRCS TR-55, and the EPA SWMM. The results comparing each of the methods for scenarios 1 through 7 are presented in Tables 3A3-17 and 3A3-18.

Table 3A3-17. Comparison of the estimated runoff (unit: inches)

Method		Direct determination		Rational method		TR-55		SWMM	
Soil Groups		B	C	B	C	B	C	B	C
1	Charleston, WV	0.82	0.82	0.83	0.84	0.36	0.53	0.82	0.83
2	Denver, CO	0.53	0.53	0.57	0.59	0.12	0.26	0.53	0.53
3	Cincinnati, OH	0.68	0.68	0.73	0.76	0.26	0.46		
4	Portland, OR	0.86	0.86	0.86	0.86	0.63	0.71		
5	Phoenix, AZ	0.42	0.42	0.46	0.48	0.06	0.17		
6	Boston, MA	0.98	0.98	0.99	1.00	0.51	0.70		
7	Atlanta, GA	1.17	1.17	1.17	1.19	0.73	0.97	1.19	1.23

As shown in the above table, the estimated runoff results from direct determination, the Rational method, and SWMM are relatively similar. Runoff volumes using TR-55 are lower than the other estimates. SWMM modeling results using NRCS 24-hour rainfall distributions were nearly identical to the results based on uniform distribution.

Table 3A3-18. Applicability of the methods for analyzing on-site control measures

Purpose	Direct determination	Rational method	TR-55*	SWMM
Planning Tool	Applicable	Applicable	Applicable	Applicable
Preliminary Design	Applicable	Applicable	Applicable	Applicable
Detailed Design	Not applicable	Not applicable	Not applicable	Applicable
Actual Assessment (Long-term)	Not applicable	Not applicable	Not applicable	Applicable
Water Quality	Not applicable	Not applicable	Not applicable	Applicable

* Use with caution when applying this method for small storms

Conclusions

Although sites varied in terms of climate and soil conditions, in most of the scenarios selected, the 95^{th} percentile storm event could be managed on-site with GI/LID systems. Other infiltration, evapotranspiration and capture and use stormwater management options are available in addition to those used in these analyses. These options provide site managers additional flexibility to choose appropriate systems and practices to manage site runoff.

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Resources: Runoff Methodology Parameter Assumptions

Runoff from each land cover was estimated by the following equation:

$$Runoff = Rainfall - Depression\ Storage - Infiltration\ Loss \quad (1)$$

Depression Storage

Reference depression storage (inches)

Reference	Impervious	Pervious
1	0.05–0.1	0.1–0.3
2	0.01–0.11	0.02–0.6
3	0.1	0.2

1. ASCE. 1992. Design & Construction of Urban Stormwater Management Systems. New York, NY.

2. Marsaleck, J., B. Jimenez-Cisreros, M. Karamouz, P.R. Malmquist, J. Goldenfum, and B. Chocat. 2007. *Urban Water Cycle Processes and Interactions. Urban Water Series*, UNESCO-IHP, Tyler & Francis.

3. Walesh, S.G. 1989.*Urban Surface Water Management*. John Wiley & Sons, Inc.

On the basis of the above reference data, depression storage (or initial abstraction, the rainfall required for the initiation of runoff) to the direct determination method was assumed as follows:

- Rooftop: 0.1 inches
- Pavement: 0.1 inches
- Pervious area: 0.2 inches

Infiltration

Infiltration loss occurs only in pervious areas. In this analysis, infiltration was estimated by Horton's equation:

$$Ft = f_{min} + (f_{max} - f_{min})\ e - k\ t \quad (2)$$

where

Ft = infiltration rate at time t (in/hr)
f_{min} = minimum or saturated infiltration rate (in/hr)
f_{max} = maximum or initial infiltration rate (in/hr)
k = infiltration rate decay factor (/hr)
t = time (hr) measured from time runoff first discharged into infiltration area

Reference infiltration parameters

Maximum infiltration rate (in.hr), f_{max}

Infiltration (in/hr)	Partially dried out with		Dry soils with	
	No vegetation	**Dense vegetation**	**No vegetation**	**Dense vegetation**
Sandy	2.5	5	5	10
Loam	1.5	3	3	6
Clay	0.5	1	1	2

Reference: Huber, W. C. and R. Dickinson. 1988. *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Minimum infiltration rate (in/hr), f_{min}

Hydrologic Soil Group	Infiltration (in/hr)
A	0.45–0.30
B	0.30–0.15
C	0.15–0.05
D	0.05–0

A: well drained sandy; D: poorly drained clay

Reference: Huber, W.C., and R. Dickinson. 1988. *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Decay coefficient, k

Soils	k (sec^{-1})	k (hr^{-1})
Sandy	0.00056	2
↕	0.00083	3
	0.00115	4
Clay	0.00139	5

Reference: Huber, W.C., and R. Dickinson. 1988. *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

On the basis of the above reference data, infiltration parameters to the direct determination method were assumed as follows:

- Hydrologic Soil Group B
  - Maximum infiltration rate: 5 in/hr
  - Minimum infiltration rate: 0.3 in/hr
  - Decay factor: 2 /hr

- Hydrologic Soil Group C
  - Maximum infiltration rate: 3 in/hr
  - Minimum infiltration rate: 0.1 in/hr
  - Decay factor: 3.5 /hr
- Hydrologic Soil Group D
  - Maximum infiltration rate: 1 in/hr
  - Minimum infiltration rate: 0.02 in/hr
  - Decay factor: 5 /hr

Infiltration loss for the 24-hour rainfall duration was estimated by the following equations with assumptions of a half hour Δt:

$$\text{Infiltration Loss at the } n^{th} \text{ time-step} = (f \times \Delta t) = \{(f_{n-1} + f_n)/2) \times \Delta t\} \quad (3)$$

$$\text{Integrated Infiltration Loss for 24 hours} = \sum (f \times \Delta t) \quad (4)$$

Integrating infiltration loss during 24 hours with a half hour Δt

Time-step	t (hr)	Infiltration rate (in/hr)[a]			Infiltration volume (inches)[b]		
		Soil B	Soil C	Soil D	Soil B	Soil C	Soil D
0	0	5	3	1	0	0	0
1	0.5	2.03	0.60	0.100	1.757	0.901	0.275
2	1	0.94	0.19	0.027	0.741	0.198	0.032
3	1.5	0.53	0.12	0.021	0.368	0.076	0.012
4	2	0.39	0.10	0.02	0.230	0.054	0.01
5	2.5	0.33	0.1	0.02	0.179	0.05	0.01
6	3	0.31	0.1	0.02	0.161	0.05	0.01
7	3.5	0.30	0.1	0.02	0.154	0.05	0.01
8	4	0.3	0.1	0.02	0.15	0.05	0.01
9	4.5	0.3	0.1	0.02	0.15	0.05	0.01
10	5	0.3	0.1	0.02	0.15	0.05	0.01
11	5.5	0.3	0.1	0.02	0.15	0.05	0.01
12	6	0.3	0.1	0.02	0.15	0.05	0.01
13	6.5	0.3	0.1	0.02	0.15	0.05	0.01
14	7	0.3	0.1	0.02	0.15	0.05	0.01
15	7.5	0.3	0.1	0.02	0.15	0.05	0.01

Time-step	t (hr)	Infiltration rate (in/hr)[a]			Infiltration volume (inches)[b]		
		Soil B	Soil C	Soil D	Soil B	Soil C	Soil D
16	8	0.3	0.1	0.02	0.15	0.05	0.01
17	8.5	0.3	0.1	0.02	0.15	0.05	0.01
18	9	0.3	0.1	0.02	0.15	0.05	0.01
19	9.5	0.3	0.1	0.02	0.15	0.05	0.01
20	10	0.3	0.1	0.02	0.15	0.05	0.01
21	10.5	0.3	0.1	0.02	0.15	0.05	0.01
22	11	0.3	0.1	0.02	0.15	0.05	0.01
23	11.5	0.3	0.1	0.02	0.15	0.05	0.01
24	12	0.3	0.1	0.02	0.15	0.05	0.01
25	12.5	0.3	0.1	0.02	0.15	0.05	0.01
26	13	0.3	0.1	0.02	0.15	0.05	0.01
27	13.5	0.3	0.1	0.02	0.15	0.05	0.01
28	14	0.3	0.1	0.02	0.15	0.05	0.01
29	14.5	0.3	0.1	0.02	0.15	0.05	0.01
30	15	0.3	0.1	0.02	0.15	0.05	0.01
31	15.5	0.3	0.1	0.02	0.15	0.05	0.01
32	16	0.3	0.1	0.02	0.15	0.05	0.01
33	16.5	0.3	0.1	0.02	0.15	0.05	0.01
34	17	0.3	0.1	0.02	0.15	0.05	0.01
35	17.5	0.3	0.1	0.02	0.15	0.05	0.01
36	18	0.3	0.1	0.02	0.15	0.05	0.01
37	18.5	0.3	0.1	0.02	0.15	0.05	0.01
38	19	0.3	0.1	0.02	0.15	0.05	0.01
39	19.5	0.3	0.1	0.02	0.15	0.05	0.01
40	20	0.3	0.1	0.02	0.15	0.05	0.01
41	20.5	0.3	0.1	0.02	0.15	0.05	0.01
42	21	0.3	0.1	0.02	0.15	0.05	0.01
43	21.5	0.3	0.1	0.02	0.15	0.05	0.01
44	22	0.3	0.1	0.02	0.15	0.05	0.01
45	22.5	0.3	0.1	0.02	0.15	0.05	0.01
46	23	0.3	0.1	0.02	0.15	0.05	0.01
47	23.5	0.3	0.1	0.02	0.15	0.05	0.01
48	24	0.3	0.1	0.02	0.15	0.05	0.01
Sum: Infiltration loss during 24 hours [c]					9.743	3.430	0.769

[a] Calculated infiltration rate at each time by Equation (2)

[b] Calculated infiltration volume from the previous time to the current time by Equation (3)

[c] Integrated infiltration volume for 24 hours with a half hour Δt by Equation (4)

On the basis of the above calculation, 24-hour infiltration losses for pervious areas and bioretention areas were modeled as follows:

- Soil Group B: 9.743 inches
- Soil Group C: 4.430 inches
- Soil Group D: 0.769 inches

Infiltrations of underlying soils at paver blocks were modeled conservatively by applying the minimum infiltration rate for each soil type (Infiltration loss = f_{min} × 24) because the soils under the paver blocks could require or be subjected to some compaction for engineering stability. The estimated infiltration losses for each soil are presented below:

- Soil Group B: (0.3 in/hr) × (24 hrs) = 7.2 inches
- Soil Group C: (0.1 in/hr) × (24 hrs) = 2.4 inches
- Soil Group D: (0.02 in/hr) × (24 hrs) = 0.48 inches

Design Storage of Management Practices

Bioretention

Reference	Ponding (inches)[1]	Mulch (inches)	Soil media (ft)	Soil media porosity	Underdrain
1	up to 12	2–4 (optional)	1–1.5	about 40%	bioretention systems utilize infiltration rather than an underdrain
2	6–12	2–3	2.5–4	about 40%	recommended, especially if initial testing infiltration rate < 0.52 in/hr
3	6–12		2–4		
4		2–3	1.5–4		if necessary
5	up to 6		1.5–2	30%–40%	Optional
6	6–18	as needed	2–4		if necessary

1. State of New Jersey. 2004. *New Jersey Stormwater Best Management Practices Manual* www.nj.gov/dep/stormwater/tier_A/pdf/NJ_SWBMP_9.1 print.pdf.

2. MDE (Maryland Department of the Environment). 2000. *2000 Maryland Stormwater Design Manual, Volumes I & II*, prepared by the Center for Watershed Protection and the Maryland Department of the Environment, Water Management Administration, Baltimore, MD. www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp.

3. Clar, M.L., and R. Green. 1993. *Design Manual for Use of Bioretention in Storm Water Management*, prepared for the Department of Environmental Resources, Watershed Protection Branch, Prince George's County, MD, by Engineering Technologies Associates, Inc. Ellicott City, MD, and Biohabitats, Inc., Towson, MD.

4. USEPA (U.S. Environmental Protection Agency). 1999. *Storm Water Technology Fact Sheet: Bioretention*. EPA 832-F-99-012. Office of Water. US Environmental Protection Agency. Washington, D.C. www.epa.gov/owm/mtb/biortn.pdf.

[1] Ponding is a measure of retention capacity

5. Prince George's County. *Bioretention Design Specifications and Criteria*. Prince George's County, MD. www.co.pg.md.us/Government/AgencyIndex/DER/ESG/Bioretention/pdf/bioretention_design_manual.pdf.

6. City of Indianapolis. 2008. *Indianapolis Stormwater Design Manual*. www.sustainindy.org/assets/uploads/4_05_Bioretention.pdf.

Paver Blocks

Reference	Media (inches)	Void space
1	12 or more	40%
2	9 or more	40%
3	12–36	40%

1. University of California at Davis. 2008. *Low Impact Development Techniques: Pervious Pavement*. http://extension.ucdavis.edu/unit/center_for_water_and_land_use/pervious_pavement.asp.

2. AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and Atlanta Regional Commission. 2001. Georgia Stormwater Management Manual Volume 2: Technical Handbook www.georgiastormwater.com/.

3. Subsurface Infiltration Bed. www.tredyffrin.org/pdf/publicworks/CH2 - BMP4 Infiltration Bed.pdf.

Green Roofs

Reference	Media (inches)
1	3–4
2	1–6
3	2–6

1. Charlie Miller. 2008. Extensive Green Roofs. Whole Building Design Guide (WBDG). www.wbdg.org/resources/greenroofs.php.

2. Great Lakes WATER Institute. Green Roof Project: Green Roof Installation. www.glwi.uwm.edu/research/genomics/ecoli/greenroof/roofinstall.php.

3. Paladino & Company. 2004. Green Roof Feasibility Review. King County Office Project. http://your.kingcounty.gov/solidwaste/greenbuilding/documents/KCGreenRoofStudy_Final.pdf.

On the basis of the above reference data, design storages to the direct determination method were assumed as follows:

- Bioretention: up to 10 inches (depending on practice used, site conditions, and the like)
- Green roof: 1 inch (2.5 inches deep media with 40 percent void space)
- Porous pavement: 4 inches (10 inches deep media with 40 percent void space)

Factors that influence total storage available include, ponding depth, available media void space, and supplemental storage if the system is designed with gravel or open pipes underneath the media.

Chapter 4. Forestry

Contents

1 Nonpoint Source Pollution and the Chesapeake Bay: Forests in Perspective

The Chesapeake Bay Program has published a report on the health of the Chesapeake Bay almost annually since 1999 (CBP 2009a). In that report the program provides information on the primary sources of nitrogen (N), phosphorus (P), and sediment—the pollutants of most concern in the Chesapeake Bay. The list of largest contributors of nutrients to the Bay in the annual reports invariably has included agriculture, atmospheric deposition, wastewater, and urban/suburban lands. The 2007 report also includes septic systems as a primary contributor.

Of the states in the Chesapeake Bay watershed, only Virginia notes silviculture as a source contributing to water quality impairment. Virginia lists silviculture as a probable source of impairment for 14.8 miles of rivers and streams, or 0.069 percent of the total river and stream miles reported (USEPA 2008). Silviculture was not listed as a source of impairment to any other waterbody types.

Forest harvesting and other silvicultural activities, therefore, are generally not identified in state reports as having a significant adverse effect on the Chesapeake Bay. Forests play an important role in helping to protect water quality in the Bay. Some excerpts from the reports about the importance of forests in the Chesapeake Bay are provided below.

- Forests protect and filter drinking water for 75 percent of the Bay watershed's residents and provide valuable ecological services and economic benefits including carbon sequestration, flood control, wildlife habitat and forest products. Retaining and expanding forests in the Chesapeake Bay watershed is critical to our success in restoring the Chesapeake Bay. Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter and retain water, as well as absorb pollution from the air (CBP 2008).

- In addition to preserving the watershed, well-maintained forest buffers naturally absorb nutrients and sediments, thus improving water quality in neighboring streams. Riparian forest buffers also provide a source of large, woody material input to streams that helps form and maintain important fish habitat and provide for channel stability (CBP 2008).

- Scientific findings clearly show that well-managed forests are the most beneficial land use for clean water. Experts agree that healthy forests are directly linked to the health of rivers in the Chesapeake Bay watershed and, ultimately, the Bay. Large areas of healthy forest and streamside forests are essential to keeping nutrient and sediment pollution out of the rivers and Bay (CBP 1999).

A relatively new EPA initiative—the Healthy Watersheds Initiative—augments the Agency's well-established watershed approach with proactive, holistic, aquatic ecosystem conservation and protection. EPA recognizes the numerous benefits that healthy watersheds provide. For instance, forested watersheds protect aquifer recharge zones and surface water sources and reduce water treatment costs: For every 10 percent increase in forest cover in an aquifer's source area, chemical and treatment costs decrease by 20 percent. Healthy watersheds also provide benefits like habitat for fish, amphibians, birds, and insects; recreational opportunities such as fishing, water-based recreation, and tourism; and vast carbon storage capabilities. Healthy watersheds are also less vulnerable to floods, fires, and other natural disasters, which reduces costs to communities.

The Healthy Watersheds Initiative includes both assessment and management approaches that encourage states, local governments, watershed organizations, and others to take a strategic, systems approach to conserve healthy components of watersheds. The initiative combines understanding of the biological, chemical, and physical condition of waterbodies with watershed functional attributes, such as hydroecology, geomorphology, and natural disturbance patterns and, thus, helps us manage watersheds as integrated systems that can be understood through the dynamics of essential ecological attributes.

Forested watersheds are well recognized to provide water quality benefits. The full suite of the economic values of forested watersheds is difficult to quantify, however. Forest cover intercepts rainfall, protecting soils from erosion; the roots of trees and forest litter covering a forest floor prevent soil erosion; trees absorb water, delaying the input of stormwater runoff to streams; and forest vegetation absorbs nutrients that could otherwise be lost to surface waters through surface runoff and groundwater. All these water quality services provided by forests are valuable to society, but their dollar value varies by the location of the forest (e.g., Is it in a watershed that provides municipal drinking water?), species and sizes of trees, condition of the forest, climate, rainfall characteristics, and soil characteristics (e.g., erodibility, nutrient content) (CWP no date). The water quality protection service of an acre of forest, therefore, cannot be assigned a single dollar value. Studies have estimated the value of forest conservation (Table 4-1), resulting in a range of $25 million to $6 billion of capital costs that have been avoided through watershed protection.

Table 4-1. Avoided costs of constructing filtration plants through watershed protection

Metropolitan area	Avoided costs
New York City, NY	$1.5 billion spent on watershed protection over 10 years to avoid at least $6 billion in capital costs and $300 million in annual operating costs
Boston, MA	$180 million (gross) avoided cost
Seattle, WA	$150-200 million (gross) avoided cost
Portland, OR	$920,000 spent annually to protect watershed in avoiding a $200 million capital cost
Portland, ME	$729,000 spent annually to protect watershed has avoided $25 million in capital costs and $725,000 in operating costs
Syracuse, NY	$10 million watershed plan is avoiding $45-60 million in capital costs
Auburn, ME	$570,000 spent to acquire watershed land is avoiding $30 million capital cost and $750,000 in annual operating costs

Source: CWP No date

Forests, especially well-managed forests, are a key element in any state, local, or federal water quality protection program. It is estimated that between 50 and 75 percent of the population of the United States relies on forest lands for good quality water (Neary et al. 2009). Forests and forested land—whether in a rural setting, along streams on agricultural land, intermixed with other land uses in suburban settings, or in urban locations—possess characteristics that other soil types do not that make them act as natural filters for stormwater and one of the least expensive and most effective means of protecting water quality. (Further information about the benefits of trees and forests in urban settings is provided in Chapter 3 of this guidance [Chapter 3: *Urban and Suburban*]). These characteristics include high levels of organic matter on the forest floor that intercepts rain drops, and soil porosity from root growth and decay, cracking from freeze/thaw and wetting/drying processes, animal burrowing, and other natural processes. Much rain water is thus stored in the forest soil and its delivery to streams is primarily via groundwater flow; surface runoff is rare in forest settings. Good water quality is a result of the nutrient uptake and cycling and contaminant sorption processes that occur as water passes through the soil before reaching stream networks (Neary et al. 2009).

One strategy that states use to achieve well-managed forests is training programs for licensed loggers. Such logger training programs are run by state departments of forestry, universities, or nonprofit forestry groups, and they are critical to the effective use of best management practices (BMPs) on harvest sites. The New York Logger Training is a cooperative effort of timber harvesters, forest industry, government, educators, and foresters working together to deliver resources that allow loggers to learn environmentally sound practices and improved skills (NYLT 2010). The Sustainable Forestry Initiative Program in Pennsylvania has developed a comprehensive training program for loggers. A variety of courses cover topics from basic compliance with local, state, and federal laws; to in-depth discourses on business management, wildlife, forest management, and ecology; BMPs for erosion control; and others (Loggertraining

2010). In West Virginia, the West Virginia Division of Forestry provides workshops on BMPs for practicing loggers (WVDOF 2010). The logger training program in Virginia is referred to as the SHARP (Sustainable Harvesting and Resource Professional). To achieve SHARP Logger standing, participants must complete a core program of 18 hours of classroom and field training (Virginia Tech 2010). Of those 18 hours, 6 hours cover sustainable forestry, and 6 hours are devoted to BMPs. The *Sustainable Forestry* session combines classroom sessions with field exercises. Participants review the principles of sustainable forestry, and then tour a forest site to observe examples of forest ecology and silviculture. The *Harvest Planning and Best Management Practices* session includes visiting a forested site, discussion of how to use topographic maps, and training on the essential elements for an environmentally sound harvest plan.

Another important development in forest management is the increasing acceptance and use of sustainable forest management techniques through third-party forest certification programs. Forest certification began to become established in the mid- to late-1990s and is gaining attention, participation, and acceptance (Mercker and Hodges 2007). Forest certification programs often offer a more robust approach to preharvest planning activities and offer a host of economic and sustainability benefits. One of the principles of sustainable forestry is to protect waterbodies and riparian zones and to conform to BMPs to protect water quality (SFI 2010). The most commonly cited benefits of forest certification programs are market access, credibility, and improved forest management. A second potential benefit from certification is assurance that landowners are managing their property in the most sustainable way possible. A third-party audit provides a system for validating sustainable management claims. That could assure public agencies and the general public that the landowner is engaged in long-term forest management (University of Florida 2007). On a per-acre basis, direct costs will generally increase as ownership size decreases and can vary from less than $1/acre to many dollars per acre (University of Florida 2007).

As described fully in the *Riparian* chapter of this document, forested riparian buffers can provide some measure of flow regulation under certain watershed conditions. A primary way in which buffers reduce flow velocity is by creating physical barriers that slow down the flow and allow infiltration of water into soil. They also maintain streamside soils in a condition to absorb water by virtue of their extensive root systems and organic litter production that provide the soil structure necessary for a large quantity of infiltration. Rainfall and runoff intensity, soil characteristics, hydrologic regime, and slope of the buffer and runoff source area are some of the factors that determine a forested riparian buffer's ability to regulate stream flow. A narrow forested buffer on a steep, nonvegetated slope has little ability to regulate flow, whereas a wide forested buffer on a gentle, vegetated slope could help reduce peak flow levels and provide for dry season flow.

Leaders of the Chesapeake Bay Program clearly recognize the importance of forests and forested riparian areas to the Bay's health. For example, the current Federal Leadership Committee strategy is to protect 2 million acres of lands throughout the watershed currently identified as high conservation priorities at the local, state, and federal level (including 695,000 acres of forest land of highest value for maintaining water quality) by 2025 (Federal Leadership Committee 2010). An original goal of 2,010 miles of forest buffer restoration by 2010 was achieved ahead of time, and a new goal to restore forests along at least 70 percent of streams and shorelines in the Bay watershed was set in 2003. The Bay was to have at least 10,000 shoreline miles forested by 2010 (CBP 2009b). The progress as of 2009 was 6,901 miles. A federal implementation plan was developed as part of the initiative. For federally managed lands—approximately 1.9 million acres of the 2.2 million acres of federal lands in the Chesapeake watershed are forested—this plan focused on protecting existing forests from development, incorporating forest conservation into land use planning, and working with forest landowners to promote forest conservation.

Research in N saturation shows that young forests capture more N from atmospheric inputs. Old forests generally do not *leak* N unless there is a large input source of N, such as from atmospheric pollutants (Kyker-Snowman no date). The retention of atmospheric N in forested watersheds is directly influenced by species composition and many factors that can change that composition, e.g., natural succession, climate change, forest management practices, forest pest infestations (Lovett et al. 2002). Undisturbed and properly managed forested ecosystems have considerable capacity to retain and efficiently cycle reactive N and prevent it from entering waterways. If, however, a forested system experiences a disturbance—such as widespread removal of vegetation—its ability to retain N is diminished. Implementing sound forest management practices can minimize such effects (SUNY 2010).

Deforestation is the long-term conversion of forest to another land use or the long-term reduction of the tree canopy cover below a 10 percent threshold. Chesapeake Bay Program land analyst scientists have a very good idea where deforestation will occur in the coming years in the Bay watershed. Forests that are vulnerable to development and that without action would be expected to be developed are critical to protecting the Bay watershed. Preventing the loss of those forests is referred to as *avoided deforestation*, and it has been used as a measure of credit for more than 10 years.

The nutrient reduction efficiency of avoided deforestation can be considerable because of the difference in nutrient loading to the Chesapeake Bay between a natural forest versus typical development. Bay scientists ran a model to compare N contributions to the Bay under the scenario that all high-value, vulnerable forests are lost versus those forests remaining protected. The model predicted that if the forests are protected, 3.1 million pounds of N would be prevented from flowing into the Bay.

The focus on forestry in the Bay is on preserving forests, maintaining forested shorelines and streambanks, and restoring forests near Bay waters and throughout the Bay watershed where they have been removed.

The lessons from the above-mentioned reports and initiatives—and the message to be gained from this guidance—are the following:

- Forests and forested buffers are extremely important to maintaining and improving water quality in the Chesapeake Bay.
- Maintaining well-managed, protective forested riparian buffers in a condition that conserves or enhances their ability to trap pollutants; protect the water quality of the Bay; and provide high-quality habitat for aquatic species is vitally important.
- Most forests in the Bay watershed are privately owned (approximately 80 percent) (Blankenship 2006). The objectives and motivations of private landowners must be considered in determining what BMPs should be recommended to successfully engage forest owners in maintaining their forests for the future. The Chesapeake Bay Program estimates that as much as 35 percent of the region's private forests are vulnerable to development (CBP 2004).

2 Forestry Practices for Water Quality Protection

2.1 Introduction

The effects of forestry activities on surface waters are of concern because healthy, clean waters are important for aquatic life, drinking water, and recreational use. Surface waters and their ecology can be affected by inputs of sediment, nutrients, and chemicals, and by alterations to stream flow that can result from forestry activities. The purpose of implementing measures and BMPs to protect surface waters during and after forestry activities is to protect important ecological conditions and characteristics of the surface waters in areas with roads and logged, forested areas. Such conditions vary with waterbody type, but, in general, the ecological conditions that implementation measures and BMPs are intended to protect include the following:

- General water quality, by minimizing inputs of polluted runoff
- Water temperature, by ensuring an adequate amount of shade along shorelines and streambanks
- Nutrient balance, by providing for an adequate influx of carbon and nutrients that serve as the basis of aquatic food chains
- Habitat diversity, by ensuring that inputs of large organic debris to the aquatic system are appropriate for the system
- Hydrologic processes, by limiting disturbances to ground cover, overland flow, and stream flow patterns, both seasonal and annual

Logging a forested area can affect all those ecological conditions to some extent. Preharvest conditions might consist of canopy, subcanopy, and herbaceous vegetative layers; a thick litter layer; a complex of tree, shrub, and herbaceous roots surrounded by uncompacted soils; 70–100 percent shade at ground level; nutrient cycling between vegetation and soils; and a vegetation-buffered hydrologic process. Post-harvest, the canopy and subcanopy are reduced; the litter layer is removed in some areas and compacted in others; roots of removed vegetation decompose; sunlight penetration to the ground is increased; nutrient absorption by vegetation is reduced; and more rainfall reaches the ground, less rain water evaporates back to the atmosphere, and runoff increases. Those changes can lead to increased water, sediment, and nutrient delivery to streams, but the post-harvest effects can be minimized through the use of appropriate BMPs during and immediately after a harvest, followed by regular BMP maintenance. Forestry activities and their potential effects on forest hydrology and water quality (through nonpoint source pollution) are discussed below.

Sediment

Sediment deposited in surface waters is addressed in this document because of its potential to affect in-stream conditions and aquatic communities. Sediment is the pollutant most associated with forestry activities. Soil is lost from the forest floor by surface erosion following ground disturbances typically associated with a forest harvest (e.g., use of heavy machinery, skidding, truck traffic), or through mass wasting (e.g., landslides on steep slopes induced by loosened soil from decomposed tree roots after a harvest).

In undisturbed forests, surface erosion generally contributes minor quantities of sediment to streams and the quantity of surface erosion depends on factors mentioned earlier, such as soil type, topography, and amount of vegetative cover (Spence et al. 1996).

Rill erosion and channelized flow occur where rainwater and snowmelt are concentrated by landforms, including berms on roads and roadside ditches. They cause erosion most severely where water is permitted to travel a long distance without interruption over steep slopes because the combination of distance and slope tends to increase the volume and velocity of runoff. Sheet erosion, or overland flow, occurs occasionally on exposed soils where the conditions necessary for it exist—including saturated soil or a rainfall intensity that is greater than the ability of soil to absorb the water—but it is not common on forest soils because the forest floor and associated litter layer have a very high infiltration capacity.

Nutrients

Nutrients, such as N and P in soil and plant material, are primary chemical water quality constituents. They can enter waterbodies attached to sediments, dissolved in the water, or transported by air. Forest harvesting can locally increase nutrient leaching from the soil through its disruption of the cycling of nutrients between the soil and overlying vegetation, although the effect generally subsides to near precutting levels within 2 years of a harvest, provided that all appropriate post-harvest measures are taken to revegetate the site. Excessive amounts of nutrients can stimulate algal blooms or an overgrowth of other types of aquatic vegetation. That can, in turn, lead to an increase in the amount of decomposing plant material in an aquatic system and increased turbidity and biological oxygen demand. The latter effect can decrease dissolved oxygen concentrations, with potentially detrimental effects to aquatic biota. Chapter 3, section I *(Forest Chemical Management)* of EPA's 2005 guidance *National Management Measures to Control Nonpoint Sources of Pollution from Forestry* (USEPA 2005), discusses methods for minimizing the adverse effects of forestry activities on nutrient balances.

Organic debris, discussed below, can be an important source of nutrients in an aquatic environment. Streamside Management Areas (SMAs) play an important role in organic debris inputs and maintaining nutrient balances in aquatic forest ecosystems.

Organic Debris

Organic debris—primarily composed of leaves, twigs, branches, and fallen trees—is an important element of water quality because it provides nutrients and stream structure that are important to supporting aquatic life. The presence of organic matter in the form of woody debris is one of the primary influences on the microbial denitrification process. It ranges in size from suspended organic matter in water to fallen trees. Large, woody debris, or LWD, can be whole trees or tree limbs that have fallen into streams. It contributes to the physical habitat diversity essential to support aquatic life. As a structural element, LWD influences the movement and storage of sediment and gravel in streams and stabilizes streambeds and banks. Small, organic litter—primarily leaves in deciduous forests and cones and needles in coniferous forests—is an important source of nutrients for aquatic communities. It usually decomposes over a year or more, depending on the forest type.

When streamside vegetation is removed—especially when riparian canopy trees are removed—inputs of organic debris decrease and the amount of sunlight reaching the water increases. For a stream that might have relied primarily on sources of nutrients external to the stream (fallen debris), vegetation removal can force the stream to rely primarily on in-stream sources (such as algal growth and in-stream vegetation), which might not be present in low-order streams.

Organic debris generated during forestry activities include residual logs, slash, litter, and soil organic matter. Such materials can perform some of the same positive functions as naturally occurring LWD and organic litter. If their abundance in a stream is substantially greater than normal, however, they can also block or redirect streamflow, alter nutrient balances, and decrease the concentration of dissolved oxygen as they decompose and consume oxygen.

In 2005 EPA published *National Management Measures to Control Nonpoint Sources of Pollution from Forestry* (USEPA 2005). Little has changed with respect to the commonly accepted best practices of protecting surface waters from inputs of sediment and nutrients during and after forestry activities since that guidance was published. The 2005 guidance was based on a comprehensive review of both the scientific literature and state forestry practices at the time. A review of state forestry practices and the recent literature indicates that the information in the 2005 guidance is still as relevant today as it was when it was published.

Recent research on forest harvesting has focused on better understanding how some BMPs work (and why they fail) and on methods that can be used to reduce the cost and effort involved in forest planning and harvesting. One of the greatest risks to water quality from forestry activities come from having unprotected streams. SMAs have proven to be an important component of water quality protection in forested areas, and recent research has focused on understanding the width requirements and vegetative and soil characteristics that give SMAs their water-quality protection abilities.

The other major risk to water quality from forestry activities comes from sediment-laden runoff from areas disturbed by forestry activities, especially roads, landings, and skid trails. Not surprisingly, those have also been the focus of the bulk of the research over the past 5 years. Road building and timber removal are among the most costly aspects of forest harvesting, and much research has focused on reducing the costs of forest harvest planning, road building, and timber removal.

Below is a review of the implementation measures from EPA's 2005 guidance, with minor changes made to a few. Some of the implementation measures are not updated in this guidance because the 2005 guidance adequately identifies and discusses the best practices for protecting water quality from forestry activities. For those implementation measures that are updated, the relevant sections below provide a brief overview of the BMP-specific guidance provided in EPA's forestry guidance, some recommendations suggested by the recent research that could help improve on the advice provided in the 2005 guidance, and a brief review of some recent research relating to the recommendations.

2.2 Preharvest Planning

Implementation Measure F-1:

Perform advance planning for *timber harvesting* and *forest road systems* that includes the following elements, where appropriate:

1. Identify the harvest area and road layout and areas to be avoided during harvest and road construction (for example, waterbodies, wetlands, protected species locations and habitat, and highly erosive soils). Avoid locating roads, landings, and skid trails on steep grades and in SMAs. Use electronic and paper topographic and soil maps and a handheld global positioning system unit to facilitate marking the features, and mark them in a highly visible manner before the harvest.
2. Consider all water quality-related factors when planning the harvest and road system. Factors to consider include soil moisture conditions when the harvest and heaviest traffic will occur, BMPs for erosion control during and after the harvest, and existing water quality conditions in all potentially affected waterbodies.
3. Design roads to withstand the anticipated amount of traffic during the anticipated season of harvest such that ruts will not form and the effectiveness of road surface drainage features will not otherwise be compromised.

4. Design road drainage structures to discharge runoff in small quantities to off-road areas that are not hydrologically connected to surface waters.
5. Design the road layout to minimize the number of stream crossings.
6. For fish-bearing streams, design stream crossings to permit fish passage.

The Preharvest Planning implementation measure is to ensure that all forestry activities are planned with water quality considerations in mind and conducted to minimize the delivery of nonpoint source pollutants to streams and other surface waters. Road system planning is an essential part of this implementation measure. Two basic tenets of road planning are to minimize the number of road miles constructed and to locate roads so as to minimize the risk of water quality effects. Those two tenets of road planning are excellent and important guidelines for forest road network planning. Although the drive to reduce costs is what has led to much recent research on how road planning can be improved, minimizing costs can also be good for water quality because the fewer road miles and skid trails that are developed to harvest an area, the less water quality is likely to be adversely affected.

More than any other aspect of forest harvesting and management, forest roads have been identified as a major source of sediment delivered to streams and wetlands in forests. Soil sediment delivered to streams affects public resources such as water quality, aquatic and wildlife habitat, and riparian resources. Soil sediment causes problems when three components—source, resource, and delivery—are combined. Roads that are not eroded do not have the source to cause sediment problems. Roads that are far from streams do not have the resource to cause sediment problems. Roads that have adequate drainage structures to deliver the sediment onto stable forest floors do not deliver the sediment to the stream.

Forest roads have an important role in managing forest resources. They need to be constructed in such a way that forestry workers and machines can gain access to operational sites and carry out operations safely and efficiently. On the other hand, forest roads are at risk of road surface erosion and are subject to cut-and-fill slope failures. Therefore, it is important that forest road design incorporates consideration of cost efficiency *and* the appropriate management of water and soil.

Best Management Practices

1. If feasible, consider using a combination of geographic information system (GIS) data, Light Detection and Ranging (LiDAR) data, and one of the many computer optimization techniques modified for use in natural resources and forest harvest planning to determine road layouts, road and skid trail combinations, and landing locations that will

minimize the amount of road construction or skid distance, or both, expose the least amount of forest soil, and minimize the risk of water quality degradation from harvesting.

GIS data are widely available today for many areas of the country, and where they are not available, they are easy to collect quickly using a handheld global positioning system (GPS) device. LiDAR is a remote sensing technique that is rapidly being incorporated as a common technique in natural resources planning. Forest harvest planning, including road network layout and determining a best combination of roads and skid trails for an area is a field where computer optimization is being used with increasing success.

Designing a road network and determining an ideal combination of roads and skid trails to minimize cost and maximize water quality protection is difficult because so many possible layouts exist. Computer optimization techniques permit forest planners to analyze many more possibilities than manual techniques and can arrive at an optimum solution using any desired set of weighed factors.

Discussion

The location and operation of forest machinery, and the design and construction of forest roads are important issues in forest planning and account for up to 55 percent of production costs (Epstein et al. 2006). A major challenge of any forestry operation is designing an operation that minimizes the costs of road construction, installing and operating harvest machinery, and transporting timber, while at the same time protecting the forest environment. Forest planners are increasingly using computerized approaches to forest planning to reduce costs, collect the information necessary to plan a harvest, find road and landing layouts that minimize forest disturbance, and determine how best to manage existing road networks.

Aruga et al. (2005b) used two computer optimization techniques (the genetic algorithm and Tabu search) in combination with linear programming and compared the results obtained with the computer approaches to a manually designed forest road profile. They found that the profiles designed by computer cost less than the manually designed profile, that using such optimization techniques found good solutions for road system layout in a reasonable amount of time, and that more road profile alternatives could be evaluated in less time using computers. Aruga et al. also looked at the effect of the number of road profile control points (used in the optimization programming) on construction costs, and their results indicate that increasing the number of control points reduces the construction costs. That results from the forest road profile becoming closer to the ground profile—and the earthwork volume then being reduced—as the number of control points is increased (Aruga et al. 2005b).

LiDAR is a commercially available remote sensing system that is used in natural resources applications. LiDAR is a laser system that calculates the 3-dimensional (3D) coordinates of objects from reflections on the earth's surface (Akay et al. 2009). Various forestry activities can be performed rapidly and efficiently using LiDAR remote sensing technology. From the scans, various structures of individual trees, including crown width, diameter, volume, and height, can be estimated. The last scan can provide a very high-quality Digital Elevation Model (DEM) with approximately 1-meter (m) spatial resolution and about 10 to 20 centimeter (cm) height accuracy (Akay et al. 2009), which is useful for road and landing layout planning.

Forestry activities can sometimes be done more quickly and less expensively using LiDAR than using ground-based systems for wide-scale areas. LiDAR is one of the fastest growing technologies in the natural resources field and it is expected to provide higher resolution and more accurate data as the technology and GIS technologies advance (Akay et al. 2009). Of course, the use of technologies such as LiDAR and GIS must be balanced against the current availability of information about a forest stand, the cost of the technology, and the size of intended harvest. Small harvest operations, such as those typical of nonindustrial private forest landowners, might not benefit as much from the use of the technologies as would larger, corporate forest owners.

Aruga (2005) emphasizes the importance of using DEM and LiDAR data over something such as computer assisted drawings (CAD), which are widely used to draw road plans, road profiles, and cross sections, and to calculate earthwork volumes. But when planning a complicated road system for accessing numerous locations that might not be accessible from existing roads, CAD is not well suited to finding the best alignment with the lowest total road cost that is made up of construction, maintenance, user, social, and environmental costs. For such a complicated calculation, Aruga (2005) recommends using a high-resolution DEM derived from LiDAR data, which is then used to optimize horizontal and vertical alignments of forest roads. Where primary and secondary access routes are required, road intersection points are selected manually, from which the computer program using the DEM and LiDAR data generates alternative horizontal and vertical road alignments. The DEM generates ground profile and cross sections and calculates earthwork volumes for curved roadways. It also estimates construction and maintenance costs. The optimization model used by Aruga (2005) can find the best solution taking all the factors into account, and it helps forest engineers design a forest road by evaluating many alternatives (Aruga 2005).

Aruga et al. (2005a) also used a program to optimize forest road alignments but combined it with a method for predicting surface erosion and sediment delivered to streams, again using a high-resolution DEM. Because the program generates forest road alignments using a high-resolution DEM, it can calculate factors required by standard methodology to predict soil sediment delivered to streams. Aruga et al. (2005a) investigated the effects of road surface materials, culvert distance to stream, and out-sloped roads on total road costs and soil sediment delivered to streams. Using the model, Aruga et al. (2005a) found that using lower-quality rock surfacing on forest roads reduced total costs, but the amount of soil sediment from lower-quality rock surfacing was 1.5 times more than that on a higher-quality rock surface, and recommend that lower-quality rock surfacing not be used near streams. They also found that placing near-stream culverts 15 m upstream and using an out-sloped road template significantly reduces total road cost and soil sediment. Using the model permitted Aruga et al. (2005a) to successfully optimize forest road alignments, which reduced total road cost and soil sediment.

Other researchers have also been investigating the use of computer programming for forest planning. Epstein et al. (2006) used a mixed-integer programming system, PLANEX, that incorporates many parameters like the technical characteristics of machinery operation, road construction, transport and harvest costs, exit points, and economic variables that restrict the harvest. GIS was used in the process to provide timber volumes, topographic information, and information on the existing road network. Forestry companies have applied the technology and have reported that its advantages include operation designs that use fewer roads, which translates into lower total costs and the environmental benefits that come from less ground disturbance (Epstein et al. 2006).

Numerous authors have investigated the use of computer programs to find optimal road layouts for forest harvesting. Najafi et al. (2008) developed a method to evaluate forest road network variants using a systematic grid layout. They collected terrain condition and stand data at grid points using GIS and prepared maps of forest potential for road construction and maps of forest capacity for harvesting on the basis of the data they collected. A primary objective of the work was to determine whether the environmental impacts and costs of road network development could be reduced using GIS technologies. They determined that the method can be used to evaluate road networks easily, precisely, and in detail, with very little cost incurred to gather the grid point data (Najafi et al. 2008).

Ghaffarian et al. (2007) used an optimization program to find an optimal layout for a forest harvested by skidder in northern Iran. The program showed which roads could be eliminated from the existing forest road network, thus reducing the potential for road failure and sediment runoff and road maintenance costs, while still permitting efficient forest harvest (Ghaffarian et al. 2007).

Chung et al. (2008) developed a road network optimization model and applied it to a 11,540-acre (4,760 hectare) forest in the upper part of the Mica Creek watershed in Idaho, an area owned by Potlatch Forest Holdings. The model is used to identify cost-efficient road networks for timber harvesting given cost constraints and with options for on-road transportation of logged timber on new roads and off-road timber transportation using skidders, taking into consideration terrain conditions and stream locations. Costs that are input to the model and that partially determine the outcome include timber volume, road construction cost, skidding cost, and stream crossing cost (Chung et al. 2008). The latter purposefully tends to favor fewer or simpler stream crossings.

The model selects the least-cost activity using costs of skidding versus road construction and timber volume. For example, if enough timber volume is in an area or road construction cost is low compared with skidding cost, the road building option is selected so as to decrease the average skidding distance. On the contrary, if timber volume is not large enough or road cost is high, the skidding option is selected because building a new road would not be economically feasible even though the average skidding distance increases. Such a process eventually generates a road network that most cost-efficiently serves the entire area of interest for the purpose of timber harvesting (Chung et al. 2008).

Rackley and Chung (2008) used NETWORK2000, a forest transportation planning model, to produce alternative road system layouts that simultaneously minimize transportation costs and overall sediment delivery using inputs of estimated sediment delivery. They applied the methodology to the Mica Creek watershed in northern Idaho, where 11 alternative road networks were developed. The results of the modeling effort indicates that incorporating environmental effects into transportation planning can generate alternative road networks that reduce a large amount of estimated sediment delivery at the expense of a relatively small increase in transportation costs (Rackley and Chung 2008).

It is important to be able to include all relevant factors in any computerized system for optimizing forestry operations, because while many methods of finding optimal landing locations and determining the best skidding distance have been developed, they simplify harvest units and do not consider many factors that influence landing, skid trail, and road location (Contreras and Chung 2007). Contreras and Chung (2007) used a computerized model to determine the optimal landing location for harvesting using raster-based GIS data. The model found skid trails from stump to candidate landing locations and selected the best location on the basis of minimizing total skidding distance and spur road costs. The model included harvest unit boundary shapes, volume distribution, obstacles, terrain conditions, and spur road construction as factors taken into account in the optimization task. Using the model, Contreras and Chung (2007) found a range of cost savings associated with the various factors to be from $0 to $9,443, with an average savings per factor considered of $1,788. Data needed for the model are easy to obtain because LiDAR and GIS can provide most of it (Contreras and Chung 2007).

LiDAR can also be used to obtain detailed information on a forest harvest area (Akay et al. 2009). A LiDAR data set for forested areas is generated by light pulses reflected from different levels of vegetation canopy, including the top of the vegetation surface (first return), intermediate surfaces (second and following returns), and the ground surface (last return). From the first and second returns, various structures of individual trees (crown width, diameter, volume, and height) can be estimated. Using the last return, LiDAR can provide a very high-quality DEM. LiDAR is one of the fastest growing technologies in the natural resources field, and it is expected to provide higher resolution and more accurate data as the technology and GIS technologies advance (Akay et al. 2009).

1b. Where the use of LiDAR and DEM are not feasible (for instance, because data are lacking or because their use is too costly), consider integrating the use of digital topographic maps and aerial photography with data collected using a handheld GPS unit for forestry planning.

A handheld GPS unit combined with freely available or low-cost digital topographic maps and aerial images is a method ideally suited to forest planning uses for small properties to determine harvest unit boundaries, road layouts, road and skid trail combinations, and landing locations.

LiDAR and DEM are expensive, technology-intensive tools for forestry operations that are suitable for use by large-scale forestry operations and government agencies, but they are beyond the reach of smaller forest owners. A handheld GPS receiver used in combination with digital topographic maps and a computer mapping program is technology that is within the reach of and suitable for small forestry operations, such as those typical of nonindustrial private landowners. A variety of functions related to forestry—including collecting and storing specific GPS points, paths, and routes, and transferring the stored information between the GPS unit and a computer—can be performed with a handheld GPS receiver. Distances and areas can be calculated in the field or afterward on a computer using a mapping program, and adjustments to boundaries and paths can be made in the computer and then transferred back to the GPS unit for later use in the field, if necessary. Using a simple GPS receiver, a landowner or forester could gather complete location information on a forest unit to be harvested, walk candidate access road and skid trail routes while collecting GPS locations, and then conduct final harvest planning in more detail on a computer using a free or commercially available computer digital mapping software package. Free software packages include USAPhotoMaps, Google Earth, EasyGPS, and GPS Utility, while commercial software is available for purchase if required to provide greater accuracy and up-to-date maps.

2.3 Streamside Management Areas (SMAs)

Implementation Measure F-2:

Establish and maintain an SMA along all (perennial and ephemeral) waterbodies. Avoid all activity inside SMAs along all waterbodies. SMAs should be wide enough to provide a preharvest level of shade to surface waters, detain and capture water and sediment runoff from the harvest site and roads, and a sustainable source of large woody debris for in-stream channel structure and aquatic habitat.

Section 3B of EPA's guidance, *National Management Measures to Control Nonpoint Source Pollution from Forestry* (USEPA 2005) presents EPA's recommendation for SMAs in areas affected by forestry activities such as harvesting and post-harvest site preparation. The 2005 guidance describes the implementation measure, discusses the benefits of SMAs, and presents BMPs that can be used to meet the intent of the implementation measure.

The recommendations of the 2005 guidance with respect to SMAs still hold. Forested areas along streams and rivers are considered vital for providing habitat, food, and shelter for wildlife and protecting water quality by reducing nutrient and sediment input from upland areas. The Chesapeake Bay Program Forestry Workgroup emphasized the importance of streamside areas when it developed the *2003 Directive for Expanded Riparian Forest Buffer Goals* (CBP 2003). The directive recommends that forest buffers exist on at least 70 percent of all shorelines and streambanks in the Chesapeake Bay watershed. An estimated 60 percent of the shorelines in the watershed are now forested. Protecting the forests along streams in areas harvested for wood products is one of the key components to achieving the goal of the 2003 directive.

Most states incorporate SMAs as a major component of their forestry practice guidelines, and the recommendations of the states for establishing and protecting SMAs in harvest areas to protect water quality have not changed since publication of the 2005 EPA guidance. A general rule for the width of an SMA is a minimum of 25 to 50 feet, with 5 feet of additional width added for each 1 percent of slope of the contributing land (Klapproth and Johnson 2000). Of course, state, federal, or other applicable guidelines or rules for SMAs must be followed where they are applicable. For instance, many states (e.g., Virginia, Kentucky, Georgia, North Carolina, and South Carolina) prescribe wider SMAs along waters that protect cold water fisheries (Hodges and Visser 2004).

The importance of SMAs for water quality protection is well-established. Over the past 5 to 7 years, researchers have been investigating the use of technology for improving the accuracy and ease with which variable-width SMAs can be established. Technology has also been applied to preventing concentrated runoff flows from entering and passing through SMAs to reach streams. Also, in response to landowner concerns over lost revenue by not harvesting in SMAs, researchers have investigated the extent to which thinning in SMAs might be permitted while still retaining the nutrient- and sediment-trapping capabilities of the SMA. Recommendations to augment the information on SMAs in the 2005 EPA guidance are provided below, and the findings of the recent research are summarized. For more information on SMAs, see Chapter 5 Riparian Area Management.

Best Management Practices

1. Use GIS data or digital topographic maps and a GPS unit to determine SMA boundaries.

Field-based determination of variable-width SMA boundaries is a time-consuming process that can sometimes be accomplished in less time using GIS data or digital topographic maps. The width of SMAs is measured horizontally from the streambank, and the slope of land often varies along a stream course, which requires an SMA with a width that varies with the slope. Using GIS data or digital topographic maps, slope, and distance to stream, boundary points for an SMA can be determined quickly and accurately. Those points can then be loaded onto a handheld GPS unit and taken into the field for marking before harvest.

2. Use high-resolution stream maps when planning SMAs to ensure that all streams are protected.

When planning for stream protection, it is important to use the highest resolution stream map available. Lower resolution maps might not indicate the location of lower-order and ephemeral streams. When SMAs are planned, if these streams are left unprotected, water quality could be seriously compromised during and after a harvest.

Discussion

SMAs are delineated along streams in forested areas before harvesting. Generally, the width of an SMA varies by the slope of the terrain perpendicular to a stream, with the width increasing as the adjacent slope increases. That is because additional distance is necessary to prevent more rapidly moving runoff from reaching a stream channel. The process of establishing a variable-width SMA involves extensive field mapping, which requires traversing streams, measuring side slopes, determining where the limits of the SMA should be, marking the boundaries for easy identification during the harvest, and transferring the boundaries to aerial photos and retransferring them to the forest planning map. Although a variable-width SMA is advantageous for water quality protection, such an involved process of establishing them complicates forest operation planning (Williams et al. 2003). Williams et al. (2003) discuss how managers can use GIS as an aid to forestry management planning by accurately mapping SMAs without the need for on-the-ground field determinations. Basically, the process involves using maps of stream-bottom position and the topographic information in a GIS database to accurately and quickly determine the boundary location of variable-width SMAs. Details of the GIS software approach to delineating and mapping variable-width SMAs are provided by Williams et al. (2003).

Baker et al. (2007) evaluated the influence of stream map resolution on measures of the stream network and explored how predictions of nutrient retention potential might be affected by the resolution of a stream map. They noted that stream network maps from a broad range of map resolutions have been employed in watershed studies of riparian areas and were concerned that map resolution could affect important attributes of riparian buffers determined from the maps—for instance, the connectivity between source lands and small stream channels could be missing on coarse-resolution maps. They found that using fine-resolution stream maps significantly increased estimates of stream order, drainage density, and the proportion of watershed area near a stream (Baker et al. 2007).

When Baker et al. (2007) used stream maps of decreasing resolution for the same area, estimates of the mean distance from streams to source areas and mean buffer width were reduced, and the areas found to be unprotected by streamside buffers increased. Increasing the stream map resolution revealed portions of river networks reaching out farther into landscapes and closer to watershed divides, dissecting the landscape more finely while simultaneously decreasing the average proximity of the stream channels throughout watersheds (Baker et al. 2007).

Measures of percent land cover within 100 m of streams were found to be less sensitive to stream map resolution, and overall, increasing stream map resolution led to reduced estimates of nutrient retention potential in riparian buffers (Baker et al. 2007). That study also demonstrated that stream map resolution can also affect a user's ability to determine whether sediment retention occurs in riparian zones. In some watersheds, switching from a coarse-resolution to a fine-resolution stream map completely changed the perceptions of the authors of a stream network from one that was well-buffered to one that was largely unbuffered.

Best Management Practice

1. Establish wider-than-recommended SMAs where an SMA of recommended width will not sufficiently protect water quality.

The width of SMAs is generally prescribed by state or local ordinance, but under some circumstances, it can be too narrow to adequately protect water quality. For instance, the litter layer in an SMA is critical to stopping sediment- and nutrient-laden runoff from reaching streams. If the litter layer is disturbed or lacking, an SMA might have to be wider than recommended to adequately stop runoff.

Similarly, sediment and nutrients can be trapped as runoff infiltrates into the soil. But if the soil in an SMA has poor infiltration, runoff that does reach the SMA is more likely to reach surface waters. Extending the width of an SMA where soils have poor infiltration provides extra distance between the sediment and nutrient source to surface waters within which runoff can be slowed and stopped to prevent water quality degradation.

Discussion

White et al. (2007), working in the Piedmont region of Georgia, noted that a large portion of sediment is removed in the first 2 m of forested filter strips whether they are disturbed or not. In their study, only 2–3 percent of the total sediment was removed in each meter beyond the first 2 m. Significant reductions also occur in finer, silt-sized sediment in undisturbed filter strips, and "it appears that it is within this size fraction that increased filter strip width is the most important." If fine sediment is a concern, according to White et al. (2007), a 16-m filter strip should be sufficient to reduce the 2- to 20- micrometer (μm) particle concentrations in runoff to near zero. Filter strips will have little effect on surface flow sediment concentrations, however, where delivered sediment is colloidal size. That points again to the importance of considering soil characteristics when determining the appropriate SMA width for water quality protection.

White et al. (2007) also recommend that forested filter strip width be based on soil infiltration characteristics. They also note a trend toward increased sediment retention with increased depth of the litter layer, so it is probable that using harvesting equipment in an SMA would affect the litter layer and reduce sediment retention. In areas where coarse sediment is of concern, narrow filter strips should provide sufficient opportunity for settling and should be effective even if relatively little runoff infiltrates the soil. They report that narrow filter strips can remove coarse-textured sediment (> 20 μm in diameter) and that filter strips 16-m wide should remove most 2- to 20-μm sediment from runoff water (White et al. 2007).

The study highlights the potential limitation of using only slope as a tool for prescribing SMA width during harvesting for nutrient control. There is a disconnect between guidelines for slope as a modifying factor for buffer width establishment and slope as a causal factor affecting riparian zone nutrient concentrations. Stand characteristics, particularly the presence of N-fixing species in riparian areas, can also be an important factor influencing soil N concentrations. Vegetation in the SMA and soil properties are important factors to consider when determining the width of an SMA for water quality protection purposes.

Best Management Practice

1. Follow preharvest plan when harvesting in SMAs where upland, soil, and vegetative or litter layer characteristics are such that sediment and nutrients would likely be intercepted before reaching streams in a thinned SMA.

Where water quality would not be compromised and site characteristics are such that runoff from harvest sites would be stopped adequately before reaching streams, thinning harvests could be permitted in SMAs. Where permitted, harvesting in SMAs should always be done using techniques that minimally disturb the litter layer or compact soils. Additionally, managers must consider factors other than water quality protection when determining whether to permit thinning in SMAs. For instance, adequate shade should be provided post-harvest to regulate stream temperature in streams home to temperature-sensitive fish species, such as trout. Also, an adequate number of trees to supply woody debris to the stream must be retained to ensure the ecological health of stream biota.

Discussion

Lauren et al. (2007) investigated the possibility that SMA thinning could accommodate both the landowner's desire to maximize timber revenue and the need to protect water quality. While it is established that uncut buffer zones between clear cuttings reduce export of nutrients, they also reduce harvested stock and harvest revenue, a common and justified concern of landowners. Thinning in buffer zones could increase the volume and revenue of a harvest, but the effect of thinning on nutrient export is not well known. Lauren et al. (2007) compared N export in a 90-m, unthinned buffer zone to that in a 10-m, thinned buffer zone and found that the N export decreased by 53.4 kilograms (kg) in the 90-m, unthinned buffer zone but by only 4.3 kg in the 10-m, thinned buffer zone. Interestingly, however, was their conclusion that a prescribed target for water quality protection (e.g., reduce N export from a watershed by 25 kg in 5 years) can be achieved with several management options or by combining different management schemes. For example, a buffer zone around a stream could be divided into subzones, such as an area in which clearcutting is permitted with restricted site preparation, another zone in which thinning is permitted without the need for site preparation, and a third, completely unmanaged zone. Rivenbark and Jackson (2004) also noted the possibility that SMAs consisting of subzones could be used to meet water quality goals. If the relative strengths of the types of zones for nutrient and sediment reduction are known for an area, for a given water quality protection goal, a mixture of zones in which different harvesting activities are permitted and required could be recommended depending on individual landowner needs and site characteristics (Lauren et al. 2007).

2.4 Forest Road Construction/Reconstruction and Forest Road Management

Implementation Measures:

F-3. Guard against the production of sediment when installing stream crossings. Maintain permanent stream crossings and associated fills and approaches to reduce the likelihood (a) that stream overflow will divert onto roads and (b) that fill erosion will occur if the drainage structures become obstructed.

F-4. Protect surface waters from slash and debris material from roadway clearing.

F-5. Expedite the revegetation of disturbed soils on unstable cuts and fills. Use temporary structures such as straw bales, silt fences, mulching, or other appropriate practices until an area is adequately stabilized.

F-6. Conduct maintenance practices, when conditions warrant, including cleaning and replacing deteriorated structures and erosion controls, grading or seeding road surfaces, and, in extreme cases, slope stabilization or removing road fills where necessary to maintain structural integrity.

F-7. Evaluate the future need for a road and close roads (including temporary spur roads and seasonal roads) that will not be needed. Road closure should include stabilizing closed roads and drainage channels against failure during storms, ensuring that runoff from a closed road will be directed away from the roadway, removing drainage crossings and culverts if there is a reasonable risk of plugging, and removing all temporary stream crossings.

EPA's 2005 forestry guidance emphasizes the importance of good road planning for preventing sediment delivery to streams in the Road Construction/Reconstruction and the Road Management implementation measures. Road construction remains one of the largest potential sources of forestry activity-produced sediment, and providing road and drainage crossing structures that minimize the potential for sediment delivery to surface waters from roads, landings, and skid trails is still an essential task for long-term water quality protection from forest roads.

Road planning and construction can be even more effective today by using advances made in computerized techniques to find the best layouts for roads that can reduce both costs and the potential for road runoff to reach streams.

Forest roads also need to be maintained to correct breakdowns in road drainage structures that can lead to sediment runoff and inputs to streams. When properly planned and constructed, forest road drainage prevents or minimizes the connection between road runoff and the stream network. When roads are left unmaintained, road drainage paths can lead to the stream network. Road drainage hydrologically connected to the stream network is a direct path for sediment input. Additionally, managers should analyze forest roads that are no longer needed, and determine whether returning them to vegetative cover would reduce the risk of sediment runoff.

Best Management Practices

1. Provide extra road drains, especially near streams and stream crossings, to minimize the creation of concentrated runoff flows

In addition to protecting the litter layer and extending SMAs in areas with poor soil infiltration, it is important to ensure that roads and skid trails near drainages and streams are kept hydrologically disconnected from the drainage network. Such a practice means that road segments near streams and stream crossings could need extra drainage structures installed and runoff directed away from streams to minimize the chance of sediment-laden runoff reaching a stream.

Discussion

Preventing concentrated runoff flow from reaching SMAs—or stopping concentrated flows within an SMA if they do reach it—is important to protecting water quality. Rivenbark and Jackson (2004) surveyed SMAs in the Georgia Piedmont to determine the efficacy of BMPs in preventing concentrated overland flow. Recording where flow broke through SMAs and where it did not break through to streams, they found that 50 percent of breakthroughs were at areas of convergence (swales) and gullies, and 25 percent were concentrated runoff from roads or skid trails. They determined that breakthroughs tend to occur in areas with a large contributing area, little litter cover, and steep slopes. They recorded some breakthroughs that traveled 100 feet before being filtered. More than half of breakthroughs traveled 50 feet before reaching stream channels and 14 percent traveled more than 100 feet before reaching streams, though 75 percent of breakthroughs were stopped within the first 20 feet of an SMA. Runoff travel distance before dispersal was not really related to slope, and breakthrough frequency did not differ between sites that were prepared post-harvest and sites that were clearcut and not prepared (Rivenbark and Jackson 2004).

Rivenbark and Jackson (2004) noted the importance of protecting the litter layer in an SMA to prevent concentrated flow from reaching the stream channel. In looking at concentrated flow, White et al. (2007) recorded significant formation of concentrated flow after runoff had traveled 6 m through forested filter strips. According to their study, removing the litter layer can have a major effect on overland flow travel time, especially on steeper slopes. On terrain of the same slope but with a disturbed and undisturbed litter layer, runoff from the terrain with the disturbed litter layer traveled 40 seconds per meter faster on 15–17 percent slopes and 12 seconds per meter faster on 5–7 percent slopes (White et al. 2007).

The effectiveness of SMAs in protecting water quality, therefore, could be improved by protecting the litter layer, dispersing road runoff better, introducing hydraulic resistance to likely flow paths, and widening SMA at key locations (Rivenbark and Jackson 2004). Additionally, the width of SMAs could be varied on the basis of physical features of the site. For instance, SMAs could be extended in sensitive areas, their width could be based on the potential hydrologic load of upland areas rather than being a set width, they could be wider where the contributing area is large and slopes are steeper, and a sub-SMA—a width beyond the primary SMA—could be established where clearcutting is allowed but ground cover is not disturbed and burning and herbicide use is prohibited. It could also be beneficial to stack logging slash along SMA boundaries to intercept and slow concentrated flows (Rivenbark and Jackson 2004).

2. Analyze the connectivity of a road network to streams (using computerized models and risk analysis, if feasible) to determine where the risk of sediment runoff to streams is greatest and where road maintenance efforts should be concentrated, or road sections should be removed or modified.

Within a forest road network, a small portion of the road surface generally contributes disproportionately to water quality deterioration. Finding out which road segments are responsible for water quality deterioration can best be accomplished with computerized techniques that can analyze a variety of information about individual road segments to determine those where maintenance or decommissioning will have the greatest effect.

Discussion

The computer programming methods mentioned above are best used to plan a forest road network before one has been constructed to minimize costs and environmental damage. Computerized techniques for managing existing forest road networks, including road maintenance for water quality protection and road decommissioning, are also being developed. Because runoff and sediment delivery is the dominant process by which water resources are affected by forestry activities, the concept of a forest road system's hydrological connectivity to a stream network has been the focus of much recent research. By managing runoff delivery pathways and the resultant pattern of hydrological connectivity of the road system to the stream network, the potential adverse effects of forest harvesting on in-stream water quality can be limited (Croke and Hairsine 2006).

Computer programming methods are not necessarily needed to analyze small forest road networks where main access roads lead off of public roads and feeder roads are either limited in number or lacking. Under such circumstances, field monitoring of road conditions performed at regularly scheduled intervals or after storms to check for signs of erosion and road failure should be sufficient to determine where road maintenance or road decommissioning is necessary to minimize water quality impacts.

The various links between site runoff, transport, and movement through an extensive forest system into the river system at a site can be difficult to quantify accurately partly because it is difficult to accurately measure the amount of sediment and attached nutrients delivered to, stored and remobilized within, and eventually transported from a river system (Croke and Hairsine 2006). A combined approach of reducing the source strength and enabling the delivery path to trap mobilized sediment, thereby reducing connectivity, is a sound approach to managing the sediment delivery problem.

Three types of runoff delivery pathways from forest roads exist: stream crossings, gullied pathways, and diffuse pathways (Takken et al. 2008). Sediment delivery to streams depends on source strength and the characteristics of the delivery path. Importantly, the degree of connectivity of a road to surface waters depends on catchment characteristics such as topography, road placement, drain spacing, and road and drainage density (Takken et al. 2008).

Takken et al. (2008) evaluated the risk of road-derived runoff delivery. They created risk assessment maps using road-stream hydrological connectivity to highlight hot spots and to evaluate procedures for road rehabilitation. Examining the relatively steep Albert River catchment in Australia, they found that diffuse overland flow could be minimized with additional road drains, particularly by adding more stream crossings per kilometer (km) of road where drainage area is large and roads are lower on the hillslope. Road segments that are highly connected to the stream network, however, were found to require the relocation of the road to manage sediment delivery to streams (Takken et al. 2008).

Croke et al. (2005) demonstrated that a strong association exists between runoff pathway and drain type. They found that most (90 percent) of gullied pathways were at culvert pipes that drain cut-and-fill roads, whereas miter drains and push outs were predominantly associated with dispersive pathways. They studied main access roads, feeder access roads, and minor access roads. Initial sediment concentrations at road outlets ranged from 2 grams per liter (g/L) to 15 g/L and were highest from well-used main access roads compared with less-frequently used feeder access and dump access roads. Road usage alone explained 95 percent of the variation in sediment concentrations in runoff from the road surfaces studied. Most (more than 50 percent) sediment in runoff from the road outlets was silt- and clay-sized material, but sediment concentrations in runoff plumes from main access roads had about 3.5 times higher concentrations of < 63-μm material than those from feeder access roads (Croke et al. 2005).

Croke et al. (2005) concluded that the potential effect of road-related sediment on in-stream water quality can best be assessed in terms of the nature and connectivity of the delivery pathway. Forest roads have a delivery pattern largely determined by runoff source strength and connectivity. *Connectivity* is the arrangement and location of drainage structures such as culverts and miter drains with respect to the natural drainage system in the catchment (Croke et al. 2005).

Examining the hydrological connectivity of a forest road network and stream system can help determine where best to focus efforts to reduce sediment and nutrient inputs to surface waters. Fu et al. (2007) developed and applied a road erosion and sediment transport model. In the areas in southeastern of Australia that they studied, approximately 21 kilotons (kt) and 35 kt of sediment were produced annually from road erosion. They found that less than 10 percent of the sediment produced was delivered to streams, and about half of the delivered sediment was derived from only 4 percent of the total road network (Fu et al. 2007).

Allison et al. (2004) conducted research to demonstrate that decision analysis can be used to organize the complex nature of forest road decisions using road deactivation as an example decision. Road segments that are candidates for deactivation were ranked using factors of interest, which in the case of this study was to reduce the susceptibility of roads to landslides and debris flows. The rankings distinguish between road sections that offer high expected benefit from those that offer moderate to low expected benefit. Allison et al. (2004) applied the analysis to an area with steep terrain, but it could be applied to any terrain type and with various factors of interest. They found in their case that 17 of 171, 100-m road segments accounted for 18 percent of the cumulative cost of deactivation but 98 percent of the cumulative expected net benefits from road deactivation. The results point out that some road segments have a higher benefit-cost ratio than others and that most of the total potential restoration benefit (reduced sediment delivery to streams, maintenance cost, and such) can be obtained from a small proportion of the total road network and potential cost (Allison et al. 2004).

Road decommissioning is expensive, and Eastaugh et al. (2007) assessed the outcomes of different forest road decommissioning options to determine whether costs and environmental impacts could be lowered. They present a method of quantifying the degree to which a road is hydrologically connected to a stream network and the likely effects of different configurations of road construction on water quality. Their method permits the quantification of road/stream connectivity without the need for extensive parameterization, which reduces both the time and cost of implementing the method. They noted that several models exist for predicting road-derived sediment production and delivery, but those models suffer from the practical disadvantage of being highly parameterized, requiring a large number of input data that are often difficult to obtain or accurately estimate. In contrast, the method used by Eastaugh et al. (2007) uses a high-resolution DEM based on 1-m spaced LiDAR measurements to represent catchment topography. The road morphology data necessary for the evaluation was collected during an intensive field survey using a GPS receiver to record the location of road edges, culvert locations, and drain outlets from the road surface (Eastaugh et al. 2007).

Eastaugh et al. (2007) applied the model to an actual road decommissioning and replacement project in southeast Australia. For the application, road areas and drainage outlets were surveyed in the field, and flow paths to streams were derived from a 1-m resolution LiDAR-based DEM. The results of the application demonstrated that the road decommissioning project examined would have been unlikely to reduce runoff to the stream network and that the overall effect of the decommissioning would likely have been a net *reduction* in stream water quality from *increased* sedimentation (Eastaugh et al. 2007).

Best Management Practices

1. Avoid having traffic on forest roads when road water content is high.

Truck traffic on forest roads when the water content of the road is high leads to deformation of the road surface, which redirects runoff and reduces the effectiveness of drainage structures.

2. Use aggregate on forest roads near stream crossings.

Sediment runoff from roads surfaced with an aggregate chosen to withstand the intended traffic load can be much less than from unprotected roads or roads with an aggregate of insufficient quality to handle the traffic load. It is especially important to protect and maintain roads near streams and stream crossings.

Discussion

Suspended sediment makes up 96 percent of the total sediment load from runoff, and a practical option to limiting it in runoff is to reduce the generation rate by surfacing roads adequately with aggregate and maintaining road drainage so it functions as intended (Sheridan et al. 2006).

Sheridan et al. (2006) investigated the effect of truck traffic intensity on runoff water quality from unsealed, gravel-surfaced forest roads. In their studies, traffic explained 36 percent of the variation in erodibility, pointing to the importance of adequately surfacing and maintaining forest roads. Under wet-road conditions, it is common for the cross-sectional profile of a road to become deformed by longitudinal rutting caused by traffic. That compromises lateral road drainage and concentrates flows along the road surface, bypassing drainage structures and leading to rilling of the road surface and high sediment generation rates (Sheridan et al. 2006). The results of Sheridan et al. (2006) indicate that surfacing a road adequately and maintaining it in good condition can reduce sediment production.

Roadside ditches and other drainage features often produce finer sediment than natural conditions, and roads with only marginal-quality aggregate containing low-durability fine particles can produce 4 to 17 times more sediment than those with good-quality aggregate (Witmer et al. 2009). Witmer et al. (2009) recommend that because of limited budgets and the need for cost-effective water quality protection, a priority listing of unpaved road-stream crossings is needed before restoration and sedimentation reduction strategies can be implemented.

Witmer et al. (2009) addressed the problem of determining where to focus road rehabilitation efforts by developing a sedimentation risk index (SRI) for unpaved road/stream crossings to help managers determine which road-stream crossings should receive priority for restoration and sedimentation reduction. The SRI created by Witmer et al. uses 12 metrics to weigh factors involving soil erodibility, road sedimentation abatement features, and steam morphology alteration to arrive at a final index score for each stream crossing. All types of stream crossings—round culvert, box culvert, and bridge—can be included, and they found no significant difference in SRI scores among crossing structure type, indicating that one type is not necessarily better when it comes to less sediment production than others. Limited budgets make prioritizing unpaved road crossings a key means for efficient sedimentation abatement, and the SRI or a similar rating scheme can be used to make water quality protection more effective (Witmer et al. 2009).

2.5 Timber Harvesting

Implementation Measures:

F-8. Install landing drainage structures to avoid sedimentation to the extent practicable. Disperse landing drainage over stable side slopes. Protect landing surfaces used during wet periods. Locate landings outside SMAs.

F-9. Conduct harvest and construct landings away from steep slopes to reduce the likelihood of slope failures.

F-10. Protect stream channels and significant ephemeral drainages from logging debris and slash material.

The goal of the Timber Harvesting implementation measure in the 2005 guidance is to minimize the likelihood of water quality effects resulting from timber harvesting. Precautions taken during preharvest planning to minimize road and skid trail miles, and follow the contour of the land to the extent feasible, are important aspects of protecting the forest floor from disturbance. Using equipment well suited to the topography and forest type to limit erosion and sedimentation during harvesting operations is also important.

When conducting a harvest, it is important to pay attention to the potential for soil disturbance from the operation. Doing so can result in improved water quality protection. Disturbances to forested watersheds can have severe adverse effects on soil and soil nutrients. Road construction and skidding associated with forest harvesting can cause serious soil disturbance that can increase suspended sediment in streams. It is vitally important that the forest floor be protected from disturbance to the maximum extent feasible during all aspects of harvesting.

Best Management Practice

1. When constructing roads, landings, and skid trails, and during harvesting, use methods that maximize protection of the forest floor to the extent feasible.

Most sediment and nutrient runoff from forest harvest sites originates in areas where the forest floor has been disturbed and the soil has been exposed, disturbed, or compacted. Protecting the litter layer and soils of the forest floor where it is possible (that is, where it need not be disturbed for road construction or skidding) is vital to ensuring the protection of water quality. Although roads and skid trails are generally maintained or protected after a harvest to limit sediment runoff, disturbed areas beyond these can go unnoticed and not receive the rehabilitation that roads and skid trails do to prevent sediment runoff. Unintentionally disturbed areas also are not usually provided with runoff control features, so any runoff originating from them could drain unchecked to streams and rivers.

Discussion

Protecting the forest floor outside the SMA is important to protecting the water quality of forested streams. Surface erosion generally does not occur in an undisturbed forest because of the infiltration capacity of the litter layer and forest soils (Hotta et al. 2007). Following that logic, in an unharvested forest where the source area of suspended sediment is limited to the stream, suspended sediment transport should correspond well with water discharge. Certain forest practices, such as constructing forest roads and skid trails and serious soil surface disturbances such as those caused by skidder activity and plowing, are known to increase suspended sediment yields.

Most studies have investigated the effects of the practices associated with harvesting rather than the harvesting itself. Hotta et al. (2007) investigated whether harvesting would increase suspended sediment yields if harvesters took appropriate measures to prevent surface disturbance, including using skyline logging treatments and piling branches and leaves at selected locations in the watershed. They performed the study in an experimental watershed in a steep-sloped forest near Tokyo, Japan. Hotta et al. (2007) measured suspended sediment yield from areas harvested using such methods and found that annual suspended sediment yields did not increase despite post-harvest increases in annual water yields. They found that after harvesting, there were no increases in suspended sediment yields concurrent with heavy rainfall events, when most suspended sediment was normally transported in the watershed. They concluded that post-harvest increases in suspended sediment yields can be controlled by using careful harvesting techniques (Hotta et al. 2007).

2.6 Site Preparation

Implementation Measure F-11:

Protect surface waters during site preparation by

1. Selecting a method of site preparation and regeneration that is suitable for the site conditions.
2. Conducting mechanical tree planting, ground-disturbing site preparation activities, and bedding on the contour of sloping terrain and outside SMAs and ephemeral drainages.
3. Protecting surface waters from logging debris and slash material, including locating windrows far enough from drainages and SMAs to limit the entry of material into surface waters during high-runoff conditions.
4. Suspending operations during wet periods if equipment begins to cause excessive soil disturbance that will increase erosion. Conduct bedding operations in high-water-table areas during dry periods of the year.

The Site Preparation and Forest Regeneration implementation measure in the 2005 guidance discusses how important it is to revegetate harvested areas to minimize erosion and runoff from disturbed soils that could degrade water quality. Vegetative cover on disturbed soils reduces erosion and slows runoff, and roots stabilize soils. Minimizing disturbance to the forest floor litter layer during all phases of forestry activities—from road construction to site preparation operations—minimizes soil compaction and detachment, which helps maintain infiltration and slow runoff. Such factors, in turn, reduce erosion and sedimentation after site preparation is complete.

Where soil and the litter layer have been disturbed, and in instances where it would not prevent the regrowth of planted trees or natural regeneration, protecting the soil by applying wood chips or slash could be a viable method to both protect the soil and prevent the loss of N from the soil to surface waters.

Best Management Practice

1. Apply wood chips or slash to disturbed areas after a harvest to reduce nutrient runoff.

N as nitrate is commonly leached from a forest after clearcut harvesting because the N cycle is disrupted when vegetation that would normally use the N is removed. The amount of nitrate that is made available for leaching depends on the amount of vegetation removed (generally, selective cutting or diameter-limit harvesting do not result in nitrate leaching), vegetative characteristics of the forest, and the time elapsed since the harvest. Nitrate leaching generally decreases as vegetation regrows on the clearcut site. Applying wood chips derived from logging slash can significantly reduce nitrate leaching after a harvest during the time when vegetation is re-establishing itself. The wood chips are thought to immobilize much of the nitrate in the forest floor.

Discussion

N as nitrate is a pollutant that can be released after forest harvest, especially after clearcutting. Soil temperature can also be increased, which can increase microbial activity, organic matter decomposition, and inorganic N production. Homyak et al. (2008) tested whether applying wood chips derived from logging slash after harvesting would immobilize nitrate and thus reduce its flux to streams. They applied wood chips to the soil surface in a stand of northern hardwoods that was patch clearcut in the Catskill Mountains, New York, and found that between 19 and 38 kg of nitrate per hectare were immobilized in the first year after harvesting, depending on the quantity of wood chips applied, which contributed to water quality protection. They suggest that additional research on wood chip application as a new BMP after harvesting is warranted, particularly in regions that receive elevated levels of atmospheric N deposition (Homyak et al. 2008).

Immobilizing nitrate in the forest floor by either leaving some logging slash on the ground or by adding woody material after logging might be a feasible way to reduce nitrate flux to streams and limit water quality impacts. Other studies in Japan, the Mediterranean, New Hampshire, and the Appalachian Mountains have shown similar results (Homyak et al. 2008).

2.7 Fire Management

Implementation Measures:

F-12. Prescribed and wildland fire should not cause excessive erosion or sedimentation because of the combined effect of partial or full removal of canopy and removal of ground fuels and the litter layer, to the extent practicable.

F-13. All bladed firelines, for prescribed fire and wildfire, should be stabilized with water bars or other appropriate techniques if needed to control excessive sedimentation or erosion of the fireline.

F-14. Consider the potential nonpoint source pollution consequences on watercourses of wildfire suppression and rehabilitation activities, while recognizing the safety and operational priorities of fighting wildfires.

The Fire Management implementation measure in the 2005 forestry guidance emphasizes the importance of using prescribed fire in a way that does not remove the litter layer so that erosion is not a problem after a fire. Recent research examines the mechanism by which fire can protect a forest from erosion or expose it to erosion and emphasizes the importance of fire management to protect a forest from post-fire erosion.

Best Management Practice

1. Ensure that prescribed fires are burned at a low enough intensity and at a burn rate such that the litter layer that remains behind is sufficient to protect the forest floor from erosion after the fire. Also, do not set prescribed fires or allow prescribed fires to burn in SMAs.

The presence of a litter layer on the forest floor is key to reducing and avoiding sediment runoff. A low-intensity prescribed fire is more likely to leave an intact litter layer and reduce nutrient runoff after a fire than a high-intensity fire.

Discussion

The importance of protecting the forest litter layer during forestry operations was stressed earlier. Because exposure of bare forest soils is the critical link to sediment and nutrient runoff, it is equally important to maintain the litter layer during and after a prescribed fire.

Studies have shown that low-severity prescribed fire removes the upper forest floor layer (the Oi layer of the soil O horizon) but retains a large proportion of the portions of the O horizon below that (the Oe and Oa horizon layers) (Knoepp et al. 2009). Those layers protect surface soils from potential erosion and represent a large reservoir of plant nutrients.

Knoepp et al. (2009) investigated N responses on sites in subwatersheds that drained a first-order stream in the Blue Ridge Physiographic province of the southern Appalachian Mountains. All prescribed fires were done in the dormant season and were low to moderate intensity. All sites lost a significant amount of forest floor mass due to burning: 82 to 91 percent of the Oi layer and 26 to 46 percent of the Oe + Oa layer. Soil NH_4-N concentrations increased immediately after burning in the top 5 cm of surface soils only but returned to pre-burn levels by mid-summer. Burning had no measurable effect on soil solution inorganic N concentrations. No inorganic N was lost from the sites (Knoepp et al. 2009).

Elliot and Vose (2005) conducted low- to moderate-intensity and low-severity prescribed burning to restore shortleaf pine/mixed-oak forest (Elliot and Vose 2005). Fires of a low intensity in the study were ones that left the Oe and Oa layers intact but reduced the uppermost litter layer (Oi), exposed little soil, and had heat penetration only near the soil surface. They measured soil solution and stream water nutrient concentrations and stream water sediment concentration (TSS). Soil solution and stream water (N) did not increase after burning on any of the sites, and they found no differences in TSS between the burn and control streams. No detectable differences between control and burned sites for concentrations of PO^4, SO^4, Ca, Mg, K, or pH in soil solution or stream water were found, either. The results suggest that low-intensity, low-severity fires can be conducted and used as a management tool without negatively affecting water quality (Elliot and Vose 2005).

2.8 Revegetation of Disturbed Areas

Implementation Measures:

F-15. Revegetate disturbed areas (using seeding or planting) promptly after completing the earth-disturbing activity. Local growing conditions will dictate the timing for establishing vegetative cover.

F-16. Use mixes of species and treatments developed and tailored for successful vegetation establishment for the region or area. Native species are generally preferred, although nonnative species can be acceptable as long as they are noninvasive.

F-17. Concentrate revegetation efforts initially on priority areas such as disturbed areas in SMAs or the steepest areas of disturbance (e.g., on roads, landings, or skid trails) near drainages.

The 2005 forestry guidance describes the Revegetation of Disturbed Areas implementation measure, and the practices provided in the 2005 guidance are still the best advice for quickly restoring vegetation on disturbed forest areas. This chapter provides no additions to the information in the 2005 guidance. Revegetating disturbed areas is still important because it restabilizes the soil, reduces erosion, and helps prevent pollutants from entering surface waters. As knowledge of the ecological damage that can be caused by nonnative species has expanded after numerous unsuccessful introductions of nonnative species for erosion control or other purposes, it must be emphasized, however, that native species are preferred for revegetating disturbed areas and any species used, whether native or nonnative, should be noninvasive for the habitat into which it is to be introduced. Local or regional offices of a cooperative extension service can offer excellent advice on species selection for revegetation uses.

2.9 Forest Chemical Management

Implementation Measures:

F-18. Establish and identify buffer areas for surface waters. (This is especially important for aerial applications.) Conduct applications by skilled and, where required, licensed applicators according to the registered use, with special consideration given to effects on nearby surface waters. Carefully prescribe the type and amount of pesticides appropriate for the insect, fungus, or herbaceous species.

F-19. Before applying pesticides and fertilizers, inspect the mixing and loading process and the calibration of equipment, and identify the appropriate weather conditions, the spray area, and buffer areas for surface waters. Immediately report accidental spills of pesticides or fertilizers into surface waters to the appropriate state agency. Develop an effective spill contingency plan to contain spills.

The 2005 forestry guidance describes the Forest Chemical Management implementation measure. This chapter provides no additions to the information in the 2005 guidance. Chemicals used in forest management include pesticides (insecticides, herbicides, and fungicides) and fertilizers. Mixing, transporting, and applying the chemicals correctly and according to manufacturer directions, and disposing of containers properly will prevent water quality issues related to those substances to a great degree. For information relevant to forest chemical management, see the 2005 guidance.

2.10 Wetlands Forest Management

Implementation Measure F-20:

Plan, operate, and manage normal, ongoing forestry activities (including harvesting; road design, construction, and maintenance; site preparation and regeneration; and chemical management) to adequately protect the aquatic functions of forested wetlands.

The 2005 forestry guidance describes the Wetlands Forest Management implementation measure. This chapter provides no additions to the information in the 2005 guidance. The 2005 guidance discusses special harvesting methods for use in forested wetlands, road design and construction practices especially applicable to forested wetlands, wetland crossing practices, site generation and regeneration practices for use in forested wetlands, fire management practices for forested wetlands, and chemical management for working in forested wetlands. The information provided in the 2005 guidance is still EPA's official guidance for forestry work in wetland environments.

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Chapter 5.
Riparian Area Management

Contents

1 Introduction

1.1 What is a Riparian Area?

A riparian area is defined as

> A vegetated ecosystem along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of those two landforms. They will sometimes, but not in all cases, have all the characteristics necessary for them to be also classified as wetlands (USEPA 2005).

In other words, riparian areas are the areas between uplands and adjacent waterbodies that encompass the floodplain and some transitional upland area (Tjaden and Weber 1998). Both soils and vegetation in riparian areas are usually distinctly different from the surrounding uplands and typically support a diverse and unique population of animals as compared to uplands. They act as natural filters of nonpoint source pollutants, including sediment, nutrients, pathogens, and metals, to waterbodies such as rivers, streams, lakes, and coastal waters. The term *riparian buffer* is used to distinguish a specific area adjacent to the stream within a riparian area (see Figure 5-1) or, in some cases, it might include the entire area. Riparian buffers can also be referred to as riparian management zones, buffer strips, and streamside management zones.

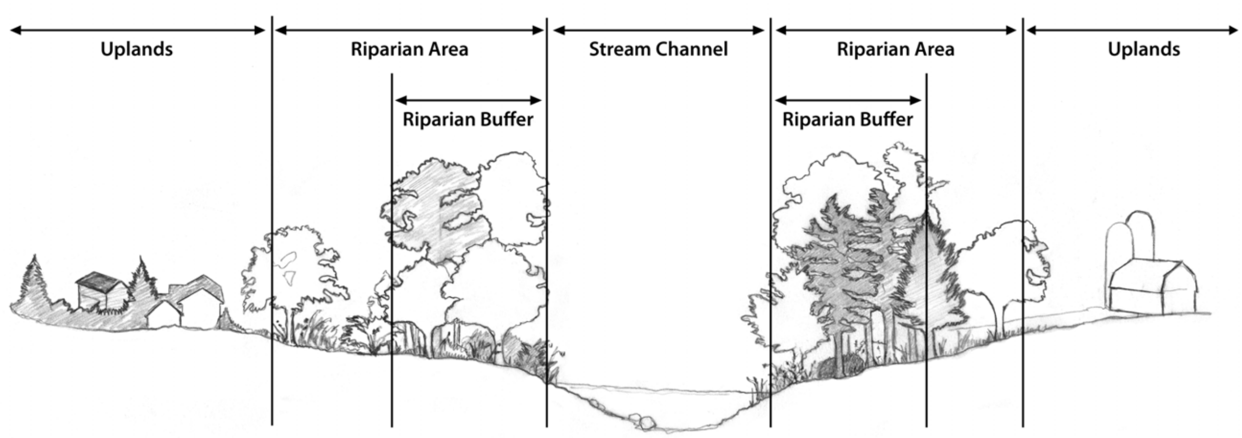


Figure 5-1. Relationship between uplands, riparian areas, riparian buffers, and the stream channel.

Riparian areas are inextricably linked to the stream itself. Disturbances that affect the riparian area affect the stream and vice versa. *Stream corridor* is a term used to describe the combined riparian/stream ecosystem (FISRWG 1998). Stream corridors in the Chesapeake Bay region evolved within temperate, forested watersheds (Williams 1989). Thus, system structure, functions, and biota in the corridor all developed within a range of natural conditions associated with forest ecosystems. For that reason, management plans aimed at restoring streams to a more natural state typically focus on restoring and protecting riparian forest buffers.

1.2 Why Riparian Buffers?

Riparian buffers (Figure 5-2) can significantly aid in reducing pollution contributions to the Chesapeake Bay, including nitrogen (N), phosphorus (P), and sediments. They also contribute to the protection of streams and streambanks and provide habitat for a multitude of species. Ideally, a network of buffers along a stream can act as a natural right-of-way, allowing the stream to move through the landscape *buffered* from direct influences of development in the watershed. Riparian forested buffers in particular have long been recognized as a vital part of the Chesapeake Bay ecosystem. For those reasons, the U.S. Environmental Protection Agency (EPA) considers the protection and restoration of riparian buffers to be a critical element of the Chesapeake Bay Program.

Figure 5-2. A riparian buffer.

> ***Riparian Buffer Goal for the Chesapeake Bay**:* Forest buffers should exist on at least 70 percent of all shorelines and streambanks in the watershed.

The Chesapeake Executive Council adopted the 70 percent riparian buffer goal for the Bay in 2003 (Chesapeake Executive Council 2003). EPA reiterates that goal in this guidance. An interim goal to achieve 63 percent by 2025 was adopted as part of the Chesapeake Bay Strategy under the Executive Order.

Approximately 58 percent of the Bay's riparian areas are forested. To reach both the interim goal of 63 percent and long-term goal of 70 percent coverage in the entire watershed, the Chesapeake Bay Program and its partners will need to restore at least 30,000 miles of riparian buffers and conserve all riparian areas that are forested. The following two implementation measures for riparian buffers will enable the forested riparian buffer goals to be met.

Implementation Measures:

R-1. Promote the restoration of the preexisting functions in damaged and destroyed riparian systems, especially in areas where the systems will serve a significant nonpoint source pollution-abatement function as well as the suite of valuable ecosystems services riparian buffers provide.

R-2. Protect from adverse effects riparian areas that are serving a significant nonpoint source pollution-abatement function and maintain this function while protecting the other existing functions of these riparian areas.

The measures are in line with past EPA guidance (USEPA 2005) as well those described in the National Research Council report *Riparian Areas: Functions and Strategies for Management* in 2002 (NRC 2002). Specifically, that restoration of riparian functions along America's waterbodies should be a national goal, and protection should be the goal for riparian areas in the best ecological condition.

1.3 Who is This Chapter For?

This chapter of the guidance document is written for federal land managers who manage riparian areas. EPA anticipates that it will be useful for others involved in watershed planning, including conservation districts, local municipalities landowners, and land use managers, total maximum daily load developers, conservation trusts, and natural resource contracts specialists.

1.4 What Does This Chapter Cover?

This chapter has three main sections:

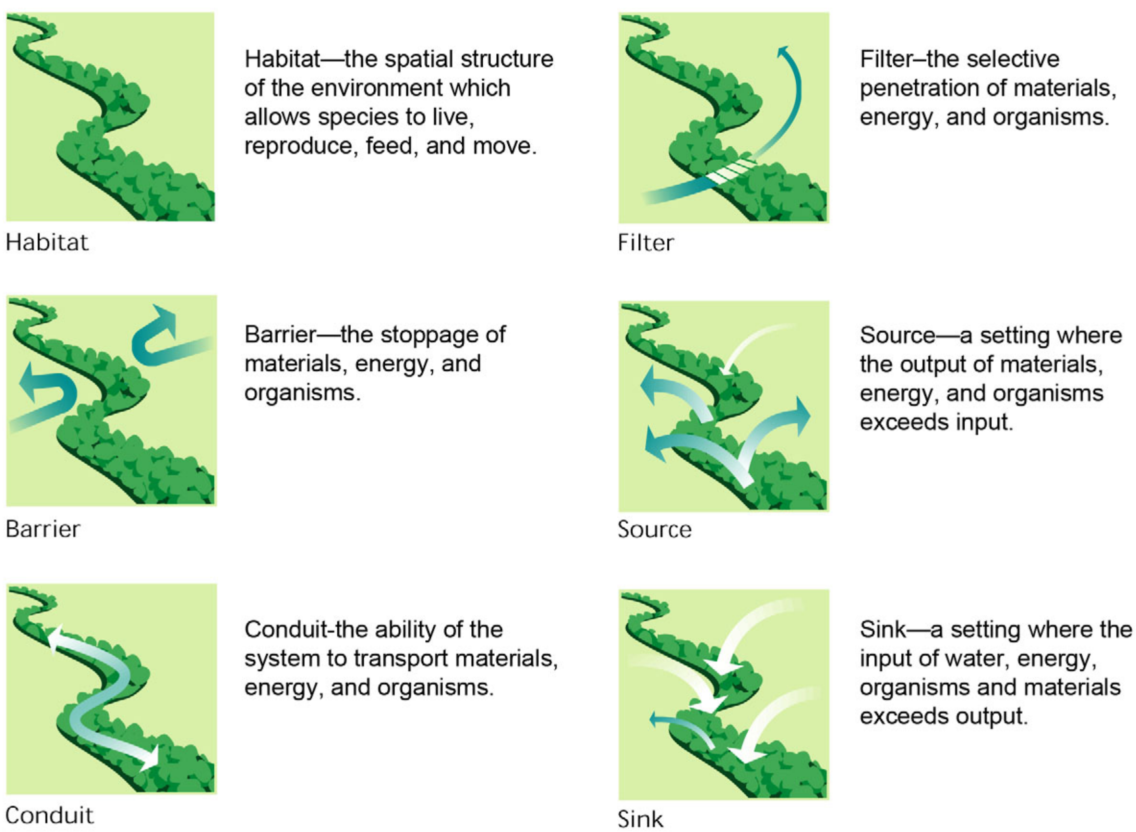
- Section 2 describes the benefits of buffers, including pollutant-removal efficiency and factors that affect it.
- Section 3 outlines recommendations for the restoration of forested buffers in the Chesapeake Bay and includes site selection, planting, and short-term maintenance of newly restored sites.
- Section 4 discusses strategies for the long-term maintenance and the protection of existing forested riparian areas. Such areas must first be identified and assessed before they can be properly maintained and protected.

2 Benefits of Natural Riparian Areas

Many benefits are associated with forested riparian areas. Some of those benefits can be replicated with technology such as reservoirs (flood control) and treatment plants (pollutant removal). However, none of those single-function replacement technologies provide the multiple, simultaneous functions of a healthy forested riparian area.

This section describes a few of the most important of the many benefits. In general, benefits can be categorized into one or more of six broad ecological functions (FISRWG 1998) (Figure 5-3):

- *Barrier and Filter*—The ability to stop or limit penetration of water, materials, energy, and organisms into, through, or along the stream corridor
- *Habitat*—The spatial structure of the riparian area and stream, which allows organisms to live, feed, and reproduce



Source: FISRWG 1998

Figure 5-3. Critical ecosystem functions.

- *Conduit*—The ability of the corridor to serve as a flow pathway for water, materials, energy, and organisms
- *Source* and *Sink*—The net movement of water, materials, energy, and organisms in or out of the buffer

2.1 Water Quality Benefits

2.1.1 Filtering Sediment Pollution

Erosion, transport, and deposition of various-sized soil particles from the watershed into the stream channel are natural processes that shape the landscape over time. Those processes are disturbed by human activities such as urban development and agriculture. The exposure of soil during construction, because of overgrazing or between growing seasons, combined with the increased surface runoff associated with increased impervious surfaces and soil compaction increase sediment loading to streams. That causes a variety of negative in-stream effects, including the following:

- Destroying beneficial channel structures such as pool and riffles
- Damaging gills of fish and aquatic insects
- Filling in pore spaces on the stream bed and suffocating benthic biota
- Interfering with fish spawning habitat, and egg and larval survival
- Reducing light penetration and interfering with algae and aquatic plant photosynthesis

Riparian areas help regulate the amount and size of sediment that reaches the stream from upland sources. Assuming that sediment-laden runoff moving through the riparian area is not allowed to concentrate, channelize, and convey directly to the stream, sediment will be deposited as riparian vegetation slows runoff and water infiltrates the soil.

2.1.2 Filtering Nutrient Pollution

N and P are two nutrients essential for the growth of algae and other aquatic plants. When present in excessive amounts, however, they can trigger algal blooms, nuisance levels of plant growth, and overall degradation of a stream. Altering land use for human activity has greatly increased the amount of nutrients in aquatic systems. Those excess nutrients come from lawn and agricultural fertilizers, animal wastes, sewage treatment plants, and septic systems. The potential pathways to a stream of the two nutrients differ, however, because of different chemical properties. Correspondingly, the filtering mechanisms for P and N within riparian areas also differ.

P has a strong tendency to sorb to soil particles and organic matter. Therefore, it is usually moved across the landscape attached to sediment that is carried in surface runoff. Consequently, the conditions and mechanisms that serve to filter out sediments in riparian areas serve to filter out P. As sediment settles from runoff and water infiltrates the soil, the attached P can either remain in the soil or be taken up by riparian vegetation.

On the other hand, N does not sorb strongly to sediment. While N in particulate form can be physically filtered by vegetation, similar to sediments, nitrate in dissolved form can infiltrate the soil, move with groundwater, and potentially enter the channel with shallow subsurface flow or baseflow.

Bacteria residing in riparian soils play an important role in filtering N through a process called *denitrification*. That process reduces nitrate to primarily dinitrogen gas (N_2) with possible production of trace amounts of nitrous oxide, a potent greenhouse gas, both of which are released into the atmosphere. The basic requirements for denitrification are anaerobic conditions or restricted oxygen availability (saturated soil conditions), a good supply of nitrate and electron donors such as organic material, and warm conditions (above 50 degrees Fahrenheit [°F]). Other microorganisms and biota in the soil take up N, as do plants if the root zone is saturated part of the time.

2.1.3 Estimated Pollutant Removal

The Mid-Atlantic Water Program at the University of Maryland led a project in 2006–2007 to review and refine definition and effectiveness estimates for best management practices (BMPs) in the Chesapeake Bay watershed, including grassed and forested riparian buffers in agricultural areas. The objective was to develop estimates that reflect the average operational condition representative of the entire watershed to better reflect monitored data in modeling scenarios and watershed plans. Table 5-1 summarizes the nutrient and sediment reduction efficiencies for forest and grass buffers in agricultural areas on the basis of the literature review performed for this study. As indicated by the results, forest buffers are better at reducing N loads to the Chesapeake Bay; however, forest and grass buffers are the same in their ability to reduce P and sediment loads.

Table 5-1. Average nutrient and sediment reduction efficiency comparison of riparian forest and grass buffers

	TN reduction (%)		TP reduction (%)		TSS reduction (%)	
Location	**Forest**	**Grass**	**Forest**	**Grass**	**Forest**	**Grass**
Inner Coastal Plain	65%	46%	42%	42%	56%	56%
Outer Coastal Plain Well Drained	31%	21%	45%	45%	60%	60%
Outer Coastal Plain Poorly Drained	56%	39%	39%	39%	52%	52%
Tidal Influenced	19%	13%	45%	45%	60%	60%
Piedmont Schist/Gneiss	46%	32%	36%	36%	48%	48%
Piedmont Sandstone	56%	39%	42%	42%	56%	56%
Valley and Ridge—marble/limestone	34%	24%	30%	30%	40%	40%
Valley and Ridge—sandstone/shale	46%	32%	39%	39%	52%	52%
Appalachian Plateau	54%	38%	42%	42%	56%	56%

Source: Simpson and Weammert 2009
Note: TN = total nitrogen; TP = total phosphorus; TSS = total suspended solids

It is important to remember that all buffers do not have the same efficiency for pollutant reduction (Speiran et al. 1998). Pollutant-removal estimates in Table 5-1 are based on average conditions in agricultural areas and were developed for use in EPA's Chesapeake Bay Water Quality Model. Research on pollutant removal in urban and suburban areas is limited. In addition, site-specific conditions can greatly affect pollutant-removal processes. Hot spots, regions of disproportionately high reaction rates compared to the surrounding area, or hot moments, short periods when disproportionately high reaction rates occur compared to typical conditions, can occur and alter annual contaminant budgets at the watershed scale (Vidon et al. 2010).

Hydrology plays a significant role in buffer effectiveness. The filtering functions of a buffer are greatly reduced when runoff enters the riparian area as concentrated flow or channelizes while flowing through the buffer. Denitrification in riparian zones is affected by the depth of the water table and the presence of subsurface carbon and dissolved oxygen in groundwater. Pollutant removal is reduced where ideal conditions do not occur. For example, in urban areas, surface runoff is usually diverted into a stormwater management system that conveys water directly into streams. Similar short circuiting occurs in agricultural areas that are tile drained. In those situations, runoff completely bypasses riparian buffers and does not receive any of their pollutant-removal benefits.

Because of those and other factors, pollutant source control, discussed in the other chapters of this document, is extremely important in addition to the use of riparian forest buffers for water quality.

The U.S. Department of Agriculture (USDA) Agricultural Research Service Southwest Watershed Research Laboratory developed the Riparian Ecosystem Management Model (REMM), for researchers and natural resource agencies to help quantify the water quality benefits of riparian buffers under varying site conditions. REMM requires weather data, pollutant input information, riparian soils, vegetation, and litter information and is calibrated only for the Coastal Plain in Georgia, but it would be useful in areas with similar conditions where the required input parameters are available.

2.2 Floodplains and Streambanks

During intense storms, water levels in the stream can rise above bankfull elevation and spill into the hydrologic floodplain. Flooding is important because it reconnects the floodplain to the stream and provides habitat conditions critical for the reproductive cycle of some species of fish, insects, amphibians, and reptiles. Increased impervious surfaces or compacted soils associated with urban development in a watershed increases flow energy in streams, which can cause greater rates of streambank erosion. That erosion can become so significant that even with the increased runoff entering the stream, the stream becomes incised and completely disconnected from its floodplain.

The presence of a healthy riparian area can mitigate the effects of such altered hydrology. One study found that vegetation restoration of bare ground and livestock trampled riparian zones reduced catchment export of sediment from more than 100 kilograms per hectare per year to less than 10 within one year, mainly by reducing bank erosion and stabilizing the stream channel (McKergow et al. 2003).

Woody riparian vegetation in the floodplain serves to dissipate flow energy during floods. Root systems of riparian vegetation immediately adjacent to the stream help bind sediments, which can reduce bank erosion. Riparian forests contribute large woody debris to streams, such as branches, logs, and root wads. The roughness they create in the channel can slow stream velocity, which promotes channel bed and bank stability and sediment deposition (Harmon et al. 1986). Dams created by the debris can also increase sediment deposition in channels and increase flooding frequency that promotes sediment deposition on floodplains (Dosskey et al. 2010). Deposition of sediment also removes sediment-bound chemicals (such as P) and soil organic matter from the water column, which in turn contributes to biogeochemical processes in floodplains and the stream channel.

2.3 Maintaining Aquatic Habitat

Stream biota, including bacteria, algae, macrophytes, zooplankton, macroinvertebrates, fish, amphibians, reptiles, and mammals, all require a hospitable aquatic environment to live, reproduce, interact, and thrive. The riparian area plays a crucial role in maintaining a range of suitable habitats and conditions within the channel for a diverse and self-sustaining cycle of aquatic life. Good quality terrestrial habitat is essential for maintaining water quality and natural flows in the stream channel.

As discussed in Section 1 of this chapter, a riparian area usually includes the streambank, floodplain, and some portion of the transitional upland area. Natural features within such areas add structural variety and might include wetlands, natural levees, oxbow lakes, and other landforms. Diversity of riparian features usually results in corresponding diversity in soils, vegetation, and biota—important attributes of a healthy terrestrial habitat.

A few important benefits of forested riparian areas for habitat are described below.

- *Contributing wood debris to the channel*—Large, woody debris that falls into the channel creates additional habitat diversity for fish and other aquatic biota, especially in smaller streams. They often create a damming effect that traps sediment and create scour holes and function as fish habitat.
- *Provides allochthonous input of organic matter*—Energy sources that drive metabolic activity in a stream come from either autochthonous sources (within the stream channel via algae and aquatic plant photosynthesis) or allochthonous sources (outside the stream channel). In smaller, shaded headwater streams, there is little aquatic primary production because of lower light levels. Here, allochthonous input of woody material, leaves, and other organic matter is critical for the base of the food chain. Bacteria and fungi break the material down, and their microbial biomass becomes food for shredding invertebrates. Organic particles are subsequently transported to provide energy for downstream organisms.
- *Maintaining stream temperature*—Water temperature determines the range and viability of aquatic species. Some species, such as trout, require cold water temperatures. Other species, such as smallmouth bass, tolerate warmer temperatures. Riparian vegetation that covers the channel reduces solar radiation and keeps water temperatures cooler. Baseflow (from groundwater inflow) helps keep water temperatures stable year round.

2.4 Aesthetic Value

Besides water quality and habitat benefits, riparian areas can add value to property providing seasonal changes, such as shade in summer, flowers and birds in spring, and color in fall (Baird and Wetmore 2003). A study in 2006 in Missouri found that residents are willing to pay to live in an area with community-owned and accessible buffers and are willing to pay even more to live adjacent to such areas (Qiu et al. 2006). That pattern is consistent with other studies (Patterson and Boyle 2005; Netusil 2006).

2.5 Forested versus Grassed Buffers: Increased Focus on the Buffer/Stream Interface

Sweeney and Blaine (2007) point out that buffers have been historically viewed almost exclusively in terms of their barrier and filter functions; specifically, their ability to filter out upland sediment, nutrients, and other pollutants before they reach the channel. Such a focus on the upland/buffer interface resulted in a general acceptance of grass buffers as a reasonable alternative to forested buffers, because some studies show similar pollutant-removal efficiencies. For cultural, sociological, budgetary, and other reasons, grass buffers were even sometimes promoted as the preferred choice for riparian vegetation.

Research in the past decade, however, has revealed that grass buffers are about 68 percent as effective as forest buffers in reducing total nitrogen (TN) (Todd 2002). But perhaps more significant, the positive effects that riparian forest buffers have on stream systems have been more fully explored and documented. Sweeney (1992, 1993) reinforced the idea that stream processes, functions, and biota were developed in concert with riparian forests rather than riparian grasslands, and the absence of trees creates considerable stress on the natural aquatic ecosystem. For example, a study of forested and deforested small streams in the Piedmont region demonstrated that deforestation caused significant channel narrowing which, in turn, reduced stream habitat and processing of organic matter and nutrients (Sweeney et al. 2004). The study also determined that a forested stream ecosystem had 2 to 10 times more uptake of N than a grass ecosystem. For those reasons, this chapter focuses on forested riparian buffers.

That is not to say that upland/buffer interface is not an important consideration for buffer design, because that is where most sediment deposition and much biogeochemical removal occurs. However, the buffer/stream interface must not be overlooked.

3 Restoring and Reestablishing Riparian Forest Buffers

Implementation Measure R-1:

Promote the restoration of the preexisting functions in damaged and destroyed riparian systems, especially in areas where the systems will serve a significant nonpoint source pollution-abatement function as well as the suite of valuable ecosystems services riparian buffers provide.

3.1 Introduction

Approximately 58 percent of the streams in the Chesapeake Bay have riparian forest buffers, short of the 2025 goal of 63 percent, and the long-term goal of 70 percent. That means that restoring or reestablishing riparian forests is required to meet the Bay goal. Maryland, Virginia, Pennsylvania, and the District of Columbia have proposed in their tributary strategies to restore some 50,000 miles of riparian forest buffers to help reach water quality goals for major rivers that drain into the Bay (Greiner and Vogt 2009).

Successful restoration and reestablishment of buffers in the Chesapeake Bay area require that landowners, managers, public agencies, and other responsible parties assess ecological functions provided by existing riparian soils and vegetation and then make the best adjustments and improvements possible given cost, funding, and other practical constraints. In many cases, restoration will include planting seedlings and eventually reestablishing fully functioning riparian forest.

3.1.1 Organization of This Section

This section is organized to cover the basic steps for undertaking a successful riparian forest buffer restoration project.

- Selecting and prioritizing areas for restoration (Section 3.2)
- Analyzing existing conditions and identifying potential problems at the site level (Section 3.3)
- Importance of connectivity and determining the appropriate buffer width (Section 3.4)
- Selecting, planting, and protecting tree seedlings (Section 3.5)

Much of the information presented in Sections 3.2 and 3.4 are based on the Maryland Department of Natural Resources Forest Service (DNR FS) manual, *Riparian Forest Buffer Design and Maintenance* (2005). For details about the methods and procedures described, see that manual.

Section 3.6 wraps up the chapter by discussing costs of riparian buffer restoration.

3.2 Selecting and Prioritizing Areas for Restoration

As discussed in Section 2.1, to get certain pollutant-removal benefits, riparian buffers must intercept pollutants. While seemingly obvious, it is usually easier said than done. While it is easy to identify areas where runoff would bypass riparian buffers, such as areas with stormwater outlet pipes and gullies, other factors are less obvious. A few studies have found that groundwater seeps due to macropores from roots can also reduce buffer effectiveness and have a significant effect on stream chemistry (O'Driscoll and DeWalle 2010; Angier and McCarty 2008). Identifying those conditions is expensive and time consuming, and it is not possible on every riparian restoration site. Fortunately, land managers can use information such as stream order and geographic information system (GIS)-based data analysis tools to locate areas where maximum pollutant-removal benefits are most likely.

3.2.1 Stream Order

As a mainstem stream moves through its watershed, it drains an increasing amount of land area. The mainstem stream is continuously fed by a network of feeder streams. Strahler (1957) proposed a classification system to identify the position of all streams in a watershed network. Small streams with no tributaries are first-order streams (Figure 5-4). When two first-order streams flow together, they become a second-order stream. The confluence of two second-order streams creates a third-order stream, and so on.

Lower order streams dominate the landscape in terms of numbers and stream mileage. It is estimated that 75 percent of streams in the United States are first- and second-order streams and 90 percent are first-, second-, or third-order streams (FISRWG 1998; Leopold et al. 1964). Therefore, meeting the short- and long-term goals for forested riparian buffer coverage in the Chesapeake Bay watershed requires managers to focus primarily on restoring buffers of lower order streams.

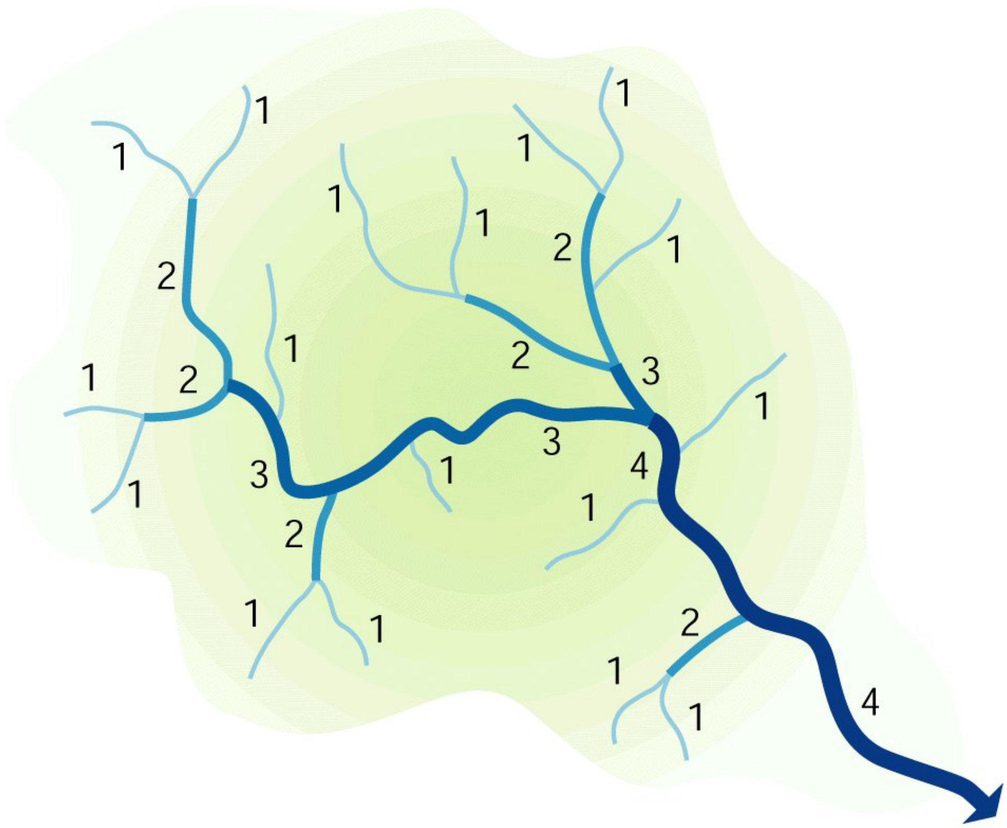


Figure 5-4. Strahler's stream classification.

The relatively small scale of headwater streams also increases the magnitude of influence the riparian area has on them (Sweeney and Blaine 2007). A forest canopy, for example, can easily extend across small streams and keep stream temperature cool. Large, woody debris adds proportionally more structure to the channel, and allochthonous materials are distributed throughout the channel and support life in virtually all microhabitats.

Because a small stream's watershed is also smaller in size, a forest buffer of even modest proportions can effectively regulate the lateral flow of water and filter a commensurate volume of sediments, P, and other pollutants (Dosskey et al. 2005; Polyakov et al. 2005). Groundwater flow is usually shallower and therefore more likely to pass within the root zone of trees as it travels downslope. That increases the opportunity for N uptake before groundwater flow reaches the channel (Craig et al. 2008). In addition, as stream order increases, direct surface runoff to the channel tends to increase, meaning that in smaller watersheds, a greater proportion of upland runoff will actually be intercepted by the riparian zone (McGlynn and Seibert 2003; Tomer et al. 2003; Wondzell and Swanson 1996).

3.2.2 GIS Tools for Buffer Placement

Stream order is only one factor in determining where buffers might have the most influence on water quality. Upland nutrient loading, depth to water table, and slope are some of the many factors that land managers should take into account to prioritize areas for restoration in terms of maximum pollutant-removal benefit. Several GIS tools are being developed to synthesize the information and identify critical areas where buffers are most needed in terms of water quality benefit. One example is the Chesapeake Bay Riparian Forest Buffer Targeting Scheme.

In 2008 the Chesapeake Bay Forestry Workgroup developed a scientifically based scheme to identify areas in the watershed where performance of riparian forest buffers might be expected to be high. The scheme is in the form of a targeting matrix that captures the variables that influence the efficiency of nutrient removal in a buffer, namely, hydrology (specifically depth to water table), slope, land use, and source nutrient loading.

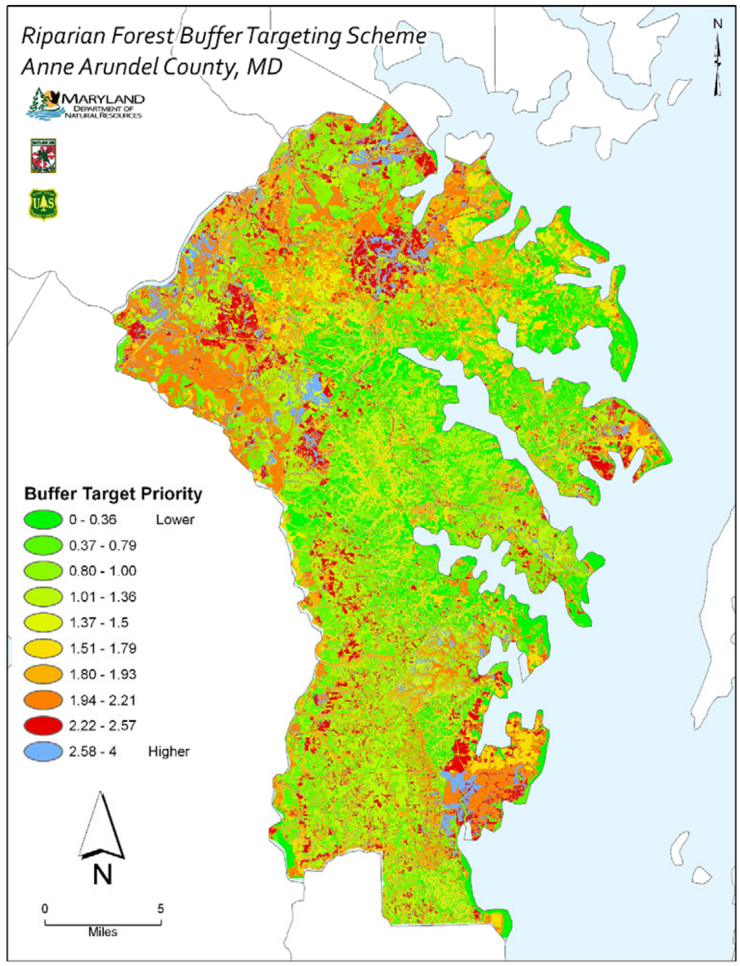


Figure 5-5. Riparian Buffer Prioritization Map of Anne Arundel County, Maryland.

Each of the attributes is weighted according to importance and then scored, with a higher score given to conditions that would result in more pollutant removal (such as a shorter depth to water table). The scores are analyzed in GIS to create a map like the one in Figure 5-5. For more information on the matrix, including an explanation of why the attributes listed here are the most likely to result in the successful placement of riparian forest buffers in areas of the Chesapeake Bay watershed, see http://archive.chesapeakebay.net/pubs/calendar/FWG_11-18-08_Handout_3_9152.pdf and http://archive.chesapeakebay.net/pubs/calendar/FWG_11-18-08_Presentation_1_9152.pdf.

3.3 Analyzing Existing Conditions and Identifying Potential Problems

Every riparian forest buffer has a unique set of conditions that managers must understand before developing a restoration plan. How those conditions link to pollutant removal and ecological function is important to success. Three key areas that need to be addressed are (1) hydrology, (2) soils, and (3) existing vegetation. In addition, special characteristics and potential problems associated with converting a previous land use to a forest buffer should be considered.

3.3.1 Hydrology

As discussed throughout this chapter, riparian areas are driven by hydrology (NRC 2002). Identifying pathways of water flow through the site provides clues on how well beneficial functions in the riparian area will operate once reforested. Ideal site hydrological conditions include the following:

- Local groundwater originating from adjacent upland takes a relatively shallow path through the soil and comes into contact with the root zone of buffer vegetation. That contact increases the likelihood that N will be taken up by vegetation, immobilized by microorganisms, or undergo denitrification by bacteria.
- Runoff water originating from the uplands does not concentrate, channelize, and convey directly to the stream and bypass riparian vegetation and groundwater recharge areas. Gently sloping vegetative landscapes are preferred because they promote sheetflow and naturally reduce runoff velocity. These attributes increase the residence time of surface runoff and increase the likelihood of infiltration. Lower slopes also tend to reduce the velocity of groundwater flow and increase its contact time with buffer vegetation roots and other processes that remove or immobilize N.

Hydrologic analysis at the site should include an evaluation on how well the above conditions are met.

3.3.2 Soils

Success in regulating the lateral flow of water, filtering sediment and nutrient pollution, and maintaining important processes and functions in the stream itself ultimately depends on riparian soils and the organisms that reside in them. Features within the riparian area such as natural levees and wetlands have their own unique soil characteristics. Soil complexity is beneficial because different soil attributes affect the occurrence and efficiency of ecological functions as well as supporting a diverse vegetative community (FISRWG 1998). Some important soil characteristics to assess include the following:

- *Soil composition and texture*—Soils are composed of various inorganic mineral particles that can be categorized by size (sand, loam, or clay) and organic matter (in various stages of decomposition). Soils that promote infiltration and transmission of water need to have a high porosity, such as coarse-textured sandy/loamy soils held together with organic matter, as opposed to fine-textured clayey soils.

- *Soil moisture*—The ability of the upper layer of soil to hold water by surface tension in fine pores is very important to the growth and survival of vegetation. Loamy/clayey soils have the best water-holding properties. Sandy soils are the most porous and do not have much capacity to hold water.

- *Soil compaction*—Human activity, especially in urban areas, can compact natural soils and reduce infiltration and water-holding capacity as well as killing root systems. About 50 percent pore space is ideal (MDNR FS 2005).

- *Wetland soils*—Wetlands in riparian areas typically occur where the water table is at or near the surface. Soils are hydric, meaning they are saturated during all or portions of the growing season and develop anaerobic conditions. Only plants adapted to these conditions can survive in wetlands. Saturated areas are also important areas for denitrification, a bacterial process that removes nitrate from groundwater before it reaches the stream channel, and should be identified and protected.

The Pennsylvania Stream ReLEAF Forest Buffer Toolkit, section 2 of the Maryland DNR *Riparian Forest Buffer Design and Maintenance* guide, and section 4 of the *Chesapeake Bay Riparian Handbook: a Guide for Establishing and Maintaining Riparian Forest Buffers* (Palone and Todd 1997) contain guidance on soil evaluation.

3.3.3 Riparian Vegetation

Soil properties, topography, shading, seed stock, water availability, and other factors determine the density and distribution of vegetative species within a riparian area. Plants play an important role in filtering, storing, and processing pollutants and lessening their effect on stream quality. Riparian vegetation also performs several ecological functions. Restoring vegetative structure, especially reestablishing trees, is often the most visible aspect of a riparian restoration project.

Different attributes affect the occurrence and efficiency of ecological functions. Important characteristics that managers need to assess and then maintain or restore include the following:

- *Trees adjacent to the stream*—The importance of trees to stream ecology is discussed in Section 2 of this chapter. The annual cycle of growth and senescence of trees provides organic material to the stream, which serves as the base of the food chain in headwater streams. Streamside trees also add large, woody material to the channel, which provides important habitat functions for a variety of aquatic biota. Additionally, the root systems of streamside trees help bind bank sediments and reduce the potential for erosion.

- *Horizontal complexity*—A riparian area with diverse population of vegetation is generally a reflection of a diversity of soils, drainage conditions, flooding patterns, and other conditions across the area. A mix of herbaceous plants, shrubs, and trees provide varying levels of sediment, nutrient, and pollutant removal efficiencies (FISRWG 1998). Complex vegetation habitat also typically results in a wider variety of wildlife.
- *Edge habitat*—Two distinct habitats within a riparian forest area are edge habitat and interior habitat. The edge habitat is the area of transition between an upland ecosystem and the interior forest. Compared to interior habitat, edge habitat, by virtue of its position, receives higher and more fluctuating levels of solar and wind energy, precipitation, and water and materials flowing from the adjacent land use. Therefore, it functions as the first line of defense for regulating runoff and filtering pollutants. Flora and fauna that inhabit edge habitat are species that can tolerate more intense and fluctuating conditions.
- *Interior habitat*—Interior habitat is a more stable environment, sheltered from conditions endured by edge vegetation. In general, more sensitive and rare species of plants and animals are in interior habitat, away from the dynamic processes in the edge habitat. Therefore, if protecting sensitive or rare species is an objective of riparian forest buffer restoration, managers must ensure that there is adequate interior habitat in the buffer.
- *Vertical complexity*—Birds and other tree-dwelling wildlife depend on a variety of layers of vegetation to thrive and reproduce. A vertically complex area also reflects a diversity of age composition and indicates a successful pattern of succession and new growth.

3.3.4 Special Characteristics and Potential Problems Associated with a Previous Land Use

If all or a portion of the riparian area being restored was used for some other purpose (e.g., cropland, pastureland, lawns, parkland), there might be special characteristics or potential problems that should be assessed. As described in *Riparian Forest Buffer Design and Maintenance* (MDNR FS 2005), those could include the following:

- *Compacted soils*—Soil compaction is often a problem in developed areas. Compacted soil restricts the movement of water into the ground and inhibits root penetration. It is often a problem in urban and suburban soils because of vehicle or foot traffic, playing areas, or other use. Compacted soils in pastureland might be due to cow paths or other animal or equipment traffic. Usually soil compaction is not a problem in agricultural lands; however, there might be a compacted layer of soil below the plow zone. If compaction presents a problem for tree rooting, a moderate amount of discing or tilling can be employed to loosen the soil.

- *Fill material or other problem soils*—Fill material, especially in suburban and urban areas, might have been imported and placed on the site. Fill can contain any variety of material not amenable for growth of native trees and vegetation. Conditions could include low fertility, high sand content, high clay content, low organic matter content, excessive rocks, and low microfauna content. Soil testing that includes composition and pore analysis, pH, and organic and nutrient content can help determine soil limitations and what amendments might be needed for healthy growth. Depending on the results, amendments might include fertilizers, composted manure, peat moss, mulch, or decompaction agents.

- *Noxious or invasive weeds*—Weeds can and often will outcompete and kill young trees. Present and future generations of noxious or evasive weeds might reside at the site (Figure 5-6). Weed seeds are very hardy and can lay dormant in the soil for years waiting for favorable conditions to germinate. Controlling noxious and invasive weeds should occur before tree planting through a mowing or other removal method. In some cases, it is prudent to even delay planting for a year to get more complete control of weed populations. When converting cropland to riparian forest buffer, establishing a cover crop is a convenient weed control method.

- *Animal damage*—A variety of animals can damage tree seedlings by rubbing or trampling them or by feeding on leafs, stems, bark, or roots. Managers need to make plans to keep them away from planted areas.

Figure 5-6. *Ailanthus altissima*, or Tree of Heaven is a common invasive found in riparian forest buffers.

- *Human damage*—Riparian buffers are sometimes damaged by the actions of well-meaning residents. Mowing, clearing, and other landscaping *improvements* can limit ecological functions. Public education and creating an awareness of the buffer value and purpose will help limit this problem.

3.4 Buffer Width and Connectivity

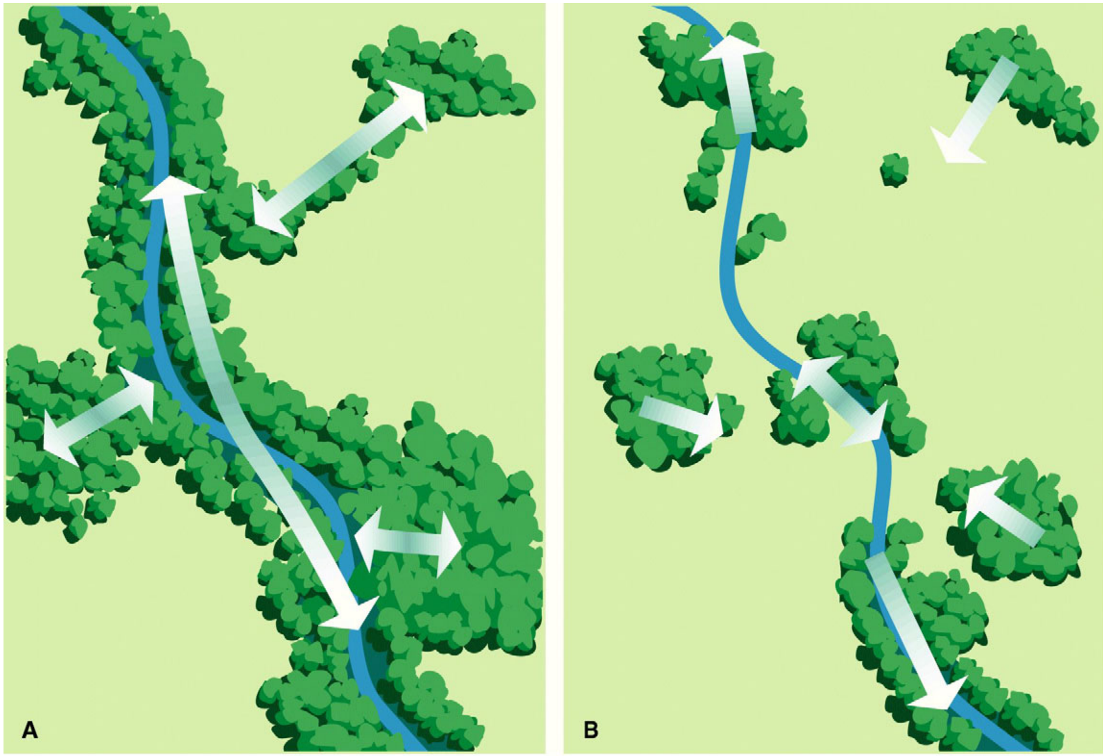
Two important dimensional characteristics of riparian buffers are

- *Width*—The lateral measure of buffer vegetation on either side of the stream.
- *Connectivity*—The measure of how continuous the buffer is both laterally and longitudinally. Gaps or breaks in the buffer serve to lessen connectivity (Figure 5-7).

In general, ecological functions are enhanced when buffers are wide and connected rather than narrow and full of gaps. For example, wider contiguous buffers create more space and a wider diversity of soils and vegetation to filter out sediment, nutrients, and other pollutants from upland sources before they reach the stream. Gaps in the buffer decrease buffer continuity and increase the chance of upland runoff concentrating and shooting through the gap to the stream. Gaps also discourage the movement of wildlife along the stream corridor. For those and other reasons, buffer-restoration objectives typically include making the buffer as wide and as connected as possible.

Width is a controversial aspect of buffer design and protection. There is much variation in buffer width recommendations in state and federal guidelines and peer-reviewed literature. Because factors that influence ideal buffer widths such as soil type and subsurface biochemistry, are site-specific, the location of a forest buffer can be more important than buffer width (Speiran 2010). Additionally, optimal widths are function dependent. In other words, the ideal buffer width at a location will also vary depending on whether the highest priority in terms of buffer function is water quality, stream temperature, or wildlife habitat. For example, DeWalle (2010) found that increasing buffer widths beyond 12 meters has a limited effect on stream shade and that the density and height of buffer vegetation near the stream are more important.

For further discussion on the scientific data related to width and pollutant removal, see Mayer et al. 2005 and Okay 2007. Todd (2002) points out that a clearly defined relationship does not exist between buffer efficiency and width that can be applied to the Chesapeake Bay region but concludes that the potential risk for failure of a buffer to remove excess nutrients before they reach the stream clearly increases with decreasing buffer width.

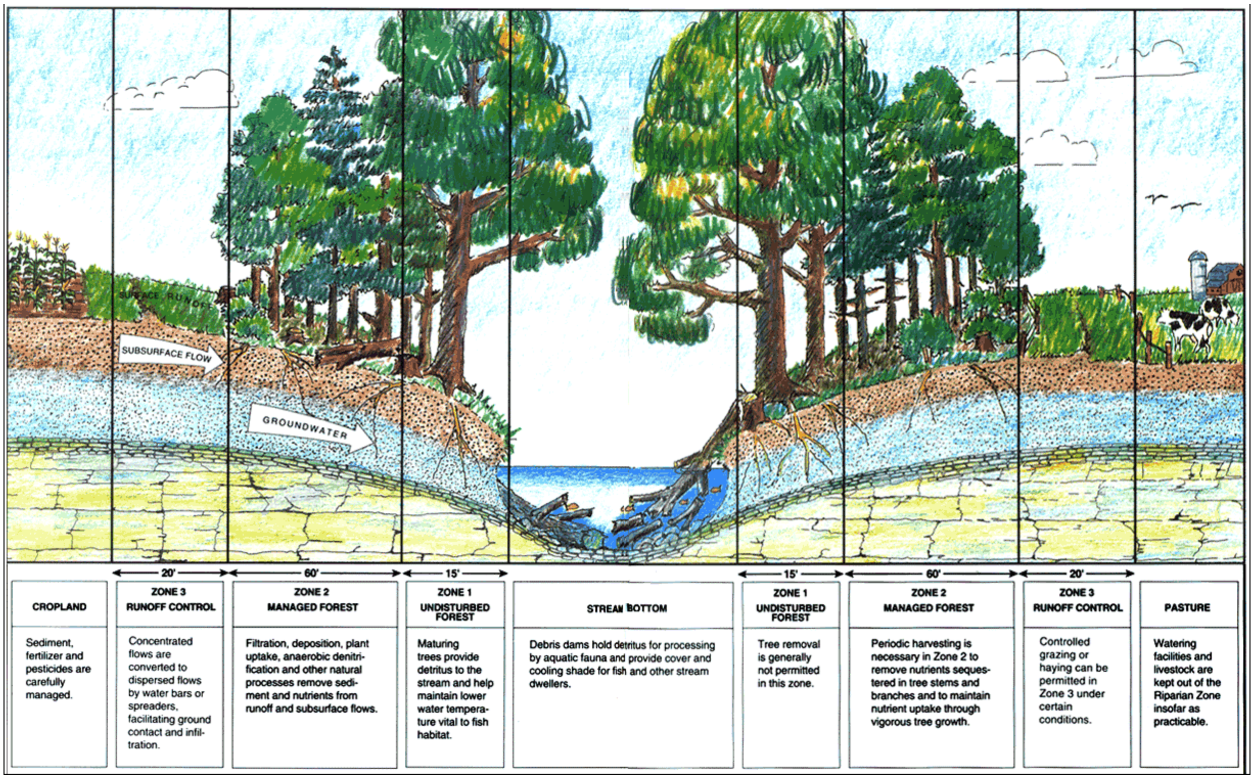


Source: FISRWG 1998

Figure 5-7. Connectivity within a landscape.

In 1991 the U.S. Forest Service released specifications for riparian forest buffer design for protecting and enhancing water resources (Welsch 1991). That document recommends that a riparian buffer should follow a *three-zone* design, illustrated in Figure 5-8.

While buffers will vary in accordance with factors discussed above, generally, the first zone next to the stream should be at least 15 feet wide and consist of mature tree cover, which protects streambanks, reduces thermal impacts, and contributes organic matter to the stream. Immediately adjacent to the first zone is the second zone, which typically should have a minimum width of 60 feet and consists of trees and shrubs. The primary purpose of the second zone is to capture and transform nutrients, sediments, and other pollutants from surface runoff and shallow groundwater. Zone three should be approximately 25 feet wide and contain natural grasses. That zone is an important area for the spreading, filtration, and infiltration of surface water.



Source: Welsch 1991

Figure 5-8. A typical 3-zone buffer design.

Following those guidelines, the minimum buffer width should be 100 feet for maximum pollutant-removal benefits, or wider where pollutant flows are greater or there is greater risk to downstream waterbodies. That is consistent with riparian buffer ordinances in Virginia, Pennsylvania, and Maryland (Baird and Wetmore 2003; MD CAC 2010; CWA PA 2009). Natural Resources Conservation Service (NRCS) Conservation Practice Standards for Riparian Forest Buffers in Maryland, Pennsylvania, and Virginia require a minimum 35-foot width of forested area for cost sharing. However, a wider buffer is recommended in high nutrient, sediment, and animal waste application areas, to include wetlands, steep slopes, and other critical elements, or when buffers are planted for carbon storage (NRCS 2006, 2008, 2009). Additionally, in areas where sediment is a major concern, a grassed filter strip (zone 3) at least 24 feet wide is required.

More information about the benefits of the 3 zone design is in the USDA booklet titled *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources* at http://www.na.fs.fed.us/spfo/pubs/n_resource/riparianforests/ (Welsch 1991).

3.5 Establishing Riparian Vegetation

Choosing the species of trees to populate a riparian forest buffer requires matching growing requirements with site conditions and planning objectives. In general, managers should strive to create species patterns that mimic reference conditions in the area. Managers should also consider the following when selecting plant species:

- Vegetation in the riparian forest buffer should be tolerant of different types of meteorologic and hydrologic conditions.
- Choose plants that have multiple values, such as erosion control, nesting habitat, food sources (nuts and fruit), and filtering capability.
- In areas of high erosion or where concentrated flow is an issue, trees, leaves, and woody debris might be ineffective for the amount of sediment retention desired (Daniels and Gilliam 1996; Knight et al. 2010). Consider adding a grass filter between the upland and the riparian forest. Tall, dense, stiff grass species are preferred in such areas (Dosskey 2001).

3.5.1 Natural Regeneration

Natural regeneration is the least expensive option for establishing a riparian forest buffer. Generally, natural regeneration will take longer to reach mature forest conditions, but it eliminates the need (and costs) for selecting and planting trees. Key attributes for success are the availability of native trees to function as a natural seed source and quality, non-compacted soils that promote good seed contact. To achieve that latter attribute, some site preparation work might be necessary.

Common tree species that generate windborne seeds that travel reasonably far distances include poplar, ash, pine, sycamore, birch, sweetgum, and maple. Seeding by heavier seed species (e.g., oaks and hickories) require trees that are fairly close by, preferably upslope.

Initial germination might yield thousands of seedlings per acre (Bradburn et al. 2010). Therefore, thinning the buffer at some point might be appropriate to create a healthier population of trees.

More information is in chapter 3 of the Maryland DNR FS *Riparian Forest Buffer Design and Maintenance Guide* (http://www.dnr.state.md.us/forests/download/rfb_design&maintenance.pdf).

3.5.2 Planting Trees

Planting results in more control of the location, density, and species on the site. It also speeds up the restoration process. However, it can be considerably more expensive than natural regeneration. Seeds, seedlings, or more mature trees can be planted on the site, depending the budget and objects of the planting.

- *Direct seeding*—Seed can be directly sown in the soil and aided by raking or discing, depending on the density of the seeds. Because of potential predation by squirrels, birds, and other animals, a fairly large number seeds is required. If germination is successful, dense stands can develop, which might need to be eventually thinned.
- *Seedling planting*—Seedlings can be planted by hand or using a planting machine. Unlike direct seeding, managers can tightly control tree location, pattern, and density. In addition to a good selection of seedling species available from nurseries, planting seedlings is usually the most cost-effective method of establishing trees in a riparian forest buffer. Care must be taken, however, to not damage or dry out seedlings during the plant process. Managers generally choose to plant seedlings in rows because such a configuration is easiest to design, install, and maintain. It also generates a full canopy closure more rapidly than other configurations.
- *Tree planting*—In some cases, managers might want to plant more mature trees at the site. Digging planting holes is more costly, but it avoids trampling high-traffic areas.
- *Species choice*—Choosing the species of trees to populate in the riparian forest buffer requires matching growing requirements with site conditions and planning objectives. In general, managers should strive to create species patterns that mimic reference conditions in the area.

Forest conditions, and corresponding ecological functions, develop more quickly with a high density of trees. If the rapid creation of a canopy for shading out weeds or providing cover and shade to a stream is the objective, high-density planting is recommended (e.g., 500 trees per acre). However, thinning back to 100 to 150 trees per acres will eventually be needed to create a healthy, self-sustaining riparian forest buffer (MDNR FS 2005).

The Stroud Water Research Center recommends planting at least 8 to 10 species when restoring a riparian area. In all cases, species must match the environmental characteristics of the site, and plans should be defined to protect seedlings from weeds and animals.

Additional information, including suggestions for the species to plant in the Chesapeake Bay area, is in the following resources:

- Pennsylvania Stream ReLeaf ToolKit (http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StreamReleaf/Forestbufftool/default.htm)
- Chapter 3 of the Maryland DNR FS *Riparian Forest Buffer Design and Maintenance Guide* (http://www.dnr.state.md.us/forests/download/rfb_design&maintenance.pdf).
- Chesapeake Bay Alliance (http://www.alliancechesbay.org/project.cfm?vid=158)
- University of Maryland (http://www.riparianbuffers.umd.edu/fact/FS725.html)
- Virginia Department of Forestry (http://www.dof.virginia.gov/mgt/rfb/rfb-common-plants.htm)

3.5.3 Protecting Seedlings

Young seedlings are susceptible to competition from weeds and animal damage. Protecting the investment is an important part of riparian forest buffer management.

Many species of grasses and weeds can out-compete tree seedlings for light, water, nutrients, and growing space. Fortunately, riparian forest buffer managers have several options to protect the planting investment until they get a foothold.

- *Hand clearing*—Pulling and cutting weeds species by hand is an option for small riparian areas. It is labor intensive, however. Some invasive species require the removal of entire root systems.
- *Mats, collars, and mulch*—Physical barriers for weed growth can be very effective in preventing weed competition around young trees. Some mats and tree collar products can be treated with a selective herbicide for added protection. Mulch can also provide a physical barrier to protect seedlings from weeds, but it too can be expensive and must be replenished.
- *Tree shelters*—Tree shelters are designed to protect young trees from weeds and wildlife. Sweeney et al. (2002) found that using shelters yields a survival rate four times higher than seedlings without shelters. In addition, sheltered trees have 19 times better vertical growth. Tubes that are ventilated, lighter in color, and designed to let in more light tend to work best (Figure 5-9).

Figure 5-9. Trees protected with tubes.

In addition to weeds, several animal species can harm seedlings above and below the ground. Manager can use several techniques to discourage or prevent their access to young trees.

- *Fencing*—Fencing can be used to limit access to the riparian forest buffer by livestock, deer, and other larger animals (Figure 5-10). It can be electric or woven wire. To be effective, deer fencing needs to be well-designed and around 8 feet tall. Gates might need to be built in for human access. Additional information on livestock exclusion fencing is in the Agriculture chapter.

- *Tree shelters*—Shelters are a physical barrier for browsing deer. They also keep voles from seedling roots provided that the tube is pushed into the soil a few inches.

Figure 5-10. Fencing limits access to the stream.

3.5.4 Reinforcement Planting

Reinforcement plantings might be necessary if some portion of original seedlings die. Before undertaking such an action, however, riparian managers should investigate why they did not survive or how they were damaged and then adjust planting methods and follow-up care accordingly. In some cases, a single factor might be the cause of tree mortality; in other instances, a combination of factors might be in play.

3.6 Cost

Costing is, of course, a key part of the planning process. The Maryland Cooperative Extension Service estimates that a typical forest buffer costs between $218–$729 per acre to plant and maintain (Tjaden and Weber 1998). However, costs vary widely and depend on the size and type of buffer. Managers must make choices at each step in the development process; from site-preparation alternatives, to planting methods, to seedling protection approaches, and follow-up maintenance. There is also a cost in taking the land out of crop production if the landowner or a renter is farming the land. The National Agroforestry Center developed an Excel-based tool called Buffer$ (http://www.unl.edu/nac/buffer$.htm) to help landowners analyze cost benefits of buffers compared to traditional crops.

The following resources are available for helping landowners determine the cost of establishing a riparian buffer on property:

- Klapproth and Johnson. 2009. *Understanding the Science Behind Riparian Forest Buffers: Resources for Virginia Landowners*.
- Maryland Cooperative Extension. Fact Sheet 774. *When a Landowner Adopts a Riparian Buffer—Benefits and Costs* (http://www.riparianbuffers.umd.edu/PDFs/FS774.pdf).
- North Carolina State University, Cooperative Extension Service. 2003. *Cost and Benefits of Best Management Practices to Control Nitrogen in the Upper and Middle Coastal Plain* (http://www.neuse.ncsu.edu/Ag%20621.pdf).
- USDA NRCS. 1997. 1997 Conservation Reserve Program practice cost and flat rate payment estimates for Virginia, March 1997.

4 Protection and Maintenance of Riparian Areas

Implementation Measure R-2:

Protect from adverse effects riparian areas that are serving a significant nonpoint source-abatement function and maintain that function while protecting the other existing functions of the riparian areas.

4.1 Background

The current rate of loss of riparian forests in the Chesapeake Bay is unknown. The long-term goal of having riparian forests on 70 percent of all streambanks and shorelines in the Chesapeake Bay requires not only the restoration of buffers, but also strong protections for existing buffers to maintain that goal. Existing riparian buffers and restored riparian buffers (Figure 5-11) that have been established for several years must be protected and maintained to keep them functioning as desired.

Figure 5-11. A healthy riparian buffer.

The previous section discusses restoring and reestablishing riparian forest buffers. This section provides information on recommended long-term maintenance activities and methods jurisdictions can use to protect existing riparian buffers.

An example of a riparian area evaluation on the watershed scale is that of Johnson County, Indiana (Letsinger 2004). In that study, the author assessed the current status of buffers (width and type) in the watershed. She digitally mapped existing buffers on an aerial photograph base and used multiple field surveys to ground truth the remote-sensing methods. Next she used a simplified numerical model to simulate hydraulic routing. She used the model to identify all riparian areas, impaired areas, and areas with the potential for flooding or increased erosion. That is useful in determining which areas should be the focus protection and maintenance efforts.

4.2 Long-Term Maintenance

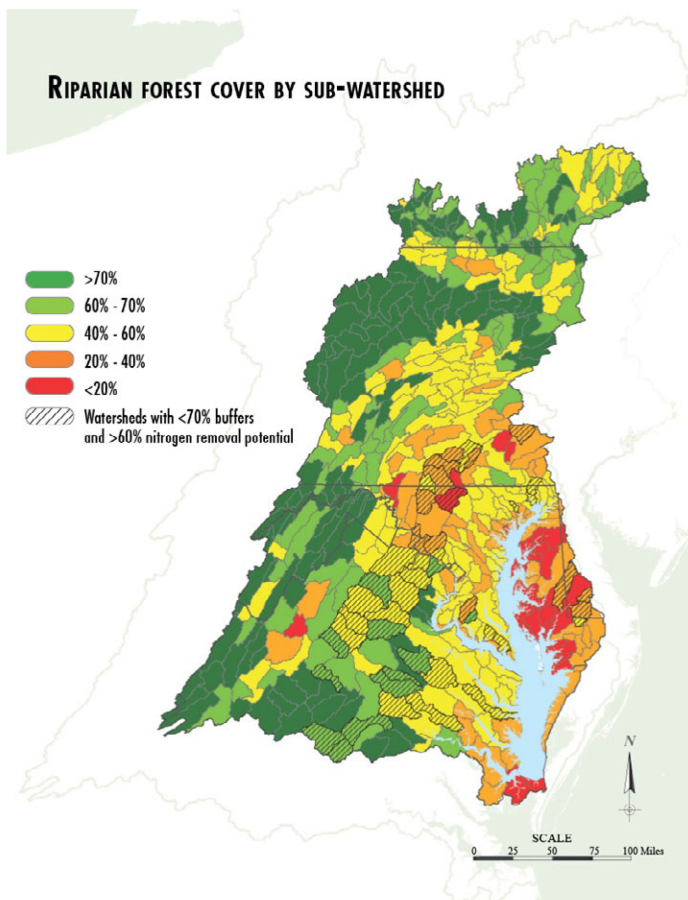
Existing riparian buffers, including those that have been restored, require long-term maintenance to maintain their desired functions, especially in terms of filtering P, N, and sediments from upland areas and preventing those pollutants from entering the Chesapeake Bay.

4.2.1 Watershed-Scale Evaluation

The first step in determining long-term maintenance of riparian buffers on a broad scale (at the state or county level) is to determine the extent of riparian buffers in the watershed.

Buffer boundaries can be mapped and, with proper legal authority, specific rules can be applied to protect and manage the buffer. Some maps already exist that show riparian buffer areas in the Chesapeake Bay. For example, Pennsylvania State University mapped the extent and change in riparian forest buffers for the entire Chesapeake Bay watershed (Day and Crew 2005) using the 1992 National Land Cover Dataset and the University of Maryland's MA-RESAC 2001 data set (Claggett et al. 2010). The extent of riparian buffers in any watershed can be determined using tools such as GIS, remote sensing, and hydrologic modeling. Satellite images and high-resolution aerial photography can help in the evaluation of each riparian area. For example, the Connecticut's Changing Landscape project, at the University of Connecticut's Center for Land Use Education and Research used basic GIS analysis tools and remotely sensed land use data to evaluate land cover change within riparian corridors between 1986 and 2006. (http://clear.uconn.edu/projects/riparian_buffer2/index.htm).

The Riparian Buffer Mapper (RBMapper) software developed by GDA Corp with support from the Chesapeake Bay Program,



Source: Chesapeake Bay Program 2005.

Figure 5-12. A forest cover map.

U.S. Geological Survey (USGS), and USDA FS is a tool that might be helpful for buffer delineation. The program outputs a land cover map of riparian buffers (Figure 5-12) and a text report with land cover statistics.

On-site methods might also be needed, such as performing various types of field surveys that look at geomorphology, hydrology, habitat, wildlife, soils, plant inventories, and so forth. A good approach would be to use a combination of remote and on-site methods to evaluate the streambanks in the watershed in terms of channel geometry, land use, soil types, and vegetation. The targeting matrix proposed by the Chesapeake Bay Program Forestry Workgroup and described in Section 3.3 might also be useful in helping to identify areas where riparian buffers are most likely to exist.

Some sources of maps, satellite imagery, and land cover data in the Chesapeake Bay watershed include the following:

- RBMapper (http://gdacorp.web5.hubspot.com/rb-mapper/)
- Chesapeake Bay Program (www.chesapeakebay.net/maps.aspx?menuitem=16825)
- USGS (http://www.usgs.gov/pubprod/)
- Mid-Atlantic Regional Earth Science Applications Center (MA-RESAC) (www.geog.umd.edu/resac/)

It is also important to evaluate the size (length, width) of each existing riparian buffer area to determine whether it is adequate to protect the Chesapeake Bay from nonpoint source pollution or serve other functions such as providing wildlife habitat, stabilizing streambanks, or protecting the fish population. Typically, longer and wider buffers are better at filtering and removing pollutants and provide better wildlife and aquatic habitat, as described earlier in this chapter.

4.2.2 Evaluation of Buffer Quality

Once the buffers are located in the watershed, it is important to determine whether they are achieving the desired functionality. Riparian buffers that are functioning well should be maintained and protected, while those buffers not functioning well might need more significant restoration (see Section 3 of this chapter). Specifically, land managers should evaluate the following:

- Hydrologic Condition
- Adjacent Land Use
- Wildlife Habitat

Hydrologic Condition

> As described in earlier sections, one of the most important functions of a riparian buffer is to protect water quality by filtering nonpoint source pollution coming from adjacent land. While that is an important function, riparian buffer managers should not alter riparian areas to improve their water quality function at the expense of other functions.

Managers must understand existing and future hydrogeomorphic conditions and consider them when developing management plans to ensure that riparian buffers maintain their functions. Hydrologic and geomorphic conditions help maintain many of the functional aspects of a riparian area, such as pollutant removal, habitat maintenance, and water storage and transport. It is important to understand the natural flow patterns (frequency, magnitude, duration) associated with each riparian buffer, especially where flow regimes have been modified (NRC 2002). Channel incision and widening from certain land use practices can curtail overbank flows. Information on historical conditions from overbank flood events is useful to know whether healthy riparian communities are possible and whether incision and widening is reversible (NRC 2002).

Climate change creates uncertainty in managing riparian areas in the Chesapeake Bay. In the upcoming years, plant species might experience a change in their growth rates and be exposed to higher average temperatures and changes in typical rainfall (Sprague et al. 2006). In light of this, hydrologic regimes are likely to change. Streams might experience more frequent effects of severe floods, droughts, and hurricanes. To prepare for that, managers should assess how the stream channel will function ecologically under extreme low-flow or high-flow conditions and inspect the condition of a riparian buffer after a significant metrological or hydrological event occurs to determine if any maintenance is needed.

Adjacent Land Use

Land use directly affects the characteristics of runoff through a riparian buffer. The pollutant-removal effectiveness of the buffer will depend on the conditions of the upland land cover where the runoff originates (i.e., urban, suburban, pervious, impervious, agricultural, tilled, no till) (NRC 2002). Therefore, addressing practices in the upland land uses that contribute to riparian degradation is an important component of a successful riparian restoration project.

Agriculture runoff (high in nutrients, bacteria, and TSS) will be different from urban runoff (high in nutrients, heavy metals, pesticides, hydrocarbons, temperature, oxygen-demanding substances, and trash and debris) (USEPA 1996). Forested land has unique factors that managers should consider in terms of maintaining and protecting existing riparian areas. For example, timber harvesting must be managed so it does not increase water and sediment yields and lead to stream channel destabilization and loss of aquatic habitat. The forest landowner should also not decrease woody, in-stream cover. Doing so could destabilize streambanks, reduce shading, increase water temperatures, reduce inputs of fine litter to the waterbody, and reduce the diversity of plants and animals in the area. From a landscape perspective, managing a greater proportion of the riparian area for uneven-aged, mixed stands of longer-lived species suitable to the site can help protect riparian functions and values. The Agriculture, Forestry, and Urban and Suburban chapters of this document provide detailed information on managing different land uses to prevent and reduce nonpoint source pollution from entering the Chesapeake Bay.

Habitat

Managers should evaluate habitat to determine whether it is adequate to support the desired plant and animal species. Examples of both terrestrial and aquatic habitat assessments include the following:

- Maryland DNR (http://www.dnr.md.gov/streams/pubs/ea03-4phi.pdf)
- Ohio Environmental Protection Agency (http://epa.ohio.gov/portals/35/wqs/headwaters/PHWHManual_2009.pdf)
- The Nature Conservancy Active River Area (http://www.nature.org/initiatives/freshwater/files/active_river_area.pdf)

Additional Information

The following sources have additional information on the proper assessment of riparian buffers:

- *Riparian Area Management—Process for Assessing Proper Functioning Condition* (USDI 1998)
- *Methods for Evaluating Riparian Habitats with Applications to Management* (Platts et al. 1987)
- *Riparian Assessment Using the NRCS Riparian Assessment Method* (NRCS 2004)
- *Development of Methodologies to Evaluate the Health of Riparian and Wetland Areas* (Hansen et al. 2000)

4.2.3 Managing Plants

In addition to the factors discussed in the previous section, the plant species in riparian buffers need to be maintained so that the areas retain their desired functions. Some studies have found that pollutant-removal functions can increase over time (Rheinhardt et al. 2009). Consider the planting, harvesting, pruning, and nurturing protocols required to protect the riparian species from degradation. Managers might need to deal with new plants, invasive species control, wildlife damage issues, and disease issues. A landowner can contact the local NRCS office or a nursery for assistance.

Plantings

To manage existing areas so that they are effective long into the future, managers should determine the variations in riparian communities in a watershed and whether they are appropriate on the basis of factors such as soil type, hydrology, and land use. The species that exist in the riparian buffer need to be examined to determine whether they are appropriate for the desired effects of the buffer (such as wildlife and aquatic habitat) and whether they are suitable for the site conditions. Native vegetation is typically better capable of withstanding local water, climate, soil, and pest conditions.

Riparian buffer managers should consider the following:

- Climate change could bring about changes in temperature and rainfall amounts that could affect vegetation’s growth and survivability and could increase the types or amount of invasive species.
- Keep an eye on riparian areas for plant die-off. First, determine the cause of the issue (for example, is the die-off due to wildlife damage, or are the site conditions inappropriate for the plants that are struggling?). Next, act quickly to repair any damage or replant additional vegetation.
- Some riparian sites warrant botanical generalists, whereas other might warrant wetland specialists. It depends on the site conditions. Remove certain species that are not appropriate to the site conditions or plant new vegetation.

Weed Control

Riparian buffers should be managed over the long-term to ensure that native vegetation is being established/maintained along the waterways. As mentioned in Section 3, weeds and invasive species can overtake a riparian area, causing damage to other species by competing for resources. Techniques to remove weeds, such as mowing and hand clearing, are important to consider using for long-term maintenance of a riparian buffer. For details on those techniques, see Section 3.

Some good resources for identifying weeds and invasive species in the Chesapeake Bay are

- USDA NRCS (http://plants.usda.gov/java/noxiousDriver)
- Native plant societies

- Virginia (www.vnps.org/)
- Maryland (www.mdflora.org/)
- District of Columbia (www.botsoc.org/)
- Pennsylvania (www.pawildflower.org/)

Preventative management, however, is the best method of weed control. This includes things like not disposing of plant clippings in riparian areas, not planting invasive species nearby, and removing problem plants as soon as they are spotted.

Note: When considering weed removal, when mechanized clearing is employed in an aquatic area, a permit may be required from the U.S. Army Corps of Engineers pursuant to Clean Water Act section 404.

Pruning, Harvesting, and Nurturing

In an existing riparian forest buffer, riparian buffer managers should check the conditions of any plants in the buffer periodically, especially after significant storm events, and consider planting additional species if needed to maintain the buffer's integrity. Check the area for damaged, diseased, or dying trees and shrubs that might need to be pruned or removed and replaced (contact NRCS, a cooperative extension, or local nursery for assistance). Check for fallen or leaning trees and whether they present a hazard to upland land uses. Although fallen trees can provide valuable habitat, trees threatening to cause significant damage might need to be pruned or removed.

Check during drought conditions, and water plants if necessary. Some trees might need to be harvested to remove nutrients and chemicals stored in their stems (Schultz et al. 1997) and to allow stronger trees to grow. However, managers must take care not to overharvest because that could be disruptive to the existing plant and animal communities and could lead to increased streambank erosion (USEPA 2005).

Below are sources of additional information on pruning, harvesting, and nurturing protocols.

- USDA FSA (http://plants.usda.gov/java/noxiousDriver)
- Maryland DNR Forest Service (http://www.dnr.state.md.us/Forests/)
- Virginia Forest Service (http://www.vaforestservice.com/Forest_Management.aspx)
- Pennsylvania DNR (http://www.dcnr.state.pa.us/trees.html)
- Weeds Gone Wild (http://www.nps.gov/plants/alien/)

If the riparian forest buffer is part of an ongoing forestry operation, some limited harvest in accordance with BMPs for water quality (and associated guidelines for streamside management zones) may be allowed in the buffer, but workers should minimize land disturbance. Burning and pesticide and fertilizer use might also be restricted. For more information, see Chapter 4 of this document.

Agricultural land that has forested riparian buffers should be addressed using these same principles for selective harvest and could be subsequently reforested or used for other agricultural pursuits. For more information, see Chapter 2 of this document.

Fencing

Fencing, in some cases, can be an effective means of protecting riparian vegetation. Fences can be used to keep out or control livestock movement and grazing and to direct human activities into other areas. Fences serve to delineate land uses and prevent human activity from encroaching on the riparian zone. Many different fencing options exist, and it is important to identify the specific management requirements so that the location and design of fencing and gates, is appropriate and effective. Fencing needs to be inspected regularly for damage caused by weather, wildlife, or vandalism, and repaired if needed. Additional information on livestock exclusion fencing is in Chapter 2 of this document.

Erosion and Sediment Control

Riparian buffers should be inspected annually and after significant rainfall events for signs of erosion. Bare areas should be replanted, and additional soil might need to be added. In addition, over time or after a significant rainfall event, sediment that is trapped in the riparian area can build up and bury groundcover. Sediment can also build up at the edge of a buffer and block water flow. In those cases, the sediment should be removed, and some vegetation might need to be replanted. If it becomes an ongoing problem, the adjacent area might need better management practices installed.

4.3 Protection

Federal, state, nonprofit, and private programs, both regulatory and nonregulatory, exist to protect riparian functions. Creating ordinances and zoning to protect existing riparian areas is likely to be less expensive than establishing new areas or restoring degraded ones (Mayer et al. 2005). It has been recommended by a federal interagency report that states should, “Limit or eliminate development within riparian areas, using a similar approach such as Maryland’s Critical Areas legislation and Virginia’s Chesapeake Bay Preservation Act” and “create incentives to ensure that restored buffers remain intact” (Greiner and Vogt 2009).

4.3.1 Acquisition

The vast majority of land within the Chesapeake Bay watershed is held by private landowners. However, a government agency, nonprofit organization, or private citizen can purchase land where riparian areas exist as a means of protecting them from future degradation. Millions of acres of habitat in the 64,000-square-mile Chesapeake Bay watershed are already protected by federal, state, and local government programs and private organizations such as The Nature Conservancy, The Natural Lands Trust, and other land trusts (Greiner and Vogt 2009).

Fee Simple Acquisition

A local government or conservation group can do a fee simple acquisition, which gives it the full ownership of riparian land and provides the greatest amount of control over the use and maintenance of a property. This type of ownership is most desirable if the resources on the land are highly sensitive, and protection of the resources cannot be reasonably guaranteed using other approaches for conservation.

Conservation Easement

An alternative to buying riparian land is to purchase the property owner's right to use that riparian land for specific purposes by purchasing a conservation easement. A conservation easement is a written legal agreement between a landowner and a land trust or a local government that permanently restricts some landowner rights to the use of a property to protect its conservation value.

Some easement transactions offer tax benefits. A landowner who donates an easement or sells it for less than fair market value (for example, to a land trust) could be entitled to a federal income tax deduction. Such land must be used exclusively for conservation purposes. The easement is legally transferred but at no cost or at below-market value to the easement holder. That allows the landowner to qualify for a tax-deductible charitable donation.

4.3.2 Zoning and Protective Ordinances

Local governments often administer the regulations or incentives necessary to encourage private landowners to protect riparian areas. Land use ordinances are commonly used for that purpose. Land use ordinances define land use restrictions and plans. Zoning is one of the most common types of land use ordinances. Zoning that protects riparian buffers might be part of an existing natural resource protection ordinance, stormwater ordinance or floodplain ordinance in a state. Managers should review such regulations for their adequacy in protecting riparian areas. An overlay zoning ordinance pertaining to riparian buffer protection is appropriate in a municipality that already has a zoning ordinance in place. For a municipality that does not have zoning ordinances in place, a separate, freestanding ordinance might be necessary to protect riparian buffers.

A stream buffer ordinance can be used to establish minimal acceptable requirements for buffer design to protect streams and waterbodies in and around the Chesapeake Bay and to provide for the environmentally sound use of the jurisdiction's land resources. To see examples of ordinances that can be used to protect natural resources, see www.stormwatercenter.net. The stream buffer ordinance is an example of a model ordinance that can be used to guide future growth while safeguarding local natural resources. By examining the example provided, community decision makers should find the language to craft an ordinance that is appropriate for their conditions. A strong buffer ordinance is one step in preserving stream buffers.

> An example of a nonprofit agency that obtained a conservation easement in the Chesapeake Bay is the Conservation Fund (http://www.conservationfund.org/chesapeake_bay_initiative). The Conservation Fund launched an ambitious program that seeks to protect 100,000 acres of high-priority land and water within the watershed by 2010. Three miles of historic Chester River shoreline, 600 acres of unique Delmarva Bays, a 90-acre waterfowl sanctuary, and important habitat for bald eagle and endangered fox squirrel are now preserved forever under the 5,200-acre Chino Farms conservation easement—the largest in Maryland's history. The fund, collaborating with the landowner, Maryland DNR, Queen Anne County, and U.S. Fish and Wildlife Service, ensured the protection of more than 8 square miles of critical riparian habitat and wetlands. This easement keeps Chino Farms in agricultural production while conserving valuable natural resources in the Chesapeake Bay watershed.

Another example of a riparian buffer ordinance is the Riparian Buffer Conservation Zone Model Ordinance, which was prepared in 2005 by the Passaic River Coalition and New Jersey Department of Environmental Protection, Division of Watershed Management: http://www.marsh-friends.org/marsh/pdf/ordinance/StreamBufferOrdinance.pdf.

In some cases, through the municipal planning code, municipalities can take a regulatory or incentive-based approach to protect riparian areas in new developments. The degree of riparian area protection is likely to vary with the approach. Best results occur when a municipality identifies riparian areas to protect early in the planning stage of a new development. Communication during early planning stages, before commitments and decisions have been made, often promotes goodwill efforts from the developer. Amenities such as greenways or trails along stream corridors that result from municipal intervention can benefit the developer and protect the water resource because such green spaces can enhance the desirability of property in a new development.

In some jurisdictions, developers can be awarded increased building densities for developments that conserve natural areas, such as riparian corridors. Conversely, municipalities can employ density limits to encourage conservation of natural areas. For example, a jurisdiction could establish a minimum and maximum density and permit the higher density to a developer that plans for natural areas and open space techniques while lowering the allowable density for developments that do not incorporate preservation of natural areas.

Vermont River Management Program

Created in 1999, this program strives to manage toward, protect, and restore natural geomorphic conditions in streams. A big part of this program is river corridor protection. The two protection mechanisms are state and municipal land use restrictions on development in fluvial erosion hazard area and the purchase of river corridor conservation easements. The state used Stream Geomorphic and Reach Habitat Assessment protocols to delineate river corridors throughout the state and used this information to develop FEH areas. River corridor easements were created to augment the FEH land use ordinances. The purpose of the easement is to give the river the space to re-establish a natural slope, meander pattern, and floodplain connection (Kline and Cahoon 2010). More information on this program can be found at http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm

The Stormwater Center (http://www.stormwatercenter.net/) includes a template and sample ordinances, including one from Baltimore County, Maryland. Some of the major sections of a stream buffer ordinance are

- The intent of the ordinance
- Examples of what type of land buffers are applied to (i.e., forest, agriculture)
- Plan requirements (i.e., maps, surveyed streams and forest buffers, limits of a 100-year floodplain, mapped hydric soils, slopes measures, summary of species of vegetation)
- Design standards for forest buffer (i.e., width, slope)
- Management and maintenance of buffers (i.e., limitations on alteration of natural conditions, maintenance of roads, bridges, paths, utilities, stormwater management)
- Enforcement procedures (i.e., checking for violations, civil or criminal penalties)
- Waivers/Variance (i.e., ordinance applies to all development after effective date)
- Conflict with other regulations (i.e., more restrictive regulation will apply)

In some states, like Pennsylvania, a riparian buffer can be used as a stormwater credit, which is a technique that developers can use to reduce their stormwater management costs (Alliance for the Chesapeake Bay 2004). A stormwater credit for a stream buffer would be given when runoff from upland areas is treated by a grass or wooded buffer. Such techniques reduce runoff volumes, which helps to avoid the construction of costly stormwater management facilities.

4.3.3 Water Quality Standards

A state can use its water quality standards to protect existing riparian areas. For example, North Carolina has the Sediment Pollution Control Act, under which it declares that for forestry operations, a streamside management zone (SMZ) (i.e., buffer) must be established and maintained along the margins of intermittent and perennial streams and perennial waterbodies. The SMZ must be of sufficient width to confine within the SMZ visible sediment resulting from accelerated erosion (NCDENR 1999).

In Maryland's water quality standards, it is the policy that riparian forest buffers adjacent to certain waters must be retained when possible to maintain water temperature to protect salmonid fish. Maryland and Virginia have water quality standards that allow certain waters to be listed as exceptional state waters, which receive certain protections from antidegradation. (MDE 2009; VDEQ 2009).

4.3.4 Regulation and Enforcement

Individual local governments create and adopt development regulations to help retain riparian forest buffers in urbanizing areas. In Virginia, many local buffer ordinances (Section 4.3.2) were developed as part of implementing the Chesapeake Bay Act (VDCR 2010). An evaluation of the Maryland Critical Area Program found a much higher rate of loss of resource lands outside the designated critical areas after the program's enactment (Hillyer 2003). Maryland also has the Forest Conservation Act, which requires conservation of forests and mitigation of forest loss within a hierarchy that recommends that riparian forests be the highest priority for protection (MDNR FS 1991).

4.3.5 Education and Training

Activities that encroach on buffers are often not done purposefully but out of a lack of awareness. Education and outreach are important tools for promoting an understanding of the importance of riparian areas in maintaining water quality and protecting habitat and other valuable functions that they perform (USEPA 2005). Communities should work to make buffers more visible to the public and publicize the buffer's purpose and value to adjacent property owners. That can be accomplished in many ways, as recommended by EPA and the Center for Watershed Protection, including

> Baltimore County Public Schools have an annual Forest Buffer Restoration Project and Forest Buffer Maintenance Project where every high school in Baltimore is invited to participate. In the spring of 2008, almost 900 high school students from 18 Baltimore County Schools took part in the restoration effort and planted over 700 native trees and shrubs in conjunction with the Chesapeake Bay Trust, Baltimore County Forestry Board, and Baltimore County Department of Recreation and Parks and either take place on school land or at another designated location. During the Forest Buffer Maintenance Project students will map the planting areas to show where the trees and shrubs were planted, complete a survival/mortality count, and perform maintenance on the plantings such as pruning and staking. These activities are taught in the Forestry Unit of the High School Environmental Science Curriculum.

- Marking buffer boundaries with permanent signs that describe allowable uses (see Figure 5-13)
- Educating property owners about buffer benefits and uses via newsletters, pamphlets, meetings, and such and encourage a stewardship ethic
- Teaching courses in restoration techniques for landowners
- Ensuring that when property is sold, the new owners receive information about allowable uses and limits of the buffer
- Conducting annual *buffer walks* to assess buffer health and check for encroachment

Figure 5-13. Sign for a 1.2-acre riparian forest buffer restoration in Virginia.

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Chapter 6. Decentralized Wastewater Treatment Systems

Contents

1 Nitrogen-Reduction Implementation Measures

The U.S. Environmental Protection Agency (EPA) recommends protecting surface waters in the Chesapeake Bay watershed from nitrogen (N) discharged by decentralized wastewater treatment systems by using N-reduction technologies and enhanced system management.

Implementation Measures:

D-1. Specify the following risk-based, N-removal performance levels for all new and replacement individual and cluster systems:

- 20 milligrams per liter (mg/L) total nitrogen (TN) standard* for all new subdivisions and commercial and institutional developments and all system replacements throughout the Chesapeake Bay watershed.
- 10 mg/L TN standard* for all new developments and all system replacements in sensitive areas—i.e., between 200 and 1,000 feet of the ordinary high water mark of all surface waters, or between 200 and 500 feet of an open-channel MS4.
- 5 mg/L TN standard* for all new developments and system replacements in more sensitive areas—i.e., between 100 and 200 feet of the ordinary high water mark of all surface waters, or between 100 and 200 feet of an open-channel MS4.
- 100-foot setback from surface waters and open channel MS4s for all effluent dispersal system components.

> * Effluent standards can be met by either system design or performance, as verified by third-party design review or field verification. Except in sandy or loamy sand soils, a 5 mg/L N reduction credit is given when using time-dosed, pressurized effluent dispersal within 1 foot of the ground surface and more than 1.5 feet above a limiting soil/bedrock condition.

D-2. Ensure wastewater treatment performance effectiveness and cost efficiency by using cluster systems with advanced N-removal technology sufficient to meet the standards specified above for all newly developed communities and densely populated areas.

D-3. Sustain treatment system performance in perpetuity through management contracts with trained and certified operators for all advanced N-removal systems, and responsible management entity (RME) operation and maintenance (O&M) for all cluster and nonresidential systems. RMEs include sanitation districts, special districts, and other public or private entities with the technical, managerial, and financial capacity to assure long-term system performance.

D-4. Preserve long-term treatment system performance with management practices designed to protect system investments, by doing the following:

- Conducting GIS-based inventories of all individual and cluster (i.e., decentralized) wastewater systems in all areas that drain into the Chesapeake Bay or its tributaries. Inventory information includes system location (i.e., latitude/longitude), type, capacity, installation date, owner, and relevant information on complaints, service (including tank pump-out), repairs, inspections, and dates. Inventory data is stored electronically in a format amenable for use in watershed studies, system impacts analyses, and supporting general management tasks. EPA offers *The Wastewater Information System Tool* (TWIST) (USEPA 2006) as a free resource for managing that information in a user-friendly database. Health departments, state agencies, RMEs and others can adapt, amend, or otherwise modify TWIST without restriction or obligation.
- Requiring inspections for all systems on a schedule according to wastewater type, system size, complexity, location, and relative environmental risk. At a minimum, qualified inspectors inspect all systems at least once every 5 years and inspect existing systems within sensitive areas at least once every 3 years. Inspect advanced treatment systems, cluster systems, and those serving commercial, institutional, or industrial facilities at least semiannually and manage such systems under an O&M agreement or by an RME. Inspections are consistent with EPA management guidelines for individual and cluster systems. A service professional or other trained personnel conducts routine monitoring of all systems, and periodic effluent sampling for cluster and nonresidential systems, on the basis of system type, operating history, manufacturer's recommendations, and other relevant factors.
- Repairing or replacing all malfunctioning systems when discovered, with new or replacement technologies capable of meeting the N-removal standards specified above.
- Requiring reserve areas for installing a replacement soil dispersal system that is equal to at least 100 percent of the size of the original effluent

dispersal area. Treatment systems using effluent time-dosing (i.e., not demand-dosing) to the soil can have reserve areas equal to at least 75 percent of the total required drainfield area. Systems with pressurized drip effluent dosing or shallow pressurized effluent dispersal and those with dual drainfields operated on active/rest cycles (i.e., alternating drainfields) can have reserve areas equal to at least 50 percent of the original required dispersal area.

D-5. Remove nitrate in subsurface effluent plumes that enter surface waters by using effective, low-cost technologies such as permeable reactive barriers (PRBs). PRBs are low-cost, pH-controlled trenches filled with sand and a degradable carbon source, such as sawdust, shredded newspaper, or wood chips, designed to intercept groundwater plumes and reduce the TN concentration via denitrification.

2 Introduction and Background

Individual on-site and cluster (*decentralized*) wastewater systems treat household and commercial wastes in suburban, exurban, and rural areas throughout the Chesapeake Bay watershed. The Chesapeake Bay Program (USEPA 2009) estimates that about 25 percent of the homes in the watershed—2.3 million total—rely on these systems, which disperse treated effluent to the soil. EPA predicts that decentralized system installations will increase over the next 20 years by about 35 percent (i.e., 800,000 new systems), eventually reaching 3.1 million (USEPA 2009).

Nearly all the solids and phosphorus (P) discharged from decentralized wastewater systems are retained by the soil, through physical filtration, adsorption, and precipitation processes (USEPA 2004), although release of P into the environment is a concern in sandy soils under certain conditions, especially with poor vertical separation distance with groundwater (Bussey 1996). However, N in wastewater is ultimately converted to nitrate upon infiltration into aerobic soils, a stable, soluble, and highly mobile form of this nutrient that negatively affects groundwater and surface water quality. For those reasons, in this guidance EPA focuses on implementation measures to reduce N.

Decentralized wastewater systems contribute approximately 12.5 million pounds of N to the Chesapeake Bay annually, or about 4.5 percent of the total load. According to current Chesapeake Bay nutrient loading models, most of the N load from such systems—about 60 percent—comes from the Potomac and Susquehanna river drainage areas within Pennsylvania, Virginia, and Maryland. With 800,000 new systems predicted over the next 15 years, significant reductions in N loads from new and existing systems are needed.

The Chesapeake Bay nutrient and sediment reduction goals include decreases in current and future pollutant loads from decentralized treatment systems. A new generation of “hardware and software”—treatment technologies and management practices—are needed to achieve the reductions. This section describes those technologies, management practices, and associated implementation measures. Implementation measures for achieving the reductions include installing treatment units with optimal N-removal capabilities in sensitive areas near surface waters; using standard N-removal systems in other areas; and ensuring that all treatment systems are appropriately operated, maintained, and managed. The measures encompass a range of treatment technologies, planning and performance considerations, and management actions needed to address N export from decentralized systems.

The implementation measures described in this chapter support two primary goals for addressing N inputs to the Chesapeake Bay from these systems:

- Prevent further impairment of the Chesapeake Bay by significantly reducing N levels in wastewater from new residential, commercial, and institutional developments using decentralized systems
- Reduce N inputs to the Chesapeake Bay from existing individual and cluster wastewater systems by replacing malfunctioning systems with better-performing technologies and by managing all systems to ensure long term performance

Implementation measures to achieve those goals include repairing or replacing malfunctioning systems, targeting high-risk systems in sensitive areas for replacement with advanced treatment units, clustering replacement systems where possible to implement better-performing and more efficient community treatment facilities, inspecting all systems throughout the Chesapeake Bay watershed, and installing PRBs where technically and economically feasible to reduce N concentrations in targeted effluent plumes. Those approaches are based on more than 2 decades of research and field studies on decentralized system applications.

Key findings on system performance, effects on groundwater, and the opportunities presented by next-generation treatment technologies are summarized in the *Final Report for the La Pine National Decentralized Wastewater Treatment Demonstration Project* (Rich 2005), a joint effort of EPA and other federal, state, and local agencies:

> The groundwater investigations have found significant existing nitrogen pollution and the 3-D model has predicted extensive future contamination of the aquifer. The model also predicted, based on the field performance of denitrifying systems in the project, that contamination could be slowed or stopped using onsite wastewater treatment technologies, and that, as the region is retrofitted with denitrifying technologies, the existing contamination would be flushed from the groundwater system via existing natural discharge points.
>
> The field test program, in addition to identifying systems that can remove a large proportion of the nitrogen in residential wastewater, found that conventional systems are not protecting the aquifer from nitrate contamination. Conventional systems that were previously thought to denitrify up to 50% of the nitrate discharged from septic tanks were found to achieve significantly less denitrification when process and environmental variables were accounted for.

The La Pine Project, EPA's Environmental Technology Verification (ETV) program, the National Sanitation Foundation standards program, and other research efforts across the country have identified and tested a number of denitrifying wastewater systems and found that performance varies considerably. However, some systems do perform optimally in removing TN from the effluent—e.g., to concentrations lower than 5 mg/L—and others are capable of N effluent levels in the 10 and 20 mg/L range.

Higher treatment performance levels are needed in sensitive areas to protect or restore surface water quality. Research and field studies confirm that effluent plumes with elevated nitrate levels move laterally over long distances—i.e., greater than 300 feet in unconfined, sandy aquifers (Walker et al. 1972; Robertson and Cherry 1992). N concentrations in effluent plumes are affected by soil oxygen levels, soil composition, plant uptake, labile carbon content, travel distance, rate of movement, mixing, and other factors. The measures specified in this chapter include descriptions of treatment and dispersal systems that can meet the performance standards needed to protect the Chesapeake Bay and its tributaries and include more stringent treatment levels in sensitive areas near waterbodies. Such measures are consistent with efforts in the states that have already been adopting treatment zone setbacks and treatment standards to address N and other pollutants in coastal areas (Joubert et al. 2003).

3 Nutrient-Reduction Processes for the Decentralized Wastewater Sector

Nutrients—primarily P and N—are usually present in significant levels in domestic and commercial wastewater. Nutrient treatment and removal involve processes that occur either in treatment system components or in the receiving environment, as summarized below.

3.1 Nitrogen

N is the primary pollutant of concern along the coastal areas of the eastern United States, including the Chesapeake Bay. N discharges are a concern both as a drinking water contaminant (nitrate) and as an aquatic plant nutrient, particularly in N-sensitive surface waters and nearshore marine waters. N is not readily or consistently removed in conventional individual and cluster soil-based systems because conventional soil-discharging systems are not designed to remove N, and most soils have a limited capacity to retain or remove N. Organic N in wastewater is generally converted to ammonium N in the septic tank. Ammonium N is quickly nitrified as the wastewater infiltrates the aerobic soil. Nitrate-N is stable, soluble, and highly mobile in the subsurface environment. Biological denitrification of the nitrate is usually limited because the soil is often aerobic near the ground surface and usually has very little organic carbon, which is required by heterotrophic denitrifying microorganisms. Therefore, where N removal is required for dispersal, pretreatment that achieves both nitrification and denitrification is usually necessary before the wastewater is dispersed to the soil.

3.2 Nitrogen Pretreatment

Many reasonably priced natural and mechanical pretreatment systems, specifically designed for individual and cluster systems, are available today. The most popular example of such systems is the recirculating media filter, with timed pressure-dosing effluent dispersal. The filter media is typically sand, gravel, textile, or peat. A portion of the filtered effluent is recycled back to the septic tank (or pump/recirculating tank) and filter several times before discharge. Denitrification is supported by the low-oxygen, high-carbon environment that exists in the recirculating tank. The systems are able to consistently remove an average of 50 percent or more of the TN in the septic tank effluent—reducing the TN from a typical influent range of 40–50 mg/L for single family homes to 15–20 mg/L (Otis 2007; USEPA 2002a; Jenssen and Siegrist 1990; Higgins et al. 2002; Smith et al. 2008; Rich et al. 2003).

To achieve TN levels of 3–5 mg/L and lower, an additional denitrifying unit process is usually installed to augment the pretreatment system. To sustain a denitrification process capable of high levels of N removal, the nitrified effluent from the pretreatment process must be exposed to a reactive carbon source in a low-oxygen environment before discharge. For larger installations, methanol, acetic acid, molasses, or other organic chemicals are added to the anaerobic reactor. However, the cost of building, operating, and maintaining an external chemical feeding system, coupled with the cost of chemicals, power for a feed pump, controls, and chemical storage increase N-removal expenses substantially.

Carbon sources are not equal in terms of O&M requirements. For example, methanol is very sensitive to under- or over-dosing, and thus requires special attention to ensure that the system is monitored enough to control dosing for optimal N-removal and biochemical oxygen demand control. By contrast, sawdust and newspapers need to be replaced only when effluent N breaks through (i.e., the denitrification capacity of the sawdust or newspaper has been exhausted).

Proprietary denitrifying units, which avoid the need for additional feed pumps, controls, and chemicals, are now available. Such units include a slowly degradable organic material in the reactor tank that can last several years. Field testing has documented TN effluent concentrations of 3–5 mg/L and even lower (Smith et al. 2008; Lombardo et al. 2005).

Further N removal occurs in the soil, particularly when pretreated effluent is dispersed uniformly via alternating dose/rest cycles. Plant uptake of N, soil oxygen levels, carbon sources, temperature, and residence time are key factors in N-removal levels during this final stage of treatment, which are estimated in the 50 percent reduction range (Long 1995; Otis 2007). Additionally, some soils contain sufficient labile carbon to denitrify effluents regardless of the method of dispersal (Anderson 1998; Gold et al. 2002; Starr and Gillham 1986; Bushman 1996; Hiscock et al. 1991). Other important variables could include seasonal use (Postma 1992), in-stream processes, including the matrix through which the groundwater enters nearby surface waters (Birgand 2000; Stewart and Reneau 1984), and the distance from the source to the receiving surface waters (Stacey 2002). One study from the U.K. (Hiscock et al. 1991) estimates that average groundwater carbon content would account for removal of 3 mg/L of nitrate.

3.3 Phosphorus

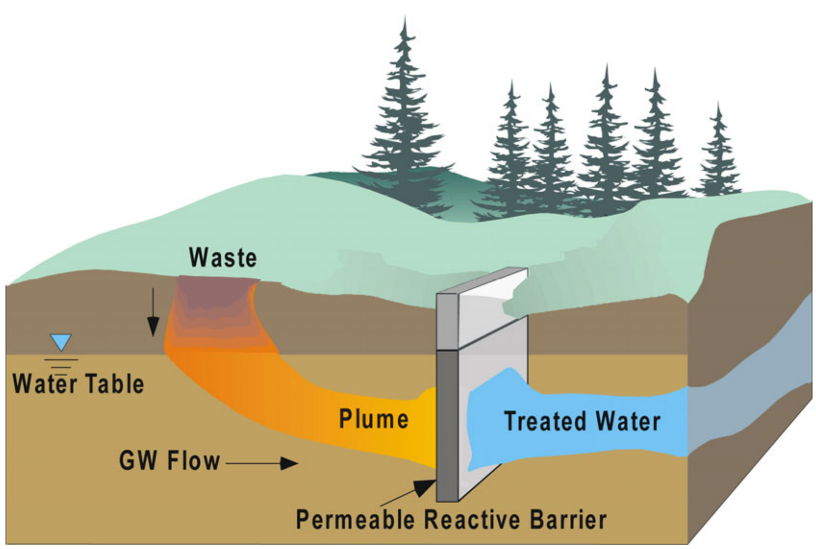
Approximately 20 to 30 percent of the P in wastewater is removed in septic tanks (Lombardo 2006). P removal in soil effluent dispersal systems is achieved primarily by mineral precipitation. The process involves sorption and complex biogeochemical mechanisms that rely on dissolved P mineralization with iron, calcium, and aluminum (Tyler et al. 2003; Stone Environmental 2005; Lombardo 2006). The stability of those processes is influenced by pH, redoximorphic conditions, and the chemistry of aluminum and iron. The soil's capacity to remove P is significant both spatially and temporally. Sorption can be reversible—as with sands, or relatively permanent, as in soils high in iron oxides.

In general, most regions of the Chesapeake Bay watershed have soils that retain high levels of P from decentralized systems. Areas where soil-based, P-removal rates are low include highly permeable soils, such as sands, loamy sands, and soils very high in gravel. In areas with sufficient soil P-removal capacity, saturation fronts of P move only inches or less per year. Wastewater system designers maximize P-removal rates by locating the infiltration system in medium- to fine-textured soils that are as far from surface waters as possible, and extending the infiltration system along the topographic contour of the installation site. Also, uniform dosing and resting dispersal by pressure or drip distribution will optimize P removal in the soil by increasing the contact time between the effluent and the soil.

If native soils are not amenable to adsorption removal, other adsorption methods are available (Stone Environmental 2005; Dimick et al. 2006; USEPA 2002a). Although some P can be removed by pretreatment systems that contain high concentrations of adsorptive elements or by biological P removal, soil adsorption is by far the most common and least expensive means of removal. Where soils are inadequate for P removal, mound systems that use more appropriate soil (possibly imported) might be required. System use over time slowly reduces the capacity of the soil to remove P.

3.4 Permeable Reactive Barriers

Specific types of PRBs have been developed to remove nitrate from groundwater plumes that would otherwise adversely affect surface water quality. PRBs consist of a trench filled with a degradable carbon source (e.g., sawdust, newspaper) and are sited to intercept high-nitrate groundwater plumes (WE&T 2009) before they enter surface waters (Figure 6-1). As the plumes pass through the low-oxygen, carbon-rich barrier, bacteria break down nitrate molecules to use the oxygen for cell respiration. In areas where receiving waters are already eutrophied, the trenches provide immediate relief by removing nitrate from the incoming groundwater. Addressing the source of the high-nitrate plume (i.e., densely sited septic systems) would also produce results, but any measureable effects would likely take several years



Source: USEPA 1998

Figure 6-1. PRB conceptual approach.

because of slow effluent plume movement in most soils and could be more expensive and require more maintenance than installing PRBs.

PRBs are typically installed as long, narrow trenches perpendicular to the incoming plume and parallel to the shoreline. The most effective ones for removing nitrate from plumes are filled with a carbon-based media mix that controls for changes in pH. Such systems have been successfully demonstrated in North America and Europe (Vallino and Foreman 2008; Robertson and Cherry 1995; Lombardo et al. 2005; USEPA 1998). Costs range from about $5,000 to $15,000 per equivalent dwelling unit (i.e., in the plume sourcing area), depending on soils, geology, depth to groundwater, subsurface hydrology, construction access, existing infrastructure, and other factors. Zero valent iron, now used for some industrial wastewater treatment applications, has been studied as a nutrient-removal media in PRBs and other system components. Obstacles with this technology include reduction of nitrate to ammonia rather than N gas and relatively high costs (Cheng 1997). New variations of this technology hold promise for removing some of these obstacles (Lee et al. 2007).

3.5 System Configuration

As noted above, a certain level of treatment process sophistication and soil discharge technique (e.g., pressure dosing, drip dispersal) are required for optimum N removal. Their cost in terms of both hardware and management needs can be significantly mitigated through the use of cluster systems that treat wastewater from multiple homes or businesses. Cluster systems, also called community or distributed systems, have become extremely popular in areas where high levels of wastewater treatment are required, where space is too limited for on-site conventional soil-discharging systems, and local funding capacity precludes conventional sewage collection and treatment (see Section 4.6).

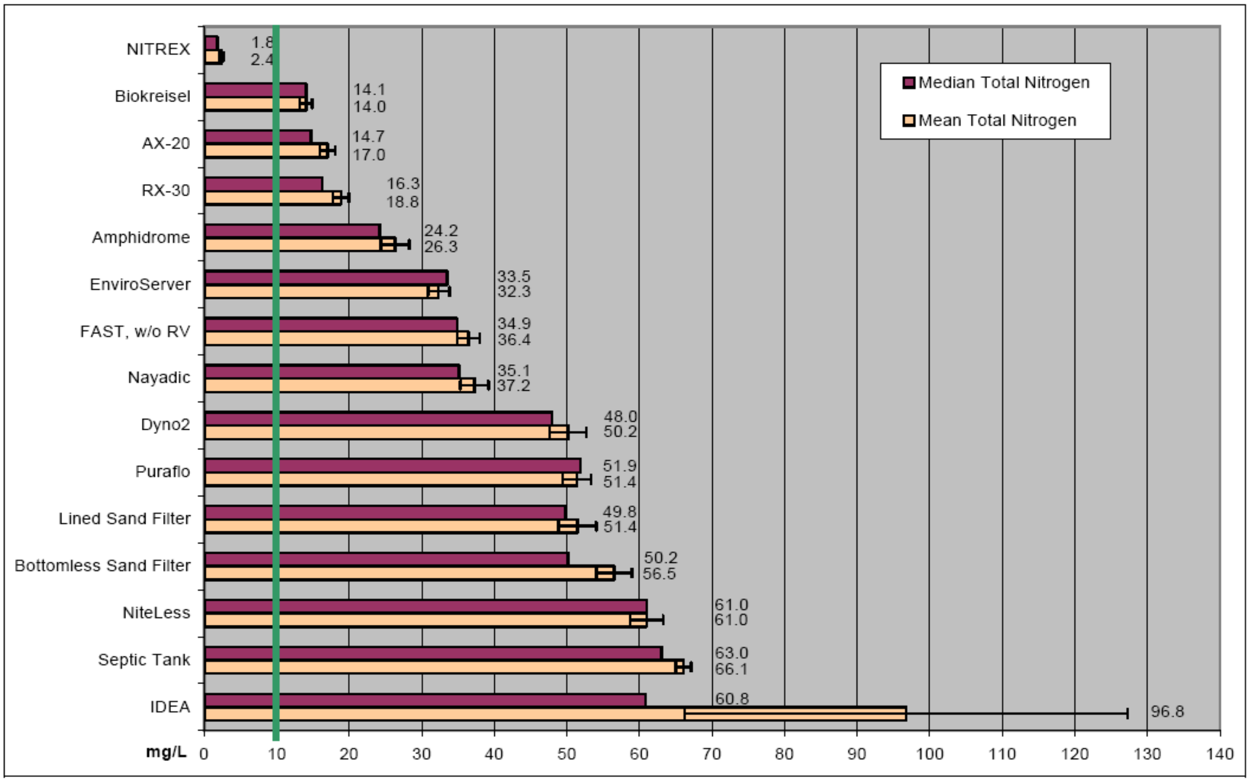
It should be noted that soil-discharging wastewater systems that have the capacity to serve 20 or more people per day are defined by EPA as Class 5 underground injection wells and are therefore subject to permitting and other requirements for large-capacity septic systems under the federal Safe Drinking Water Act. Further, any decentralized system that accepts waste other than sanitary wastewater (such as industrial waste) is an Underground Injection Control (UIC) Class 5 Injection Well. UIC regulatory information for large-capacity septic systems is posted at http://www.epa.gov/safewater/uic/class5/types_lg_capacity_septic.html.

4 Treatment Technologies and Costs

Key considerations in treatment system selection are wastewater flow, strength (i.e., biochemical oxygen demand), the presence of nonconventional organic or inorganic constituents, the sensitivity of the receiving environment, and the capacity of system managers to operate and maintain it over the long term. Given those factors, both the *selection* and ongoing *use* of a specific technology is driven by management considerations. For example, wastewater characterization and assessment of the receiving environment are planning-level activities that result in establishing performance standards, which begin to identify the narrow range of treatment technology options and related design considerations. Once a specific system is selected, construction oversight, operation, inspection, maintenance, and residuals removal—all management program elements—become paramount in ensuring perpetual performance.

The La Pine Decentralized Wastewater Demonstration Project (Rich 2005) has provided some of the most comprehensive field data on the performance of various system types. The project—funded by EPA and supported by the Deschutes County, Oregon, Environmental Health Division; Oregon Department of Environmental Quality; and the U.S. Geological Survey—monitored system performance between 1999 and 2005 (see Figure 6-2 and Table 6-1). System performance was found to be affected by a number of variables, but in general the level of analysis provides insight on the range of pollutant removal that can be expected from the various system types. The figure and table that follow summarize key data from the project; detailed performance results, system descriptions, and other information are available in the final project report (Rich 2005).

The subsections that follow discuss the main classes of treatment system technologies. The final section of this chapter summarizes management program elements that support the implementation measures provided at the beginning of this chapter. Table 6-2 provides examples of biological N-removal performance from the literature for a variety of technologies. Table 6-3 contains details on specific treatment systems described in the subsections below.



Source: Rich 2005.

Figure 6-2. Effluent TN concentrations for systems tested in the La Pine Project.

Table 6-1. System components and type classifications for Figure 6-2

System component/type	General classification
Septic Tank	Primary treatment vessel
Lined Sand Filter	Attached growth, sand media
Bottomless Sand Filter	Attached growth, sand media
AdvanTex AX-20	Attached growth, textile media
AdvanTex RX-30	Attached growth, textile media
Puraflo	Attached growth, peat media
Dyno2	Attached growth, gravel media, wetland polishing
Amphidrome	Attached growth/suspended growth hybrid
Biokreisel	Attached growth/suspended growth hybrid
EnviroServer	Attached growth/suspended growth hybrid
FAST Bio-Microbics	Attached growth/suspended growth hybrid
IDEA	Suspended growth
Nayadic	Suspended growth
NiteLess	Suspended growth with add-on anoxic filter
NITREX	Add-on anoxic filter

4.1 Conventional Systems

Conventional treatment systems featuring septic tanks and soil infiltration systems are the most commonly used wastewater treatment technologies. The soil dispersal system facilitates aerobic treatment, degradation, filtration, and adsorption of contaminants not treated or retained by the septic tank. However, N removal is somewhat limited, with TN concentrations before soil application typically in the 40–50 mg/L range. In sandy soils with little organic content, high oxygen levels, and poor downgradient mixing, N concentrations can remain high even after several hundred feet of effluent plume movement (Walker et al. 1973; Robertson and Cherry 1992; Cogger 1988; Joubert et al. 2003). Given the low N-removal rates of conventional systems (i.e., averaging 20 percent TN removal; Otis 2007; Smith et al. 2008; Jenssen and Siegrist 1990), they are no longer appropriate for use in new communities or densely developed areas in the Chesapeake Bay watershed.

4.2 Land/Vegetative Treatment Systems

Land treatment systems, such as spray irrigation systems, are permitted in some places but have not been widely used because of their large land area requirements (USEPA 2000). In general, such vegetative treatment systems have shown poor performance with regard to N removal. However, in recent years, significant advances have been made. The Living Machine, a proprietary decentralized wastewater treatment system has been used successfully for large-capacity applications, such as schools. While the system delivers advanced N removal, it relies on multiple treatment processes including anaerobic and aerobic reactors, a clarifier, and an *ecological fluidizer bed* (USEPA 2002b), which drive up the cost. Eco-machines are similar in concept to The Living Machine and are capable of advanced N removal. Costs for both of these technologies make sense for only fairly large-capacity applications. They are not practical for individual residential systems but could be useful for cluster and large system applications.

4.3 Suspended Growth Systems

Suspended growth systems, such as activated sludge-based aerobic treatment units (ATUs), are generally effective in nitrifying septic tank effluent. Denitrification is somewhat limited but can be aided by process controls (e.g., recirculation) and effluent dispersal via time-dosing into the upper soil horizon (Stewart 1988). Aerobic units that feature aeration that periodically stops and starts show improved denitrification. Sequencing batch reactors, which first fill and then draw, in alternating aerobic/anoxic cycles in a single tank might also meet the 20 mg/L recommended effluent limit for areas more than 1,000 feet from surface waters in the Chesapeake Bay watershed, when effluent is dispersed to the soil via time-dosed pressure application (Washington State Department of Health 2005). Capital costs for conventional on-site suspended growth systems range from $7,500 to $15,000 per equivalent dwelling unit

(EDU), with O&M expenses of $400 to $800 per EDU per year when all suggested O&M tasks are performed (Tetra Tech 2007).

N removal in larger cluster applications of suspended growth systems (i.e., > 200 homes) can be enhanced by incorporating a membrane bioreactor process (MBR) unit, which screens wastewater through very small pore-size filters. MBRs are more common to centralized treatment facilities because of operating costs and economy of scale issues. However, individual home-sized and small cluster units are beginning to be developed for the U.S. market (e.g., BioBarrier, ZeeWeed; WERF 2006). The high-quality effluent provides opportunities for treated water reuse. Cost and performance data for individual and small cluster applications of MBRs are not widely available and are likely to vary greatly. Energy costs, particularly to operate the pumping components, are often significant, especially in smaller system applications (USEPA 2007).

4.4 Attached Growth Aerobic Systems

These systems (sometimes called trickling filters or media filters) use natural aeration instead of mechanical, produce less sludge for disposal, and require less power and O&M than the suspended growth units in performing the same tasks. All the systems listed in Table 6-3 are varieties of attached growth system types. Like suspended growth systems, attached growth treatment units also require a recirculation step to meet more stringent TN-removal objectives. Commercially available systems come in lightweight packages and employ lightweight media for easy installation. They also require about 20 percent less physical footprint than typical trickling filters. When properly loaded and operated, they can produce very high nitrification levels that must be followed by a denitrification step to exceed the typical 50 percent N-removal rate. Attached growth systems are also often quite stable compared with suspended growth processes, which might be important, particularly for decentralized systems serving periodically or seasonally used facilities. On-site capital costs are slightly higher in general than the suspended growth ATUs ($10,000–$16,000 per EDU), but O&M costs are significantly less, e.g., about $200–$300 per EDU per year (USEPA 2010; Tetra Tech 2007).

N removal in attached growth media filters can be optimized through internal treatment system process controls. Single-pass media filters—sand filters, textile filters, peat systems, mounds, and other packed media bed units—achieve excellent nitrification levels but generally do a poor job with denitrification unless some, or all, of the effluent passes through a carbon-rich, low-oxygen environment after the nitrification stage. That can be accomplished by recirculating a portion of the effluent back to the septic tank or a pump tank, or by adding a denitrification unit to the system, or both. Media filters have a long record of excellent performance, with nitrification rates as high as 95 percent (Otis 2007; Smith et al. 2008; USEPA 2002a). The treatment process is stable year-round and can be employed through either custom-built, nonproprietary engineered systems or commercial units that can be installed in a single day. Capital costs for single-pass filters range from $5,500 to $13,000 per EDU, with O&M expenses of $200 to $400 per EDU per year (USEPA 2010; Tetra Tech 2007).

Recirculating media filters have been in use for many years and feature high nitrification rates with about 50–70 percent TN reduction. The systems recycle part of the effluent back to the septic tank or the recirculating tank, where the anoxic environment and available carbon facilitate denitrification processes. Design considerations include the ratio of effluent recirculated and the configuration of the recycle plumbing, i.e., ensuring that the recycled effluent is discharged to a tank location with low oxygen and some carbon. TN effluent concentrations can be as low as 10 mg/L, which can be further reduced in the soil by using time-dosed, pressure-drip effluent dispersal. Engineered systems and proprietary units are widely available and can serve single homes or large subdivisions. Capital costs for recirculating systems range from $9,500 to $20,000 per EDU, with O&M expenses of $350 to $600 per EDU per year (USEPA 2010; Tetra Tech 2007; Washington State Department of Health 2005).

4.5 Add-On Anoxic Filters with a Carbon Source

Optimal denitrification can be achieved by passing nitrified effluent through a low-oxygen, carbon-rich environment before soil dispersal. Engineered and proprietary systems featuring add-on anoxic filters with an external carbon source (e.g., methanol, sawdust, newspapers) have performed successfully in single-home and cluster applications. For example, at least one commercially available product (NITREX) regularly produces effluent with N concentrations of less than 5 mg/L (Heufelder et al. 2007, see also Figure 6-2 and Table 6-2). Others claim to have similar systems with comparable performance, although, to date, independent field verification is lacking. NITREX relies on a passive nitrate remediation biofilter unit that uses a processed wood by-product as the filter medium. Other system designs discussed above can approach that level when paired with time-dosed, shallow pressurized dispersal. Capital costs for add-on denitrification systems range from $3,500 to $7,000 and more per EDU, with O&M expenses of less than $100 per year (Washington State Department of Health 2005). Note that those are added costs and do not include costs for the septic tank, nitrification process unit, or soil dispersal system—just the add-on component.

Table 6-2. Examples of biological N removal performance from the literature

Technology examples	TN removal efficiency (%)	Effluent TN (mg/L)
Suspended growth		
Aerobic units w/ pulse aeration	25%–61%[a]	37–60[a]
Sequencing batch reactor	60%[b]	15.5[b]
Attached growth		
Single-Pass Sand Filters (SPSF)	8%–50%[c]	30–60[c]
Recirculating Sand/Gravel Filters (RSF)	15%–84%[d]	10–47[d]
Multi-Pass Textile Filters (AdvanTex AX20)	64%–70%[e]	3–55[e]
RSF w/ Anoxic Filter	40%–90%[f]	7–23[f]
RSF w/ Anoxic Filter & external carbon source	74%–80%[g]	10–13[g]
RUCK system	29%–54%[h]	18–53[h]
NITREX	96%[i]	2.2[i]

Source: Adapted from Washington Department of Health 2005

Notes: Overall performance can vary, depending on system configuration and other factors. For detailed descriptions of treatment processes and technologies, see http://www.psparchives.com/publications/our_work/hood_canal/hood_canal/n_reducing_technologies.pdf.

a. California Regional Water Quality Control Board 1997; Whitmeyer et al. 1991

b. Ayres Associates 1998

c. Converse 1999; Gold et al. 1992; Loomis et al. 2001; Nolte & Associates 1992; Ronayne et al. 1982

d. California Regional Water Quality Control Board 1997; Gold et al. 1992; Loomis et al 2001; Nolte & Associates 1992; Oakley et al. 1999; Piluk and Peters 1994; Ronayne et al. 1982

e. NSF International 2009

f. Ayres Associates 1998; Sandy et al. 1988

g. Gold et al. 1989

h. Brooks 1996; Gold et al. 1989

j. Rich et al. 2003

4.6 Composting Toilet Systems

Composting toilet systems that contain and treat toilet wastes can reduce watershed N discharges significantly, because such wastes account for 70–80 percent of the TN load in domestic wastewater. Composting systems have been used successfully in both private and public facility settings. Like all systems, they require appropriate design and ongoing maintenance. A graywater treatment system is needed if the facility generates sink, laundry, or other graywater, therefore adding to the cost. Capital costs for composting systems (and excluding the cost of graywater systems) range from $2,500 to $10,000, with O&M expenses of $50 to $100 per year (USEPA 1999). The single-house viability of such systems depends on local codes and the owner's attitude, though acceptance and use of composting systems is increasing because of improved designs, performance, and lower maintenance requirements. The systems are more frequently used in public settings, such as parks and campgrounds.

4.7 Cluster Treatment Systems

Generally, cluster systems collect wastewater from multiple houses through low-cost sewerage and treat and disperse the effluent to soil-based dispersal systems similar to on-site systems. Many homes and businesses can be served by a single treatment facility. Most cluster systems feature septic tanks on each building lot; collection piping that operates via gravity, vacuum, or pressure; a treatment facility with attached growth process units; and a soils-based dispersal field for the effluent. Add-on anoxic denitrification filters can be included. Effluent is typically dispersed to the soil under pressure (e.g., pressure, drip, time or demand dosing) to assure uniform application throughout the larger drainfield. Collection technologies include grinder pump systems, which macerate and transport all sewage; effluent sewers, such as the septic tank effluent pump (STEP); the septic tank effluent gravity (STEG) collection system; and vacuum systems.

Advanced treatment systems can facilitate local reuse of the treated effluent for toilet flushing, irrigation, industrial purposes, or just be used to replenish aquifers. The cost of a cluster collection system varies significantly according to the number of users, collection system logistics, treatment facility design, land availability, materials, labor costs, and other factors. Cluster systems can achieve economies of scale to provide high levels of treatment at costs significantly less than individual systems and centralized sewer systems. New cluster systems generally range from $10,000 to $18,000 per EDU in non-urbanized areas of new development, with higher costs for retrofits in urban areas, depending on the treatment technology used (USEPA 2010; Tetra Tech 2007). Replacement and retrofit systems have similar costs, but collection system installation can drive costs higher. An RME with the technical, financial, and managerial capacity to ensure viable, long-term, cost-effective performance is essential for cluster system applications. Total system annual O&M costs range from $450 to $750 per EDU per year (Tetra Tech 2007).

4.8 Soil Dispersal Systems

Gravity-based, soil dispersal systems generally include conventional perforated pipe, laid in stone-filled trenches or purchased with Styrofoam beads surrounding the pipe and wrapped in netting; and gravelless, open-bottomed leaching chambers. N removal in the soil increases when effluent is dispersed in a time-dosed manner (i.e., dose/rest cycle) in the uppermost soil horizon (i.e., within one foot of the ground surface). Time-dosed, pressure-drip dispersal in the top 12 inches of soil has been credited with a 50 percent reduction in Tennessee (Long 1995), making the option an important feature for achieving the performance standards recommended in this chapter. As in all effluent dispersal systems, maximizing the separation distance between effluent application and restrictive soil boundaries (e.g., hardpan, bedrock, perched water tables, seasonal high water tables) improves performance.

Another effluent-dispersal strategy that improves performance is the use of alternating soil dispersal fields. Most conventional systems continuously load drainfields with effluent, resulting in a gradual reduction of the soil's capacity to treat effluent over time. Alternating drainfields that are used for 6 months then rested for 6 months improves the performance of the soil dispersal system and should be favored over conventional drainfields. Such systems require relatively low additional investment and can greatly extend the life of the soil dispersal system (Noah 2006). Maintenance programs for such systems should be designed and implemented in concert with the local health department or RME to ensure that flow-diversion devices are operated on schedule. Because this strategy applies to conventional septic drainfields, this recommendation applies primarily to areas of new development outside sensitive areas and subdivisions.

4.9 Effluent Reuse

Reusing treated wastewater system effluent can significantly reduce N discharge to the environment. Many of the technologies suggested for advanced decentralized wastewater treatment in the Chesapeake Bay watershed can, with adaptations, be used to produce reclaimed water for beneficial reuses, including aquifer recharge, landscape irrigation, toilet flushing, fire protection, cooling and other nonpotable indoor and outdoor purposes (USEPA 2004). When reclaimed water is used for irrigation, reuse can offset potable water demand by augmenting supply while sequestering nutrients in vegetative matter and offsetting fertilizer use (WERF 2010). Reclaimed water technologies generally include recirculating filtration systems and membrane bioreactors, amended with disinfection systems (most commonly, chlorination or ultraviolet disinfection or both), online monitoring systems, on-site storage, and sometimes specific chemical feed systems for conditioning treated effluent to meet water quality demands for specific reuses (e.g., pH adjustment for cooling water). Nonreactive dye injection is sometimes required by building codes for reclaimed water to be used indoors. Costs for decentralized reclaimed water systems are highly context-specific and dependent on the intended reuse application, system size, and local or state regulatory requirements (WERF 2010) but can be assumed to add 50 percent to the costs of a more traditional decentralized system.

Table 6-3. Products that have completed the EPA ETV process for N reduction in domestic wastewater from individual homes, as of May 2005

System name	Technology	Description of process	Performance	Cost
Waterloo Biofilter® Model 4-Bedroom Waterloo Biofilter Systems, Inc. 143 Dennis St.: P.O. Box 100 Rockwood, Ontario Canada N0B 2K0 http://www.nsf.org/business/water_quality_protection_center/pdf/Waterloo-VS-SIGNED.pdf	Fixed film trickling filter.	The biofilter unit uses patented lightweight open-cell foam that provides a large surface area. Settled wastewater from a primary septic tank is applied to the surface of the biofilter with a spray distribution system. The system can be set up using a single pass process (without any recirculation of biofilter treated effluent) or can use multi-pass configurations. The ETV testing results were generated by returning 50% of the biofilter effluent back to the primary compartment of the septic tank.	It averaged 62% removal of TN with an average TN effluent of 14 mg/L over the 13-month testing period. Earlier testing of this product in a single pass mode demonstrated that it could produce a 20–40% TN reduction.	$13,000–$17,000 for total system installation. The Waterloo Biofilter unit only would cost approximately $7,000.
Amphidrome™ Model Single Family System F.R. Mahony & Associates, Inc. 273 Weymouth St. Rockland, MA 02370 http://www.nsf.org/business/water_quality_protection_center/pdf/Amphidrome_VS.pdf	Submerged growth sequencing batch reactor (SBR) in conjunction with an anoxic/equalization tank and a clear well tank for wastewater treatment	The bioreactor consists of a deep bed sand filter, which alternates between aerobic and anoxic treatment. The reactor operates similar to a biological aerated filter, except that the reactor switches between aerobic to anoxic conditions during sequential cycling of the unit. Air, supplied by a blower, is introduced at the bottom of the filter to enhance oxygen transfer.	It averaged 59% removal of TN effluent of 15 mg/L over the 13-month testing period at the Massachusetts Alternative Septic System Test Center (MASSTC).	$7,500 for unit only. The manufacturer estimates it would cost $12,000–$15,000 for a complete installation.
SeptiTech® Model 400 System SeptiTech, Inc. 220 Lewiston Road Gray, ME 04039 http://www.nsf.org/business/water_quality_protection_center/pdf/SeptiTech_VS.pdf	Two-stage fixed film trickling filter using a patented highly permeable hydrophobic media	Clarified septic tank effluent flows by gravity into the recirculation chamber of the SeptiTech unit. A submerged pump periodically sprays wastewater onto the attached growth process and the wastewater percolates through the patented packing material. Treated wastewater flows back into the recirculation chamber to mix with the contents. Treated water flows into a clarification chamber and is periodically discharged to disposal unit (drainfield, drip irrigation, etc.)	Averaged 64% removal of TN with an average TN effluent of 14 mg/L over the 12-month testing period at MASSTC.	$11,000 for SeptiTech unit includes shipping and installation. The manufacturer estimated that a total system with pressure distribution drainfield would cost approximately $20,000.

Table 6-3. Products that have completed the EPA ETV process for N reduction in domestic wastewater from individual homes, as of May 2005 *(continued)*

System name	Technology	Description of process	Performance	Cost
Bioclere™ Model 16/12 Aquapoint, Inc. 241 Duchanine Blvd. New Bedford, MA 02745 http://www.nsf.org/business/water_quality_protection_center/pdf/Bioclere-VS-SIGNED.pdf	Fixed film trickling filter.	Septic tank effluent flows by gravity to the Bioclere clarifier unit from which it is sprayed or splashed onto the fixed film media. Treated effluent and sloughed biomass are returned to the clarifier unit. A recirculation pump in the clarifier periodically returns biomass to the primary tank. Oxygen is provided to the fixed film by a fan located on the top of the unit.	Averaged 57% removal of TN with an average TN effluent of 16 mg/L over the 13-month testing period at MASSTC.	$7,500 for unit itself. Price for total system would need to include primary septic tank, Bioclere unit and disposal option, with costs in the range of $12,000–$15,000. The manufacturer recommends use in clusters to reduce per home costs and facilitate maintenance. Experience with a 27-home cluster resulted in costs of $6,800– $8,000 per home.
Retrofast 0.375 System Bio-Microbics 8450 Cole Parkway Shawnee, KS 66227 http://www.nsf.org/business/water_quality_protection_center/pdf/Biomicrobics-FinalVerificationStatement.pdf	Submerged attached-growth treatment system, which is inserted as a retrofit device into the outlet side of new or existing septic tanks.	The RetroFAST 0.375 System is inserted into the second compartment of the septic tank. Air is supplied to the fixed film honeycombed media of the unit by a remote blower. Alternate modes of operation include recirculation of nitrified wastewater to the primary settling chamber for denitrification. Intermittent use of the blower can also be programmed to reduce electricity use and to increase nitrification.	Averaged 51% removal of TN with an average TN effluent of 19 mg/L over the 13-month testing period at MASSTC.	Product and installation cost for the Retrofast 0.375 System ranges is estimated to be $4,000–$5,500 depending on existing tankage. That cost includes the FAST unit, blower, blower housing and control panel. The local representative for Bio-Microbics units believes costs could be as low as $3,500 for multiple units.
Recip® RTS-500 System Bioconcepts, Inc. P.O. Box 885 Oriental, NC 28571-0885 http://www.nsf.org/business/water_quality_protection_center/pdf/Bioconcepts_Verification_Statement.pdf	Fixed film filter	This is the newest product to complete ETV Program testing. It is a patented process developed by the Tennessee Valley Authority (TVA) and uses a fixed film filter medium contained in two adjacent, equally dimensioned cells. Timers on each of the two reciprocating pumps control the process.	Averaged 58% removal of TN with an average TN effluent of 15 mg/L over the 12-month testing period at MASSTC.	Very limited experience with this single-family unit. The unit built for ETV testing was a prototype. The cost per unit, by itself, is estimated to be $8,000–$10,000. Cost of the septic tank and disposal unit would be extra and the cost would depend on site conditions. Conservatively, cost for a total system could be $11,000–$15,000.

Source: Adapted from Washington Department of Health 2005

5 Wastewater Planning and Treatment System Management

The previous section describes N-removing individual or cluster wastewater system technologies, system configurations, and effluent dispersal options. This section describes management considerations that are essential for optimizing treatment system selection, sizing, performance, and long-term use, such as inventory systems, wastewater planning, performance standards, siting and installation guidelines, operation, inspection, maintenance, and residuals handling. The management tasks described in this section are paramount for reducing nutrient inputs to the Chesapeake Bay because they establish the framework for selecting and using specific treatment systems in particular locations. For example, advanced cluster systems are the best approach for protecting and restoring the Chesapeake Bay when considering wastewater facilities for new subdivisions and replacing significant numbers of malfunctioning systems in existing subdivisions.

The following subsections summarize key management program elements viewed as important for controlling the input of nutrients and other pollutants to the Chesapeake Bay. EPA has provided extensive guidance, case studies, resources, references, and links on these management program topics (USEPA 2005, 2010). Specific, detailed information on each topic below is provided in EPA's (2005) *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems,* available online at http://cfpub.epa.gov/owm/septic/septic.cfm?page_id=289.

5.1 Public Education and Involvement

Decentralized wastewater management programs require public support. The success of such programs will depend on how well homeowners, system service providers, and other stakeholders are involved in the development process. Unless people understand the need for a management program, there is little chance it will be adopted. Once in operation, the program must keep the community engaged, involved, and informed. Managers should give special consideration to explaining the need for new requirements for system upgrades, inspections, or other performance measures.

EPA has partnered with a variety of nonprofit organizations involved in decentralized wastewater management to improve public education, outreach, and involvement through development of informational materials, technical products, and training programs. Links to these partner organizations and the educational, technical, and other resources they provide are provided at http://cfpub.epa.gov/owm/septic/septic.cfm?page_id=260. EPA maintains a repository of print, radio, and TV public service announcements and other materials specifically pertaining to septic system education in its Nonpoint Source Outreach Toolbox, online at http://www.epa.gov/nps/toolbox/.

5.2 Planning

Planning can be used to integrate management strategies for areas served by both centralized and decentralized wastewater treatment facilities, serve as the basis for ordinances and subdivision regulations, and synchronize the community growth plan in harmony with the water and wastewater infrastructure investments. Integrating wastewater planning functions provides better long-term management of facilities and can help local officials deal with a number of needs such as sewer overflows, National Pollutant Discharge Elimination System effluent limitations, total maximum daily loads (TMDLs), and antidegradation requirements. For example, integrated planning can minimize problems associated with competition for infiltration areas between wastewater and stormwater management facilities in new developments, and is useful in anticipating and preventing adverse water quality effects. Variables to consider during the planning process include wastewater flows, proximity and uses of nearby water resources, landscape topography, hydrology, hydrogeology, soils, environmentally sensitive areas, infrastructure system options and locations, population densities, and need and potential for clustering treatment or reuse facilities.

EPA supports a wide range of water resource planning and management functions through programs such as the Clean Water Act section 319 nonpoint source management program, the Clean Water Act 305(b) assessment reports, TMDLs, wellhead and source water protection programs, watershed planning initiatives, coastal management, National Estuary Program, wetlands protection programs, water quality standards, continuous planning processes under section 303(e), water quality management processes under section 205(j) and 604(b), the Clean Water State Revolving Fund, and so on. Ideally, the planning and management activities supporting decentralized wastewater treatment would be integrated, or at least coordinated, with these and other water resource programs, many of which the states operate.

5.3 Performance Requirements

Performance requirements for systems are necessary to minimize the risks they pose to health and water resources. Performance requirements specify objectives for each wastewater management system, which can include physical, chemical, and biological process components. Performance compliance is based on pollutant-removal estimates for the various system components (e.g., septic tank, suspended-growth or fixed-film reactors, lagoons, wetlands, soil, disinfection), verified by periodic field inspections and sampling. Performance can be measured via numeric or narrative criteria. Numeric criteria reflect time-based, mass loadings or pollutant-concentration limits designed to protect sensitive water resources. Pollutants commonly targeted in performance requirements include nutrients, bacteria, oxygen demand, and solids.

5.4 Recordkeeping, Inventories, and Reporting

System inventories provide the nuts and bolts for on-site management. Basic system information—location, type, design capacity, owner, installation, and servicing dates—is essential to an effective program. The best record-keeping programs feature integrated electronic databases with field unit data entry (i.e., using a handheld personal digital assistant), save-to-file computer assisted design drawings, user-specified reporting formats, and GIS-based spatial data management and user interface systems.

5.5 Financial Assistance and Funding

Financial assistance might be needed to (1) develop or enhance a management program; (2) provide support for constructing and modifying wastewater facilities; and (3) support operation of the program. Funding for program development and operation is often available from public and private loan or grant sources, supplemented by local matching funds. It can also be derived from some form of resource sharing among management program partner organizations such as planning departments or health and water resource agencies. Developing an RME and financing for constructing and operating facilities require larger investments that might come from grants and loans or public-private partnerships. Long-term operating costs are usually borne by system users through payment of fees and assessments.

5.6 Site Evaluation

Evaluating a proposed site in terms of its environmental conditions, physical features, and soil characteristics provides the information needed to size, select, and locate an appropriate wastewater treatment system. Regulatory authorities issue installation permits on the basis of the information collected and analyses performed during the site evaluation. Prescriptive site evaluation, design, and construction requirements are based on experience with conventional septic tank/soil dispersal systems and empirical relationships that have evolved over the years. A soil analysis to a depth of 4 to 6 feet using a hand auger, drill rig, or a backhoe pit, rather than a simple percolation test, provides a better approach for assessing soils, seasonal water table fluctuations, and other subsurface site features. Performance-based approaches require a more comprehensive site evaluation. Site evaluation protocols can include some presently employed empirical tests, specific soil properties tests, and soil pits to characterize soil horizons, mottling, and a variety of other properties. Modeling groundwater and surface water impacts of multiple systems in defined areas (e.g., stream subwatershed) can help to further refine performance requirements and related system site and design considerations.

5.7 System Design

Decentralized wastewater treatment system design requirements focus on protecting public health and water resources. However, systems should also be affordable and aesthetically acceptable. Prescriptive codes that specify standard designs for sites meeting minimum criteria simplify design reviews, but they limit development options and the potential for efficiently meeting performance requirements. Where management programs rely on the state code for design, there might not be any need for special review procedures for alternative system designs. However, in sensitive environments where performance codes are employed, there is a need to include allowances for alternative designs even if they only expand the number of prescriptive system choices and site parameters for sites that do not meet the conditions for conventional systems. Design considerations should address the potential implications of water conservation fixtures, effects of different pretreatment levels on hydraulic and treatment performance of soil-based systems, and the O&M requirements of different pretreatment and soil dispersal technologies.

5.8 Construction/Installation

Poor installation can adversely affect performance of both conventional and advanced systems that rely on soil dispersion and treatment. Most jurisdictions allow installation or construction to begin after issuance of a construction permit, which occurs after the design and site evaluation reports have been reviewed and approved. Performance problems linked to installation/construction are typically related to soil wetness during construction, operation of heavy equipment on soil infiltration areas, use of unapproved construction materials (e.g., unwashed aggregate containing clay or other fines), and overall construction practices (e.g., altering trench depth, slope, length, location). The effects of improperly installed soil-based systems generally occur within the first year of operation in the form of wastewater backups. Some improper construction practices might not be as evident and could take years to manifest themselves in the form of degraded groundwater or surface water. The regulatory authority or other approved professionals should conduct inspections at several stages during the system installation process to ensure compliance with design and regulatory requirements.

5.9 Operation and Maintenance

O&M is important for all wastewater treatment systems, especially those that rely on components that are difficult to remedy if damaged—such as a soil dispersal system. Most system user information includes building awareness of inputs that might affect treatment processes, such as strong cleaners, lye, acids, biocides, paint wastes, oil and grease, and the like. Gravity-flow, soil-infiltration systems require little O&M beyond limiting inputs to normal residential wastes, cleaning effluent screens/filters, and periodic tank pumping (e.g., every 3 to 7 years). Systems employing advanced treatment technologies and electromechanical components require more intensive O&M attention, e.g., checking switches and pumps, measuring and managing sludge levels (important for all systems), monitoring and adjusting treatment process and system timers, checking effluent filters, monitoring effluent quality, and maintaining disinfection equipment. Operators and service technicians should be trained and certified for the types of systems they will be servicing; services should be logged and reported into a management tracking system, such as EPA's TWIST (USEPA 2006), so that long-term performance can be tracked. The use of a dial-up modem or Internet-based monitoring equipment can improve operator efficiency and performance tracking when large numbers of systems are involved.

5.10 Residuals Management

Septic tanks contain settleable solids, fats, oils, grease, and other residuals that require periodic removal. The primary objective for septage management is to establish procedures for handling and dispersing the material in a manner that protects public health and water resources and complies with applicable laws. Approximately 67 percent of the estimated 12.4 billion gallons of septage produced annually in the United States is hauled to publicly owned treatment works or other facilities for treatment, while the remaining 33 percent is applied to land. Federal regulations (under Title 40 of the *Code of Federal Regulations* Part 503) and state/local codes strive to minimize exposure of humans, animals, and the environment to chemical contaminants and pathogens that are often present in septage. Residuals management programs should include tracking or manifest systems that identify sources, pumpers, transport equipment, final destination, and treatment or management techniques.

5.11 Training and Certification/Licensing

A variety of professionals and technicians including planners, regulators, designers, installers, operators, pumpers, and inspectors, are all involved in some aspect of a decentralized wastewater management program. Training, along with certification or registration, provides system owners and users with competent service providers and promotes professionalism among the industry. Service providers need to have a solid working knowledge of treatment processes, system components, performance options, O&M requirements, and laws/regulations. Universities, colleges, technical schools, agency-sponsored training programs, regional/local workshops, or formal/informal apprenticeship programs can provide such training. Service providers should have extensive and detailed knowledge of their own service areas and a general grasp of other related activities (e.g., planning or site evaluation). Service providers should pursue opportunities for cross-training, joint accreditation/certification, and sharing of training resources wherever possible.

5.12 Inspections and Monitoring

Perhaps the most significant shortcoming in existing management programs is the lack of regular inspections and performance monitoring. Area-wide monitoring regimes include testing groundwater and surface waters for indicators of substandard treatment, such as the presence of human fecal bacteria and excess nutrients. All systems need to be inspected, at an interval defined by the technological complexity of system components, the receiving environment, and the relative risk posed to public health and valued water resources. The best approach is to establish an inspection regime and schedule on the basis of the system's relative reliance on electromechanical components combined with health and environmental risk. Less effective surrogate approaches include, in order of descending effectiveness (1) requiring comprehensive inspections at regular intervals; (2) third-party inspections at the time of property transfer; (3) inspections only as part of complaint investigations.

5.13 Corrective Actions and Enforcement

A decentralized wastewater management program should be enforceable to assure compliance with laws and to protect public health and the environment. Management agencies should have the legal authority to adopt rules and assure compliance by levying fines, fees, assessments, or by requiring service providers to respond to system malfunctions. Program administrators should emphasize those tools that encourage compliance, rather than punishment. It also helps to have the support of the courts to implement an effective enforcement program. To assure compliance, management agencies typically need authority to do the following:

- Respond promptly to complaints
- Issue civil and criminal actions or injunctions
- Provide meaningful performance inspections
- Condemn systems or property
- Issue notices of violation (NOVs)
- Correct system malfunctions

- Implement consent orders and court orders
- Restrict real estate transactions
- Hold formal and informal hearings
- Issue fines and penalties

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Chapter 7. Hydromodification

Contents

1 Overview

The Chesapeake Bay and its tributaries, representing the nation's largest estuary, is a resource of important economic, social and environmental significance. The Chesapeake Bay ecosystem, however, remains severely degraded primarily because of pollution from excess nitrogen (N), phosphorus (P), and sediment, which enters surface waters. Those pollutants come from multiple diverse sources within the Chesapeake Bay watershed, but the primary sources are agriculture, urban and suburban runoff, wastewater, and airborne contaminants (Chesapeake Bay Program 2009). Another contributor of pollutants to the Chesapeake Bay is hydromodification. The states in the U.S. Environmental Protection Agency's (EPA's) Region 3 report in their biennial water quality report that a cumulative total of 1,427 miles of assessed rivers and streams, 1,687 acres of assessed lakes and reservoirs, and 1,916 square miles of assessed bays and estuaries in the mid-Atlantic are impaired by hydromodification.

The term *hydromodification* as used in this guidance refers to the alteration of the hydrologic characteristics of waterbodies, which in turn could cause degradation of water resources. Many activities that are considered forms of hydromodification have been conducted and continue to be conducted because they are considered to be critical to human activities, such as dredging shipping channels for commerce or constructing culverts at stream crossings for transportation. Hydromodification can also refer to activities that are conducted in and adjacent to stream channels to maintain stream functions or reduce damage to streams or adjacent properties such as clearing of debris or armoring of streambanks.

While hydromodification activities likely occurred within the Chesapeake Bay watershed before European settlement (e.g., fish traps, secondary effects from riparian agriculture) the scale and scope of hydromodification increased dramatically with the advent of European expansion on the east coast of North America. Early settlers constructed dams to harness hydropower and drained floodplain areas for farming (Walter and Merritts 2008; Schenk and Hupp 2009). As development accelerated through the colonial, post revolutionary and industrial periods hydromodification activities expanded to include dredging of natural and man-made waterways for commerce, construction of water supply, recreational and flood control dams, and channel straightening and dredging for flood control and agriculture. In more recent years, development of the built environment has resulted in secondary channel erosion within and downstream of urban centers.

1.1 Sources

Hydromodification activities are grouped into three general categories for the purposes of this chapter: (1) channelization and channel modification, (2) dams, and (3) streambank and shoreline erosion. Such broad categories are useful in that they provide a logical organization for hydromodification activities. However, as is described later in this chapter, implementation measures and practices can apply across these three activity categories. In addition certain hydromodification activities might not fit neatly within any of the three categories.

1.1.1 Streambank and Shoreline Erosion

Streambank and shoreline erosion refers to the degradation of stream, estuary, and lake shore areas resulting in loss of soil and other material landward of the bank along nontidal streams and rivers. Streambank erosion occurs when the sediment on streambanks detaches and becomes mobilized within or near the stream channel. Detachment is a complex process resulting from the interaction of streamflow, vegetation, cohesive properties of soil, and the soil water interface. Eroded material is often carried downstream and re-deposited in the channel bottom or in point bars along bends in the waterway. Shoreline erosion occurs in large, open waterbodies, such as larger lakes and the lower estuarine portion of the Chesapeake Bay, where waves and currents sort coarser sands and gravel from eroded banks and move them in both directions along the shore away from the area being eroded. While the underlying forces causing the erosion could be different for streambank and shoreline erosion, the results, erosion and its impacts are usually similar. It is also important to note that streambank and shoreline erosion are natural processes and that natural background levels of erosion also exist and might be necessary to ensure the health of a particular stream. However, human activities along or adjacent to streambanks or shorelines can accelerate erosion and other nonpoint sources of pollution.

In both urban and rural areas, streambank erosion is often associated with changing land use characteristics within a watershed such as increased impervious surfaces. Because the erosion of streambanks and shorelines is often closely related to upland activities that occur outside riparian areas, it is often necessary to consider solutions to these issues as a component of overall watershed protection and restoration objectives. The topic of upland effects on stream channels is covered in more detail in the Urban and Suburban chapter of this guidance.

1.1.2 Channelization

Channelization and channel modification include activities such as straightening, widening, deepening, and clearing channels of debris and accumulated sediment. Objectives of channelization and channel modification projects include flood control, infrastructure protection, channel and bank stabilization, habitat improvement/enhancement, recreation, and flow control for water supply (source). Channelization activities play an important role in nonpoint source pollution in the Chesapeake Bay by affecting the timing and delivery of pollutants that enter the water. Channelization can also be a cause of higher flows during storm events, which increases the risk of flooding.

Historically, channelization occurred to reduce flooding, drain wet areas for agriculture and to allow for commerce among, other reasons. In recent years, however, regulatory requirements primarily driven by the Clean Water Act have limited traditional hydromodification activities within stream channels and waterbodies. Simultaneously, water resource managers have recognized the critical role that healthy stable stream corridors play in the protection and improvement of water quality and living resources within the Chesapeake Bay. As a result, many of the hydromodification activities occurring are those related to maintenance and restoration of channel corridors and shorelines.

1.1.3 Dams and In-Stream Structures

Dams and in-stream structures are artificial barriers on waterbodies that control the flow of water. Such structures can be built for a variety of purposes, including flood control, power generation, irrigation, navigation, and to create ponds, lakes, and reservoirs for uses such as municipal water supply, fish farming, and recreation. While these types of structures are constructed to provide benefits to society, they can contribute to nonpoint source pollution and have detrimental effects on living resources. For example, dams can alter flows that ultimately can cause effects on water quality and roadway culverts can result in the scour of stream sediments at their outlet. While the structures were often built for purposes related to human needs, in many cases that need is no longer present (e.g., small hydropower dams to support manufacturing). As a result, water resource managers have conducted detailed cost benefit analysis at many dams, and the results often show that the benefits of dam removal outweigh the benefits of continuing to maintain and operate the dam.

An important development in the effect of dams in water quality is the increasing trend of dam removal within the Chesapeake Bay. As dams reach their life expectancy, many will be removed for safety concerns or to restore the connectivity of aquatic ecosystems. This phenomenon is covered extensively in one of the practices (Legacy effects of Dams and Dam Removal) recommended in Section 3 of this chapter.

1.2 Contribution to Nonpoint Source Pollution in Chesapeake Bay

The contribution of hydromodification activities to sediments and nutrient loads to the Chesapeake Bay is poorly defined in the current research literature. Traditionally, land use managers and water resources professionals categorized nonpoint source pollutant loadings based on specific land uses (such as agricultural, urban and silviculture). Contribution of specific hydromodification activities such as channel erosion or dams is less well defined. With recent research on the topic, however, increased attention and research activity has been focused on separating the contribution of specific activities such as stream corridor instability to the overall pollutant loading to the Bay.

The interaction between pollutants from upland sources and those that originate within the stream corridor is a complex relationship in which in-stream transported pollutants are often affected by historic or current upland activities. During the 1700s and 1800s eroding upland agricultural areas resulted in significant sediment storage within stream corridors typically called *legacy* sediment (USGS 2003). The construction of mill dams during that period resulted in the impoundment and storage of sediment behind tens of thousands of mill dams in the mid-Atlantic region. Subsequent removal of these dams during the late industrial period and urban and suburban development in the past 100 years has led to remobilization of the legacy sediments as stream corridors have become instable and streambanks have eroded (USGS 2003).

Because of the intimate nature of hydromodification activities with the stream corridor, there is understandably a close relationship between those activities and sediment delivery to surface waters. A summary of existing information of the impacts of stream hydromodification on the quality of the Chesapeake Bay is provided in Table 7-1. These studies demonstrate the importance of stream restoration and protection in achieving pollutant reduction in the Chesapeake Bay, particularly for sediment and the P that accompanies sediment loading.

While the contribution of sediment from streambank erosion might be a significant source in many streams, the percentage of *unstable* streams within the Chesapeake Bay watershed is unknown (USGS 2003).

The contribution of hydromodification to other pollutants of concern in the Chesapeake Bay is even less well documented. N contribution throughout the watershed is primarily from agricultural, wastewater, and airborne sources. N in its most commonly observed forms is present in very low levels within contributions from hydromodification sources. P on the other hand, given its tendency to become soil and particulate bound, is often present in the legacy sediments, which are significant contributors to eroding streams.

Table 7-1. Studies quantifying the impact of sediment loading from stream hydromodification on Chesapeake Bay water quality

Study	Findings
A Summary Report of Sediment Processes in Chesapeake Bay and Watershed, USGS, Water-Resources Investigations Report 03-4123, 2003	Summarizes the impacts and sources of sediment and notes that sediment yield from urbanized areas can remain high after active construction is complete because of increased stream corridor erosion due to altered hydrology
Schueler et.al. 2000. *The Practice of Watershed Protection, Technical Note #119 from Watershed Protection Techniques 3(3):729-734*, Center for Watershed Protection, 2000.	Stream enlargement, and the resulting transport of excess sediment, is caused by urban development
U.S. Environmental Protection Agency. 2001. Protecting and Restoring America's Watersheds: Status, Trends, and Initiatives in Watershed Management, EPA 840-R-00-001. www.epa.gov/owow/protecting/restore725.pdf.	Straightened and channelized streams carry more sediments and other pollutants to their receiving waters. Up to 75% of the transported sediment from the Pocomoke watershed on the Eastern Shore of Maryland was found to be erosion from within the stream corridor
Gellis et al. *Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management, Chapter 6: Sources and Transport of Sediment in the Watershed*. 2007, U.S. Geological Survey Circular 1316.	Sediment sources are throughout the Chesapeake Bay watershed, with more in developed and steep areas
Gellis et al. 2009, *Sources, transport, and storage of sediment in the Chesapeake Bay Watershed: U.S. Geological Survey Scientific Investigations Report* 2008–5186	In the Piedmont region, streambank erosion was a major source of sediment in developed Little Conestoga Creek; 30% of sediment from the Mattawoman Watershed on the Coastal Plain (flat land) is from streambanks
Devereux et al. Suspended-sediment sources in an urban watershed, Northeast Branch Anacostia River, Maryland. Hydrological Processes, Accepted 2009.	Streambank erosion was the primary source of sediment in the Northeast Branch Anacostia River

2 Chesapeake Bay Hydromodification Implementation Measures

In 2007 EPA published a guidance document titled *National Management Measures to Control Non-point Source Pollution from Hydromodification* whose purpose was to provide background information on nonpoint source pollution and to offer a variety of solutions for reducing nonpoint source pollution resulting from hydromodification. Background information includes a discussion of the sources of nonpoint source pollution and mechanisms for transport into the nation's waters. The guidance further presents a series of *Management Measures* for use on a national scale to directly address the causative factors for nonpoint source pollution. Management measures as presented in the 2007 document establish performance expectations and, where appropriate, specific actions that can be taken to prevent or minimize nonpoint source pollution.

A series of practices was also described for each management measure. Practices are specific actions taken to achieve, or help achieve, a management measure. Practices are often termed best management practices (BMPs); however, the word best was dropped from the 2007 hydromodification guidance and will not be used in this chapter because the use of the adjective is too subjective.

This chapter expands on the extensive resources provided in the 2007 document while focusing on the pollutants, sources, and practices considered important to the overall goal of restoring the health of the Chesapeake Bay. Implementation measures (formerly management measures) presented are either the same or improved versions of those presented in the 2007 guidance. Where available, information on the application, design, and performance of specific practices suitable for use in the Chesapeake Bay are provided. To support one of the key steps required by the Executive Order 13508 to define *next generation* tools, a number of practices have been added to this chapter, which exhibit proven capability to address the nonpoint source issues within the Chesapeake Bay. This chapter and the 2007 guidance are intended to be used in tandem to provide the reader with an updated summary of tools and techniques appropriate for addressing nonpoint source pollution in the Chesapeake Bay.

2.1 General Principles and Goals

The purpose of this chapter is to provide the user with background information on how hydromodification activities affect nutrient and sediment impacts within the Chesapeake Bay and to provide guidance on a range of practices that can be implemented to reduce the impact of hydromodification activities on Bay water quality. While this chapter focuses on practices that are relevant to the Chesapeake Bay and its associated watershed specifically, the information provided is also widely relevant wherever hydromodification activities result in degradation of surface waters.

While the primary focus of this chapter is on reducing loading of sediment, N, and P, it is important to note that there are often numerous secondary benefits to each specific practice detailed herein. To that end, appropriate additional information is provided on secondary benefits such as those associated with living resources (and complementing the activities suggested in draft report 202(g) of Executive Order 13508). For example, bioengineering techniques such as live staking and brush mattressing are typically applied to an eroding streambank principally to reduce sediment loading to the associated stream. However, the function of those practices is based on establishing riparian vegetation, which is an important component in improving aquatic riparian habitat.

For many hydromodification activities and their associated effects, a close relationship exists to other chapters of this guidance. In such cases, the reader might be directed to the respective section for additional guidance. For instance, increased rate and volume of stormwater runoff from urbanizing areas often leads to channel and streambank erosion. In that case, the causative factor of the effect (urbanization) is covered in the urban section of this chapter. Because streambank erosion is itself considered a form of hydromodification, the effect is described in detail and number of structural practices recommended to address the effect within the stream corridor.

While this chapter recommends a series of approaches and information on specific tools and techniques to address nonpoint source pollution in the Chesapeake Bay watershed on a project basis, each project must be considered within the context of the watershed or subwatershed in which it is prescribed. The successful implementation of watershed restoration requires that projects be identified and selected consistent with watershed assessments and prioritized according to the overall watershed restoration goals (Beechie et al. 2008). Furthermore, individual projects should be considered as a component of watershed restoration and measured according to the cumulative benefits of other similar watershed restoration projects that might be proposed (Kondolf et al. 2008).

2.2 Implementation Measures

To accomplish the goals set forth above, this chapter suggests a series of implementation measures that are recommended to address the effects of hydromodification. The reader might notice that the 2007 guidance document includes six *Management Measures* that tribal, state, or local programs could implement to address nonpoint source pollution from hydromodification activities. In this chapter, the six management measures have been reduced to five categories and renamed implementation measures. That terminology is used in this chapter because they are measures that can be implemented to address specific functional causes of impacts of hydromodification activities.

Implementation Measures:

H-1. Protect Streambanks and Shorelines from Erosion

H-2. Control Upland Sources of Sediment and Nutrients at Dams

H-3. Restore In-stream and Riparian Habitat Function

H-4. Reduce Pollutant Sources through Operational and Design Management

H-5. Restore Stream and Shoreline Physical Characteristics

2.2.1 Implementation Measure H-1: Protect Streambanks and Shorelines from Erosion

Implementation Measure H-1:

The protection of streambanks and shorelines from erosion refers to the installation of structural or biological practices at or near the land water interface. The primary goals of this implementation measure are the following:

1. Protect streambank and shoreline features with the potential to reduce nonpoint source pollution
2. Protect streambanks and shorelines from erosion from uses of either the shorelands or adjacent surface waters

Implementation Measure H-1 focuses on preserving stable streambanks and shorelines to limit the loss of pollutants, most notably sediment, from the erosion at the land water interface. This measure is most closely related with Management Measure 6 of the 2007 guidance (Eroding Streambanks and Shorelines). Practices appropriate for addressing Implementation Measure H-1 consist of both structural practices such as riprap as well as management practices such as non-eroding roadways. Where possible, the practitioner should consider the protection of streambanks and shoreline within the context of overall watershed goals and select practices that address multiple watershed objectives where possible.

The application of bioengineering stream armoring techniques, which use vegetation and natural systems, to address erosion for instance, should be considered before implementing more rigid, structural controls such as riprap. While bioengineering techniques might not be suitable for all applications, they often support the objectives of other implementation measures and overall watershed goals.

Practices

The practices noted in Table 7-2 are suggested as appropriate to address Implementation Measure H-1 and are described in more detail in Section 3 of this chapter. The table categorizes practices according to whether they were detailed in the previous guidance, updated within this chapter, or identified as a next generation tool or technique for addressing nonpoint source pollution in Chesapeake Bay. Updated practices are those that are described in detail in the 2007 guidance but have updated or region-specific information in Section 3. Next generation tools and techniques are those newer practices that had not been previously identified as appropriate for addressing Implementation Measure H-1 but are described in detail in Section 3.

Table 7-2. Practices appropriate for use in addressing Implementation Measure H-1

Practice	Described in 2007 guidance?	Updated?	Next generation tools and techniques?	Page
Breakwaters	Yes			
Bulk Heads and Seawalls	Yes			
Groins	Yes			
Multi-Cell Culverts			Yes	7-53
Non-Eroding Roadways	Yes	Yes		7-60
Return Walls	Yes			
Rip Rap	Yes	Yes		7-68
Toe Protection	Yes	Yes		7-77

Note: Clicking this link will access the 2007 document (*National Management Measures to Control Non-point Source Pollution from Hydromodification*). To find a specific practice, use the bookmarks.

2.2.2 Implementation Measure H-2: Control Upland Sources of Sediment and Nutrients at Dams

Implementation Measure H-2:

The control of upland sources of nonpoint source pollutants at dams and other hydromodification facilities refers to the active implementation of pollutant control techniques and practices that minimize the source generation and reduce the transport of sediments and nutrients into the Chesapeake Bay and its watershed. This implementation measure is well described in the 2007 guidance document (formerly titled *Erosion and Sediment Control for Construction of New Dams and Maintenance of Existing Dams*). The goals of this implementation measure are

1. Reduce the generation of sediment and nutrients during and after construction
2. Retain eroded sediment and nutrients on-site
3. Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface waters

Implementation Measure H-2 is identical to Management Measure 3 from the 2007 hydromodification guidance. No updated information is provided on this measure whose purpose is to prevent sediment and nutrients from entering surface waters during the construction or maintenance of dams. Because of the extensive environmental permitting necessary for the construction of dams in the Chesapeake Bay watershed and the developed nature of the region's water resources, it is unlikely that significant dam construction will occur in the near future. Maintenance of existing dams and impoundments, therefore, is likely to be the most significant activity to which this measure is applicable.

No updated design or performance information is available for the practices recommended for this implementation measure. As a result, for more information on specific practices, see the 2007 hydromodification guidance.

Practices

The practices noted in Table 7-3 are suggested as appropriate to address Implementation Measure H-2.

Table 7-3. Practices appropriate to addressing Implementation Measure H-2

Practice
Check Dams
Coconut Fiber Roll
Construction Runoff Intercepts
Construction Management
Erosion Control Blankets
Locate Potential Land Disturbing Activities away from Critical Areas
Mulching
Preserve Onsite Vegetation
Phase Construction
Retaining Walls
Revegetate
Project Scheduling
Sediment Basin/Rock Dams
Sediment Fences
Sediment Traps
Seeding
Site Fingerprinting
Sodding
Soil Protection
Surface Roughening
Training ESC
Wildflower Cover

Note: Clicking this link will access the 2007 document (*National Management Measures to Control Non-point Source Pollution from Hydromodification*). To find a specific practice, use the bookmarks.

2.2.3 Implementation Measure H-3: Restore In-Stream and Riparian Habitat Function

Implementation Measure H-3:

The restoration of in-stream and riparian habitat function refers to the direct implementation of practices that address functions of the aquatic environment. Because the practices recommended as part of this implementation measure often do not address the causative factors behind habitat degradation, other implementation measures described in this chapter should be considered for implementation. This implementation measure is well described in the 2007 guidance document (titled *Protection of Surface Water Quality and In-stream and Riparian Habitat*). The primary goal of this implementation measure is

1. Provide for safe passage of fish and other aquatic species upstream or downstream of dams and other structures

Physical structures that block or impede fish migrations to historic spawning habitats have been identified as potentially the most important factor in the decline in migratory fish such as American shad, river herring, and the American eel. The removal of blockages or the installation of structures that encourage or enable fish passage such as fish lifts, fish ladders, and other passageways are important measures that can be implemented within the Chesapeake Bay to ensure that migratory fish are able to move freely throughout historical migratory routes. Approximately 1,924 miles of stream in the Chesapeake Bay watershed have been opened to fish passage, and Executive Order 13508 states that an additional 1,000 stream miles will be opened by implementing 100 priority dam-removal, fish-passage projects by 2025.

The restoration of in-stream and riparian habitat function is closely related to Implementation Measure H-5, Restore Stream and Shoreline Physical Characteristics, described below. The practices recommended for use to address Implementation Measure H-5 often directly support the primary goal of this implementation measure. EPA encourages practitioners to consider these two implementation measures and their respective practices as collaborative techniques to address nonpoint source pollution in the Chesapeake Bay and its effect on living resources.

Practices

The practices noted in Table 7-4 are suggested as appropriate to address Implementation Measure H-3 and are described in more detail in Section 3 of this chapter. The table categorizes practices according to whether they were detailed in the previous guidance, updated within this chapter, or identified as a next generation tool or technique for addressing nonpoint source pollution in Chesapeake Bay. Updated practices are those that are described in detail in the

2007 guidance but have updated or region-specific information in Section 3. Next generation tools and techniques are those newer practices that had not been previously identified as appropriate for addressing Implementation Measure H-3 but are described in detail in Section 3.

Table 7-4. Practices recommended to address Implementation Measure H-3

Practice	Described in 2007 guidance?	Updated?	Next generation tools and techniques?	Page
Behavioral Barriers	Yes			
Collection Systems	Yes			
Establish and Protect Stream Buffers	Yes	Yes		7-28
Fish Ladders	Yes			
Fish Lifts	Yes			
Legacy Effects of Dams and Dam Removal			Yes	7-37
Physical Barriers	Yes			
Riparian Improvements		Yes		7-66
Shoreline Sensitivity Assessment	Yes	Yes		7-72
Transfer of Fish Runs	Yes			
Vegetated Buffers	Yes	Yes		7-80
Vegetated Filter Strips	Yes	Yes		7-82

Note: Clicking this link will access the 2007 document (*National Management Measures to Control Non-point Source Pollution from Hydromodification*). To find a specific practice, use the bookmarks.

2.2.4 Implementation Measure H-4: Reduce Pollutant Sources through Operational and Design Management

Implementation Measure H-4:

Reduction of pollutant sources through operational and design management of dams refers to the design and management of dams so as to minimize the source generation and reduce the transport of sediments and nutrients into the Chesapeake Bay and its watershed. This implementation measure is well described in the 2007 guidance document (formerly titled *Erosion and Sediment Control for Construction of New Dams and Maintenance of Existing Dams*). The goals of this implementation measure are

1. Reduce pollutant generation and impact on living resources through programmatic dam management
2. Design structures to limit pollutant generation

Implementation Measure H-4 addresses pollutants resulting from operational activities at in-stream facilities such as dams and impoundments. The operation and management of such facilities typically has minimal impact on the delivery of nonpoint source pollutants to downstream waters. One notable exception is the removal of impoundments, which is covered in detail in Implementation Measure H-5 and in the practice: Legacy Effects of Dams and Dam Removal.

Operational practices do have significant implications on the living resources within and downstream of structures via their effect on other water quality parameters such as water temperature and dissolved oxygen. Management should focus on tools and techniques to reduce the impact of dam and in-stream structure operation on water quality through the management of physical flow processes to meet environmental criteria (Olden and Naimen 2010; Merritt et al. 2010).

Practices

The practices noted in Table 7-5 are suggested as appropriate to address Implementation Measure H-4 and are described in more detail in Section 3 of this chapter. The table categorizes practices according to whether they were detailed in the previous guidance, updated within this chapter, or identified as a next generation tool or technique for addressing nonpoint source pollution in Chesapeake Bay. Updated practices are those that are described in detail in the 2007 guidance but have updated or region-specific information in Section 3. Next generation tools and techniques are those newer practices that had not been previously identified as appropriate for addressing Implementation Measure H-4 but are described in detail in Section 3.

Table 7-5. Practices recommended as appropriate to address Implementation Measure H-4

Practice	Described in 2007 guidance?	Updated?	Next generation tools and techniques?	Page
Advanced Hydroelectric Turbines	Yes	Yes		7-22
Flow Augmentation	Yes	Yes		7-32
Selective Withdrawal	Yes	Yes		7-71
Turbine Operation	Yes	Yes		7-78
Turbine Venting	Yes	Yes		7-79

2.2.5 Implementation Measure H-5: Restore Stream and Shoreline Physical Characteristics

Implementation Measure H-5:

The restoration of stream and shoreline physical characteristics is important to restoring predevelopment hydrology and reducing loading from larger and scouring flows. Degraded streams can themselves become a source of downstream pollution, such as when P-laden sediments are mobilized during high-flow events. In such cases, stream restoration can be a useful strategy to improve downstream water quality. However, it is important to keep in mind that the elevated flows causing sediment mobilization must also be addressed (see the Urban and Suburban chapter). Stream stabilization requires restoration of the stream's energy signature. The predevelopment hydrology of the watershed must be restored to regain the predevelopment character of the stream; however, in existing urban areas, that might be a longer-term goal. The primary goal of this implementation measure is to

1. Restore stable relationship between watershed hydrology and stream and shoreline geometry. Where streambank or shoreline erosion is a nonpoint source pollution problem, streambanks and shorelines should be stabilized. Vegetative methods are strongly preferred unless structural methods are more effective, considering the severity of stream flow discharge, wave and wind erosion, offshore bathymetry, and the potential adverse effect on other streambanks, shorelines, and offshore areas.

Many methods have been developed to restore the physical characteristics of streams and shorelines to address lost function and instability. While many of the techniques can be applied in isolation to address specific physical characteristics, for instance installing root wad revetments to address bank erosion, EPA encourages practitioners to consider the practices listed below and detailed in Section 3 as components of an overall restoration strategy. It is important to note that restoration strategies should consider leveraging the natural characteristics of the stream and shoreline hydrology, geometry, and ecology to address physical function, such as biological engineering techniques, such as live fascines and brush layering in preference to techniques that rely on structural characteristics such as revetments. Where possible, measures should focus on the restoration of physical characteristics that are appropriate to overall watershed goals and future conditions.

Physical restoration can help to restore the natural ecosystem function of nutrient removal that occurs in streams. Studies that evaluate the N-removal ability of restored streams are summarized in Table 7-6.

Table 7-6. Studies evaluating the N removal ability of restored streams in the Chesapeake Bay watershed

Study	Finding
Kaushal et al. 2008. Effects of Stream Restoration on Denitrification in an Urbanizing Watershed. *Ecological Applications* 18(3):789–804.	Streams with ecological functions intact remove N at a much higher rate than degraded urban streams, and stream restoration practices can restore this N removal function
Klocker et al. *Nitrogen uptake and denitrification in restored and unrestored streams in urban Maryland, USA*. Aquatic Sciences, Accepted October 2009.	Degraded urban streams, deeply eroded and *disconnected* from their floodplain have substantially lower rates of N removal that than streams hydraulically connected to their riparian banks via low slopes, and reconnecting the stream to the floodplain can increase

In addition to the water quality improvements that can be achieved through stream restoration, the flood management community has become increasingly aware of the benefits of restoration in preventing flood damages. The Association of State Floodplain Managers (ASFPM) has prepared a white paper called *Natural and Beneficial Floodplain Functions: Floodplain Management—More than Flood Loss Reduction* (http://www.floods.org), which emphasizes the multiple benefits of protecting and restoring streams and their associated floodplains.

Techniques for stream and floodplain restoration are also described in the Riparian chapter of this guidance document. Example references for stream restoration and information on the impacts of urban runoff on stream ecosystems are provided in Table 7-7.

Table 7-7. References on urban stormwater effects on streams with emphasis on restoration and habitat

USDA Natural Resources Conservation Service, *Part 654 Stream Restoration Design National Engineering Handbook,* 210–VI–NEH, August 2007
Federal Interagency Stream Restoration Working Group (FISRWG) (1998*). Stream Corridor Restoration: Principles, Processes, and Practices*, ISBN-0-934213-60-7, Distributed by the National Technical Information Service at 1-800-533-6847.
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Federation (WERF 2006) Appendix B. Assessment of Existing Watershed Conditions: Effects on Habitat.

Practices

The practices noted in Table 7-8 are suggested as appropriate to address Implementation Measure H-5 and are described in more detail in Section 3 of this chapter. The table categorizes practices according to whether they were detailed in the previous guidance, updated within this chapter, or identified as a next generation tool or technique for addressing nonpoint source pollution in the Chesapeake Bay. Updated practices are those that are described in detail in the

2007 guidance but have updated or region-specific information in Section 3. Next generation tools and techniques are those newer practices that had not previously been identified as appropriate for addressing Implementation Measure H-5 but are described in detail in Section 3.

Table 7-8. Practices recommended for addressing Implementation Measure H-5

Practice	Described in 2007 guidance?	Updated?	Next generation tools and techniques?	Page
Bank Shaping and Planting	Yes	Yes		7-23
Branch Packing	Yes			
Brush Layering	Yes			
Brush Mattressing	Yes	Yes		7-24
Cross Vanes			Yes	7-26
Dormant Post Planting	Yes			
Joint Planting	Yes	Yes		7-35
Legacy Effects of Dams and Dam Removal			Yes	7-37
Live Crib Walls	Yes	Yes		7-41
Live Fascines	Yes	Yes		7-43
Live Staking	Yes	Yes		7-46
Check Dams (Log & Rock)	Yes			
Marsh Creation and Restoration	Yes	Yes		7-51
Natural Channel Design and Restoration			Yes*	7-55
Revetements	Yes	Yes		7-64
Rock and Log Vanes			Yes	7-69
Root Wad Revetements	Yes			
Step Pools			Yes	7-73
Streambank Dewatering			Yes	7-75
Tree Revetements	Yes			
Vegetated Gabions	Yes	Yes		7-84
Vegetated Geogrids	Yes	Yes		7-85
Vegetated Reinforced Soil Slope (VRSS)	Yes	Yes		7-86
Weirs	Yes	Yes		7-87
Wing Deflectors	Yes	Yes		7-89

Note: Clicking this link will access the 2007 document (*National Management Measures to Control Non-point Source Pollution from Hydromodification*). To find a specific practice, use the bookmarks.

* This practice was originally named Rosgen's Stream Classification Method in the 2007 guidance document.

3 Chesapeake Bay Hydromodification Practices

The practices detailed in this section are suggested as appropriate for use in the Chesapeake Bay and nationally to address causative factors and impacts of hydromodification. While many of these practices were previously described in detail in the 2007 guidance document, some are new and represent the next generation of tools and actions to address nonpoint source pollution. For those practices described in the 2007 guidance and for which no additional information is relevant, the reader is directed to the earlier guidance. For those practices described previously and for which additional information is available, new information is presented; the reader is directed to refer to both this chapter and the 2007 guidance. For those practices that are not included in the earlier guidance and have been identified as appropriate for use in the Chesapeake Bay, detailed information is provided to describe the practice and discuss appropriate applications and purpose as well as information on practice costs and performance if available.

3.1 Existing Practices

The practices listed in Table 7-9 are described in detail in the 2007 National Hydromodification guidance document. For additional information on the practices, see that document. Limited additional information exists regarding these practices and their use in the Chesapeake Bay watershed.

Table 7-9. Practices described in the 2007 guidance document

Practice	IM1	IM2	IM3	IM4	IM5
Behavioral Barriers			X		
Branch Packing					X
Breakwaters	X				
Brush Layering					X
Bulkheads and Seawalls	X				
Check Dams		X			
Coconut Fiber Roll		X			
Collection Systems			X		
Construction Runoff Intercepts		X			
Construction Management		X			
Dormant Post Plantings					X
Erosion Control Blankets		X			
Fish Ladders			X		

Table 7-9. Practices described in the 2007 guidance document *(continued)*

Practice	IM1	IM2	IM3	IM4	IM5
Fish Lifts			X		
Groins	X				
Locate Potential Land Disturbing Activities away from Critical Areas		X			
Mulching	X	X			
Phase Construction		X			
Physical Barriers			X		
Preserve Onsite Vegetation		X			
Project Scheduling		X			
Retaining Walls		X			
Return Walls	X				
Revegetate		X			
Root Wad Revetments	X				X
Sediment Basin/Rock Dams		X			
Sediment Fences		X			
Sediment Traps		X			
Seeding		X			
Site Fingerprinting		X			
Sodding		X			
Soil Protection		X			
Surface Roughening		X			
Training ESC		X			
Transfer of Fish Runs			X		
Tree Revetments					X
Wildflower Cover		X			

Note: Clicking this link will access the 2007 document (*National Management Measures to Control Non-point Source Pollution from Hydromodification*). To find a specific practice, use the bookmarks.

3.2 Updated and Next Generation Practices

The practice sheets included in the section below are either updates to practices described in the 2007 guidance document or are next generation tools and techniques that have been identified as appropriate to address nonpoint source in the Chesapeake Bay watershed.

3.2.1 Advanced Hydroelectric Turbines

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☑ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Description

Advanced hydroelectric turbines are the result of engineering studies of how the hydraulic components interact with biota and optimization of turbine operations designed to reduce effects on juvenile fish passing through the turbine as it operates.

Application and Purpose

Most research on advanced hydroelectric turbines has been conducted by electric power producers in the western United States. Improving the survival of juvenile fish by encouraging development of low impact turbines is also being pursued on a national scale by the U.S. Department of Energy and the U.S. Army Corps of Engineers. Research includes biological studies of turbine passage at field sites and hydraulic model investigations leading to innovative concepts for turbine design that will have environmental benefits and maintain efficient electrical generation.

Efficiency Data

Previous field studies have shown that improvements in the design of turbines have increased the survival of juvenile fish and researchers continue to examine the causes and extent of injuries from turbine systems, as well as the significance of indirect mortality and the effects of turbine passage on adult fish. Ongoing research is continuing to assess improvements in turbine design and operation as well as modeling to assess turbine-passage survival.

3.2.2 Bank Shaping and Planting

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Description

Bank shaping and planting involves regrading a streambank to establish a stable slope angle, placing topsoil and other material needed for plant growth on the streambank, and selecting and installing appropriate plant species on the streambank.

Application and Purpose

Bank shaping and planting is most successful on streambanks where moderate erosion and channel migration are anticipated. Reinforcement at the toe of the bank is often required, particularly where flow velocities exceed the tolerance range for plantings and where erosion occurs below base flows.

Efficiency Data

Nearly 400 rock riprap grade-control structures (GCS) were recently placed in streams of western Iowa to reduce streambank erosion and protect bridge infrastructure and farmland. In that region, streams are characterized by channelized reaches, highly incised banks, and silt and sand substrates that normally support low macroinvertebrate abundance and diversity. Therefore, GCS composed of riprap provide the majority of coarse substrate habitat for benthic macroinvertebrates in these streams. Litvan et al. (2008) sampled 20 sites on Walnut Creek, Montgomery County, Iowa, to quantify macroinvertebrate assemblage characteristics (1) on GCS riprap, (2) at sites 5–50 meters (m) upstream of GCS, (3) at sites 5–50 m downstream of GCS and (4) at sites at least 1 kilometer (km) from any GCS (five sites each). Macroinvertebrate biomass, numerical densities and diversity were greatest at sites with coarse substrates, including GCS sites and one natural riffle site and relatively low at remaining sites with soft substrates. Densities of macroinvertebrates in the orders Ephemeroptera, Trichoptera, Diptera, Coleoptera and Acariformes were abundant on GCS riprap. Increases in macroinvertebrate biomass, density, and diversity at GCS might improve local efficiency of breakdown of organic matter and nutrient and energy flow, and provide enhanced food resources for aquatic vertebrates. However, lack of positive macroinvertebrate responses immediately upstream and downstream of GCS suggest that positive effects might be restricted to the small areas of streambed covered by GCS. Improved understanding of GCS effects at both local and ecosystem scales is essential for stream management when these structures are present.

3.2.3 Brush Mattressing

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Description

A brush mattress is a layer (mattress) of interlaced live branches placed on a bank face, often with a live fascine and/or rock at the base. The mat is then secured to the bank by live and/or dead stakes and partially covered with fill soil to initiate growth of the cuttings.

Application and Purpose

Brush mattressing is commonly used in Europe for streambank protection. It involves digging a slight depression on the bank and creating a mat or mattress from woven wire or single strands of wire and live, freshly cut branches from sprouting trees or shrubs. Branches approximately one inch in diameter are normally cut 6 to 9 feet long (the height of the bank to be covered) and laid in criss-cross layers with the butts in alternating directions to create a uniform mattress with few voids. The mattress is then covered with wire secured with wooden stakes 2.5 to 4 feet long. It is then covered with soil and watered repeatedly to fill voids with soil and facilitate sprouting; however, some branches should be left partially exposed on the surface. The structure might require protection from undercutting by placement of stones or burial of the lower edge. Brush mattresses are generally resistant to waves and currents and provide protection from the digging out of plants by animals. Disadvantages include possible burial with sediment in some situations and difficulty in making later plantings through the mattress.

Brush mattresses can restore riparian vegetation and habitat and enhance conditions for colonization of native plants. They reduce soil erosion and intercept sediment flowing down the streambank. After vegetation reaches a height of a few feet, it can improve fish habitat by shading the stream, lowering water temperatures and offering protection from predators (Allen and Fischenich 2000). Brush mattresses are also useful on steep, fast-flowing streams.

Cost Data

Costs for brush mattresses range between $3 and $14 per square foot (Allen and Fischenich 2000). Costs can be reduced by using free material from donation sites and volunteer labor. Costs related to project permitting or planning are not included in the estimate.

Design Guidance and Additional Information

Installation guidelines are available from the U.S. Department of Agriculture–Forest Service (USDA-FS) *Soil Bioengineering Guide* (USDA-FS 2002). Under the Ecosystem Management and Restoration Research Program (EMRRP), the U.S. Army Corps of Engineers has presented research on brush mattresses in a technical note (Brush Mattresses for Streambank Erosion Control).

3.2.4 Cross Vanes

Description

A rock cross vane is a stone structure consisting of footer and vane rocks constructed in a way that provides grade control and reduces bank erosion. The vane is composed of a center section perpendicular to the streambanks joined to two arms that extend into the streambank at the channel flow height. The rock cross vane accumulates sediment behind the vane arms, directs flow over the cross vane, and creates a scour pool downstream of the structure.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Low-profile, in-stream structures, such as cross vanes, are primarily used to create aquatic habitat in the form of scour pools and for grade control on incising streams and rivers. Additionally, they are well-suited for channeling flow away from unstable banks. Cross vanes are typically suited for use in moderate- to high-gradient streams. When constructed and spaced properly, cross vanes can simulate the natural pattern of pools and riffles occurring in undisturbed streams while forming gravel deposits, which fish use as spawning grounds. Cross vanes can also be used to stabilize banks when designed properly. Cross vanes should be avoided in channels with bedrock beds or unstable bed substrates, and streams with naturally well-developed pool-riffle sequences.

Cross vanes are appropriate for the following:

- Stabilization of a vertically unstable stream bed requires grade control
- To direct erosional forces away from the streambanks and to the center of the channel
- When fish habitat enhancement and grade control are both desired
- For bridge protection. Cross vanes provide grade controls, prevent lateral migration of channels, increase sediment transport capacity and competence, and reduce footer scour
- To enhance or create recreational paddling opportunities
- Most suitable for rapid-dominated stream systems with gravel/cobble substrate

Cost Data

Construction costs for cross vanes are highly variable, depending on the design, size of the stone, availability of materials, and site constraints.

3.2.5 Establish and Protect Stream Buffers

Description

Stream buffers can provide cost-effective, long-term pollutant removal without having to construct and maintain structural controls. Specific stream buffer practices include establishing a stream buffer ordinance, developing vegetative and use strategies within management zones, establishing provisions for stream buffer crossings, integrating structural runoff management practices where appropriate, and developing stream buffer education and awareness programs.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Establishing and protecting these areas is important to water quality protection. Land acquisition programs help to preserve areas considered critical to maintaining surface water quality. Stream buffers can also protect and maintain near-stream vegetation that attenuates the release of sediment into stream channels. Stream buffers should be protected and preserved as a conservation area because they provide many important functions and benefits, including the following:

- 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

Efficiency Data

The biennial National Water Quality Inventory surveys shows no reduction in the percentage of degraded miles of streams since the early 1990s despite an exponential increase in river restoration projects to improve water quality, enhance in-stream habitat, and manage the riparian zone (Langendoen et al. 2009). This might suggest that many river restoration projects fail to achieve their objectives. This was found to be partly from a lack of understanding of the dynamics of the degraded riverine system and its interaction with the riparian zone. Vegetative riparian conservation measures are commonly used to stabilize failing streambanks. The shear strength of bank soils is greatly affected by the degree of saturation of the soils and root reinforcement provided by riparian vegetation. An integrated model was used to study the effectiveness of woody and herbaceous riparian buffers in controlling streambank erosion of an incised stream in northern Mississippi. Comparison of model results with observations showed that pore-water pressures are accurately predicted in the upper part of the streambank, away from the groundwater table. Simulated pore-water pressures deviate from those observed lower in the streambank near the phreatic surface. The discrepancies are mainly caused by differences in the simulated location of the phreatic surface and simulated evapotranspiration in case of the woody buffer. The modeling exercise further showed that a coarse rooting system, e.g., as provided by trees, significantly reduced bank erosion rates for this deeply incised stream.

The impact of different management of similar riparian land uses was studied in two pasture subreaches by Zaimes et al. (2008), who found that total streambank soil loss can be estimated by using magnitude of bank erosion, soil bulk density, and severely eroded bank area. Significant seasonal and yearly differences in magnitude of bank erosion and total soil loss were partially attributed to differences in precipitation and associated discharges. Riparian forest buffers had significantly lower magnitude of streambank erosion and total soil loss than the other two riparian land uses. Establishing riparian forest buffers along all the nonbuffered subreaches would have reduced streambank soil loss by an estimated 77 to 97 percent, significantly decreasing sediment in the stream. The pasture with cattle had consistently higher magnitudes of bank erosion than those for the pasture with horses for the entire study period. The pasture with cattle was also the only subreach to show an increase in eroding stream length (3 percent) and eroding area (10 percent) from 1998 to 2002. Riparian vegetation and land use are an integral part of streambank erosion, but high precipitation levels and associated high discharges can also influence the erosion process. Differences in the magnitude of bank erosion, severely eroded bank lengths and areas, and soil losses throughout this study are partially attributable to differences in precipitation that were associated with the occurrence of substantial discharge events. Other processes such as freeze and thaw events and season, which affected the density of the vegetation cover of the watershed were also implicated. The variation in soil losses from streambank erosion over the entire study period also suggest that a data set of many years is needed to get a good estimate of bank erosion contributions to stream sediment load. One-year data sets can be misleading in estimating the long-term contributions of bank erosion to stream sediment loads.

A partnership involving more than a dozen organizations, agencies, and businesses joined forces to construct a 800-foot *living shoreline* that rebuilt the barrier between the creek and the cove with natural materials, which was then planted with native plants to provide more stability (Blankenship 2009). The project relied on volunteers and multiple funders and was the first project in the Chesapeake Bay that involved the Corporate Wetland Restoration Partnership, which brings together government on environmental projects. That type of restoration project was envisioned in the draft habitat report that responded to President Barack Obama's Chesapeake Bay Executive Order of May of 2009. The report calls for using partnerships to build strategically placed "largescale, multifaceted restoration [projects] targeted at improving living resources."

Besides the living shoreline, curved rock structures were built at both ends of the cove to protect it from waves and to trap sand that will serve as beach habitat. The project included the construction of an oyster reef, which serves as habitat and buffers the shoreline from waves. Shallow water habitats, which had largely eroded away, were rebuilt and planted with marsh grasses. Reestablishing shallow water habitat, including oyster beds and mussel beds, will serve as foraging grounds for sea ducks, which should keep Hail Creek as one of the top five waterfowl habitats for years to come.

Langendoen et al. (2009) found that restoration projects could benefit from using proven models of stream and riparian processes to guide restoration design and to evaluate indicators of ecological integrity. The USDA has developed two such models: CONCEPTS and Riparian Ecosystem Management Model (REMM). Those models have been integrated to evaluate the impact of edge-of-field and riparian conservation measures on stream morphology and water quality. The physical process modules of the channel evolution model CONCEPTS and the riparian ecosystem model REMM have been integrated to create a comprehensive, stream-riparian corridor model that will be used to evaluate the effects of riparian buffer systems on in-stream environmental resources. The capability of REMM to dynamically simulate streambank hydrology and plant growth has been used to study the effectiveness of a deciduous tree stand and an eastern gamagrass buffer in controlling the stability of a streambank of an incised stream in northern Mississippi.

Cost Data

A study of cost-effectiveness analysis of vegetative filter strips and in-stream half-logs as tools for recovering scores on a fish index of biotic integrity (IBI) in the upper Wabash River in Indiana provided baseline data and a framework for planning and determining the cost of stream restoration (Frimpong et al. 2006). The authors found that costs per unit increase in IBI score with vegetative filter strips as the method of restoring stream health decreases with increasing stream order and decreasing recovery time. Another finding was that vegetative filter strips are likely a useful method, given cost considerations, for recovering lost IBI scores in an agricultural watershed. Three assumptions were made about recovery time for IBI scores (5, 15, and 30 years) and social discount rates (1, 3, and 5 percent), which were tested for sensitivity of the estimated cost-effectiveness ratios. The effectiveness of vegetative filter strips was estimated using fish IBIs and riparian forest cover from 49 first-order to fifth-order stream reaches. Half-log structures had been installed for approximately 2 years in the watershed before the study and provided a basis for estimates of cost and maintenance. Cost-effectiveness ratios for vegetated filter strips decreased from $387 to $277 per 100 meters for a 1 percent increase in IBI scores from first- to fifth-order streams with 3 percent discount and 30-year recovery. That cost, weighted by proportion of stream orders was $360 per 110 meters. On the basis of installation costs and an assumption of equal recovery rates, half-logs were two-thirds to one-half as cost-effective as vegetative filter strips. Half-logs would be a cost-effective supplement to filter strips in low-order streams if they can be proven to recover IBI scores faster than using filter strips alone.

Design Guidance and Additional Information

Maryland Department of the Environment Water Management Administration. 2000. *Maryland's Waterway Construction Guidelines* at http://www.mde.state.md.us/assets/document/wetlandswaterways/mgwc.pdf. Accessed February 2010.

3.2.6 Flow Augmentation

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☑ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Flow augmentation is the term used to describe operational procedures such as flow regulation, flood releases, or fluctuating flow releases that all have the potential for detrimental impacts on downstream aquatic and riparian habitat. Several options exist for creating minimum flows in the tailwaters below dams. Sluicing is the practice of releasing water through the sluice gate rather than through the turbines. For portions of the waterway immediately below the dam, the steady release of water by sluicing provides minimum flows with the least amount of water expenditure. Turbine pulsing is a practice involving the release of water through the turbines at regular intervals to improve minimum flows. In the absence of turbine pulsing, water is released from large hydropower dams only when the turbines are operating, which is typically when the demand for power is high.

Application and Purpose

The downstream effects that can be mitigated by using flow augmentation are highly variable because each impounded system is unique. The location of a dam within a river system, its age, depth and surface area, the hydraulic residence time, the regional climate, operation of the dam, and chemistry of the inflowing waters all influence how impoundments affect downstream water quality. Hydropower producers are faced with two environmental problems that can affect the water quality in areas downstream from dams (i.e., tailwaters). These are low concentrations of dissolved oxygen in the water released through the dam during generation and dry riverbeds that result when hydropower generation is shut off. Selecting any technique as the most cost-effective is site-specific and depends on several factors including adequate performance to achieve the desired in-stream and riparian habitat characteristic, compatibility with other requirements for operation of the hydropower facility, availability of materials, and cost.

Efficiency Data

Numerous studies have examined the effects of flow regulation on water quantity and quality by comparing an impounded system with an adjacent unimpounded system. Mitigation techniques to improve ecosystem health downstream of impoundments rely on the restoration of a more natural flow regime by creating and implementing site-specific, dam management plans.

A study by Ahearn et al. (2005) examined the effects of flow regulation on water quantity and quality by comparing an impounded system with an adjacent unimpounded system in California. The study showed that a strong seasonal cycle for total suspended solids (TSS), NO_3-N, TN, PO_4-P, TP, dissolved silicon, specific conductivity and flow into reservoirs in the lower Mokelumne River was attenuated by physical and chemical fluctuations creating a weak seasonal pattern. Dissolved silicon and TSS were the two constituents most efficiently sequestered by the reservoirs. While the reservoirs acted as traps for most constituents, NO_3-N and PO_4-P were produced during the drier years of the study, 2001 and 2002. In contrast, the unimpounded reference reach in the Cosumnes River was an annual source for all constituents measured. The Cosumnes delivers its highest NO_3-N concentrations during the winter months (December–April), while peak concentrations in the Mokelumne occur during the snowmelt (May–July) and baseflow (August–November) seasons. Because of downstream N limitation, the temporal shift in NO_3-N export might be contributing to accelerated algal growth in the reach immediately downstream and eventually to algal biomass loading to the downstream Sacramento–San Joaquin Delta.

In 2003 the Housatonic Valley Association (HVA) partnered with The Massachusetts Riverways Program (in the Department of Fish & Game) to begin measuring streamflow on several rivers below recreational reservoirs. The measurements indicated unnatural variations in streamflow at several sites that are detrimental to downstream aquatic life and habitat. A more *natural* flow regime is being reestablished in the streams to improve their ecological condition. The HVA has been meeting with Conservation Commissions, Lake Associations, and other stakeholders to develop guidelines for managing flows out of reservoirs. The goal is to improve ecosystem health downstream of impoundments by restoring a more natural flow regime by creating site-specific, dam management plans in the form of monthly flow recommendations using a methodology jointly developed by the U.S. Geological Survey (USGS) and the Massachusetts Department of Conservation and Recreation (DCR). The long-term goal is to develop guidance for Conservation Commissions throughout the commonwealth to help them craft Orders of Conditions for dam projects that include specific requirements to provide a year-round flow regime appropriate to the natural variability of the ecosystem downstream of the impoundment.

Cost Data

Since the early 1990s, the Tennessee Valley Authority (TVA) has spent about $60 million to address dissolved oxygen problems, including installing equipment to increase dissolved oxygen concentrations below 16 dams and operational changes and installing additional equipment to ensure minimum water flows through all its dams. TVA has since completed a second round of improvements by installing or enhancing oxygen systems at nine projects, and two new autoventing turbines have been installed at the Boone Dam. The additional oxygenation capacity will help offset the increased oxygen demands associated with delaying the seasonal drawdown of TVA reservoirs.

3.2.7 Joint Planting

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Joint planting involves tamping live stakes of rootable plant material or rooted cuttings into soil in the interstices of porous revetments, riprap, or other retaining structures.

Joint planting is useful where rock riprap is required or already in place. It is successful 30 to 50 percent of the time, with first year irrigation improving survival rates. Live cuttings must have side branches removed and bark intact. They should range from 0.5 to 1.5 inches in diameter and be long enough to extend well into the soil, reaching into the dry season water level.

Application and Purpose

Joint planting can improve aquatic habitat by providing food and cover in the riparian zone and over the water when they are used in close proximity to the edge of the stream. Stone used at the base of the joint planting produces substrates suited for an array of aquatic organisms. Some of these organisms adapt to living on and within the rocks and some attach to the leaves and stems. The leaves and stems can also become food for shredders.

Species for joint planting systems can be selected to provide color, texture, and other attributes that add a pleasant, natural landscape appearance. Such plants for these systems include willow (*Salix* spp.), which tends to be the best from an adventitious rooting perspective and is normally an excellent choice. However other species such as poplar (*Populus* spp.), *Viburnum* spp., *Hibiscus* spp., shrub dogwood (*Cornus* spp.) and buttonbush (*Cephalanthus*) also work well. After establishment, joint planting system can reduce nonpoint pollution by intercepting sediment and attached pollutants that otherwise enter the stream from overbank flow areas.

Cost Data

Joint planting ranges in cost between $1 to $5 per square foot (Gray and Sotir 1996). Costs do not include riprap and assumes a spacing of four cuttings per square yard.

Design Guidance and Additional Information

Installation guidelines are available from the USDA-FS *Soil Bioengineering Guide* (USDA-FS 2002) and the USDA NRCS *Engineering Field Handbook*, Chapter 18 (USDA-NRCS 1992).

3.2.8 Legacy Effects of Dams and Dam Removal

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Description

Dam removal is the process of dismantling and removing unsafe, unwanted or obsolete dams and restoring the original stream gradient to the extent possible.

Application and Purpose

Dams serve a variety of important social and environmental purposes, including water supply, flood control, power generation, wildlife habitat, and recreation (USEPA 2007). Dam removal is undertaken either by owners of the dam or by public agencies and might become necessary for various reasons. Those include, most notably, the physical or structural deterioration of the dam resulting in a public safety risk, sediment accumulation in the impoundment/reservoir behind the dam and corresponding deleterious effects on the quality and quantity of water supplies. There are many things to consider when removing a dam, one of which is the function(s) of the dam and the status of that function (active versus inactive). Sometimes, the need for the dam is no longer as important as it once was, usually because of economic considerations. Finally, ecological concerns sometimes drive the need for dam removal. For example, migratory fish passage throughout United States rivers and streams is obstructed by more than 2 million dams and many other barriers such as blocked, collapsed, and perched culverts (USEPA 2007). Because dams are capital-intensive, long-term ventures, the opportunity for dam removal typically occurs infrequently, often corresponding to their periodic licensing renewal.

Efficiency Data

Many rivers and streams of the mid-Atlantic region have been altered by postcolonial floodplain sedimentation (legacy sediment) associated with numerous milldams. Several studies have shown the effect that colonization has had on the deposition of sediment into floodplains and estuaries (Jacobson and Coleman 1986; Hilgartner and Brush 2006). During the same time, many mill dams were installed, trapping the sediment behind them along with nutrients washed away from farm lands. Beavers played an important role in creating anabranching stream networks in the mid-Atlantic region during pre-settlement times, and beavers were an important factor in creating wetlands, performing a similar function to dams in sediment retention.

Little Conestoga Creek, Pennsylvania, a tributary to the Susquehanna River and the Chesapeake Bay, is one of those streams. Floodplain sedimentation rates, bank erosion rates, and channel morphology were measured annually during 2004–2007 at five sites along a 28-km length of Little Conestoga Creek with nine colonial era mill dams (one dam was still in place in 2007). A study by (Schenk and Hupp 2009) was part of a larger cooperative effort to quantify floodplain sedimentation, bank erosion, and channel morphology in a high sediment yielding region of the Chesapeake Bay watershed.

Data from the five sites were used to estimate the annual volume and mass of sediment stored on the floodplain and eroded from the banks for 14 segments along the 28-km length of creek. A bank and floodplain reach based sediment budget (sediment budget) was constructed for the 28 km by summing the net volume of sediment deposited and eroded from each segment. Mean floodplain sedimentation rates for Little Conestoga Creek were variable, with erosion at one upstream site (5 mm/year) to deposition at the other four sites (the highest was 11 mm/year) despite over a meter of floodplain aggradation from postcolonial sedimentation. Mean bank erosion rates range between 29 and 163 mm/year among the five sites. Bank height increased 1 m for every 10.6 m of channel width, from upstream to downstream ($R2 = 0.79$, $p < 0.0001$) resulting in progressively lowered hydraulic connectivity between the channel and the floodplain.

A knickpoint, approximately 9 km upstream of the dam, has produced a net erosional environment in the upstream two river segments. The floodplain experienced short periods of inundation nearly annually at the USGS stream gage, between the knickpoint and the dam, despite the heightened banks from postcolonial sedimentation and subsequent dam removals. Sediment trapping was recorded at four of the five study sites, indicating that the aggraded Little Conestoga Creek floodplain still functions as a sediment sink.

The study concluded that dam removals have many benefits, but they come with the cost of remobilizing large amounts of sediment. Managers and policy makers in the Northeast and mid-Atlantic states will have the additional burden of managing the storage and transport of legacy sediment. Dam removals in those regions can lead to large and sustained sediment pulses as legacy sediment is remobilized and transported further downstream, where increased sedimentation is a critical concern for imperiled estuarine resources, in this case, the Chesapeake Bay.

Gravel-bedded streams are thought to have a characteristic meandering form bordered by a self-formed, fine-grained floodplain. This ideal guides a multibillion-dollar stream restoration industry. Walter and Merritts (2008) mapped and dated many of the deposits along mid-Atlantic streams that formed the basis for this widely accepted model. Those data, as well as historical maps and records, show instead that before European settlement, the streams were small anabranching channels within extensive vegetated wetlands that accumulated little sediment but stored substantial organic carbon. Subsequently, 1 to 5 meters of slackwater sedimentation, behind tens of thousands of 17th- to 19th-century milldams, buried the presettlement wetlands with fine sediment. The findings show that most floodplains along mid-Atlantic streams are actually fill terraces, and historically incised channels are not natural archetypes for meandering streams. The study concludes that fluvial aggradation and degradation in the eastern United States were caused by human-induced base level changes from the following processes:

- Widespread milldam construction that inundated presettlement valleys and converted them into a series of linked slackwater ponds, coupled with deforestation and agricultural practices that increased sediment supply
- Sedimentation in ubiquitous millponds that gradually converted the ponds to sediment-filled reservoirs
- Subsequent dam breaching that resulted in channel incision through postsettlement alluvium and accelerated bank erosion by meandering streams
- The formation of an abandoned valleyflat terrace and a lower inset floodplain, which explains why so many eastern streams have bankfull (discharge) heights that are much lower than actual bank heights (note that assessments of bankfull discharge are crucial to estimates of flood potential and to design criteria for stream restoration)

A study by Skalak et al. (2009) demonstrated that the effects of dams on downstream channel morphology are minor. No significant differences in the water surface slope upstream and downstream of dams were observed. The study found that although monitoring studies of dam removals are becoming more common (Wildman and MacBroom 2005; Bushaw-Newton et al. 2002; Doyle et al. 2003; Chang 2008) empirical knowledge of the effects of dam removal is still limited, and most observations and conceptual models tend to focus on the transient effects of dam removal, the shorter-term patterns of upstream sediment mobilization, and downstream sediment storage.

Very little research has been conducted on the long-term effects of dam removal, although Graf (2006) suggests that one of the most important unanswered questions involves the likely course of channel change following dam removal. Skalak et al. suggest that the results of their study can provide some useful estimates of the long-term effects of dam removal on downstream channels because the reaches upstream of existing dams provide a useful surrogate for the channel downstream before dam construction. If the dam is removed, the following scenario is likely to occur. For an initial period of adjustment, sediment will be eroded from reservoir deposits upstream, and a transient sediment pulse will likely pass into and through the reach below the dam (Pizzuto 2002). During that period, changes in channel morphology and bed composition might be expected. However, after the new channel within the reservoir reach has stabilized, the supply of sediment and distribution of discharges should approach pre-dam levels, and the channel will slowly stabilize.

The issue of removing dams is highly controversial. Dams provide water quality benefits by removing sediment and nutrients (Harrison et al. 2009), a function historically performed by beaver dams and large woody debris (Valett et al. 2002). While providing water quality benefits, dams also hinder fish migration, limit sediment transport, and alter flow regimes. Because dams and their reservoirs persist for decades, river channels typically adjust to the altered hydrologic and sediment transport regimes that dams impose. Dam removal itself therefore represents a geomorphic disturbance to a quasi-adjusted riverine system. Removing a dam unleashes cascades of erosional and depositional processes that propagate both upstream and downstream, with the upstream response driving the downstream response.

The responses of aquatic ecosystems to elevated sediment loads and transformed channel morphology and hydrology are difficult to predict. Because dam presence and operation are known to be detrimental to preexisting aquatic ecosystems, dam removal is assumed to be beneficial, and emerging studies have supported ecological resiliency after removal (Stanley et al. 2002). Dam removal can also wreak havoc on already highly disturbed ecosystems. Further, the sediment released following a dam removal will inevitably be harmful to some downstream biota. The possibility exists that reservoirs can store high levels of contaminants, including heavy metals and other organic and inorganic compounds. Release of such materials after dam removal can create contaminant plumes with wide-ranging environmental consequences.

The benefits of removing dams include restoring flow fluctuations, allowing sediment transport, preventing temperature fluctuations, and allowing fish migration. When natural flow fluctuations are restored to a river, biodiversity and population densities of native aquatic organisms increase. Wetlands adjacent to rivers also benefit from dam removal. Riparian areas would likely flood more frequently, promoting riparian plant growth, revitalizing inland wetlands, and creating small, ephemeral ponds, which serve as nurseries for aquatic species. Dams can alter a river's temperature by releasing water from the bottom of the impoundment where cooler water resides, so dam removal can restore a river's natural water temperature range. Reproductive success, which often depends on appropriate timing for reaching spawning or breeding habits, can be improved by the removal of dams. Furthermore, dam removal decreases the risk of mortality for organisms that would otherwise have to pass through dams.

Cost Data

Costs of dam removal are site-specific and can vary from tens of thousands of dollars to hundreds of millions of dollars, depending on the size and location of the dam (USEPA 2007).

3.2.9 Live Crib Walls

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Live crib walls are hollow, box-like frameworks of untreated logs or timbers filled with riprap and alternating layers of suitable backfill and live branch layers and are used for slope, streambank, and shoreline protection.

Application and Purpose

Live crib walls are constructed to protect the toes and banks of eroding stream reaches against scour and undermining, particularly at the outsides of meander bends where strong river currents are present. The log frameworks provide immediate protection from erosion while the live branch cuttings contribute long-term durability and ultimately replace the decaying logs. Additionally, live crib walls are effective in areas where encroachment into the stream channel should be avoided. When considering these structures as a stream restoration technique, the following limitations should be considered:

- Live crib walls should not be used where the channel bed is severely eroded or where undercutting is likely to occur (e.g., where the terrain is rocky or where narrow channels are bounded by high banks).
- Live crib walls are not intended to resist large lateral earth stresses, therefore their heights should be limited accordingly (as noted in the installation specifications).
- Live crib walls promote siltation and retain large amounts of bed material; therefore, they require continual monitoring for adverse streamflow patterns.

When choosing and preparing logs and woody cuttings for live crib walls, the following guidelines should be followed:

- Crib frameworks should be constructed from stripped logs or untreated lumber 4 to 6 inches (10 to 15 centimeters) in diameter.
- Live branches should be cut from fresh, green, healthy parent plants that are adapted to the site conditions whenever possible.

  1. Live branches should be 0.5 to 2.5 inches (1.3 to 6 centimeters) in diameter and should be long enough to reach the soil at the back of the wooden crib structure while projecting slightly from the crib face.

2. Commonly used woody plants for this measure include willow, poplar, and alder because they are versatile and have high growth rates with shrubby habits, fibrous root systems, and high transpiration rates especially when in leaf.
3. Live branch cuttings should be kept covered and moist at all times and should be placed in cold storage if more than a few hours elapse before installation.

- Fill soil should be native to the site, when possible, and should contain enough fine material to allow for the live branches to root and grow readily.

Cost Data

Live crib walls range in cost between $13 to $33 per square foot (Gray and Sotir 1996).

Design Guidance and Additional Information

Installation guidelines are available from the USDA-FS *Soil Bioengineering Guide* (USDA-FS 2002) and the USDA NRCS *Engineering Field Handbook*, Chapter 18 (USDA-NRCS 1992).

Additional Resources

FISRWG (Federal Interagency Stream Restoration Working Group). 1998. Stream Corridor Restoration: Principles, Processes, and Practices. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

ISU (Iowa State University). 2006. *How to Control Streambank Erosion: Live Cribwall*. Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/live_cribwall.pdf.

Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Live Cribwall*. Prepared for the U.S. Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/livecribwall.pdf.

Ohio DNR (Department of Natural Resources). 2007. *Ohio Stream Management Guide: Live Cribwalls*. Ohio Department of Natural Resources. http://www.ohiodnr.com/pubs/fs_st/streamfs/tabid/4178/Default.aspx.

3.2.10 Live Fascines

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Live fascines are a form of soil bioengineering that uses long bundles of live branch cuttings bound together in long rows and placed in shallow trenches following the contour on dry slopes and at an angle on wet slopes.

Application and Purpose

Live fascines are suited to steep, rocky slopes, where digging is difficult (USDA-NRCS 1992). When cut from appropriate species (e.g., young willows or shrub dogwoods) that root easily and have long straight branches, and when properly installed, they immediately begin to stabilize slopes. Willow, alder, and dogwood cuttings are well suited for use in live fascines. Fascine bundles can range from 5 to 30 feet (1.5 to 9 m) in length, depending on handling and transportation limitations, with diameters ranging from 4 to 10 inches (10 to 25 cm). Untreated twine or wire used to tie the bundles should be at least 2 mm thick. If inert (dead) stakes are employed to secure the bundles, they should be made from 2 by 4 inch (5 by 10 cm) lumber cut on the diagonal with lengths of 2.5 feet (0.8 m) for cut slopes and 3 feet (0.9 m) for fill slopes. The goal is for natural recruitment to follow once slopes are secured. Live fascines should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. Live fascines should be applied above ordinary high-water mark or bankfull level except on very small drainage area sites. In arid climates, they should be used between the high and low water marks on the bank. This system, installed by a trained crew, does not cause much site disturbance.

Establishing live fascines, also known as wattles, consists of the following:

- Preparing sausage-shaped bundles of live, woody plant cuttings
- Anchoring the bundles in shallow ditches in a slope or streambank with live or inert stout stakes, or both
- Partially burying the fascines to promote growth

As with other bioengineering measures, live fascines are an economical method when materials are locally available. Additionally, live fascines are often an effective measure when employed to

- Reduce runoff energy, and hence surface erosion, by braking a slope into a series of shorter slopes
- Protect other bioengineering measures from washout and undercutting
- Replace brush layers on suitable cut slopes (because they are easier to install)
- Protect streambanks from washout and seepage, particularly at toes where water levels fluctuate only moderately
- Stabilize or protect streambanks
- Provide habitat
- Reduce overland sediment loading

Cost Data

Live fascine costs range from $10 to $30 per foot for 6- to 8-inch bundles. Prices include securing devices for installation, twine (for fabrication), harvesting, transportation, handling, fabrication, and storage of the live-cut branch materials, excavation, backfill, and compaction. Costs vary with design, access, time of year, and labor rates.

Design Guidance and Additional Information

Installation guidelines are available from the USDA-FS *Soil Bioengineering Guide* (USDA-FS 2002) and the USDA NRCS *Engineering Field Handbook*, Chapter 18 (USDA-NRCS 1992). Under their Ecosystem Management and Restoration Research Program (EMRRP), the U.S. Army Corps of Engineers presents research on live fascines in a technical note (Live and Inert Fascine Streambank Erosion Control).

Additional Resources

Massachusetts DEP. 2006. *Massachusetts Nonpoint Source Pollution Management Manual: Live Fascines*. Massachusetts Department of Environmental Protection, Boston, MA. http://projects.geosyntec.com/NPSManual/Fact%20Sheets/Live%20Fascines.pdf.

Greene County Soil & Water Conservation District. No date. Construction Specification VS-01: Live Fascines. http://www.gcswcd.com/stream/library/pdfdocs/vs-01.pdf.

ISU (Iowa State University). 2006. *How to Control Streambank Erosion: Live Fascine*. Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/live_fascine.pdf.

Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Live Fascine*. Prepared for the U.S. Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/livefacine.pdf.

Ohio DNR (Department of Natural Resources). 2007. *Ohio Stream Management Guide: Live Fascines*. Ohio Department of Natural Resources. http://www.ohiodnr.com/pubs/fs_st/streamfs/tabid/4178/Default.aspx.

3.2.11 Live Staking

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Live staking is used to reestablish streambank vegetation and help stabilize selected slope areas. This form of soil bioengineering involves planting live cuttings from shrubs or trees along the streambank and is also known as woody cuttings, posts, poles, or stubs. Stakings provide long-term streambank stabilization with delayed initial onset and are best used as part of a system that includes immediate means of buffering banks from erosive flows (e.g., tree revetments, which can actually accrue sediments), a component to deter undercutting at the bed/bank interface (e.g., riprap or gabions) and a means of reducing the energy of incoming flows at their source.

Application and Purpose

Live staking is an economical method when local supplies of woody cuttings are readily available because implementing this measure requires minimal labor. When used effectively, live stakes can do the following:

- Act to trap soil particles in sediment laden water resulting from the erosion of adjacent land
- Slow water velocities, trap sediment, and control erosion when organized in clustered arrays along the sides of gullies
- Repair small earth slips and slumps that are frequently wet
- Help control shallow mass movement when placed in rows across slopes
- Promote bank stabilization

Live staking is a preventative measure and should be employed before severe erosion problems occur. Additionally, to be effective, live stakes should be

- Planted only on streams with low to moderate flow fluctuations
- Established in the original bank soil on moderate slopes of 4:1(h:v) or less
- Planted where appropriate lighting exists

- Used jointly with other restoration techniques especially on slopes with high erosion rates and incidents of mass wasting

When choosing and preparing woody material for live stakes, managers should follow these guidelines:

- Live stakes should be cut from fresh, green, healthy, dormant parent plants that are adapted to the site conditions whenever possible. Commonly used woody plants for this measure include willow, poplar, and alder because they are versatile and have high growth rates with shrubby habits, fibrous root systems, and high transpiration rates, especially when in leaf.
- Live stakes should have a diameter between 0.75 and 1.5 inches (2 to 4 cm) and should be long enough to reach below the groundwater table so that a strong root system can quickly develop. At least 1 foot (0.3 m) should be exposed to sunlight. Live woody posts with diameters up to 10 inches (0.25 m) and lengths ranging from 4 to 6 feet (1.2 to 1.8 m) can also be used at the discretion of the project manager.
- Live stakes should be kept covered and moist at all times and should be placed in cold storage if more than a few hours elapse between the cutting and replanting times.
- Vegetation selected should be able to withstand the degree of anticipated inundation, provide year round protection, have the capacity to become well established under sometimes adverse soil conditions, and have root, stem, and branch systems capable of resisting erosive flows.
- Specific site requirements and available cutting source will determine size.

Cost Data

The installed cost of live stakes typically ranges from $1 to $2 per stake, depending on local labor rates, proximity of harvesting area to site, and other site variables.

Design Guidance and Additional Information

Installation guidelines are available from the USDA-FS *Soil Bioengineering Guide* (USDA-FS 2002) and the USDA NRCS *Engineering Field Handbook*, Chapter 18 (USDA-NRCS 1992).

Additional Resources

ISU (Iowa State University). 2006. *How to Control Streambank Erosion: Live Stakes*. Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/live_stakes.pdf.

Myers, R.D. 1993. *Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners. Live Staking*. Publication 93-30. Washington Department of Ecology, Shorelands and Coastal Zone Management Program, Olympia, WA. http://www.ecy.wa.gov/programs/sea/pubs/93-30/livestaking.html.

Walter, J., D. Hughes, and N.J. Moore. 2005. *Streambank Revegetation and Protection: A Guide for Alaska. Revegetation Techniques: Live Staking*. Revised Edition. Alaska Department of Fish and Game, Division of Sport Fish. http://www.sf.adfg.state.ak.us/SARR/restoration/techniques/livestake.cfm.

3.2.12 Log and Rock Check Dams

Description

Check dams are low structures built across a stream perpendicular to the flow. The most common use for check dams is to decrease the slope and velocity of a stream to control erosion.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The plunge pool below a check dam provides excellent fish habitat, and the downstream gravel bar often associated with the dam makes an excellent spawning bed. When used to enhance fish habitat, check dams should be placed far enough apart to ensure that the pool below a dam is above the backwater of the next dam downstream. That will reduce the possibility that the habitat pool of the upper dam can fill with deposits.

When constructed and spaced properly, check dams can simulate the natural pattern of pools and riffles occurring in undisturbed streams while forming gravel deposits that fish use as spawning grounds.

Check dams have also been used to prevent the movement of fine sediments into the mainstream channel, to aerate water, and to raise water levels past culvert invert elevations, thereby allowing fish passage.

Check dams should be avoided in the following areas:

- Channels with bedrock beds or unstable bed substrates
- Channels without well-developed, stable banks
- Streams with high bedload transport
- Streams with naturally well-developed pool-riffle sequences
- Reaches where the water temperature regime is negatively affected when the current is slowed

Cost Data

Check dams vary widely in cost depending on the design, availability and selection of materials, and site conditions.

Design Guidance and Additional Information

The following document provides design information and guidance for check dams.

Maryland Department of the Environment Water Management Administration. 2000. Maryland's Waterway Construction Guidelines. http://www.mde.state.md.us/assets/document/wetlandswaterways/mgwc.pdf.

3.2.13 Marsh Creation and Restoration

Description

Marsh creation and restoration is a useful vegetative technique that can address problems with erosion of shorelines. For shoreline sites that are highly sheltered from the effects of wind, waves, or boat wakes, the fill material is usually stabilized with small structures, similar to groins, which extend out into the water from the land. For shorelines with higher levels of wave energy, the newly planted marsh can be protected with an offshore installation of stone that is built either in a continuous configuration or in a series of breakwaters.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The exposed stems of marsh plants form a flexible mass that dissipates wave energy. As wave energy is diminished, the offshore transport and longshore transport of sediment are reduced. Ideally, dense stands of marsh vegetation can create a depositional environment, causing accretion of sediments along the intertidal zone rather than continued shore erosion. Marsh plants also form a dense mat of roots, which can add stability to the shoreline sediments. The basic approach for marsh creation is to plant a shoreline area in the vicinity of the tide line with appropriate marsh grass species.

Efficiency Data

Despite rapid growth in river restoration, few projects receive the necessary evaluation and reporting to determine their success or failure and to learn from experience. As part of the National River Restoration Science Synthesis, (Alexander and Allan 2006) interviewed 39 project contacts from a database of 1,345 restoration projects in Michigan, Wisconsin, and Ohio to (1) verify project information; (2) gather data on project design, implementation, and coordination; (3) assess the extent of monitoring; and (4) evaluate success and the factors that can influence it. Projects were selected randomly within the four most common project goals from a national database: in-stream habitat improvement, channel reconfiguration, riparian management, and water-quality improvement. About half of the projects were implemented as part of a watershed management plan and had some advisory group. Monitoring occurred in 79 percent of projects but often was minimal and seldom documented biological improvements. Baseline data for evaluation often relied on previous data obtained under regional monitoring programs using state protocols. Although 89 percent of project contacts reported success, only 11 percent of the projects were considered successful because of the response of a specific ecological indicator, and monitoring data were underused in project assessment. Estimates of ecological success, using three criteria from Palmer et al. (2005), indicated that half or fewer of the projects were ecologically successful, markedly below the success level that project contacts self-reported, and sent a strong signal of the need for well-designed evaluation programs that can document ecological enhancements.

3.2.14 Multi-Cell Culvert

Description

Roadway crossing, typically of smaller streams, where the main culvert at the stream channel is sized for bankfull discharge and additional culverts are placed on the floodplain to convey overbank flow up to the design discharge.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The use of a multi-cell culvert distributes stream conveyance during larger storm events across a larger portion of the stream/floodplain cross-section than the traditional single culvert system resulting in reduced flow velocities and better floodplain connectivity. In addition, the smaller primary culvert can increase flow depths during low flows enabling fish passage.

Multi-cell culverts typically consists of a primary culvert installed in line with the stream channel and sized with a cross-sectional area equivalent to the stream at bankfull discharge. One or more secondary culverts are at floodplain or bankful elevation at variable locations across the road crossing to provide passage of floodflow. Primary culvert inverts are often placed below the channel invert to allow water and sediments to pool within the culvert to enable fish passage. The placement and geometry of the primary culvert is intended to allow the natural transport of sediment in the stream channel and prevent scour of the streambed because of flow contraction (Rosgen 1996). The combined capacity of the primary and secondary culverts is the design flow.

Multi-cell culverts might not be appropriate for streams that are incised or actively incising, exhibit high-flow velocities, or streams that often carry a heavy debris load (Johnson and Brown 2000). Use of multi-cell culverts in such systems could result in perched culverts and debris jams. Rosgen (1996) type C or E channels might be most appropriate for use of multi-cell culverts (Maryland Waterways Construction Guidelines 2000).

Performance

Published data on the performance of multi-cell culverts is primarily limited to fish passage requirements and assessment of appropriate channels systems. Laboratory-scale model experiments investigating the scour and flow depth characteristics of multi-cell culverts showed reduction in overall scour pool volume and culvert perching of 52 percent and 55 percent, respectively (Wargo and Weisman 2006).

Design Guidance and Additional Information

Maryland Department of the Environment Water Management Administration. 2000. *Maryland's Waterway Construction Guidelines* at http://www.mde.state.md.us/assets/document/wetlandswaterways/mgwc.pdf. Accessed February 2010.

3.2.15 Natural Channel Design and Restoration

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Natural stream channel design is based on fluvial geomorphology, which is the study of a stream's interactions with the local climate, geology, topography, vegetation, and land use—how a river carves its channel within its landscape. The underlying concept of natural stream channel design is to use a stable natural channel as a blueprint or template. Such a blueprint, or reference reach, will include the pattern, dimension, and profile for the stream to transport its watershed's flows and sediment as it dissipates energy through its geometry and in-stream structures. Project design (channel configuration, structures, nonstructural techniques, and the like) must account for the stream's ability to transport water and sediment.

Application and Purpose

Natural stream channel design depends on practioners accurately identifying stream classification types. Stream type is a powerful tool to use in decision making when combined with knowledge and field experience in natural stream channel design. In addition to providing a stable condition, natural stream channel design promotes a biologically diverse system. Many of the structures employed *buy time* until riparian vegetation becomes established and matures. Establishing a vegetated buffer that has long-term protection is key to natural design and provides a number of aquatic and terrestial benefits. Those benefits include root-mass that stabilizes the bank; shade that buffers stream temperature; leaves that provide energy, food, and shelter for wildlife; wildlife travel corridors; added roughness to the floodplain which helps to reduce stream energy; and the uptake of nutrients from the soil.

Many methods exist for classifying streams. One popular method for classification is Rosgen's Stream Classification System (Rosgen 1996). The purpose of that system is to classify streams on the basis of quantifiable field measurements to produce consistent, reproducible descriptions of stream types and conditions. Rosgen's classification hierarchy has four levels: geomorphic characterization (Level 1), morphological description (Level 2), stream condition assessment (Level 3), and validation and monitoring (Level 4).

Restoration of the proper dimension will ensure that the stream is connected to the floodplain so that riparian vegetation and other components that roughen the channel will mitigate damage from flood-flows. Structures used in natural stream channel design such as vanes, cross-vanes, and root-wads create and maintain pool habitat, which is often minimal in degraded channels. In other words, they maintain the dimension, pattern, and profile (or slope) of the stream. Restored streams provide for sediment transport and the sorting of bed material that results in the development of habitat diversity.

All successful natural stream channel designs achieve sediment transport, habitat enhancement, and bank and channel stabilization. The degree to which projects meet those goals depends on a project's specific objectives. Ultimately, a stream considered stable or *in equilibrium* can carry the sediment load supplied by the watershed without changing its dimension (cross-sectional area, width, depth, shape), pattern (sinuosity, meander pattern), or profile (longitudinal pattern and slope), and without aggrading (building up of bottom materials) or degrading (cutting down into the landscape and abandoning the natural floodplain).

Stream restoration is an increasingly popular management strategy for improving the physical and ecological conditions of degraded urban streams. In urban catchments, management activities as diverse as stormwater management, bank stabilization, channel reconfiguration and riparian replanting can be described as river restoration projects. Restoration in urban streams is both more expensive and more difficult than restoration in less densely populated catchments. High property values and finely subdivided land and dense human infrastructure (e.g., roads, sewer lines) limit the spatial extent of urban river restoration options, while stormwater and the associated sediment and pollutant loads can limit the potential for restoration projects to reverse degradation. To be effective, urban stream restoration efforts must be integrated within broader catchment management strategies. A key scientific and management challenge is to establish criteria for determining when the design options for urban river restoration are so constrained that a return toward reference or pre-urbanization conditions is not realistic or feasible and when river restoration presents a viable and effective strategy for improving the ecological condition of such degraded ecosystems.

Stream restoration should be performed to provide overall watershed improvement. One method for achieving that is the Stream Corridor Assessment survey developed by the Maryland Department of Natural Resources. The survey is a watershed management tool that identifies environmental problems and helps prioritize restoration opportunities on a watershed basis. Potential environmental problems commonly identified during the survey include stream channel alterations, excessive bank erosion, exposed pipes, inadequate stream buffers, fish migration blockages, trash dumping sites, near-stream construction, pipe outfalls, and unusual conditions. In addition, the survey records information on the location of potential wetlands creation sites and collects data on the general condition of in-stream and riparian habitats.

Efficiency Data

Restoration activities intended to improve the condition of streams and rivers are widespread throughout the country, but little information exists regarding types of activities and their effectiveness. Alexander and Allan (2006) developed a database of 1,345 stream restoration projects implemented from the years 1970 to 2004 for the states of Michigan, Ohio, and Wisconsin to analyze regional trends in goals, presence of monitoring, spatial distribution, size, and cost of river restoration projects. They found that data on individual projects were fragmented across multiple federal, state, and county agencies, as well as nonprofit groups and consulting firms. The most common restoration goals reported for the region were in-stream habitat improvement, bank stabilization, water-quality management, and dam removal. Hassett et al. (2005 and 2007) analyzed 4,700 stream restoration practices in the Chesapeake Bay watershed and Bernhardt et al. (2005) compiled a database for 37,099 projects in the National River Restoration Science Synthesis (NRRSS) database. Those studies found that the primary reasons for performing stream restoration are the following:

- Bank Stabilization
- Stormwater Management
- Flow Modification
- Channel Reconfiguration
- Fish Passage
- Riparian Management
- In-Stream Species Management
- Dam Removal/Retrofit
- Floodplain Reconnection
- In-Stream Habitat Improvement
- Aesthetics/Recreation/Education
- Water-Quality Management

The effects of upland disturbance and in-stream restoration on hydrodynamics and ammonium uptake in headwater streams was studied by Roberts et al. (2007) who found that the delivery of water, sediments, nutrients, and organic matter to stream ecosystems was strongly influenced by the catchment of the stream and can be altered greatly by upland soil and vegetation disturbance. Upland disturbance did not appear to influence stream hydrodynamics strongly, but it caused significant decreases in in-stream nutrient uptake. In October 2003, coarse woody debris (CWD) was added to one-half of the study streams (spanning the disturbance gradient) in an attempt to increase hydrodynamic and structural complexity, with the goals of enhancing biotic habitat and increasing nutrient uptake rates. CWD additions had positive short-term (within 1 month) effects on hydrodynamic complexity (water velocity decreased and transient storage zone cross-sectional area, relative size of the transient storage zone, fraction of the median travel time attributable to transient storage over a standardized length of 200 m, and the hydraulic retention factor increased) and nutrient uptake (NH_4^+ þ uptake rates increased). The results of this study suggest that water quality in streams with intense upland disturbances can be improved by enhancing in-stream biotic nutrient uptake capacity through measures such as restoring stream CWD.

Bukaveckas (2007) studied the interplay between hydrogeomorphic features and ecosystem processes within designed channels. Water velocity, transient storage, and nutrient uptake were measured in channelized (prerestoration) and naturalized (postrestoration) reaches of a 1-km segment of Wilson Creek (Kentucky) to assess the effects of restoration on mechanisms of nutrient retention. Stream restoration decreased flow velocity and reduced the downstream transport of nutrients. Median travel time was 50 percent greater in the restored channel because of lower reachscale water velocity and the longer length of the meandering channel. Transient storage and the influence of transient storage on travel time were largely unaffected except in segments where backwater areas were created. First order uptake rate coefficients for N and P were 30- and 3-fold higher (respectively) within the restored channel relative to its channelized state. Changes in uptake velocities were comparatively small, suggesting that restoration had little effect on biochemical demand. Results from this study suggest that channel naturalization enhances nutrient uptake by slowing water velocity.

Increased delivery of N because of urbanization and stream ecosystem degradation is contributing to eutrophication in coastal regions of the eastern United States according to Kaushal et al. (2008) who tested whether geomorphic restoration involving hydrologic *reconnection* of a stream to its floodplain could increase rates of denitrification at the riparian-zone–stream interface of an urban stream in Baltimore, Maryland. Rates of denitrification measured using in situ 15N tracer additions were spatially variable across sites and years and ranged from undetectable to 0.200 lg N (kg sediment). Concentrations of nitrate-N in groundwater and stream water in the restored reach were also significantly lower than in the unrestored reach, but that might have also been associated with differences in sources and hydrologic flow paths. Riparian areas with low, hydrologically connected streambanks designed to promote flooding and dissipation of erosive force for stormwater management had substantially higher rates of denitrification than restored high *nonconnected* banks and both unrestored low and high banks. Coupled measurements of hyporheic groundwater flow and in situ denitrification rates indicated that up to 1.16 mg NO_3-N could be removed per liter of groundwater flow through one cubic meter of sediment at the riparian-zone–stream interface over a mean residence time of

4.97 d in the unrestored reach, and estimates of mass removal of nitrate-N in the restored reach were also considerable. Mass removal of nitrate-N appeared to be strongly influenced by hydrologic residence time in unrestored and restored reaches. Results of the study suggest that stream restoration designed to reconnect stream channels with floodplains can increase denitrification rates, that there can be substantial variability in the efficacy of stream restoration designs, and that more work is necessary to elucidate which designs can be effective in conjunction with watershed strategies to reduce nitrate-N sources to streams.

Cost Data

The most common restoration activities found by Alexander and Allan (2006) were the use of sand traps and riprap, and other common activities were related to the improvement of fish habitat. The median cost was $12,957 for projects with cost data, and total expenditures since 1990 were estimated at $444 million. Over time, the cost of individual projects has increased, whereas the median size has decreased, suggesting that restoration resources are being spent on smaller, more localized, and more expensive projects. Only 11 percent of data records indicated that monitoring was performed, and more expensive projects were more likely to be monitored. Standardization of monitoring and record keeping and dissemination of findings are urgently needed to ensure that dollars are well spent and restoration effectiveness is maximized.

Design Guidance and Additional information

Craig, L.S., M.A. Palmer, D. C. Richardson1, S. Filoso, E. S. Bernhardt, B. P. Bledsoe, M.W. Doyle, P. M. Groffman, B. Hassett, S. S. Kaushal, P. M. Mayer, S. M. Smith, and P.R. Wilcock. 2008. Stream restoration strategies for reducing nitrogen loads. *Frontiers in Ecology and the Environment* 6:529–538.

Doll, B.A., G.L. Grabow, K.R. Hall, J. Halley, W.A. Harman, G.D. Jennings and D.E. Wise, 2003. *Stream Restoration: A Natural Channel Design Handbook*. North Carolina State University, North Carolina Stream Restoration Institute, Raleigh, NC.

Federal Interagency Stream Restoration Working Group. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. National Technical Information Service, U.S. Department of Commerce, Springfield, VA.

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

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3.2.16 Non-Eroding Roadways

Description

Non-eroding roadways refer to practices that reduce the sediment load to receiving waterbodies from dirt and gravel roads.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) has a chapter on the practice of Non-eroding Roadways. For additional information on the appropriate use and application of non-eroding roadways, see the 2007 guide.

In addition to the information contained in the 2007 guide, the following practices are recommended to reduce the sediment load from dirt and gravel roads.

Driving Surface Aggregate (DSA)

DSA is a specific gradation of crushed stone developed by the Center for Dirt and Gravel Road Studies specifically for use as a surface wearing course for unpaved roads. DSA achieves sediment reductions by decreasing erosion and transport of fine material from the road surface. Sandstone- and limestone-derived aggregates are preferred.

Raising the Road Profile

Raising the road profile involves importing material to raise the elevation of an unpaved road. It is typically practiced on roads that have become entrenched (lower than surrounding terrain). Raising the elevation of the road is designed to restore natural drainage patterns by eliminating the downslope ditch and providing cover for pipes to drain the upslope ditch. Removing the downslope ditch will eliminate concentrated flow conveyed in the ditch and create sheet flow. Raising the road profile achieves sediment reduction by controlling and reducing the volume of road runoff.

Raising the road profile involves importing fill material to raise the elevation of the roadway up to the elevation of the surrounding terrain. The road is filled to a sufficient depth as to eliminate the ditch on the downslope side of the road and encourage sheet flow. Shale and gravel are the most common fill materials for roads. Other potential recycled fill materials include ground glass, waste sand, automobile tires, clean concrete rubble, and the like.

Grade Breaks

Grade breaks are an intentional increase in road elevation on a downhill grade, which causes water to flow off of the road surface. It is designed to reduce erosion on the road surface by forcing water into the ditches or surrounding terrain. Erosion of the road surface is reduced by forcing runoff laterally off the road. In some cases, grade breaks are used to force water off the road entirely, serving as an additional drainage outlet. Sites where water is not forced off the road entirely convey the water into a roadside ditch.

Drainage Outlets

Drainage outlets are designed to capture water flowing in the roadside ditch and force it to leave the road area. There are two major types of drainage outlets. Turnouts (also called bleeders) or cutouts outlet water from the downslope road ditch. They usually consist of relatively simple cuts in the downslope road bank to funnel road drainage away from the road. Drainage that is carried by the upslope road ditch is usually outletted under the roadway by the use of a crosspipe (also called culvert, sluice pipe, or tile drain). Installing additional drainage outlets reduces concentrated flow, peak-flow discharges and sediment transport and delivery from unpaved roads and ditches into streams, and can increase infiltration. It does not affect sediment generation from the road surface or deliver in the upslope ditch; thus, all data on sediment reductions in this chapter are for a downslope ditch only, unless otherwise noted. Drainage outlets are to be placed in locations that have the least likelihood of reaching streams. If a newly added outlet conveys sediment to the stream, little, if any, sediment reductions will be obtained.

Berm Removal

A berm is a mound of earthern material that runs parallel to the road on the downslope side. Berms can be formed by maintenance practices and road erosion that lowers the road elevation over time. In many cases, the berm is unnecessary and creates a ditch on the downslope side of the road. The berm can be removed to encourage sheet flow into surrounding land instead of concentrated flow in an unnecessary ditch. Restoring sheet flow results in decreased runoff and sediment transport along the roadway, increase infiltration, and reduced maintenance associated with the road drainage system.

Effectiveness information for non-eroding roadway practices are summarized in Table 7-10.

Efficiency Data

Table 7-10. TSS reduction efficiencies estimated for each practice

Technique		**TSS effectiveness estimate**
Driving Surface Aggregate	Limestone*	50%
	Sandstone	55%
Raising the Road Profile		45%
Grade Breaks		30%
Additional Drainage Outlet		15%
Berm Removal		35%

Total nitrogen (TN) and total phosphorus (TP) removal is minimal with dirt and gravel road sediment control. One reason is that dirt and gravel roads are not fertilized. The other is that the environmental benefit association with dirt roads is such that N and P reductions are not anticipated, nutrient reductions are not a component of the average function of dirt and gravel roads. If N and P reductions are associated with dirt and gravel roads, sediment reductions should be tracked.

Design Guidance and Additional Information

For additional information on non-eroding roadways, see the following sources:

Controlling Nonpoint Source Runoff Pollution from Roads, Highways, and Bridges
http://www.epa.gov/owow/nps/roads.html

Erosion, Sediment, and Runoff Control for Roads and Highways
http://www.epa.gov/owow/nps/education/runoff.html

Gravel Roads: Maintenance and Design Manual—the purpose of the manual is to provide clear and helpful information for doing a better job of maintaining gravel roads. The manual is designed for the benefit of elected officials, mangers, and grader operators who are responsible for designing and maintaining gravel roads.
http://www.epa.gov/owow/nps/gravelroads

Low-Volume Roads Engineering Best Management Practices Field Guide
http://zietlow.com/manual/gk1/web.doc

Massachusetts Unpaved Roads BMP Manual
http://www.berkshireplanning.org/download/dirt_roads.pdf

Planning Considerations for Roads, Highways, and Bridges
http://www.epa.gov/owow/nps/education/planroad.html

Pollution Control Programs for Roads, Highways, and Bridges
http://www.epa.gov/owow/nps/education/control.html

Recommended Practices Manual: A Guideline for Maintenance and Service of Unpaved Roads
http://www.epa.gov/owow/nps/unpavedroads.html

The *Road Maintenance Video Set* is a five-part video series developed for the USDA-FS equipment operators that focuses on environmentally sensitive ways of maintaining low-volume roads. http://www.epa.gov/owow/nps/maint_videoset.html

3.2.17 Revetments

Description

Revetments are the stabilization of eroding streambanks and for shoreline protection by using designed structural measures, such as rock riprap, gabions, precast concrete wall units, and grid pavers.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The purpose of revetments is to protect exposed or eroded streambanks from the erosive forces of flowing water. They are generally applicable where flow velocities exceed 6 feet per second or where vegetative streambank protection is inappropriate and necessary where excessive flows have created an erosive condition on a streambank.

Because each channel is unique, measures for structural streambank should be installed according to a design according to specific site conditions. Develop designs according to the following principles:

- Make protective measures compatible with other channel modifications planned or being carried out in the channel reaches.
- Use the design velocity of the peak discharge of the 10-year storm or bankfull discharge, whichever is less. Structural measures should be capable of withstanding greater flows without serious damage.
- Ensure that the channel bottom is stable or stabilized by structural means before installing any permanent bank protection.
- Streambank protection should begin at a stable location and end at a stable point along the bank.
- Changes in alignment should not be done without a complete analysis of effects on the rest of the stream system for both environmental and stability effects.
- Provisions should be made to maintain and improve fish and wildlife habitat. For example, restoring lost vegetation will provide valuable shade, food, and/or cover.
- Ensure that all requirements of state law and all permit requirements of local, state, and federal agencies are met.

Typical materials used for revetments are as follows:

Riprap. Riprap is the most commonly used material to structurally stabilize a streambank. While riprap will provide the structural stabilization necessary, the bank can be enhanced with vegetative material to slow the velocity of water, filter debris, and enhance habitat.

Gabions. Gabions are rectangular, stone-filled wire baskets. They are somewhat flexible in armoring channel bottoms and banks. They can withstand significantly higher velocities for the size stone they contain because of the basket structure. They also stack vertically to act as a retaining wall for constrained areas.

Reinforced Concrete. Reinforced concrete can be used to armor eroding sections of streambank by constructing walls, bulk heads, or bank linings. Provide positive drainage behind such structures to relieve uplift pressures.

Grid Pavers. Grid pavers are modular concrete units with or without void areas that can be used to stabilize streambanks. Units with void areas allow vegetation to establish. Such structures can be obtained in a variety of shapes, or they can be formed and poured in place. Maintain design and installation in accordance with manufacturer's instructions.

Modular Precast Units. Interlocking modular precast units of different sizes, shapes, heights, and depths have been developed for a wide variety of applications. The units serve in the same manner as gabions. They provide vertical support in tight areas as well as durability. Many types are available with textured surfaces. They also act as gravity retaining walls. They should be designed and installed in accordance with the manufacturers' recommendations. Openings in the units provide drainage and allow vegetation to grow through the blocks. Vegetation roots add strength to the bank.

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) provides various examples of types of revetments.

Design Guidance and Additional Information

Ohio DNR (Department of Natural Resources). 2007. *Ohio Stream Management Guide: Riprap Revetments*. Ohio Department of Natural Resources. http://www.ohiodnr.com/pubs/fs_st/streamfs/tabid/4178/Default.aspx.

3.2.18 Riparian Improvements

Description

Riparian improvements are strategies used to restore or maintain aquatic and riparian habitat around reservoir impoundments or along the waterways both upstream of and downstream from dams and include reducing sediment loading in the downstream watershed, improving riparian vegetation, eliminating barriers to fish migration, providing greater in-stream and riparian habitat diversity, and reducing flow-related effects on dams.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☑ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Maintaining and improving riparian areas upstream of and downstream from dams is an important consideration. Riparian improvements might be necessary along smaller-order streams if their ability to detain and absorb floodwater and stormwater has been impaired—often the result of removing forest cover or increasing watershed imperviousness. Cumulative effects on riparian areas of smaller streams include increased discharge volumes and velocities of water, which then result in more severe downstream flooding and increased storm damage or maintenance to existing structures, including dams. Information on techniques to mitigate effects on smaller streams is also in the Urban and Suburban chapter of this guidance (Chapter 3).

Design Guidance and Additional Information

The Iowa Department of Natural Resources (no date) recommends that the property owner or developer estimate the amount of time, materials, equipment, and labor necessary to complete the work as compared to those personally available. This is a subjective decision based on time, knowledge, and resource constraints.

- Construction activities should be conducted during periods of low flow.
- Construction equipment, activities, and materials should be kept out of the water to the maximum extent possible.
- All construction debris should be disposed of on land in such a manner that it cannot enter a waterway or wetland.

- Equipment for handling and conveying materials during construction should be operated to prevent dumping or spilling the material into waterbodies, streams, or wetlands.
- Care should be taken to prevent any petroleum products, chemicals, or other deleterious materials from entering waterbodies, streams, or wetlands.
- Clearing of vegetation, including trees in or immediately adjacent to waters of the state, should be limited to that which is absolutely necessary for construction of the project. All vegetative clearing material should be removed to an upland, non-wetland disposal site.

Each of the methods described in the manual requires observation and maintenance of the streambank erosion control practices over time. Observations should be made regularly before and after major stream flow events. Maintenance activities should include the following:

- Remove any debris that becomes entangled in the erosion control material and could damage the bank materials.
- Replace missing or damaged erosion control materials during times of low stream flow.
- Apply fertilizer to plant materials to enhance their growth each year.
- Apply fertilizer and weed control to buffer strip vegetation.
- Restrict livestock from steep banks and the areas containing the erosion control measures.

Riparian Buffers

Riparian buffers are described in Chapter 5 of this document.

3.2.19 Riprap

Description

Riprap is a layer of appropriately sized stones designed to protect and stabilize areas subject to erosion, slopes subject to seepage, or areas with poor soil structure.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) has a chapter on the practice of riprap. At the time of this writing, no additional information is provided pertaining to the practice. For information on the appropriate use and application for riprap, see the 2007 guide.

Cost Data

Riprap costs vary depending on the class of riprap, the location of the quarry, and installation practices. Prices typically range from $40 to $70 per ton.

3.2.20 Rock and Log Vanes

Description

Rock and log vanes are single-arm structures that are partially embedded in the streambed such that they are submerged even during low flows.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Rock and log vanes induce secondary circulation of the flow, thereby promoting the development of scour pools. Vanes can also be paired and positioned in a channel reach to initiate meander development or migration. They essentially mimic the effect of a tree partially falling into the stream. They are usually placed along the streambank where erosion is occurring along the toe of the slope. The purpose of vanes is to reduce erosion along the streambank by redirecting the stream flow toward the center of the stream. In addition, they tend to create scour pools on the downstream side.

Vanes can be made of rock or log. They grade down from the bankfull elevation at the streambank to the channel invert at their terminus in the stream. Vanes generally extend out from the streambank one-third of the bankfull width and are angled upstream from the bank at a 20 to 30 degree angle. They should be carefully located and installed so as not to produce additional erosion on the upstream side where they meet the bank (eddy scour) or allow flows to outflank them, exacerbating existing bank erosion problems. The only difference between the log vane and the rock vane is the material used. The J-hook vane is basically the same as a rock vane with the exception that it curls around at the end in the shape of a "J." The curved end portion serves to enhance downstream scour pool formation.

The following limitations apply to vanes:

- Vanes should not be used in unstable streams unless measures have been taken to promote stream stability so that it can retain a constant planform and dimension without signs of migration or incision.
- Vanes are ineffective in bedrock channels because minimal bed scouring occurs. Conversely, streams with fine sand, silt, or otherwise unstable substrate should be avoided because significant undercutting can destroy these measures.
- Vanes should not be used in stream reaches that exceed a 3 percent gradient.

- Vanes should not be used in streams with large sediment or debris loads.
- Banks opposite the structures should be monitored for excessive erosion.

Cost Data

Rock and log vanes vary greatly in cost depending on the design, availability and selection of materials, and site conditions.

Design Guidance and Additional Information

The following documents provide design information and guidance for vanes.

Stream Restoration: A Natural Channel Design Handbook, prepared by the North Carolina Stream Restoration Institute and North Carolina Sea Grant. http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf

The Virginia Stream Restoration & Stabilization Best Management Practices Guide. Department of Conservation and Recreation, Division of Soil and Water Conservation. 2004. http://www.dcr.virginia.gov/soil_and_water/documents/streamguide.pdf

3.2.21 Selective Withdrawal

Description

Selective withdrawal describes the use of intake structures on reservoirs that are capable of releasing waters from specific locations within a stratified water column to address downstream water quality objectives.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☑ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Selective withdrawal in reservoir releases depends on the volume of water storage in the reservoir, the timing of the release relative to storage time, and the level from which the water is withdrawn. Selective withdrawal takes advantage of the phenomenon of reservoir stratification, in which the water column exhibits various quality characteristics respective to water depth. Multilevel intake devices in storage reservoirs allow selective withdrawal of water according to temperature, dissolved oxygen levels or other stratified water quality characteristics. They can be particularly useful in stratified reservoirs so that they can be operated to meet downstream water quality objectives such as to maintain downstream temperature conditions or minimize the turbidity of discharge waters. While most selective withdrawal intake structures are built during initial reservoir construction, release structures can be successfully modified to incorporate selective withdrawal as a retrofit, although doing so could be costly.

3.2.22 Shoreline Sensitivity Assessment

Description

Shoreline sensitivity assessments are methodologies that apply to shoreline areas and are used to evaluate, classify, and assess stability and erosion vulnerabilities in various types of lakes, reservoirs, estuaries, and coasts.

- ☐ Protect Streambanks and Shorelines from Erosion
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- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Langendoen et al. (2009) found that restoration projects could benefit from using proven models of stream and riparian processes to guide restoration design and to evaluate indicators of ecological integrity. The USDA has developed two such models: the channel evolution computer model (CONCEPTS) and REMM.

Efficiency Data

The physical process modules of the channel evolution model CONCEPTS and the riparian ecosystem model REMM have been integrated to create a comprehensive stream-riparian corridor model that can be used to evaluate the effects of riparian buffer systems on in-stream environmental resources (Langendoen et al. 2009). The models have been integrated to evaluate the impact of edge-of-field and riparian conservation measures on stream morphology and water quality. The capability of REMM to dynamically simulate streambank hydrology and plant growth has been used to study the effectiveness of a deciduous tree stand and an eastern gamagrass buffer in controlling the stability of a streambank of an incised stream in northern Mississippi.

3.2.23 Step Pools

Description

Step pools are rock grade-control structures constructed in the stream channel that recreate natural step-pool channel morphology.

- ☐ Protect Streambanks and Shorelines from Erosion
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- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Step-pool channels are characterized by a succession of channel-spanning steps formed by large, grouped boulders called clasts that separate pools containing finer bed sediments. They are constructed in higher gradient channels where a fixed-bed elevation is required. Step pools are built in series and allow for *stepping down* the channel over a series of drops. The steps are constructed of large rock with the pools containing smaller rock material. As flow tumbles over the step, energy is dissipated into the plunge pool.

Step-pools can be used to backwater a culvert, providing improved fish passage and can be used to connect two reaches with different elevations.

Step-pool morphologies are typically associated with well-confined, high-gradient channels with slopes greater than 3 percent, having small width-depth ratios and bed material dominated by cobbles and boulders. Step pools generally function as grade-control structures and aquatic habitat features by reducing channel gradients and promoting flow diversity. At slopes greater than roughly 6.5 percent, similar morphologic units termed cascades spanning only a portion of the channel width are formed in these channel conditions.

Step pools are not generally considered a habitat enhancement practice. The enhancement potential is in the form of maintaining fish passage and expanding the total amount of habitat available for fish.

Cost Data

Construction costs for step pools are highly variable, depending on the design, size of the stone, availability of materials, and site constraints.

Design Guidance and Additional Information

The following documents provide design information and guidance for vanes.

Stream Restoration: A Natural Channel Design Handbook, prepared by the North Carolina Stream Restoration Institute and North Carolina Sea Grant. http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf

The Virginia Stream Restoration & Stabilization Best Management Practices Guide, Department of Conservation and Recreation, Division of Soil and Water Conservation 2004. http://www.dcr.virginia.gov/soil_and_water/documents/streamguide.pdf

3.2.24 Streambank Dewatering

Description

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Streambank dewatering is the practice of using groundwater level management adjacent to an eroding streambank to lower static water pressure on bank and reduce erosion potential.

Application and Purpose

Streambank dewatering is the practice of actively or passively reducing the static water level immediately adjacent to a streambank with erosion potential for the purposes of reducing pore water pressure within the streambank. The reduced pore pressure improves the shear strength of bank soils. Because shear strength is one of several governing factors for bank failure, a reduction in bank failure rates and potential is expected.

Dewatering systems can take several forms. Specific designs that are discussed in the research literature are vertical groundwater wells managed by an active pumping system and installing horizontal tile drains, which provide passive drainage for the riparian zone. While other dewatering system designs might be possible, no published information on additional methods are available. The location, depth, capacity, and configuration of the dewatering systems vary depending on local conditions, and no published guidance on streambank dewatering is available.

Using streambank dewatering is not widespread. A number of alternative practices are available that might be more suitable for a particular application. Dewatering systems that rely on pumping systems have an inherent long-term maintenance and operational cost. For those reasons, streambank dewatering might be most appropriate for short-term use or in areas where grading and practice installation along the bank are not possible (such as because of utility conflicts, access constraints, and the like). In addition, it is important to note that streambank dewatering can affect riparian habitat condition and available groundwater for riparian habitat. Where wetlands are present adjacent to the stream, dewatering could affect the wetland condition.

Performance

Shields et al. (2009) reported that streambank dewatering resulted in reduced rates of bank erosion on a deeply incised channel in northern Mississippi. Pumped and passive drain systems exhibited bank erosion of 0.21 m and 0.23 m, respectively, over a 2-year period of two wet seasons, while a streambank without dewatering exhibited erosion of 0.43 m. While reduced bank erosion was observed where streambank dewatering was used, the researchers note that at some individual monitoring stations, bank erosion exceeded control values.

Cost Effectiveness

While no published cost information is available, Shields et al. (2009) report that initial costs of dewatering systems was significantly lower than more orthodox bank stabilization measures, while it was acknowledged that long-term pumping and maintenance costs were neglected.

3.2.25 Toe Protection

Description

Toe protection refers to the installation of erosion resistant material, typically stone, near and at the water line along shorelines and streams to reduce wave reflection and scour of the land water interface.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The purpose of toe protection is to dissipate wave and scour energy at the land water interface and therefore reduce shoreline and streambank erosion.

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) provides information on the use of toe protection to reduce shoreline erosion. While the installation techniques and methods differ slightly where toe protection is used to reduce streambank erosion, the practice is principally the same.

Efficiency Data

Efficiency data on toe protection in streambanks is limited. However, recent research projects have shown reduced loss of streambank where toe protection is implemented on eroding channels. A modeling study in the Lake Tahoe basin using the Bank-Stability and Toe-Erosion Model (BSTEM) predicted that the application of a 1.0-m-high rock toe protection would reduce bank erosion by 69–100 percent (Simon et al. 2009). It was further noted that only 14 percent of the sediment loss in the streambank of the studied reach was from the toe region, the remaining sediment loss resulted from mass wasting of the overlying streambank indicating the importance of the land water interface in overall stream sediment dynamics.

3.2.26 Turbine Operation

Description

Turbine operations include implementing changes in the turbine start-up procedures that can enlarge the zone of withdrawal to include more of the epilimnetic waters in the downstream releases.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☑ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

In an improvement effort that included changes in turbine operation, the TVA made operational changes and installed additional equipment to ensure that minimum water flows through its dams.

Cost Data

Since the early 1990s, the TVA has spent about $60 million to address dissolved oxygen problems below dams, including turbine operation.

Reference

Tennessee Valley Authority. No date. *Tailwater Improvements: Improving Water Quality Below TVA Hydropower Dams*.

3.2.27 Turbine Venting

Description

Turbine venting is the practice of injecting air into water as it passes through a turbine. If vents are inside the turbine chamber, the turbine will aspirate air from the atmosphere and mix it with water passing through the turbine as part of its normal operation. Autoventing turbines are constructed with hub baffles or deflector plates placed on the turbine hub upstream of the vent holes to enhance the low-pressure zone in the vicinity of the vent and thereby increase the amount of air aspirated through the venting system.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☑ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Developments in turbine venting technology show potential for aspirating air with no resulting decrease in turbine efficiency. However, applying turbine venting technologies is site-specific, and outcomes will vary considerably.

Efficiency Data

Turbine efficiency relates to the amount of energy output from a turbine per unit of water passing through the turbine. Efficiency decreases as less power is produced for the same volume of water. In systems where the water is aerated before passing through the turbine, part of the water volume is displaced by the air, thus leading to decreased efficiency.

3.2.28 Vegetated Buffers

Description

Vegetated buffers are naturally occurring, composed of vegetative areas that provide physical separation between a waterbody and adjacent land uses.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

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.

Efficiency Data

Protecting or restoring modest-sized patches of living shoreline can provide adequate prime waterfowl habitat (Blankenship 2009). Hail Creek, a tiny waterway at the tip of a peninsula that is separated by a narrow swath of land from the Chester River, is shorter than a half-mile long. But, despite its diminutive size, the creek and its surrounding marshes, part of the Eastern Neck National Wildlife Refuge, are one of the top five waterfowl habitats in Maryland, with large concentrations of bufflehead and scaup, as well as black ducks, Canada geese, and other species. The creek has about 100 acres of underwater grasses, in contrast with nearby areas where grasses have been declining. Those habitats have faced increasing danger in recent years from rising water levels that have been eating away at a narrow barrier of land that separates the upstream end of the creek from Hail Cove along the Chester River. If breached, the sheltered creek habitats and adjoining wetlands would suddenly be subjected to highly erosive waves.

Besides the living shoreline, curved rock structures were built at both ends of the cove to protect it from waves and to trap sand that serves as beach habitat. The project included constructing an oyster reef, which serves as habitat and buffers the shoreline from waves. Shallow water habitats, which had largely eroded away, were rebuilt and planted with marsh grasses. Reestablishing shallow water habitat, including oyster beds and mussel beds, will serve as foraging grounds for sea ducks, which should keep Hail Creek as one of the top five waterfowl habitats for years to come.

Cost Data

A partnership involving more than a dozen organizations, agencies, and businesses joined forces to construct an 800-foot *living shoreline*. They rebuilt the barrier between the creek and the cove with natural materials, which was then planted with native plants to provide more stability. The project relied on volunteers and multiple funders and was the first project in the Chesapeake that involved the Corporate Wetland Restoration Partnership, which brings together government on environmental projects. This type of restoration project was envisioned in the draft habitat report that responded to President Barack Obama's Executive Order of May 2009 that calls for using partnerships to build strategically placed "largescale, multifaceted restoration [projects] targeted at improving living resources."

3.2.29 Vegetated Filter Strips

Description

Vegetated filter strips are low-gradient vegetated areas that filter overland sheet flow. Runoff must be evenly distributed across the filter strip, and channelized flows decrease their effectiveness.

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☑ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☐ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

Vegetated filter strips should have relatively low slopes and adequate length to provide optimal sediment control 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. Such 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.

Efficiency Data

A study of cost-effectiveness analysis of vegetative filter strips and in-stream half-logs as tools for recovering scores on a fish IBI in the upper Wabash River in Indiana provided baseline data and a framework for planning and determining the cost of stream restoration (Frimpong et al. 2006). Three assumptions were made about recovery time for IBI scores (5, 15, and 30 years) and social discount rates (1, 3, and 5 percent), which were tested for sensitivity of the estimated cost-effectiveness ratios. The effectiveness of vegetative filter strips was estimated using fish IBIs and riparian forest cover from 49 first-order to fifth-order stream reaches. Half-log structures had been installed for approximately 2 years in the watershed before the study and provided a basis for estimates of cost and maintenance.

Cost Data

Frimpong et al. (2006) found that costs per unit increase in IBI score with vegetative filter strips as the method of restoring stream health decreases with increasing stream order and decreasing recovery time. Another finding of this study was that vegetative filter strips is likely a useful method, given cost considerations, for recovering lost IBI scores in an agricultural watershed. Cost-effectiveness ratios for vegetated filter strips decreased from $387 to $277 per 100 meters for a 1 percent increase in IBI scores from first- to fifth-order streams with 3 percent discount and 30-year recovery. That cost, weighted by proportion of stream orders was $360 per 110 meters. On the basis of installation costs and an assumption of equal recovery rates, half-logs were two-thirds to one-half as cost-effective as vegetative filter strips. Half-logs would be a cost-effective supplement to filter strips in low-order streams if they can be proven to recover IBI scores faster than using filter strips alone.

3.2.30 Vegetated Gabions

Description

- ☑ Protect Streambanks and Shorelines from Erosion
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- ☑ Restore Stream and Shoreline Physical Characteristics

A gabion is a rectangular basket made of heavily galvanized wire mesh filled with small-to medium-sized rock. The gabions are laced together and installed at the base of a bank to form a structural toe or sidewall. Vegetation can be incorporated by placing live branches between each layer of rock-filled baskets. The branches take root inside the gabions and in the soil behind the structures. Their roots eventually consolidate the structure and bind it to the slope.

Application and Purpose

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) contains a chapter on the practice of vegetated gabions. At the time of this writing, no additional information is provided pertaining to this practice. For information on the appropriate use and application for vegetated gabions, see the 2007 guide.

Cost Effectiveness

Vegetated gabions are comparable to vegetated geogrids and vegetated reinforced soil slope, ranging from $15 to $40 per square foot. Construction costs vary with the structure's design (materials, depth into the streambed, height and width, and such), site access, time of year, degree and type of associated channel redefinition, and equipment and labor rates.

3.2.31 Vegetated Geogrids

Description

Vegetated geogrids are the covering of soil with erosion control fabric (geotextile) on the slope of the bank. The erosion control fabric is secured by tucking it into the slope. Live cuttings are placed between the geogrids, and a root structure is established to bind the soil within and behind the geogrids. The toe of the bank is stabilized by layers of rock on top of the same geotextile fabric.

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
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- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Application and Purpose

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) has a chapter on the practice of vegetated geogrids. At the time of this writing, no additional information is provided pertaining to this practice. For information on the appropriate use and application for vegetated geogrids, see the 2007 guide.

Cost Data

Vegetated geogrids range in cost from $20 to $40 per square foot depending on the design and construction techniques (Sotir and Fischenich 2003).

3.2.32 Vegetated Reinforced Soil Slope (VRSS)

Description

- ☑ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

The vegetated reinforced soil slope (VRSS) soil system is an earthen structure constructed from living, rootable, live-cut, woody plant material branches, bare root, tubling or container plant stock, along with rock, geosynthetics, geogrids, and/or geocomposites.

Application and Purpose

The *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* document (USEPA 2007) has a chapter on the practice of vegetated reinforced soil slopes. At the time of this writing, no additional information is provided pertaining to this practice. For information on the appropriate use and application for vegetated reinforced soil slopes, see the 2007 guide.

Cost Data

Vegetated reinforced soil slopes structure costs typically range from $15 to $35 per square face foot. These prices do not include design, which can be extensive because of the required geotechnical data collection and analysis. Harvesting, transportation, handling, and storage of the live-cut branch materials or rooted plants can significantly influence cost and are included in the above range.

Construction costs also vary with the structure’s design (materials, depth into the streambed, height and width, and such), site access, time of year, degree and type of associated channel redefinition, and equipment and labor rates. Installation is relatively complex because it can require large earth-moving machinery. Installation, excavation, and soil replacement costs are usually high.

3.2.33 Weirs

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Using weirs is a technique in which boulders or logs are laced across the channel and anchored to the channel bank or bed (or both) to check the water and raise its level for diversion purposes; they are designed to allow overtopping.

Application and Purpose

Low-profile, in-stream structures such as vortex rock weirs and W-weirs are primarily used to create aquatic habitat in the form of scour pools and for grade control on incising streams and rivers. Additionally, they are well-suited for channeling flow away from unstable banks. Weirs are used to collect and retain gravel for spawning habitat, to deepen existing resting/jumping pools; to create new pools above or below the structure, to trap sediment, to aerate the water, and to promote deposition of organic debris.

There are several types of weirs, but the two most common types for stream restoration are the W-weir and the rock vortex weir. Both types provide grade control and reduce bank erosion. The weirs accumulate sediment behind the weir arms and create a scour pool downstream of the structure. A rock W-weir is a stone structure composed of footer and vane rocks and consists of four weir arms arranged in a *W* fashion across the channel. A rock vortex weir consists of footer and vane rocks, and the form of the rock vortex weir is parabolic and spans the channel width. The rock vortex weir accumulates sediment behind the weir arms and creates a scour pool downstream of the structure.

Weirs are typically suited for use in moderate to high gradient streams. W-weirs are best used in rivers with bankfull widths greater than 40 feet (12 meters). Weirs should be avoided in channels with bedrock beds or unstable bed substrates, and streams with naturally well-developed, pool-riffle sequences.

Cost Data

Construction costs for weirs are highly variable, depending on width of the channel, size of the stone, availability of materials, and site constraints.

Design Guidance and Additional Information

The following document provides design information and guidance for vanes.

Stream Restoration: A Natural Channel Design Handbook, prepared by the North Carolina Stream Restoration Institute and North Carolina Sea Grant. http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf

3.2.34 Wing Deflectors

Description

- ☐ Protect Streambanks and Shorelines from Erosion
- ☐ Control Upland Sources of Sediment and Nutrients at Dams
- ☐ Restore In-stream and Riparian Habitat Function
- ☐ Reduce Pollutant Sources through Operational and Design Management
- ☑ Restore Stream and Shoreline Physical Characteristics

Wing deflectors are devices made of a variety of materials that project outward into the channel from one or both streambanks but do not extend entirely across the channel. Wing deflectors are especially effective in wide, shallow, low-gradient streams to create pools and cover.

Application and Purpose

Wing deflectors are designed to deflect flows away from the bank and create scour pools by constricting the channel and accelerating flow. The structures can be installed in series on alternate streambanks to produce a meandering thalweg and stream diversity. The most common design is a rock and rock-filled log crib deflector structure. The design bases the size of the structure on anticipated scour. These structures need to be installed far enough downstream from riffle areas to avoid backwater effects that could drown out or damage the riffle. This design should be employed in streams with low physical habitat diversity, particularly channels that lack pool habitats. Construction on a sand bed stream can be susceptible to failure and should be constructed with the use a filter layer or geotextile fabric beneath the wing deflector structure (FISRWG 1998).

When two wing deflectors are placed opposite each other, they serve to narrow or constrict the flow of water. The double wing deflector is more often used in urban applications because it forces the water toward the center of the channel and deepens the baseflow channel. Double wing deflectors also create an area of increased velocity between them, enhancing riffle habitat between and just upstream of the structure. This increased velocity also creates an area of scour, creating pool habitat downstream of the structure. The construction is the same as a single wing deflector except that in some instances, a rock sill at the stream invert can connect the two structures.

Both single and double wing deflectors have significant habitat enhancement potential. These structures enhance habitat through pool formation, the narrowing and deepening of the baseflow channel, and the enhancement of riffle habitat. Deflectors protect the bank in the immediate area and provide desirable changes to the stream flow patterns. They are relatively easy to construct, inexpensive, easily modified to suit on-site conditions, and are adaptable for use with other treatments. They are significantly cheaper to install than dam-type structures. They are effective in sections of streams where the banks are too low or too wide for dams.

The following limitations apply to stream deflectors:

- Deflectors should not be used in unstable streams that do not retain a constant planform or are actively incising at a moderate to high rate.
- Deflectors are ineffective in bedrock channels because minimal bed scouring occurs. Conversely, streams with fine sand, silt, or otherwise unstable substrate should be avoided because significant undercutting can destroy the measures.
- Deflectors should not be used in stream reaches that exceed a 3 percent gradient.
- Deflectors should not be used in streams with large sediment or debris loads.
- Banks opposite these structures should be monitored for excessive erosion.

Design Guidance and Additional Information

Additional Resources

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Glossary

activated sludge. Highly concentrated mass of live bacteria that feed on organic wastes, which are aerated to increase the rate of decomposition.

active/rest cycles (alternating drainfields). Final treatment and soil-based dispersal component of a decentralized treatment system that is composed of multiple soil treatment areas, which are independently dosed under the control of a flow diversion valve according to a preset schedule.

advanced treatment systems. Any treatment of sewage that goes beyond the secondary or biological water treatment stage and includes the removal of nutrients such as phosphorus and nitrogen and a high percentage of suspended solids.

aerobic. Having molecular oxygen (O_2) as a part of the environment, or a biological process that occurs only in the presence of molecular oxygen.

aerobic treatment. A process by which microbes decompose complex organic compounds in the presence of oxygen and use the liberated energy for reproduction and growth. (Such processes include extended aeration, trickling filtration, and rotating biological contactors.)

aggregate. A collective term for sand, gravel, and crushed stone mineral materials in their natural or processed state.

allochthonos. Derived from outside a system, such as leaves of terrestrial plants that fall into a stream.

alluvium. Deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

alum. A double sulphate formed of aluminum and some other element (esp. an alkali metal) or of aluminum. It has 24 molecules of water of crystallization. Common alum is the double sulphate of aluminum and potassium. It is white, transparent, very astringent, and crystallizes easily in octahedrons. The term is extended so as to include other double sulphates similar to alum in formula.

alum (aluminum sulfate) treatment. Alum or aluminum sulfate is an acid that is commonly used as a poultry litter treatment. Available in either a dry or liquid form, alum's acidic properties are used to reduce ammonia levels in the poultry house, while its binding properties are used to reduce phosphorus (P) in runoff (Moore et al. No date). Alum is also used to reduce P losses from manure and wastewater, to increasing the efficiency of mechanical separation of manure, and to reduce P losses from grazing land.

ammonia volatilization. A process that commonly takes place when nitrogen is in an organic form known as urea. Urea can originate from animal manure, urea fertilizers and, to a lesser degree, the decay of plant materials. Ammonia volatilization is most likely to take place when soils are moist and warm and the source of urea is on or near the soil surface. Ammonia volatilization will also take place on alkaline soils (pH greater than 8).

anabranching channel. A distributary channel that departs from the main channel, sometimes running parallel to it for several kilometers before rejoining it.

anaerobic. Absence of molecular oxygen (O_2) as a part of the environment, or a biological process that occurs in the absence of molecular oxygen; bound oxygen is present in other molecules, such as nitrate (NO_3-) sulfate (SO_4+) and carbon dioxide CO_2.

anaerobic decomposition. The reduction of the net energy level and change in chemical composition of organic matter caused by microorganisms in an oxygen-free environment.

analyte. A substance that is undergoing analysis or is being measured.

antidegradation. Provisions in the federal Clean Water Act, codified at 40 CFR 131.12, which provide (1) a minimum level of protection for all surface waters; (2) requirements for alternatives analyses, intergovernmental coordination, and social or economic justification before allowing lowered water quality in high-quality waters; and (3) the highest level of protection for outstanding national resource waters. State water quality standards must include both an antidegradation policy and methods for implementation.

applied organic load. The quantity of organic material (e.g., manure) applied to lands or introduced to a receiving waterbody or treatment practice, typically measured as chemical oxygen demand (COD) or biological oxygen demand (BOD).

aquifer. A geologic formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit water.

attenuation. For water velocity: the slowing, modification, or diversion of the flow of water as with detention and retention ponds. For water quality: the process of diminishing contaminant concentrations in water because of filtration, biodegradation, dilution, sorption, volatilization, and other processes.

autoventing turbine. A hydroturbine with pressure-relieving ports that are open to the atmosphere.

bank shaping. Re-grading streambanks to a stable slope, placing topsoil and other materials needed for sustaining plant growth, and selecting installing, and establishing appropriate plant species.

bankfull elevation. The water surface elevation within a channel corresponding to bankfull discharge.

bankfull discharge. 1. For a natural channel that is not adapting to hydrologic change in its watershed, it is the discharge that occurs when the water just fills the channel to the top of its banks and begins to overflow onto a floodplain. 2. The discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels.

baseflow. Sustained flow of a stream in the absence of direct runoff. It includes natural and human-induced streamflows. Natural base flow is sustained largely by groundwater discharges.

bathymetry. The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

bed-load. In-stream sediment transport mode in which individual particles either roll or slide along the stream bed as a shallow, mobile layer a few particle diameters deep (the particle size depends on the energy level of the flowing water).

benthic/benthos. An organism that feeds on the sediment at the bottom of a waterbody such as an ocean, lake, or river.

berm. A low earth fill constructed in the path of flowing water to divert its direction, or constructed to act as a counterweight beside the road fill to reduce the risk of foundation failure.

bioinfiltration. A stormwater management practice where runoff is routed through a soil media that is vegetated. This practice functions in a manner analogous to bioretention systems but has a higher infiltration capacity, and thus would be categorized as an infiltration process.

biological treatment. A treatment technology that uses bacteria to consume organic waste.

bioretention. A stormwater management practice that is designed to provide both temporary surficial water storage and runoff retention subsurface in soil media. Runoff is directed to shallow depressions where it is infiltrated, filtered or evapotranspirated. These systems are typically designed with a soil media selected to promote infiltration and runoff retention and are vegetated with plants picked to withstand both inundation and drought. Bioretention systems also are used to filter runoff to trap and in some cases degrade pollutants such as oils and greases. This practice is often categorized under *filtration* although it has additional functions. Some systems are built with underdrain or overdrain systems to convey excess runoff off-site.

bioswale. A relatively wide, shallow, open channel, typically vegetated with turf grasses, with a slight gradient. These systems are designed to let water flow slowly through the turf grasses. The roughness of the turf slows the runoff velocity and provides some filtration and settling of suspended solids. Runoff volumes can also be reduced through infiltration depending on the porosity of the underlying soils. Swales can be designed with underdrains to convey excess runoff from saturated soils.

blue roofs. A practice that is designed to provide temporary storage of stormwater and slowly release stormwater runoff using the roof surface of a structure. Also referred to as *rooftop detention*.

branch packing. A form of soil bioengineering that uses alternating tiers of live branch cuttings and compacted backfill to repair small localized slumps and holes in slopes and a means of reducing the erosive potential of incoming flows at their source.

breakwater. A wave energy barrier designed to protect the land or nearshore area behind them from the direct assault of waves.

brownfield. An abandoned, idled, or underused industrial and commercial facility/site where expansion or redevelopment is complicated by real or perceived environmental contamination. They can be in urban, suburban, or rural areas. EPA's Brownfields initiative helps communities mitigate potential health risks and restore the economic viability of such areas or properties.

brush layering. A form of soil bioengineering that uses live branch cuttings laid flat into small benches excavated in the slope face perpendicular to the slope contour.

buffer strip. 1. Area between a stream and construction activities that achieves sediment control by using the natural filtering capabilities of the forest floor and litter. 2. Strips of grass or other erosion-resisting vegetation between or below cultivated strips or fields.

bulkhead. A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action.

catch basin. A device that receives stormwater drainage from an outside surface area. They are usually in parking lots or in areas where the removal of stormwater buildup is desirable.

channel incision and widening. A process of channel degradation that results in a lower elevation channel surrounded by one or more elevated terrace(s) that once were floodplains. The interplay of channel incising (deepening) and widening is caused by changes in streamflow or sediment delivery.

channel reconfiguration. River and stream channel engineering for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration potential; activities include the straightening, widening, deepening, or relocation of existing stream channels, clearing or snagging operations, the excavation of borrow pits, underwater mining, and other practices that change the depth, width, or location of waterways or embayments in coastal areas.

channelization. River and stream channel engineering undertaken for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration potential. Activities such as straightening, widening, deepening, or relocating existing stream channels and clearing or snagging operations fall into this category.

chisel plowing. Preparing croplands by using a special implement that avoids complete inversion of the soil as in conventional plowing. Chisel plowing can leave a protective cover or crops residues on the soil surface to help prevent erosion and improve filtration.

cistern. A tank or storage facility used to store water for a home or farm; often used to store rain water.

clasts. Individual sedimentary particles such as a grain of sand, pebble, or boulder that make up a sedimentary rock or deposit.

clear cut. A silvicultural system in which all merchantable trees are harvested within a specified area in one operation to create an even-aged stand.

cluster treatment system. A wastewater treatment system designed to serve two or more sewage-generating dwellings or facilities with multiple owners that is not part of a centralized collection system that discharges to any point sources and that treats and disperses effluent to soil-based dispersal systems similar to onsite systems.

coarse woody debris (CWD). A large tree part, conventionally a piece greater than 10 cm in diameter and 1 m in length.

coconut fiber roll. Cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut material to protect slopes from erosion while trapping sediment, which encourages plant growth within the fiber roll.

colloids. Very small, finely divided solids (that do not dissolve) that remain dispersed in a liquid for a long time because of their small size and electrical charge.

combined sewer overflow (CSO). A discharge of a mixture of stormwater and domestic waste when the flow capacity of a sewer system is exceeded during rainstorms.

compost amendment. Organic matter that is added to soil to improve infiltration.

composting. The controlled biological decomposition of organic material in the presence of air to form a humus-like material. Controlled methods of composting include mechanical mixing and aerating, ventilating the materials by dropping them through a vertical series of aerated chambers, or placing the compost in piles out in the open air and mixing it or turning it periodically.

concentrated flow. Rills, ephemeral gullies, gullies, channels, streams and rivers are examples on the landscape of areas where concentrated flow erosion occurs. Concentrated flow erosion is also a culprit in embankment breaching and auxiliary spillway failure on earthen dams.

construction runoff intercepts. A *temporary* berm or channel constructed across a slope to collect and divert runoff.

controlled-release or slow-release fertilizers. Inorganic or organic fertilizers that are characterized by a slow rate of release, long residual, low burn potential, and low water solubility. Several categories of slow-release nitrogen fertilizers are commercially available, including urea-formaldehyde, isobutylidene diurea, sulfur coated urea, plastic coated fertilizers, and natural organics.

conventional tilling. Tillage operations considered standard for a specific location and crop and that tend to bury the crop residues.

core aeration. Increasing air penetration of the soil by removing plugs of soil. A heavy machine with hollow prongs is moved across a lawn pushing the prongs into the soil and pulling out plugs of soil.

cover crop. A crop that provides temporary protection for delicate seedlings or provides a cover canopy for seasonal soil protection and improvement between normal crop production periods.

crown fire. The movement of fire through the crowns of trees or shrubs more or less independently of the surface fire.

cross-sectional area. The cross-sectional area of a stream or tributary stream channel is determined by multiplying the stream or tributary stream channel width by the average stream or tributary stream channel depth.

cosspipe or sluice pipe (also called culvert). A conduit used to enclose a flowing body of water to allow it to pass underneath a road, railway, or embankment.

culvert. A metal, wooden, plastic, or concrete conduit through which surface water can flow under or across roads.

curb extension. A section of sidewalk designed to contain soils and vegetation to filter runoff, reduce runoff velocities and in some cases infiltrate runoff. Curb cuts or gaps in the curbs are used to route runoff from street surfaces into this cells.

cut-and-fill. An earth-moving process that entails excavating part of an area and using the excavated material for adjacent embankments or fill areas.

demand-dosing. A configuration in which a specific volume of effluent is delivered to a component (e.g., a drainfield) according to patterns of wastewater generation from the source.

denitrification. The biological reduction of nitrate to nitrogen gas by bacteria in soil.

denitrification enzyme assay. An assay used to quantify the initial rate, or Phase I, of denitrification using the acetylene block technique to prevent the reduction of N_2O to N_2.

design flow. Projected flow through a watercourse that will recur with a stated frequency. The projected flow for a given frequency is calculated using statistical analysis of peak flow data or using hydrologic analysis techniques. (*See* storm return period).

dewater. Removing or draining the water from a site, stream, or trench.

digestion. The biochemical decomposition of organic matter, resulting in partial gasification, liquefaction, and mineralization of pollutants.

dispersal. Spreading of effluent through the final receiving environment, typically soil.

distribution box. A level, watertight structure that receives septic tank effluent and distributes it via gravity in approximately equal portions to two or more trenches or two or more laterals in a bed.

dormant post plantings. Plantings of dormant cottonwood, willow, poplar, or other species embedded vertically into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment as they grow.

dosing and resting. A configuration in which a specific volume of effluent is delivered to a component according to a prescribed interval, regardless of facility water use.

drainage. Improving the productivity of agricultural land by removing excess water from the soil by such means as ditches or subsurface drainage tile lines.

drainage density. In hydrologic terms, the relative density of natural drainage channels in a given area. It is usually expressed in terms of miles of natural drainage or stream channel per square mile of area and obtained by dividing the total length of stream channels in the area in miles by the area in square miles.

drainage intensity (DI). The drainage rate that occurs when the water table is at the soil surface; it increases with drain depth and decreases with drain spacing.

drainage water management. A practice in which the outlet from a conventional drainage system is intercepted by a water control structure that effectively functions as an in-line dam, allowing the drainage outlet to be artificially set at levels ranging from the soil surface to the bottom of the drains.

drainfield (soil treatment area). Physical location where final treatment and dispersal of effluent occurs; includes drainfields, drip fields and spray fields.

duff. The accumulation of needles, leaves, and decaying matter on the forest floor.

effluent. Partially or fully processed liquid flowing out of a sewage treatment component or device.

energy signature. The characteristics of a stream system to allow it to transport the flows of water and sediment provided by its watershed in an efficient and stable manner.

entrapped mixed microbial cells (EMMC) process. A process in which dilute wastewater is passed through a cellulose triacetate matrix containing microbial cells for the purpose of removing carbon and nitrogen.

ephemeral drainage. A channel that carries water only during and immediately following rainstorms. Sometimes referred to as a dry wash.

epilimnion. The upper waters of a thermally stratified lake subject to wind action.

erosion control blankets. A manufactured sheet, typically rolled on a spool consisting of a matrix of straw, coconut fiber, aspen fiber, jute, or polypropylene (plastic) that is woven, stitched, glued, or bound together, which is placed on disturbed areas to provide temporary erosion control and encourage establishment of vegetation.

essential turf. Turf required for the identified needs of the facility or jurisdiction, e.g., security, historic preservation, access, other designated uses such as recreation, mental health restoration or rehabilitation.

eutrophication. The slow aging process during which a lake, estuary, or bay evolves into a bog or marsh and eventually disappears. During the later stages of eutrophication the waterbody is choked by abundant plant life because of higher levels of nutritive compounds such as nitrogen and phosphorus. Human activities can accelerate the process.

evapotranspiration. The loss of water from the soil both by evaporation and by transpiration from the plants growing in the soil.

fast-release fertilizer. A synthetic fertilizer that releases its nutrients (especially N) rapidly (e.g., urea, ammonium nitrate).

feed pump. Mechanical device for driving fluid flow or for raising or lifting a fluid by either suction or pressure or both.

filter strips. Area of vegetation used for removing sediment, organic matter, and other pollutants from runoff or wastewater.

filtration. A treatment process, under the control of qualified operators, for removing solid (particulate) matter from water by means of porous media such as sand or a man-made filter; often used to remove particles that contain pathogens.

first flush. The condition, often occurring in storm-sewer discharges and CSOs, in which a disproportionately high pollutant load is carried in the first portion of the discharge or overflow.

fish ladder or lift. A series of ascending pools, similar to a staircase, that enables fish to migrate up the river past dams. Also called a fishway.

fish runs. The place where fish, such as native steelhead trout and salmon, return from the ocean each spring to spawn in the rivers or streams where they were born. They can also refer to the group of fish that is migrating up the stream.

fish tagging. The placement of identifying tags or markers, typically permanent, on individual captured fish specimens for the purposes of later retrieval and analysis for species migration, growth, and overall health.

floc. A clump of solids formed in sewage by biological or chemical action.

floodplain. The flat or nearly flat land along a river or stream or in a tidal area that is covered by water during a flood.

flow regime. Combinations of river discharge and corresponding water levels and their respective (yearly or seasonally) averaged values and characteristic fluctuations around these values.

flow velocities. The speed, expressed in units of length per unit of time, at which a fluid flows through a culvert, channel or other conveyance.

flue gas desulfurization. A technology that employs a sorbent, usually lime or limestone, to remove sulfur dioxide from the gases produced by burning fossil fuels. Flue gas desulfurization is current state-of-the art technology for major SO_2 emitters, like power plants.

flume. A natural or man-made channel that diverts water.

fluvial. Of or relating to flowing waters, especially rivers.

fluvial aggradation. General and progressive raising of a stream bed by deposition of sediment carried by the stream.

footer. Stone, concrete or other rigid structural material placed underneath other materials to provide a foundation or bearing surface.

gabion. A rectangular basket or mattress made of galvanized, and sometimes PVC-coated, steel wire in a hexagonal mesh. Gabions are generally subdivided into equal-sized cells that are wired together and filled with 4- to 8-inch-diameter stone, forming a large, heavy mass that can be used as a shore-protection device.

geomorphology. That branch of both physiography and geology that deals with the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landform.

geotextile filtration. The use of geotextiles (permeable fabrics) to separate solids and liquids in such materials as lagoon sludge and liquid manure.

grade breaks. An intentional increase in road elevation on a downhill grade that causes water to flow off of the road surface.

grade stabilization structure. A structure used to control the grade and head cutting in natural or artificial channels.

grassed swales. A term to describe a vegetated, open runoff channel planted with grasses or turf. Similar terms include grassed channel, dry swale, wet swale, biofilter, or bioswale. Such systems are designed to treat and attenuate stormwater runoff. As runoff flows along the channels, the vegetation in the channel promotes filtration, settling, and infiltration of runoff into the underlying soils. The specific design features and methods of treatment differ in each of these designs but are improvements on the traditional drainage ditch. The designs incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

graywater. Any washwater that has been used in a home or business, except water from toilets. This water is considered to be more reusable, especially for landscape irrigation purposes.

grazing. Feeding on standing vegetation, as by livestock or wild animals.

greenfields. Previously undeveloped land such as forests, meadows or other *natural lands*.

green infrastructure. A term that has two commonly used meanings. The more common usage refers to vegetated landscapes that are conserved or restored for ecological or anthropological reasons, e.g., wildlife habitat, flood protection, drinking water source protection and air quality and urban heat island concerns.

This term is also used to connote practices and strategies used to reduce the impact of wet weather events (rainfall and snow melt) on receiving waters. In this usage, green infrastructure is often also called low impact development or LID and is used to describe an array of strategies, products, technologies, and practices that are designed to mimic the behavior of natural systems as they relate to runoff, watershed and site hydrology and pollutant reduction. These systems are typically designed using an integrated design approach that relies on engineering, hydrological, biological, architectural, and planning concepts and practices to plan, design and manage runoff through plant and soil uptake, filtration, infiltration, evapotransipiration and the harvest and use of runoff.

green roof. Also known as eco-roofs or rooftop gardens, green roofs are engineered soil media systems that are planted on rooftops and designed to reduce runoff, combined sewer overflows, urban heat island impacts and provide other ecological and human benefits such as aesthetics, wildlife habitat and aesthetics. The soil media mix and vegetation are planted over existing roof structures and consist of a waterproof, root-safe membrane that is covered by a drainage system, lightweight growing medium, and plants. Green roofs reduce rooftop and building temperatures, filter pollution, lessen pressure on sewer systems, and reduce the heat island effect.

grid point data. Data that is collected at the intersections of imaginary or real lines laid over a surface in a grid pattern.

grinder pump system. A pump that shreds solids in a waste stream and conveys the resulting mixture under pressure to a subsequent system component.

groin. A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

ground fuels. All combustible materials below the surface litter, including duff, roots, peat and sawdust dumps that normally support a glowing combustion without flame.

gully. A channel or miniature valley cut by concentrated, non-continuous runoff such as during snowmelt or following heavy rains.

gully erosion. Severe erosion in which trenches are cut to a depth greater than 30 centimeters (one foot). Generally, ditches deep enough to cross with farm equipment are considered gullies.

highly erodible lands (HELs). Land that is very susceptible to erosion, including fields that have at least 1/3 or 50 acres of soils with a natural erosion potential of at least 8 times their T value. More than 140 million acres are classified as HEL. Farms cropping highly erodible land and under production flexibility contracts must be in compliance with a conservation plan that protects this cropland.

hi-input turf. Turf that requires irrigation, frequent mowing, fertilization and/or pesticide treatment.

hillslope. A part of a hill between its crest and the drainage line at the foot of the hill.

hydraulic connectivity. The ability of the soil to transmit water. Also commonly known as the permeability. Darcy found that to relate the flow rate to the hydraulic head and area of flow required a constant of proportionality (termed k) as the hydraulic connectivity. It has units of velocity. Note that the value is a function of both the porous media and the fluid.

hydraulic residence time. The average time an element spends in a given environment between the time it arrived and the time it is removed by some process. In the ocean, residence time is defined as the concentration in sea water relative to the amount delivered to the ocean per year; in groundwater, it is the time elapsed between water being recharged to the aquifer; in lakes and reservoirs, it is the time elapsed between a parcel of water entering the waterbody and leaving it.

hydraulic resistance. In hydraulics, resistance is the condition engendered by an obstruction or restriction in the flow path. Hydraulic resistance in a forest setting is the obstruction of the flow of water. Woody debris, forest litter, and surface irregularities and structures that slow the flow of water increase hydraulic resistance.

hydric soil. A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic (oxygen-lacking) conditions that favor the growth and regeneration of hydrophytic vegetation.

hydrodynamic simulations. Computer simulations of the motion or movement of water in a stream, lake or estuary.

hydrologic cycle. Movement or exchange of water between the atmosphere and earth.

hydrologic extremes. Hydrologic events that change stream flow conditions, such as droughts and floods, of significant magnitude compared to normal baseline conditions.

hydrology. The science dealing with the properties, distribution, and circulation of water.

hydromodification. Alteration of the hydrologic characteristics of landscapes, drainage ways and waters of the United States that result in changes in water balance, stream morphology, habitat, groundwater recharge, evapotranspiration rates and surface runoff.

immobilization and mineralization. In mineralization, the nitrogen (N) in plant tissue is converted by soil microbes into a form (nitrate) that subsequent plants can use. Immobilization is the process by which plant usable forms of N in the soil become unavailable for subsequent crop growth. Because microbial populations increase with the growth of a cover crop, N contained in the cover crop and the soil can be immobilized or *tied up* as part of the physical structure of the microbes. As a result, the cover crop N might not be available for uptake by the following crop. When the microbes die, the N is *mineralized* and becomes available for subsequent crop use.

impervious surfaces. A hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate of flow. Common impervious surfaces include rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, and gravel roads.

impoundment. A body of water or sludge confined by a dam, dike, floodgate, or other barrier.

incised. A channel that has been cut relatively deep into underlying formation by natural or human-induced processes.

indoor ozone systems. A controversial indoor technique that uses ozone for broiler house cleaning and in-house air contaminant (ammonia) control.

infiltration. The movement of water from the land surface into the soil.

infiltration basin or trench. A drainage facility designed to use the hydrologic process of runoff soaking into the ground, commonly referred to as percolation, to dispose of stormwater. Note: Infiltration trenches are typically not vegetated or designed to significantly filter pollutants from runoff.

inorganic nitrogen. The element nitrogen in combination with other mineral elements and not derived from plant or animal sources.

integrated pest management. The use of pest and environmental information in conjunction with available pest control technologies to prevent unacceptable levels of pest damage by the most economical means and with the least possible hazard to persons, property, and the environment.

intercropping. The growing of two or more species of crops simultaneously, as in alternate rows in the same field or single tract of land.

interstitial. The matrix of air or liquid between sediment particles.

inverts. The bottom of a drainage facility along which the lowest flows pass.

labile carbon. The highly reactive fraction of soil organic carbon with the most rapid turnover times; its oxidation drives the flux of CO_2 between soils and atmosphere. Labile organic carbon decomposes rapidly in the water column or in sediments, on a time scale of days to weeks; refractory organic carbon requires more time.

land applied. The reuse of reclaimed water or the use or disposal of effluents or wastewater residuals on, above, or into the surface of the ground through spray fields, land spreading, or other methods.

landing. A place in or near the forest where logs are gathered for further processing or transport**.**

large wood structures (LWS). *See* large woody debris.

large woody debris. Also called large wood structures. A large tree part, conventionally a piece greater than 10 cm in diameter and 1 m in length.

leaching. The process by which soluble constituents are dissolved and filtered through the soil by a percolating fluid.

leaf litter. Also called duff. Leaves and twigs fallen from forest trees.

livestock exclusion fencing. Fencing that keeps livestock away from rivers and streams.

load. The quantity of sediment transported by a current. It includes the suspended load of small particles and the bedload of large particles that move along the bottom.

longitudinal rutting. Ruts formed along the length of the road from tire pressure.

longitudinal zones. The longitudinal zones of a river corridor include the headwaters (zone 1), the transfer zone (zone 2), and the depositional zone (zone 3).

lotic system. Flowing waters, as in streams and rivers.

low-input turf. Turf that requires little or no maintenance, i.e., fertilization, irrigation, pesticide applications.

low-mow turf. Turf that is only infrequently mowed. Turf under this category would be mowed as little as possible, and mowing frequency would be based on issues such as security, pests, fire hazard, or suppression of woody species.

macroaggregate. A relatively large particle (as of soil).

macropores. Secondary soil features such as root holes or desiccation cracks that can create significant conduits for movement of non-aqueous phase liquid and dissolved contaminants, or vapor-phase contaminants.

matrix based fertilizers (MBFs). Fertilizers formulated to reduce nitrate, ammonium, and total phosphorus leaching through binding of nitrogen (N) and phosphorus (P), and in some cases via mixtures with aluminum sulfate, iron sulfate, starch, chitosan, or lignin. When N and P are released, the chemicals containing these nutrients in the MBF temporarily bind N and P to an aluminum sulfate or iron sulfate starch- chitosan- lignin matrix.

mat/tree collar. A sunlight-blocking device used to block the growth of grass or weeds immediately adjacent to a newly planted tree. It is commonly made of 2.5-mil, UV-stabilized, carbon-black plastic; about 3 feet x 3 feet (1 sq. yard) slit to easily fit around the tree.

mechanical site preparation. The practice of cutting all standing material with blades or choppers to prepare an area for establishing a future forest either by artificial or natural means. Other practices include disking, bedding, and raking.

mesohabitat. Distinct units of habitat within an ecosystem.

microfauna. Soil-dwelling micro-organisms (animals) that cannot be seen with the naked eye.

microfiltration. Using a device with a filter media to physically prevent biological contamination from passing through. Ceramic and solid block carbon are commonly used to provide microfiltration.

miter drain. A drain that is at an angle (e.g., 45 degrees) to the surface that is being drained (e.g., a grassed swale), as opposed to a drain laid flat on the surface that is being drained.

morphology. The branch of geology that studies the characteristics and configuration and evolution of rocks and land forms.

mouldboard ploughing. Conventional tillage using a moldboard plow. It turns over the soil and typically leaves less than 15 percent residue cover after planting.

native landscaping. Landscaping that is designed to use native plants adapted to the specific geographic location of their origin.

nitrate flux. The flow of nitrate (the most soluble and mobile form of nitrogen) out of a system, as from groundwater to streams, streams to rivers, and rivers to bays or oceans.

nitrification. The process whereby ammonia in wastewater is oxidized to nitrite and then to nitrate by bacterial or chemical reactions.

no-mow turf. Grasses that do not need mowing and are allowed to reach their mature state, e.g., switch grasses and other native grasses.

no till. Planting crops without prior seedbed preparation, into an existing cover crop, sod, or crop residues, and eliminating subsequent tillage operations.

no-till disk aeration. Aeration that uses methods similar to no-till or conservation tillage seeding of crops, which disrupts the soil surface in a series of parallel rows. The soil is aerated using an aeration device fashioned by attaching cores, tines, or metal flashing (disk aeration) to rows on a metal plate and pushing the implement into the soil.

nonessential turf. Turf not necessary to achieve the intended goals of the facility or jurisdiction.

nonpoint source. Diffuse runoff (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). This document uses the term *nonpoint source* broadly, as EPA has in the past, to refer to sources that currently are treated as nonpoint sources in EPA's implementation of section 319 of the Clean Water Act. Some of these sources may legally be made subject to regulation as point sources under section 402(p) of the Clean Water Act. EPA has designated several categories of these stormwater sources for regulation, such as small municipal separate storm sewer systems, and may designate others for regulation in the future.

nutrient. Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater but is also applied to other essential and trace elements.

nutrient use efficiency (NUE). A measure of how much crop is produced per unit of nutrient supplied. A greater NUE leaves less nitrogen and phosphorus available for transport to waterbodies.

on-site system. A wastewater treatment system relying on natural processes or mechanical components or both to collect and treat sewage from one or more dwellings, buildings, or structures and disperse the resulting effluent on property owned by the individual or entity.

organic turf management. Turf managed without the use of inorganic fertilizers or pesticides.

organic matter. The organic component of the soil consisting in living organisms, dry plants and residues of animal origin. In a mass unit, this organic component is the most chemically active of the soil. Such a component stores several essential elements, stimulates the proper structure of the soil, is a source with capacity for the exchange of cations and regulates the pH changes, supports the relationship between air and water in the soil, and is a huge geochemical storage of carbon.

oxidation-reduction potential. The electric potential required to transfer electrons from one compound or element (the oxidant) to another compound (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

P-saturation. The amount of phosphorus in soil divided by the amount of phosphorus that can be fixed by the soil.

particulate bound. The condition in which a pollutant constituent attaches physically, strongly or weakly, to sediments within a stream system.

pasture. Land used primarily for the production of domesticated forage plants for livestock (in contrast to rangeland, where vegetation is naturally occurring and is dominated by grasses and perhaps shrubs). Rotation pasture or cropland under winter cover crops is not included in this definition. The 1992 national resources inventory recorded 126 million acres of pastureland, 9 percent of all nonfederal rural lands.

peak flow. The maximum flow through a watercourse that will recur with a stated frequency. The maximum flow for a given frequency can be based on measured data, calculated using statistical analysis of peak flow data, or calculated using hydrologic analysis techniques.

permeable reactive barriers. A subsurface emplacement of reactive materials designed as a preferential conduit for treating contaminated groundwater flow.

phase construction. Disturbance of small portions of a site at a time to prevent erosion from the dormant parts.

phreatic surface. The free surface of groundwater at atmospheric pressure.

phytoremediation. A practice used to reduce soil contaminant loadings through the use of plants selected to uptake or breakdown the contaminants. In cases where plants cannot metabolize and breakdown the contaminants, vegetative matter might need to be removed for further processing or disposal.

phytotechnology. A term referring to technologies that use living plants.

planter box. A small, contained vegetated area that is used to collect and treat stormwater through the mechanisms provided by bioretention designs. There are three general types of planter boxes: (1) contained planter that is used for planting trees, shrubs, and ground cover that is placed over an impervious surface; (2) infiltration planter that is a structural landscaped reservoir used to collect, filter, and infiltrate stormwater run-on; and (3) flo-through planter that is similar to an infiltration planter except it has a waterproof lining allowing it to be used next to foundation walls. Other terms used for this practice include stormwater planter, vegetated planter, tree box.

plume. A definable, three-dimensional region of effluent created by the movement of groundwater beneath its source.

plunge pool. A natural or sometimes artificially created pool that dissipates energy of free falling water. The basin is at a safe distance downstream of the structure from which the water is being released.

pore water pressure. The pressure exerted on its surroundings by water held in pore spaces in rock or soil.

porosity. The degree to which soil, gravel, sediment, or rock is permeated with pores or cavities through which water or air can move.

pre-development hydrology. The runoff characteristics in a watershed before urban development in respect to the volume, rate, duration, and temperature of runoff.

production area of an AFO. That part of an animal feeding operation that includes the animal confinement area, the manure storage area, the raw materials storage area, and the waste containment areas. The animal confinement area includes open lots, housed lots, feedlots, confinement houses, stall barns, free stall barns, milkrooms, milking centers, cowyards, barnyards, medication pens, walkers, animal walkways, and stables. The manure storage area includes lagoons, runoff ponds, storage sheds, stockpiles, under house or pit storages, liquid impoundments, static piles, and composting piles. The raw materials storage area includes feed silos, silage bunkers, and bedding materials. The waste containment area includes settling basins and areas within berms and diversions that separate uncontaminated stormwater. Also included in the definition of production area is any egg washing or egg processing facility, and any area used in the storage, handling, treatment, or disposal of mortalities.

push outs. A type of road drainage structure that drains topographic lows or saddles on a road by directing runoff away from the road from both road directions.

rain garden. A depressed area of the ground planted with vegetation, allowing runoff from impervious surfaces such as parking lots and roofs the opportunity to be collected and infiltrated into the groundwater supply or returned to the atmosphere through evaporation and evapotranspiration. Rain gardens are typically cheaper to build and design than bioretention or bioinfiltration cells because they are often built without specific performance standards and without the assistance of a certified professional to design them.

recirculating media filter. A wastewater treatment system component featuring a layer of sand, gravel, or other material, on which effluent is applied and treated via microbial growth on the surface of the media, allowing the effluent to trickle through. A portion of the effluent is returned to another system component for further treatment or to facilitate a treatment process.

reforestation. The establishment of a forest through artificial plantings or natural regeneration.

reinforcement planting. Additional trees and shrubs that are planted during the short-term maintenance phase (approximately 2 years after initial plantings) of a riparian forest buffer restoration to replace any plants that did not survive and to enhance the buffer.

retrofits. Installation of a new or redesigned stormwater facility to treat stormwater from existing impervious area, including roofs, patios, walkways, and driving or parking surfaces.

return walls. Walls constructed at the ends of seawalls, bulkheads, or revetments perpendicular to the shoreline to prevent flanking of the primary shore protection structure.

revetment. A facing of stone, concrete, and the like, built to protect a scarp, embankment, or shore structure against erosion by wave action or currents.

ridge tillage. A type of soil conserving tillage in which the soil is formed into ridges and the seeds are planted on the tops of the ridges. The soil and the crop residue between the rows remain largely undisturbed. The practice offers opportunities to reduce crop production costs by banding fertilizers and pesticides and reducing the need for field trips.

riffle. A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

rill. A small channel eroded into the soil by surface runoff; it can be easily smoothed out or obliterated by normal tillage.

riparian area. Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of the two, although they will not in all cases have all the characteristics necessary for them to be classified as wetlands.

riparian buffer. A specific area to be managed within a riparian area.

riparian habitat. Areas adjacent to rivers and streams with a differing density, diversity, and productivity of plant and animal species relative to nearby uplands.

road failure. A portion or location along a forest road where generally erosion or poor construction has resulted in the surface of the road falling away and leaving the road impassable or compromising the intended drainage of the road surface.

road prism. All parts of a road including cut banks, ditches, road surfaces, road shoulders, and road fills.

road profile. The cross-sectional shape of the road surface in relation to the road corridor traversing the surrounding landscape.

root wad revetments. Logs with attached root masses that are placed in and on streambanks to provide streambank erosion, trap sediment, and improve habitat diversity.

row crop agriculture. The rows or planting beds are far enough apart to permit the operation of machinery between them for cultural operations.

scour. Soil erosion when it occurs underwater, as in the case of a streambed.

scour pool. Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

seawalls. A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action.

sediment. Topsoil, sand, and minerals washed from the land into water, usually after rain or snow melt.

sediment basin/rock dams. Barriers, often employed in conjunction with excavated pools, constructed across a drainage way or off-stream and connected to the stream by a flow diversion channel to trap and store waterborne sediment and debris.

sediment fence (also called silt fences)**.** A temporary sediment control device used on construction sites to protect water quality in nearby surface waters from sediment (loose soil) in stormwater runoff. A typical fence consists of a piece of synthetic filter fabric (also called a geotextile) stretched between a series of wooden or metal stakes.

sediment transport capacity and competence. The ability or efficiency of a stream system to move sediment.

sediment trap. A structure or vegetative barrier designed to collect soil material transported in runoff and also to reduce water flow velocity and therefore scouring and erosion. Sediment traps mitigate siltation of natural drainage features.

seeding. The establishment of vegetated cover on a disturbed site by applying plant seeds and as appropriate, fertilizer, lime, or other amendments.

septage. Liquid and residuals removed from a septic tank or other sewage pretreatment device or holding facility, such as a seepage pit, cesspool, or portable toilet.

septic tank effluent gravity (STEG) collection system. A collection system that uses septic tanks to separate solids and allow gravity flow of effluent to a subsequent component.

septic tank effluent pump (STEP) collection system. A collection system that uses a septic tank to separate solids and incorporates a pump and associated parts to convey effluent under pressure to a subsequent component.

sequencing batch reactor. A series of components designed to treat wastewater in batches, one process at a time. Typically, it involves activated sludge and other processes carried out in the same tank in stepwise order (e.g., fill, treat, settle, decant, and draw).

setback. A distance between a water resource and an activity (e.g., manure spreading) within which the activity cannot be carried out. The purpose of a setback is to reduce the potential for contaminants to reach ground or surface water. Properly managed setbacks improve water quality by acting as filters for water passing over or through the soil toward a water resource.

shear strength. The internal resistance of a body to shear stress, which typically includes frictional and cohesive components and expresses the ability of soil to resist sliding.

sheetflow. Term used to describe the movement of water laterally across the surface of the ground, rather than flowing in defined channels or depressions.

silt fence (*See* sediment fence.)

silviculture. The management of forest land for timber production.

silvopasture. An agroforestry application establishing a combination of trees or shrubs and compatible forages on the same acreage.

single-pass. A wastewater flow configuration wherein effluent moves through a treatment component only once.

site fingerprinting. 1. Site clearing and development using minimal disturbance of existing vegetation and soils. 2. Restricting ground disturbance to areas where structures, roads, and rights of way will exist after construction is completed.

skid trail. A temporary, nonstructural pathway over forest soil used to drag felled trees or logs to the landing.

slag filter. A filter filled with electric arc furnace steel slag, a by-product of making steel, to treat barnyard runoff and milkhouse waste.

slash. The unwanted, unused, and generally unmerchantable accumulation of woody material, such as large limbs, tops, cull logs, and stumps, that remains as forest residue after timber harvesting.

slit aeration. A soil aerator, the most common for agronomic use, in which tines are pushed into the soil to make elongated holes.

slough. A marshy or reedy pool that contains areas of slightly deeper water and a slow current.

sludge. Accumulated solids and associated entrained water within a wastewater pretreatment component, generated during the biological, physical, or chemical treatment; coagulation; or clarification of wastewater.

sluicing. The practice of releasing water through the sluice gate of an impoundment rather than through the turbines.

sodding. A permanent erosion control practice involving laying a continuous cover of grass sod on exposed soils.

soil dispersal field (soil treatment area). A physical location where final treatment and dispersal of effluent occurs; includes drainfields, drip fields and spray fields.

spur road. A short road that branches from a major forest road and that is generally used to access specific areas for harvesting.

stormflow. The portion of streamflow attributable to precipitation that enters the channel (generally as overland flow or shallow subsurface flow) within a short time frame in association with storms (as opposed to baseflow, which enters the channel slowly from groundwater sources).

storm return period. The recurrence interval or an estimate of the interval of time between storms of a certain intensity or size. *See also* design flow.

stream corridor. The area that consists of the stream channel itself, the floodplain, and a transitional zone between the floodplain and the surrounding landscape.

stream geometry. The physical form assumed by a stream system that includes channel depth, width, longitudinal slope, and planform.

stream morphology. The science of analyzing the structural makeup of rivers and streams and how they change over time.

streamside management area. A designated area that consists of the stream itself and an adjacent area of varying width where management practices that might affect water quality, fish, or other aquatic resources are modified. The SMA is not necessarily an area of exclusion but an area of closely managed activity. It is an area that acts as an effective filter and absorptive zone for sediments, maintains shade, protects aquatic and terrestrial riparian habitats, protects channels and streambanks, and promotes floodplain stability.

street sweeping. The use of self-propelled and walk-behind sweeping and vacuum equipment to remove sediment and other debris from streets, roadways, parking lots, and sidewalks.

struvite formation. The common name for magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4 \cdot 6(H_2O)$). Struvite can naturally form and clog pumps and pipes when recycling lagoon liquid, and struvite accumulation is a common problem in pumping systems for anaerobic treatment portions of municipal waste treatment systems. Although components designed to promote struvite formation and collection have been used to remove phosphorus from municipal waste treatment systems, the idea of promoting struvite formation and collection is a relatively new concept for livestock wastewater treatment and nutrient management.

subirrigation. Application of irrigation water below the ground surface by raising the water table to within or near the root zone.

surface roughening (also called soil roughening). Increasing the relief of a bare soil surface with horizontal grooves by either stair-stepping (running parallel to the contour of the land) or using construction equipment to track the surface.

suspended growth or fixed film reactors. A configuration wherein the microorganisms responsible for wastewater treatment are maintained in suspension within a liquid.

suspended sediment. Very fine soil particles that remain in suspension in water for a considerable period without contact with the bottom. Such material remains in suspension because of the upward components of turbulence and currents and/or by suspension.

swales. Vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume.

tailwaters. The channel or stream below a dam, often characterized by waters with low dissolved oxygen. Many nonpoint source pollution problems in reservoirs and dam tailwaters frequently result from sources in the contributing watershed (e.g., sediment, nutrients, metals, and toxics).

tank. A watertight structure or container used to hold wastewater for such purposes as aeration, equalization, holding, sedimentation, treatment, mixing, dilution, addition of chemicals, or disinfection.

thalweg. In hydrologic terms, it is the line of maximum depth in a stream. The thalweg is the part that has the maximum velocity and causes cutbanks and channel migration.

thinning. A tree removal practice that reduces tree density and competition between trees in a stand. Thinning concentrates growth on fewer, high-quality trees; provides periodic income; and generally enhances tree vigor. Heavy thinning can benefit wildlife through the increased growth of ground vegetation.

three-zone buffer system. A technique for establishing a buffer, consisting of inner, middle, and outer zones. The zones are distinguished by function, width, vegetative target, and allowable uses.

tile drains. Pipe made of perforated plastic, burned clay, concrete, or similar material laid to a designed grade and depth to collect and carry excess water from the soil.

tillage. Plowing, seedbed preparation, and cultivation practices.

time-dosed pressure drip dispersal (flow equalization). A system configuration that includes sufficient effluent storage capacity to allow for uniform flow to a subsequent component despite variable flow from the source.

time-dosing. A configuration in which a specific volume of effluent is delivered to a component according to a prescribed interval, regardless of facility water use.

topography. The shape and contour of a surface, especially the land surface, usually characterized by slope, aspect, and elevation.

total maximum daily load (TMDL). A calculation of the highest amount of a pollutant that a waterbody can receive and safely meet water quality standards set by the state, territory, or authorized tribe.

total suspended solids. A measure of the suspended solids in wastewater, effluent, or waterbodies, determined by tests for *total suspended non-filterable solids*.

turf. A surface layer of earth containing a dense growth of grass and its matted roots; sod.

turnouts (aka bleeders or cutouts). A drainage ditch that drains water away from roads and road ditches.

urban forest canopy. The land surface area that lies directly beneath the crowns of all trees and tall shrubs.

vegetated swales. A shallow drainage conveyance that has vegetative turf (typically grasses) with relatively gentle side slopes, generally with flow depths of less than one foot.

vertical stability (degradation/aggradation). The ability of a stream system to maintain a constant or balanced profile without deposition of sediment (aggradation) or incision (degredation).

vortex rock weirs. A structure designed to serve as grade control and create a diversity of flow velocities, while still maintaining the bed load sediment transport regime of a stream.

waste treatment lagoon. An impoundment made by excavation or earth fill for biological treatment of wastewater.

water quality standards. State-adopted and EPA-approved ambient standards for waterbodies. The standards prescribe the use of the waterbody and establish the water quality criteria that must be met to protect designated uses.

weir. 1. A wall or plate placed in an open channel to measure the flow of water. 2. A W-Weir is an in-stream structure constructed for the purpose of reducing shear stress on streambanks, controlling the grade of the streambed and establishing fisheries habitat. W-Weirs are typically constructed with two rock vanes on opposing sides of the stream channel forming the outside legs and two opposing vanes in the center of the channel to complete the W-Weir.

weighted usable area (WUA). The total surface area having a certain combination of hydraulic and substrate conditions, multiplied by the composite probability of use by fish for the combination of conditions at a given flow.

wetland. An area that is saturated by surface or ground water with vegetation adapted for life under those soil conditions, as swamps, bogs, fens, marshes, and estuaries.

windbreaks. A living barrier that usually includes several rows of trees, and perhaps shrubs, located upwind of a farm, field, feedlot, or other area and intended to reduce wind velocities. Windbreaks, also called shelterbelts, can reduce wind erosion, conserve energy or moisture, control snow accumulations, and provide shelter for livestock or wildlife.

windrow. Logging debris and unmerchantable woody vegetation that has been piled in rows to decompose or to be burned; or the act of constructing such piles.

WTR addition. The addition of iron-rich or aluminum-rich drinking water treatment residuals (WTR) to soils to bind with phosphorus and reduce losses of phosphorus via leaching and runoff.

Abbreviations and Acronyms

ACT	avoid, control, and trap pollutants
AFO	animal feeding operation
AMD	acid mine drainage
APS	multiple-pond system
ASCE	American Society of Civil Engineers
ATU	aerobic treatment unit
BMP	best management practice
BSTEM	Bank-Stability and Toe-Erosion Model
CAD	computer assisted drawing
CAFO	concentrated animal feeding operation
CBP	Chesapeake Bay Program
CDS	controlled drainage-subirrigation
CLEAR	Center for Land Use Education and Research
COD	chemical oxygen demand
CREP	Conservation Reserve Enhancement Program
CRF	controlled-release fertilizer
CSO	combined sewer overflow
CWD	coarse woody debris
CWP	Center for Watershed Protection
DEM	Digital Elevation Model
DIP	dissolved inorganic phosphorus
DM	dry matter
DOP	dissolved organic phosphorus
DSA	driving surface aggregate
DSS	decision support system
DU	distribution uniformity
DW	denitrification wall
EAV	emergent aquatic vegetation
EDU	equivalent dwelling unit

EI	erodibility index
EIA	effective impervious area
EISA	Energy Independence and Security Act
EMRRP	Ecosystem Management and Restoration Research Program
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ETV	Environmental Technology Verification
FEMA	Federal Emergency Management Agency
FISRWG	Federal Interagency Stream Restoration Working Group
FPC	fundamental process category
GCS	grade-control structure
GHG	greenhouse gas
GI	green infrastructure
GIS	geographic information system
GPS	global positioning system
HAP	high-available phosphorus
HEL	highly erodible land
HSI	Hotspot Site Investigation
IBI	index of biotic integrity
IPM	integrated pest management
LID	low impact development
LWD	large woody debris
MBF	matrix-based fertilizer
MBR	membrane bioreactor
MOU	memorandum of understanding
MS4	municipal separate storm sewer system
MT	metric ton
N	nitrogen
NFIP	National Flood Insurance Program
NH_3	ammonia gas
$(NH_4)_2SO_4$	ammonium sulfate
NH_4+	ammonium ions
NH_4NO_3	ammonium nitrate
NMFS	National Marine Fisheries Service

NMP	nutrient management planning
NO_2-	nitrite
NO_3	nitrate
NOAA	National Oceanic and Atmospheric Administration
NOV	notice of violation
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRRSS	National River Restoration Science Synthesis
NSQD	National Stormwater Quality Database
NUE	nutrient use efficiency
NURP	Nationwide Urban Runoff Program
OM	organic matter
P	phosphorus
PAM	polyacrylamide
POC	pollutant of concern
POP	particulate organic phosphorus
PP	particulate phosphorus
PR	phosphate rock
PRB	permeable reactive barrier
PSNT	Pre-Sidedress Nitrate Test
REMM	Riparian Ecosystem Management Model
RME	responsible management entity
RUSLE	Revised Universal Soil Loss Equation
SAV	submerged aquatic vegetation
SBR	sequencing batch reactor
SMA	streamside management area
SMZ	streamside management zone
SPCC	spill prevention control and countermeasures
SRF	slow-release fertilizer
SRI	sedimentation risk index
SRP	soluble reactive phosphorus
SS	suspended solids
SSI	Sustainable Sites Initiative
STA	stormwater treatment area

STEG	septic tank effluent gravity
STEP	septic tank effluent pump
SWPPP	stormwater pollution prevention plan
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TS	total solids
TSP	technical service providers
TSS	total suspended sediment (or solids)
TSSC	typical treatment system component
TVA	Tennessee Valley Authority
TWIST	The Wastewater Information System Tool
UD	traditional drainage
UIC	underground injection control
UOP	unit operation or process
UP3	Urban Pesticide Pollution Prevention
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VFS	vegetated filter strip
VRSS	vegetated reinforced soil slope
VSS	volatile suspended solids
VTS	vegetative treatment system
WEP	water-extractable phosphorus
WERF	Water Environment Research Foundation
WSF	water-soluble fertilizer
WTR	water treatment residual