PENNSYLVANIA

LAKE MANAGEMENT HANDBOOK

Project Sponsor:

The Pennsylvania Lake Management Society
P.O. Box 425
Lansdale, PA 19446

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March 2004

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Preface

The Pennsylvania Lake Management Society (PALMS) was established in 1989 as a state chapter of the North American Lake Management Society (NALMS). The underlying mission of the organization is to promote the further understanding of lakes, ponds, reservoirs and impoundments, their watersheds, and ecosystems of which they are a part; and their protection, restoration and management.

The primary objectives of PALMS, as noted in the by-laws, are to:

A. Promote and provide a forum for sharing of information and experiences on scientific, administrative, legal and financial aspects of lake and watershed management.

B. Foster the development of local lake restoration and protection programs in accordance with appropriate management strategies and techniques.

C. Encourage support and development of local, state and national programs, policies and legislation promoting lake and watershed management.

D. Encourage the cooperation and interaction of organizations, agencies, units of government, and individuals concerned with lake and watershed improvement and protection.

E. Encourage the development and enforcement of laws and legislation designed to protect lakes and watersheds.

In recent years, PALMS has served as an active partner to the Pennsylvania Department of Environmental Protection (DEP) and the US Environmental Protection Agency (EPA) in the ongoing development of Pennsylvania's Nonpoint Source (NPS) Management Plan. PALMS has served as the lead agency for several of the milestones listed in the "Action Plan to Address NPS in Lakes Management." These milestones include the development of a database for all Pennsylvania lakes, the establishment of an annual lake management conference, development of an Internet website that includes a technical directory for lake management, development of lake management fact sheets, assistance with statewide volunteer training, and other education and outreach initiatives. Nearly all of this work is being undertaken with the help of state and federal grant programs.

The development of this Pennsylvania Lake Management Handbook has been targeted as one of the primary responsibilities of PALMS under the NPS Management Plan. The Pennsylvania Lake Management Handbook is intended to serve as a comprehensive reference manual for lake management professionals as well as lake associations, municipalities, regulatory officials, and laypersons for all acceptable and proven Best Management Practices (BMPs) for lake management.

ACKNOWLEDGEMENTS

Many project partners were involved in the development of this handbook, and this diversity of experience and expertise makes this reference so valuable to the citizens of Pennsylvania. This project was made possible by a grant from the Growing Greener Grant Fund. Special thanks go to Russell Wagner and Barbara Lathrop for helping make this project possible. Project partners include:

Pennsylvania Lake Management Society
Pennsylvania Department of Environmental Protection
Pennsylvania Growing Greener Grant Program
F. X. Browne, Inc.
Aqua-Link, Inc.
EcoSolutions

This reference handbook is a collection of information pertaining to Pennsylvania lakes and their watersheds. It should be noted that many other excellent references have been written about the topic of lake and watershed management by renowned authors around the world. Materials from many of these other sources were pieced together for use in writing this handbook. Each section of this handbook contains a “References” subsection where the sources of the materials are credited.

The materials and information found in this handbook represent the views of the authors and do not necessarily represent the views of the Pennsylvania Department of Environmental Protection.

INTRODUCTION

Organization of the Handbook

This handbook was developed using existing reference material on lake and watershed best management practices (BMPs). It includes introductory materials on ecosystem dynamics and lake and watershed management to provide readers with a basic understanding for the selection and proper implementation of the BMPs outlined in the handbook. The handbook provides a comprehensive list of available and proven BMPs for two basic categories: in-lake management and watershed management. Each BMP is thoroughly explained and illustrated, providing information on function, applicability, design criteria, maintenance recommendations, and respective costs or cost ranges. A reference list is also included in each section to provide handbook users with sources for supplemental information. Appendices include a glossary of terms, a list of useful conversions, and a list of Internet links to state and federal agencies and other reference websites for organizations that are involved in lake and watershed management.

How to use the Handbook

The goal for this Handbook is to provide users with a basic understanding of the selection and proper implementation of lake and watershed BMPs. It is not intended to be the sole source of information about a given BMP, but rather a starting point in the selection and design process. It is assumed that any decision-making process involving the use of lake and watershed BMPs would be preceded by a thorough scientific investigation into the feasibility of each option at a particular site. In many cases, several options exist to solve a particular lake problem, and the most applicable option depends largely on the specific characteristics of a given lake or watershed and the resources available. This handbook is intended to provide objective information about the advantages and disadvantages of typical BMPs used in Pennsylvania lakes and watersheds. The following matrix table, Table Intro-1, outlines all of the BMPs that are discussed in this handbook, and categorizes them based on a particular lake problem.

Table Intro-1
Lake Best Management Practice (BMP) Selection Matrix

Lake and Watershed BMPs	Lake Problems: Nuisance Algae		Sediment Buildup		Low Fish Populations		Excessive Macrophytes		Other Lake Problems	
	In-Lake	Water-shed	In-Lake	Water-shed	In-Lake	Water-shed	In-Lake	Water-shed	In-Lake	Water-shed
Lake Aeration	X				X					
Liming					X				X	
Alum Treatment	X						X		X	
Algal Control BMPs	X									
Macrophyte Control BMPs							X			
Lake Shoreline Stabilization	X		X		X		X			
Dredging	X		X		X		X			
Fishery Management					X				X	
Nuisance Wildlife Control	X		X				X		X	
Boat Operation and Maintenance									X	
Aquatic Invasive Plant Management					X		X		X	
Environmental Planning				X						X
Stormwater Management		X		X		X		X		X
Agricultural BMPs		X		X		X		X		X
Forest Management		X		X		X		X		X
Streambank Stabilization and Restoration		X		X		X		X		X
Riparian Corridor Restoration		X		X		X		X		X
Terrestrial Invasive Plant Management										X
Construction Erosion and Sedimentation Pollution Control		X		X		X		X		X
Dirt and Gravel Road Management		X		X		X		X		X
Septic System and Wastewater Management		X		X		X		X		X

Regulatory Status

Activities in and around waterways (lakes, ponds, streams, wetlands, etc.), whether simple or complex, are generally regulated and require formal approvals and/or permits from local, state, AND federal regulatory agencies. In some cases, the permit application process may be streamlined, requiring only one application to obtain the necessary approvals and permits from the different agency levels. Permitting requirements and issues can be quite complex, and therefore, PALMS highly recommends contacting the Pennsylvania Department of Environmental Protection (DEP) Bureau of Watershed Management or a qualified consultant to discuss any proposed project during the initial planning stages, so that proper permits and approvals are determined upfront. Depending on the nature of the project, it may be best to hold a pre-application meeting with all responsible agencies present. An on-site pre-application meeting may actually be recommended for more complex projects or when site conditions warrant it. A pre-application meeting can be arranged by contacting the appropriate DEP Regional Office to discuss the project specifics and the need for such a meeting. Table Intro-2 provides a list of DEP Regional Office contact information.

For projects that involve any placement of materials into waterways or removal of materials from waterways, the most common approvals and permits that are required are Pennsylvania Chapter 105 – Water Obstruction & Encroachment Permits and Pennsylvania Chapter 102 – Erosion and Sedimentation Pollution Control Permits. There are varying degrees of approvals and permits for both Chapter 102 and 105 permits, which are based on the nature and impact of the proposed activity. Some very minor activities require only a written approval for the use of a “waiver” of more stringent permitting. Activities with slightly greater impacts, but not excessive impacts, may qualify for statewide and/or nationwide General Permits. If impacts are deemed excessive, however, more complex Individual Permits may be required by both state and federal agencies. Additionally, projects involving greater than 1 acre of total earth disturbance will also require a National Pollution Discharge Elimination Systems (NPDES) permit, in addition to Chapter 102 and 105 permits.

Other proposed activities, such as the use of chemical additives or biological controls, may require permits from the Pennsylvania Fish & Boat Commission, and may not require Chapter 102 and 105 permits.

The different permit processes generally include the gathering of pertinent physical, chemical, and biological data on the resource that will be impacted, or changed from current conditions, by the proposed project. Additionally, database searches and field surveys for archeological and historical resources and rare, threatened, and endangered species are commonly required. Alternatives to the proposed projects must also be addressed in an effort to prove that the proposed project is in fact the most suitable and will have the least impact on the environment as necessary to accomplish the project goal(s).

Table Intro-2 Pennsylvania Department Of Environmental Protection Regional Offices	
REGION:	**COUNTIES WITHIN REGION:**
NORTHWEST REGION 230 Chestnut St. Meadville, PA 16335 (814) 332-6945	Butler, Clarion, Crawford, Elk, Erie, Forest, Jefferson, Lawrence, Mckean, Mercer, Venango, Warren
SOUTHWEST REGION 400 Waterfront Drive Pittsburgh, PA 15222-4745 (412) 442-4000	Allegheny, Armstrong, Beaver, Cambria, Fayette, Greene, Indiana, Somerset, Washington, Westmoreland
NORTHCENTRAL REGION 208 West Third Street Suite 101 Williamsport, PA 17701-6448 (570) 327-3636	Bradford, Cameron, Centre, Clearfield, Clinton, Columbia, Lycoming, Montour, Northumberland, Potter, Snyder, Sullivan, Tioga, Union
SOUTHCENTRAL REGION 909 Elmerton Avenue Harrisburg, PA 17110-8200 (717) 705-4700	Adams, Bedford, Berks, Blair, Cumberland, Dauphin, Franklin, Fulton, Huntingdon, Juniata, Lancaster, Lebanon, Mifflin, Perry, York
NORTHEAST REGION 2 Public Square Wilkes-Barre, PA 18711-0790 (570) 826-2511	Carbon, Lackawanna, Lehigh, Luzerne, Monroe, Northampton, Pike, Schuylkill, Susquehanna, Wayne, Wyoming
SOUTHEAST REGION 2 East Main Street Norristown, PA 19401 (484) 250-5900	Bucks, Chester, Delaware, Montgomery, Philadelphia

Most of the Best Management Practices (BMPs) that are included in this handbook do require some level of regulatory involvement for their implementation. In many cases, the necessary approvals and permits are discussed for each BMP. However, due to variable site conditions and project specific constraints that may influence the type and nature of required permits, PALMS recommends coordination of the proposed project with the appropriate regulatory agencies. A qualified environmental consultant may also serve as the agent for your proposed project. A list of internet links to various regulatory agency websites is included in Appendix C.

Through a recent grant from the Pennsylvania Department of Environmental Protection, PALMS developed a Products and Services Directory that will assist with finding the appropriate regulatory agencies, vendors, consultants, etc. The PALMS 2002 Products and Services

Directory is available by contacting PALMS with a written request for a copy at P.O. Box 425, Lansdale, PA 19446, or on-line for download as a PDF file at http://www.palakes.org/publications/PALMS2002Directory.pdf.

How to Obtain Printed Copies of the Handbook

To obtain printed copies of the Pennsylvania Lake Management Handbook, contact the Pennsylvania Lake Management Society at:

Pennsylvania Lake Management Society
P.O. Box 425
Lansdale, PA 19446
info@palakes.org

How to Find the Handbook on the Internet

The Pennsylvania Lake Management Handbook can be found in PDF format on the PALMS website at http://www.palakes.org.

Contact Information

For information about the handbook, please contact the following:

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(717) 787-5259
blathrop@state.pa.us

LAKE ECOLOGY PRIMER

ECOLOGICAL CYCLE

In a lake, a basic ecological cycle exists. As shown in Figure Intro-1, aquatic plants like algae (microscopic aquatic plants) and macrophytes (large aquatic plants) require nutrients such as phosphorus and nitrogen along with sunlight to grow. Small aquatic animals such as zooplankton (rotifers, protozoa, etc.), snails and insects eat the algae and reproduce. Small forage fish and juvenile fish eat the small animals, and, in turn are eaten by larger game fish and other animals. This relationship is called the ecological, or energy pyramid. In a healthy lake, this ecological system exists in proper balance.

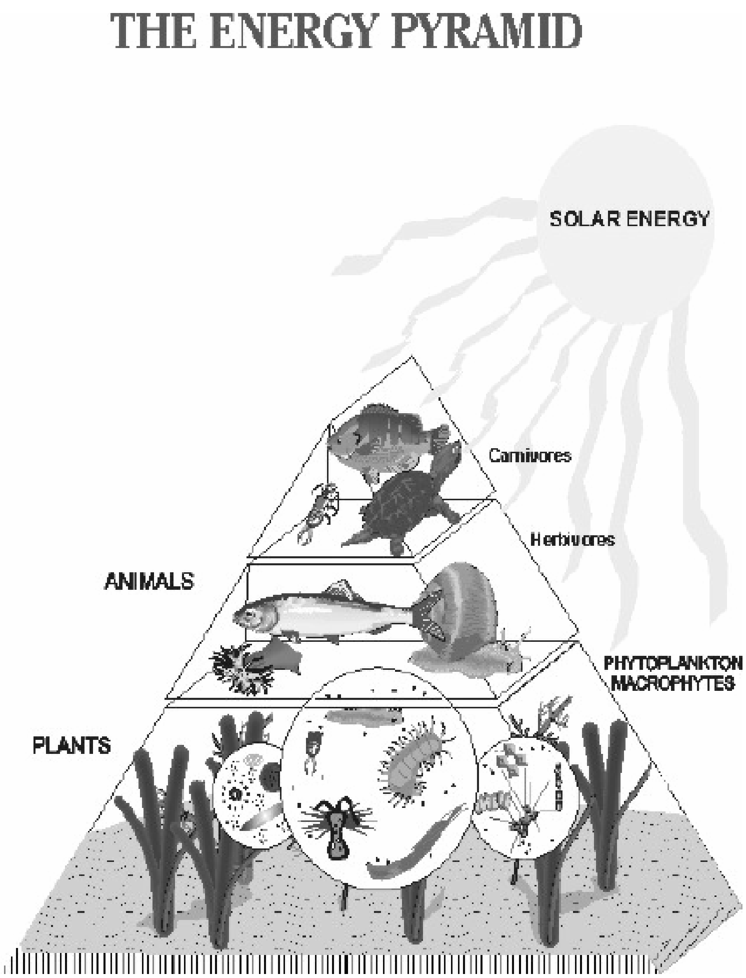

Figure Intro-1 The Ecological Pyramid of a Lake

When too many nutrients enter a lake, the algae and/or large aquatic plants grow to excess. With a larger population of algae one would expect a nice, large population of fish. However, in reality the excessive plant life is not transferred up the food chain. The small aquatic animals do not eat enough of the excess algae (they do not like some of the algae, especially the blue-green algae). Therefore, algae and other plants build up in the lake and destroy the ecological balance of the lake ecosystem. This can result in a reduction in the fish population. It often results in a change in the type of fish found in the lake.

In order to understand the processes that occur in a lake, we must first understand the concept of lake succession or aging.

LAKE SUCCESSION OVER TIME

All lakes go through an aging process called ecological succession. Succession is a natural process whereby a lake starts out as an “ecologically” young lake with few nutrients, clear water, little vegetation, and very little unconsolidated (loose) sediment on the bottom. It should be noted that ecological age is different than chronological age. The chronological age is simply the number of years a lake has existed. The ecological age, on the other hand, is a measure of the physical, chemical, and biological conditions of a lake. A lake may be chronologically young (i.e. built only 3 years ago), but it could be ecologically old. Conversely, it could be chronologically old (i.e. 12,000 years old) but ecologically young.

As a lake ages, more nutrients and sediments enter the lake from the surrounding watershed. Usually, the additional nutrients, such as phosphorus and nitrogen, cause an increase in the amount of algae and aquatic plants. The additional sediment entering the lake settles to the bottom of the lake, increasing the amount of sediment on the lake’s bottom.

Thus as a lake ages, it slowly starts to fill up with sediments, algae and aquatic weeds. Initially, the aquatic vegetation is submergent vegetation, beneath the water surface. As the lake fills up further with sediment, emergent vegetation appears above the water surface.

Ultimately, the lake fills in completely with incoming sediment from the watershed and from dead algae, aquatic plants, and animals. The lake transforms into a pond or swamp and eventually, over hundreds or thousands of years, into a forest, as shown in Figure Intro-2.

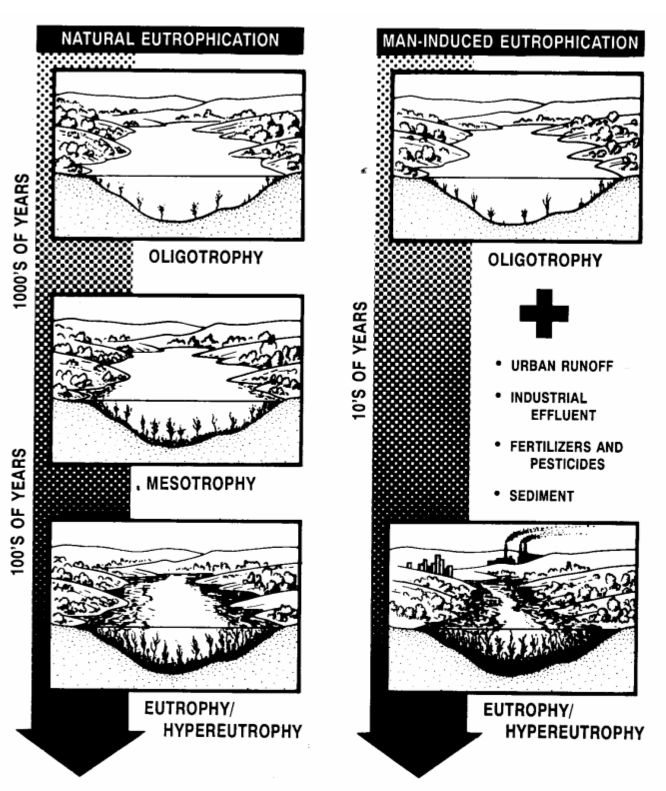

Figure Intro-2 Natural and Human-Induced Eutrophication
Source: Olem and Flock 1990

Lake succession or aging is a natural process that occurs in all lakes. However, the influence of human activities in the watershed can significantly accelerate the aging process. The lake aging process is accelerated by:

Wastewater Treatment Plant Discharges
Malfunctioning Septic Systems
Agricultural Activities (cropland and pastureland)
Construction Activities
Developed Land
Roadways
Streambank Erosion
Landfills

Human activities in a watershed can add sediments and nutrients such as phosphorus and nitrogen to a lake, resulting in accelerated aging or “cultural eutrophication”.

Lake Classification

Lakes are classified by the amount of nutrients (or food) contained in the lake. The Greek word for food is “trophic”. Therefore, we classify lakes by their “trophic” or food/nutrient state. Specifically:

Oligo = little (little nutrients)
Meso = medium (medium nutrients)
Eu = too much (too many nutrients)

The trophic state refers to the “ecological” age of the lake, not its chronological age. Therefore, an oligotrophic lake is a lake that is ecologically young. Lakes are classified by nutrient level and the presence of aquatic plants as described below.

Oligotrophic lake

ecologically young lake
low level of nutrients
low population of algae and aquatic plants

Mesotrophic lake

ecologically middle-aged lake
moderate level of nutrients
moderate population of algae and aquatic plants

Eutrophic lake

ecologically old lake
high level of nutrients
high population of algae and aquatic plants

Dissolved Oxygen and Temperature

The amount of dissolved oxygen in the water is another important indicator of overall lake health. When oxygen is reduced, organisms are stressed. When oxygen is absent, all oxygen-breathing life forms must either move to an oxygenated zone or die. Water temperature plays an important role in determining the amount of oxygen dissolved in water. Oxygen is more soluble in cold water than warm water. Thus, cold water can potentially hold more oxygen than warmer water.

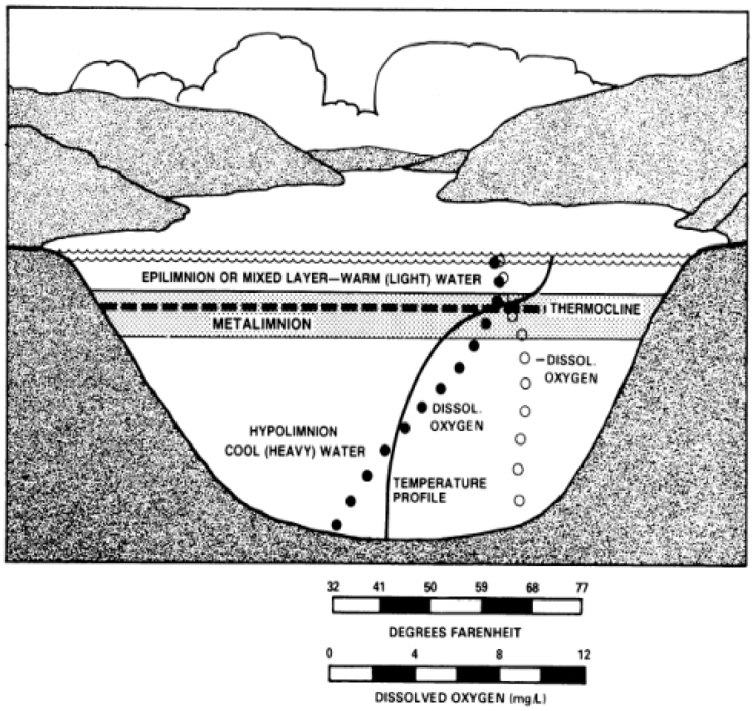

Figure Intro-3 Thermal stratification in a deep temperate lake

Source: Olem and Flock 1990

In late spring or the beginning of summer, deep temperate lakes develop stratified layers of water, with warmer water near the lake's surface (epilimnion) and colder water near the lake's bottom (hypolimnion). As the temperature difference becomes greater between these two water layers, the resistance to mixing increases. Under these circumstances, the epilimnion (top water) is usually oxygen-rich due to photosynthesis and direct inputs from the atmosphere, while the hypolimnion (bottom water) may become depleted of oxygen due to oxygen being consumed by organisms decomposing organic matter at the lake bottom. The transition point between the two layers is called the thermocline, as shown in Figure Intro-3.

Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar radiation. Deeper lakes tend to stratify during the summer and again during the winter. In the spring and fall, both deep and shallow lakes tend to have uniform, well-mixed conditions throughout the water column. Stratified lakes experience “lake turnover” during the spring and the fall, as shown in Figure Intro-4. This turnover can sometimes stir up lake sediments as the water layers mix.

Conversely, shallow temperate lakes may never develop stratified layers of water. For these shallow lake systems, wave action caused by the wind may be sufficient to keep the entire lake completely mixed for most of the year. In shallow lakes, low dissolved oxygen levels may occur above the lake sediments even though most of the water in the lake is completely mixed.

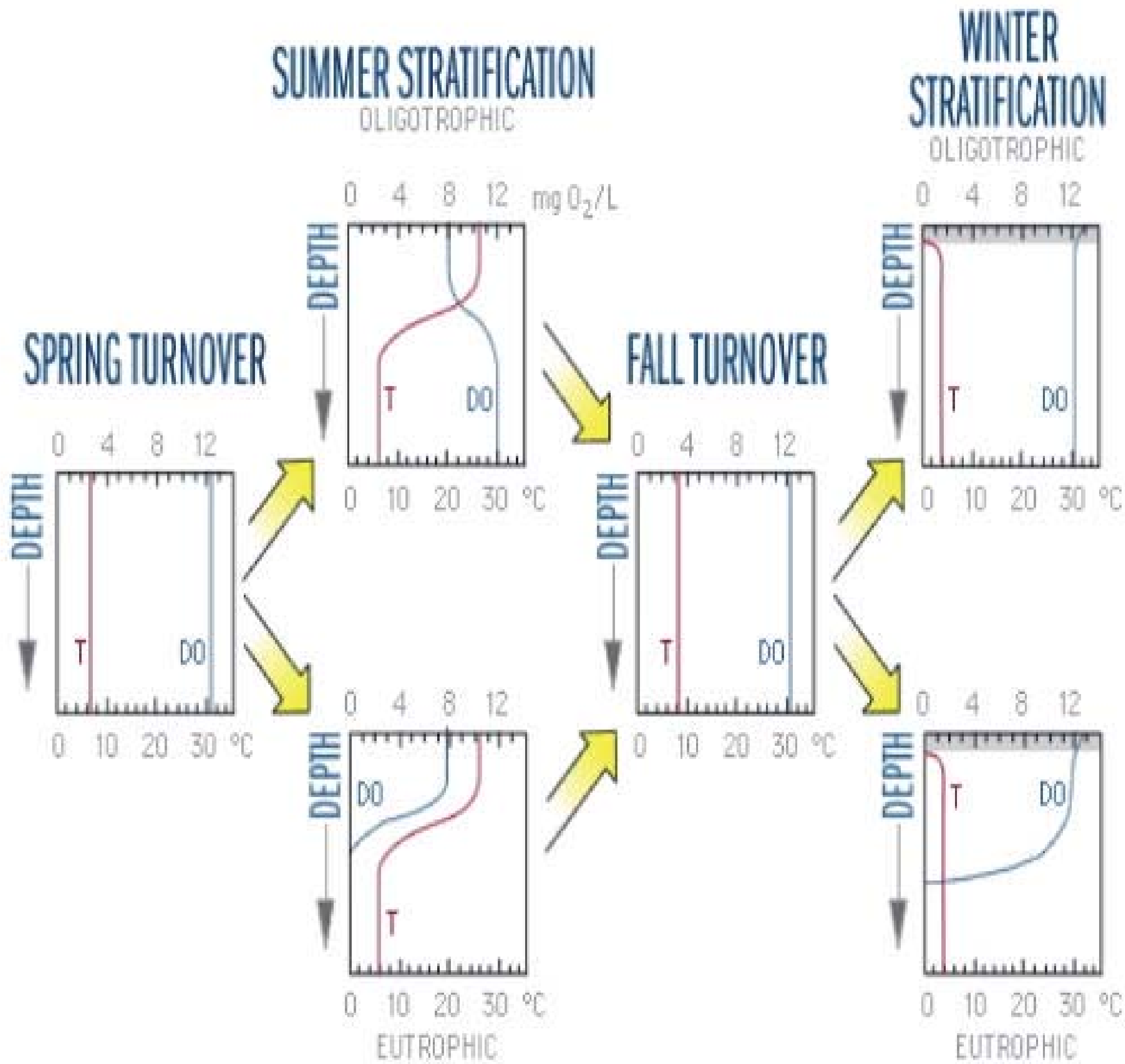

Figure Intro-4. Seasonal dissolved oxygen and temperature profiles in eutrophic and oligotrophic lakes. Source: adapted from Wetzel, R.G. 1975.

Eutrophic lakes are more likely to experience oxygen depletion in the hypolimnion than oligotrophic lakes, since eutrophic lakes tend to have more algae and more organisms depleting oxygen in the hypolimnion. In oligotrophic lakes, low algal biomass allows deeper light penetration and less decomposition. Algae are able to grow relatively deeper in the water column and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the thermocline where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water), as shown in Figure Intro-4.

Therefore, both shallow and deep temperate lakes can have low dissolved oxygen concentrations near the surface of the lake sediments. If low dissolved oxygen levels occur near the lake bottom, sediments may release significant amounts of nutrients (primarily orthophosphorus and ammonium) back into the lake, thereby contributing more nutrients for algae and aquatic plant growth. Metals such as iron and manganese can also be released from the sediments under anoxic conditions.

Lake Problems

Excessive nutrients entering a lake from its watershed cause algae blooms, excessive aquatic plants (macrophytes), lake siltation (settling of sediments in lake, loss of lake volume and capacity), and fishery problems (low dissolved oxygen levels change the fish populations from game fish species to undesirable fish species such as carp). This results in loss of recreation and other lake uses, and can reduce property values around the lake.

Lake problems are caused by both point sources and nonpoint sources of pollution. Point sources are specific outlets or pipes such as the discharge from a wastewater treatment plant. Nonpoint sources cannot be traced to a specific point of origin, but are more diffuse. Nonpoint sources of pollution contribute overland runoff from the surrounding land uses, which carries nutrients and sediment into nearby receiving waters.

Nonpoint Source Pollution

Nonpoint source pollution involves three natural processes: stormwater runoff, erosion and sedimentation. Rainwater flowing across land and entering rivers and lakes is known as stormwater runoff. The force of runoff breaking up the soils and detaching individual soil particles is termed erosion. The soil particles are eventually deposited into nearby streams, rivers, and lakes. This process is called sedimentation. Although a natural part of the water cycle, runoff, erosion and sedimentation have been artificially accelerated by the way humans develop land, leading to pollution.

Almost all nonpoint source pollution is caused by stormwater runoff and erosion. Leaky septic systems are also considered nonpoint sources. Rainwater and melting snow run over residential lawns, construction projects, streets and farm fields, picking up pollutants such as soil particles, chemicals and nutrients and carrying them into nearby water bodies. Nonpoint source pollution also occurs from infiltration of pollutants into the ground. Pollutants originating from malfunctioning landfills, abandoned mines, underground storage tanks and septic tanks are possible groundwater pollution sources.

Lake and Watershed Management

A watershed is that area of land that drains into a lake, either through rivers, streams, surface runoff, or groundwater. A watershed is best envisioned as a funnel with a glass at the bottom representing the lake. Anything that falls into the funnel will find its way into the glass. Much the same occurs in a watershed; therefore, watershed characteristics such as size, land use, slope, and soils play an important role in determining both the quality and quantity of the water that drains to a lake. For this reason, getting to know a lake's watershed and the activities that go on in the watershed are of primary concern to the individuals that manage and enjoy the lake.

Lake management refers to the practice of maintaining lake quality such that attainable lake uses can be achieved (Jones and Taggart, 2001). Management of a lake is integrally related to management of the surrounding watershed. Watershed management is the process of protecting the lakes, streams, and wetlands in the watershed from point and nonpoint source pollution. It is accomplished by developing an understanding of key factors that affect the water quality of lakes, streams and wetlands and by following a plan of action to prevent, reduce, or minimize those activities within a watershed that may negatively impact water quality. Watershed management consists of many diverse activities including controlling point and nonpoint source pollution, monitoring water quality, adopting ordinances and policies, educating stakeholders, and controlling growth and development in a watershed.

Lake Protection and Restoration

Depending on the physical traits of the lake and watershed, and the quality of the incoming water, certain lakes are suited for particular uses. It is sometimes difficult to manage a lake for conflicting uses; for example, trout fishing and motorboat racing. A lake cannot be all things to all people, and it can be difficult and expensive to force a lake to support a specific use when it is unrealistic to do so. It is important, therefore, when undergoing a lake protection or restoration project, to set specific goals that are based on a thorough investigation of the lake and its watershed. Lake protection is defined as "The act of preventing degradation or deterioration of attainable lake uses." (Olem and Flock., 1990). Lake protection projects are usually undertaken by municipalities or lake associations who fear their lake will suffer from the adverse effects of encroaching development. Lake restoration refers to the use of ecologically sound principles in attempts to return a lake or reservoir as close to its original condition as possible (Jones and Taggart., 2001). It is important to be realistic in one's expectations for lake restoration. Nonpoint sources of pollution in a watershed can be difficult to detect and control, and without proper watershed management, lake restoration efforts can fail. A comprehensive watershed management plan should be designed and implemented. The most successful lake restoration projects involve as many watershed stakeholders as possible. In any lake project, educating watershed citizens about how their activities affect the lake can be extremely helpful.

Lake Best Management Practices

Lake Best Management Practices (BMPs) are defined as "Systems, activities, and structures that human beings can construct or practice to prevent nonpoint source pollution," (Jones and Taggart, 2001). Lake professionals use a wide variety of BMPs to improve the overall quality and aesthetics of lakes. These BMPs can generally be separated into in-lake practices and watershed practices. In-lake BMPs are management practices that are applied within the lake itself to target specific lake problems such as accumulated sediment, excessive macrophytes, or algae blooms. Examples of in-lake BMPs are dredging, weed harvesting, and alum application. Watershed BMPs are management practices that are applied within the lake's watershed to solve the same kinds of lake problems. For example, streambank stabilization is a BMP employed in a lake's watershed to reduce sediment accumulation and nutrient loading to the lake. Table Intro-1 in the Introduction of this Handbook outlines the most commonly used lake and watershed BMPs in Pennsylvania, and categorizes them based on the particular lake problem that they are designed to address.

For additional reading on lake succession, lake ecology, dissolved oxygen and temperature profiles, nonpoint source pollution, lake restoration, or other lake-related topics, please refer to the references listed below. A glossary of lake and watershed terms is provided in Appendix A.

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Chapter 1: LAKE BEST MANAGEMENT PRACTICES

1.1 Introduction

This chapter discusses numerous best management practices (BMPs) commonly used to improve the water quality and aesthetics of lakes throughout the Commonwealth of Pennsylvania. Lake BMPs are often referred to as lake restoration and management techniques.

A Calm Summer Morning at Walker Lake in Snyder County. Source: Edward Molesky of Aqua-Link, Inc.

In this chapter and elsewhere in this handbook, the term lake refers to ponds, lakes and reservoirs. A glossary of lake and watershed terms is provided in Appendix A. Lakes are naturally occurring systems while reservoirs are manmade. Reservoirs generally have greater than 14 days hydraulic retention time, which differentiates them from impounded rivers or streams. Ponds can be either natural and manmade water bodies and typically are much smaller and shallower than lakes. The difference between a lake and a pond is not clear-cut, and tends to be a topic for spirited debate among limnologists around the world. Several different defining characteristics between lakes and ponds exist, including the presence of thermal stratification (lakes typically stratify thermally whereas ponds generally do not), the degree of wind mixing (lake thermal dynamics are largely driven by wind mixing, whereas ponds are generally driven by convection in the absence of wind forces), and the extent of vegetative coverage (lakes typically contain more open water, especially in the pelagic zone, while ponds usually contain aquatic plants throughout their depth). In general, lakes tend to stratify and light levels tend to become limiting for macrophyte (aquatic plant) growth at about 15 feet. However, for the purposes of lake management, the exact definition is not important. Any management techniques should be tailored to the specific lake, regardless of the classification.

In general, the goal of implementing lake BMPs is to enhance desirable lake uses such as swimming, boating, water skiing and fishing. In addition, lake best management practices are implemented to improve the overall aesthetics of the lake, to increase the potability of drinking water supply reservoirs, and to improve habitat for birds, fish, and other animals.

Principles of lake management often involve the terms *restoration*, *management* and *protection*. Often these terms are used interchangeably, but there are subtle differences in their meaning that should be recognized. *Restoration* is the use of ecologically sound principles in attempts to return a lake as close to its original condition as possible. *Management* is improving the lake to enhance its intended uses such as swimming, fishing or boating. A restored lake will likely be very attractive and will require management to remain in that condition. *Protection* is the prevention of adverse impacts to lakes (Jones and Taggart 2001).

Lake professionals use a wide variety of lake BMPs to improve the overall quality and aesthetics of lakes. The major categories of lake BMPs, along with their primary objectives, are listed in Table 1.1-1. The remainder of this chapter is devoted to those lake BMPs that are most frequently used in Pennsylvania.

Table 1.1-1
In-Lake Best Management Practices

Practice	Objectives
Aeration (artificial circulation and hypolimnetic aeration)	Increase dissolved oxygen concentrations in order to improve water quality for aquatic life including fish. Possibly reduce nutrient releases from in-lake sediments, decease phytoplankton levels and improve water clarity.
Liming	Increase pH and alkalinity. Improve water quality for aquatic life including fish.
Alum Treatment (nutrient precipitation and inactivation)	Improve water clarity. Physically settle out phytoplankton. Precipitation of in-lake phosphorus. Reduce nutrient releases from lake sediments.
Chemical Algal Control BMPs	Improve water clarity by killing or inhibiting the growth and reproduction of algae.
Macrophyte Control BMPs	Improve lake uses by reducing nuisance stands of aquatic vegetation.
Shoreline Stabilization	Reduce sediment and nutrient inputs to lakes. Improve aesthetics and public safety.
Dredging	Remove nutrient-laden sediments. Reduce internal release of nutrients from in-lake sediments. Remove aquatic macrophytes along with their seeds and roots. May improve dissolved oxygen levels in the lake.
Fishery Management	Improve overall quality of recreational fisheries.
Nuisance Wildlife Control	Improve shoreline aesthetics. Improve water quality for contact recreational activities. Remove source of nutrient loading.
Boat Operation & Maintenance	Reduce lake user conflicts. Reduce water pollution.
Aquatic Invasive Species Management	Reduce or eliminate exotic and invasive species that compete against more desirable species.

The success of any efforts to restore and/or improve the quality of lakes will largely depend upon the thoroughness of the diagnosis and evaluation of lake problems (Cooke et. al 1993). The proper evaluation of applicable lake management practices often involves performing a Phase I

Diagnostic – Feasibility Study. A Phase I Study should be performed by a qualified environmental consultant with extensive experience in lake ecology; watershed principles or dynamics; and both lake and watershed management. A Phase I Study is a two-part study designed to determine the current conditions of a lake and its surrounding watershed and to develop a lake and watershed management plan. The diagnostic phase of the study generally involves collecting, analyzing and interpreting lake and watershed data. The feasibility phase extends from the diagnostic work and its purpose is to identify and evaluate all plausible lake and watershed BMPs to restore and/or protect lake water quality. Therefore, it cannot be overemphasized that the collection, analysis and interpretation of lake and watershed data are a critical step when evaluating and selecting lake BMPs for future implementation.

In addition, the overall success and cost effectiveness of any implemented lake management practice will depend highly upon the actual nutrient and sediment loadings from the surrounding watershed. For example, the benefits of lake dredging or an alum treatment may be short-lived if high sediment and nutrient watershed loadings are not adequately addressed. Therefore, the success and cost-effectiveness of any implemented lake BMP will be maximized by first (or simultaneously) targeting watershed problems as identified in the Phase I Diagnostic – Feasibility Study.

Spinnler Point at Lake Wallenpaupack in Pike County.
Source: Edward Molesky of Aqua-Link, Inc.

Lastly, it is often beneficial to evaluate applicable lake BMPs with respect to the following criteria: effectiveness, longevity, confidence, applicability, potential negative impacts and capital costs (Olem and Flock 1990). This evaluation process, which is typically performed as part of the feasibility portion of a Phase I Study, allows lake managers to make difficult decisions on how to properly manage lakes in a cost effective and environmentally sound manner. The six criteria are briefly described below:

Effectiveness	how well a specific lake best management practice meets its goal
Longevity	reflects the duration of effectiveness of a lake best management practice (short vs. long term)
Confidence	refers to the number and quality of reports and studies supporting the effectiveness of a lake best management practice
Applicability	refers to whether or not a lake best management practice directly affects the cause of the problem
Potential for Negative Impacts	evaluation of a proposed lake management practice with respect to its potential negative impacts on the lake ecosystem and the local environment
Capital Costs	evaluation of applicable lake best management practices with respect to overall cost-effectiveness (annual costs for operation and maintenance should also be considered)

Conventional (Diffused-Air) Aeration System to Improve the Water Quality of Fawn Lake in the Pocono Mountains. Source: Edward Molesky of Aqua-Link, Inc.

References

Cooke, G.D., E.B Welch, S.A. Peterson and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. Second Edition. Lewis Publishers. CRC Press, Inc.

Jones, C. W. and J. Taggart, 2001. Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute, in cooperation with Office of Water, Assessment and Watershed Protection Division US EPA, Madison, WI.

Olem, H. and G. Flock, ed.s 1990. Lake and Reservoir Restoration Guidance Manual. 2nd edition. EPA 440/4-90-006. Prepared by North American Lake Manage. Society for U.S. EPA Washington, DC.

1.2 Aeration

Aeration is a lake management technique that involves adding more air, or more specifically more dissolved oxygen, into lake waters. There are two major approaches to aeration: artificial circulation and hypolimnetic aeration. Artificial circulation is commonly used to partially or completely mix lakes, while hypolimnetic aeration is used to add dissolved oxygen to deeper lake waters while maintaining thermal stratification (lake water layering). Sometimes artificial circulation is deliberately used to completely mix (destratify) deeper, thermally stratified lakes. This approach to lake aeration is commonly referred to as destratification aeration.

In the following sections, three different methods of aeration are discussed. These methods are surface aeration, conventional (diffused air) aeration and hypolimnetic aeration. Surface aeration and conventional aeration are forms of artificial circulation.

1.2.1 Surface Aeration

Surface aeration, a method of artificial circulation, commonly involves the installation of fountain aerators. Fountain aerators are floating systems that pump water through nozzles and subsequently shoot it into the air in a variety of different patterns. The pump floats on a platform and the water intake is only a foot or two below the lake surface. Fountain aerators have pumps ranging from one-third to 10 horsepower with pumping rates from 185 to 3,100 gallons per minute (McComas 1993).

Fountain aerator installed in a stormwater retention pond in Bucks County. Source: Edward Molesky of Aqua-Link, Inc.

Applicability

Surface aeration is generally limited to shallow, small lakes (less than 1 acre). Fountain aerators are relatively easy to install and are considered attractive water features by many. Others may find fountains unnatural or objectionable. In this case, the installation of a conventional (diffused air) aeration system should be considered. Fountain aerators are frequently installed in ponds at golf courses, parks and office complexes. Fountain aerators may be inappropriate for lakes in wooded settings.

Fountain aerators typically will not completely circulate a lake or pond if the water depth is greater than five feet. This is because the water intake for the pump is generally only one to two feet below the water surface. Circulation can be enhanced if a draft tube, which is connected to the water intake, is placed into deeper water (McComas 1993). In some cases, fountains may allow oxygen-enriched water to circulate to the lake bottom, which may assist in controlling nuisance algae. Also, the wave action produced by fountains may displace floating plants away from the fountains, thereby creating some open water (McComas 1993).

Overall, fountain aerators are primarily installed to enhance aesthetics in lakes. Fountain aerators may increase water circulation in small, shallow lakes. Under certain conditions, fountain aerators may increase dissolved oxygen concentrations and possibly decrease phytoplankton (free-floating microscopic aquatic plants or algae) if sized properly. Lake transparency (clarity) may even improve if phytoplankton levels drop significantly. However, if water quality improvements are the primary objective, conventional (diffused air) aeration is usually recommended and a fountain aerator can be installed for aesthetics only.

Design Considerations

It is not recommended to install fountain aerators in lakes that are used for swimming or boating for two reasons. First, electrical power must be brought to the fountain aerator, thereby creating a potential safety hazard. Second, the aerators are kept in position using guide cables, which are anchored along the shoreline. These guide cables create a water hazard for swimmers and boaters.

Surface aeration using fountain aerators is recommended only for small, shallow lakes if artificial circulation is the primary objective. As a rule of thumb, approximately one to three hp of aeration is required per surface acre. For more irregular or larger lakes, several smaller units may be more advantageous than using a single unit.

Maintenance Recommendations

The water intake and the spray nozzles of fountain aerators should be cleaned at least once per year. The oil in the pump motor should be changed annually. Some motors are factory sealed and subsequently do not require an oil change. Pump motors requiring oil changes tend to last longer than factory sealed units.

Fountain aerators are generally operated during the summer recreational season only. The units must be removed from the lake prior to the first ice. This is a good time to perform routine annual maintenance as described above. Fountain aerators can be operated year round, but caution is advised because the fountain aerator can be damaged by ice if a power failure occurs.

Cost Considerations

Initial Cost

The cost of a fountain aerator is highly dependent upon a number of variables such as nozzle spray patterns, optional lighting, platform materials and the size (horsepower rating) of the motor. Therefore, typical cost for fountains range from $500 to several thousand dollars. An additional cost to consider is bringing electrical power to the lake, which may entail installing additional power poles and cables.

Maintenance Costs

Annual maintenance costs for the fountain aerators are minimal and include changing the oil in the pump motors (if required) and cleaning the nozzles and water intakes. Other costs include the labor for installing and removing the units and the cost of electricity for operating the units.

1.2.2 Conventional Aeration

Conventional aeration, or diffused air aeration, is a form of artificial circulation used to either mix shallow lakes or destratify deeper lakes. In this practice, tiny air bubbles are released from a diffuser or plastic aeration pipe along the bottom of the lake. These bubbles rise into the water column and along their ascent, transport deep, oxygen-poor lake waters to the surface. The transported waters are exposed to the atmosphere and subsequently become oxygenated. Oxygen diffusion from the air bubbles to the surrounding water is considered negligible.

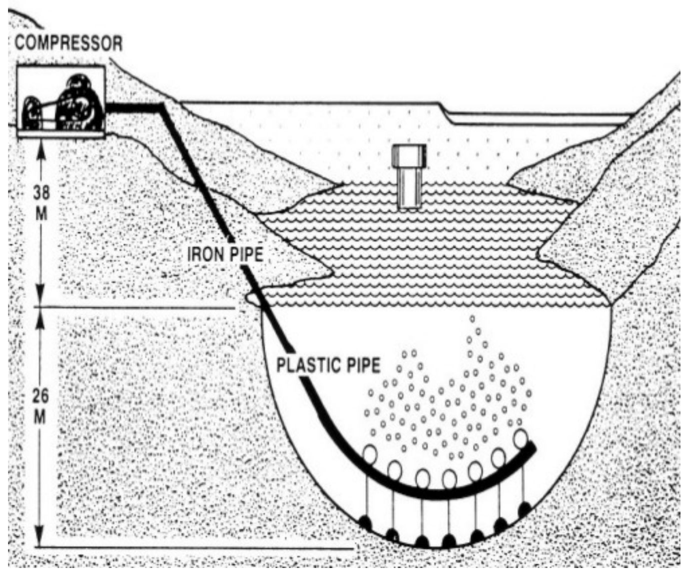
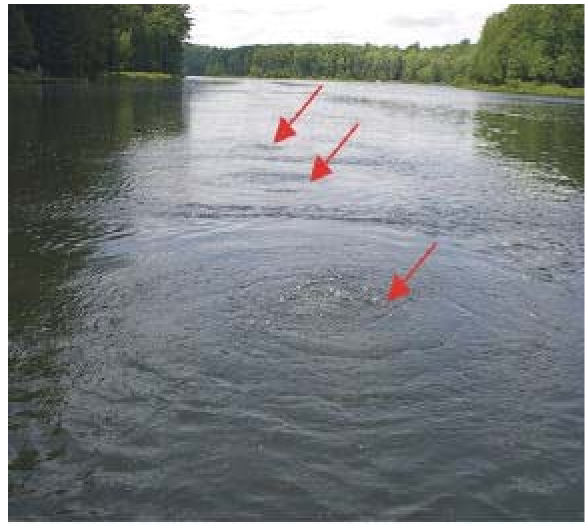


Figure 1.2-1 Conventional (Diffused Air) Aeration System. Source: Jones and Taggart 2001

There are many different types of conventional aeration systems on the market. In its simplest form, a conventional (diffused air) aeration system consists of three major components: a compressor, air lines, and a method of generating air bubbles, as shown in Figure 1.2-1. Most often, air bubbles are generated using either ceramic or membrane diffusers. Another method is to use the in-lake sections of the air lines equipped with small holes to release air.

Applicability

Conventional aeration is used to artificially circulate lakes in order to increase dissolved oxygen concentrations in deeper lake waters. Lakes that thermally stratify during the summer will completely mix when aerated, with nearly uniform water temperatures from the lake surface to the bottom. Hypolimnetic aeration may be more applicable if the primary object is to aerate deeper lake waters while maintaining thermal stratification for a coldwater fishery. One potential benefit of conventional aeration is the reduction of iron and manganese problems for water supply reservoirs. Iron and manganese can be released from lake sediments under anoxic conditions in stratified lakes, and artificial circulation can reduce this phenomenon. Another potential benefit of conventional aeration is to improve lake transparency by reducing phytoplankton biomass. Phytoplankton biomass reductions may occur as a result of the following processes (Olem and Flock 1990, NYS DEC 1990):



Plumes of air bubbles along an installed in-lake aeration line.
Source: Ed Molesky of Aqua-Link, Inc.

- Increased dissolved oxygen concentrations in deeper lake waters will decrease the release of phosphorus (and metals) from in-lake sediments. Lower phosphorus concentrations provide less food for algae growth.

- When the water column is mixed, phytoplankton may be pushed into deeper water, thereby resulting in lower growth and reproduction rates due to lower rates of photosynthesis in darker waters.

- Zooplankton are also pushed into deeper waters due to lake mixing. In darker waters, they are less vulnerable to sight-feeding fish. Under such conditions, zooplankton survival rates are expected to increase, which in turn translates into higher predation rates on phytoplankton.

- Rapid circulation of carbon dioxide-enriched bottom waters with surface waters and contact with the atmosphere may increase the carbon dioxide content and lower the pH of the surface waters. This encourages the growth of less noxious green algae as opposed to blue-green algae.

The potential side effects of conventional aeration systems include the virtual elimination of coldwater habitats for coldwater fish species like trout. In addition, in lakes where phytoplankton are nutrient-limited, artificial circulation may increase the phosphorus concentrations in the surface waters and promote the additional growth of phytoplankton. This increase in phytoplankton population causes a decrease in lake clarity (NYS DEC 1990).

Design Considerations

The literature suggests that the major cause for failure of conventional aeration systems is the under-designing of the systems. Lorenzen and Fast (1977) concluded that to adequately mix a lake, an air flow of about 1.3 cubic feet per minute (1.3 ft^3/min) is required per acre of lake surface area.

As noted by McComas (1993), positive results (e.g., algal control, improved lake clarity) are often observed in the first summer. If not, the aeration system may require more air or reconfiguration of the in-lake components by moving or adding additional diffusers or aeration lines.

MAINTENANCE RECOMMENDATIONS

Conventional (diffused air) aeration systems typically use piston, diaphragm or rotary vane compressors. These compressors should be serviced annually. The air diffusers and aeration lines should be visually inspected throughout the year. The air diffusers and aeration lines should also be cleaned annually. Air diffusers will likely need to be replaced according to the manufacturers recommendations or when a sharp drop in performance is observed.

COST CONSIDERATIONS

INITIAL COST

The range of costs for conventional aeration (diffused air) system is approximately $500 to $2,000 per surface acre. This cost is highly variable and will largely depend upon the physical and chemical characteristics of the lake. This cost does not include installation of the system or installation of electrical power at the lake.

MAINTENANCE COSTS

Annual maintenance costs for compressors can range from less than one hundred to several hundred dollars depending upon their size (horsepower rating). Other maintenance costs include the cost to replace air diffusers according to the manufacturers recommendations or when a sharp drop in performance is observed, and the cost of electricity to run the aerator.

1.2.3 HYPOLIMNETIC AERATION

Hypolimnetic aeration is a technique used to oxygenate deep lake waters without disrupting thermal stratification. By adding air to deeper lake waters, oxygen is transferred to the water. This process generates a controlled mixing force.

A hypolimnetic aeration system typically consists of the following components: an air compressor, air lift device(s), and chamber. The air compressor is located along the shoreline and is connected to the underwater air lift device (e.g., air diffuser) via an air line as shown in Figure 1.2-2. Rising air bubbles from the diffuser entrain water and bring it to the top of the chamber. The tube at the top of the chamber is an airway that

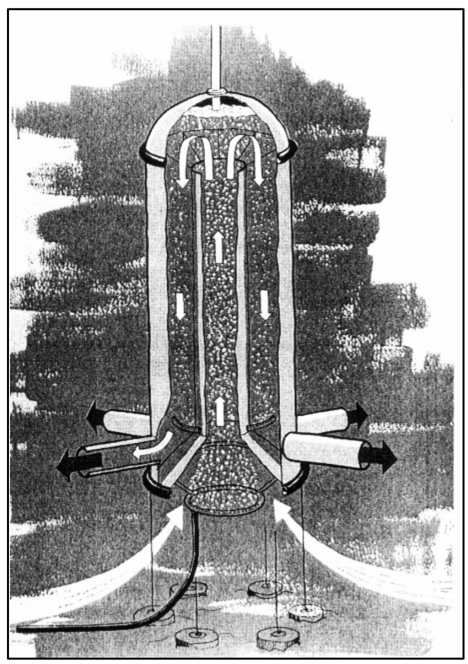


Figure 1.2-2 Hypolimnetic aerator Source: McComas 1993

sticks out of the water. Bottom water is aerated at the top of the chamber and then is forced down the side and out of the ports as new bottom water enters (McComas 1993). This reduces the introduction of phosphorus-rich bottom waters to the epilimnion.

There are three major methods of hypolimnetic aeration: full lift, partial lift, and layer aeration (Jones and Taggart, 2001). These three methods are illustrated in Figure 1.2-3 and discussed below:

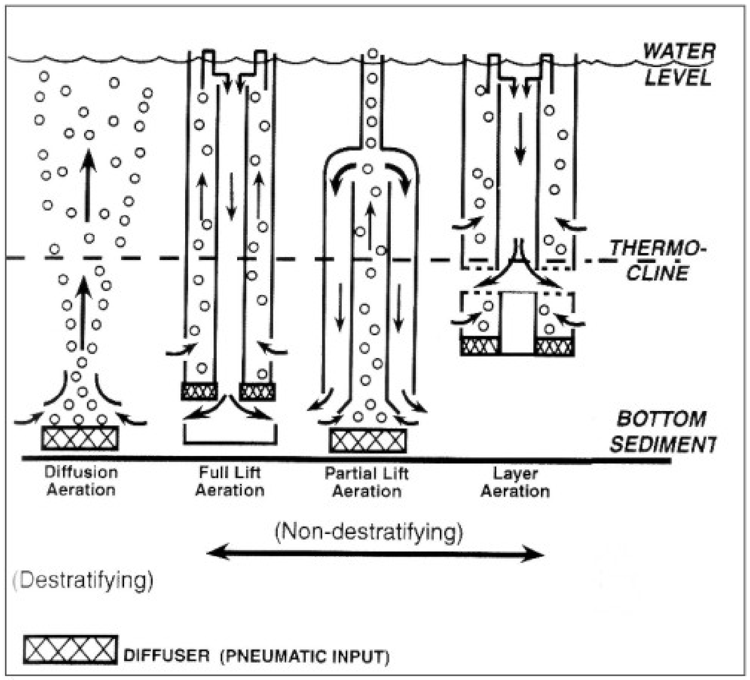


Figure 1.2-3 Three methods for hypolimnetic aeration Source: Jones and Taggart, 2001 (*modified*)

- **Full lift** pumps air into a chamber and moves hypolimnetic water to the surface where it is aerated. The aerated water is released back into the hypolimnion.

- **Partial lift** pumps air into a submerged chamber in which oxygen is exchanged with the deeper waters. The aeration chamber itself is submerged and does not interfere with lake use or aesthetics. Partial lift systems are probably the most frequently used, which may be due to greater commercial availability.

- **Layer aeration** combines water from different carefully chosen temperature (and thus density) regimes to form stable oxygenated layers anywhere from the upper metalimnetic boundary down to the bottom of the lake. Each layer retards the passage of phosphorus, metals and other contaminants from the layer below. Either part or all of the hypolimnion may be aerated to the desired oxygen level.

Hypolimnetic aeration is commonly used to improve the coldwater habitat and water quality of deep lake waters. Increased dissolved oxygen levels allow aquatic organisms, including cool and coldwater fish, to utilize deeper lake waters that were previously uninhabitable. Iron, manganese and phosphorus concentrations decrease due to the reduction in the internal release of these compounds from in-lake sediments under anoxic conditions. Iron and manganese are important metals to control for drinking water supply reservoirs since they cause problems such as staining of household fixtures and taste and odor problems. Reducing internal phosphorus loading may reduce phytoplankton biomass in the lake.

Potential side effects of hypolimnetic aeration include the super saturation of bottom waters with nitrogen gas and the formation of zones of minimal interaction. Elevated levels of nitrogen gas can lead to "gas bubble" disease in fish, although this condition is extremely uncommon. Zones of minimal interaction often occur with this technique, resulting in localized anoxia and phosphorus release (Jones and Taggart, 2001).

Applicability

Hypolimnetic aeration is appropriate only for thermally stratified lakes. Hypolimnetic aerators require a large hypolimnion in order to work properly. Consequently, caution is advised if attempting to use this lake management technique for shallow or moderately shallow lakes that are weakly stratified or unstratified (NYS DEC 1990).

Design Considerations

Hypolimnetic aeration systems are designed by first determining the oxygen demand using actual lake data. The oxygen demand for the hypolimnion is the difference in oxygen concentration between the time when stratification occurs in the lake and the time when oxygen concentrations decline below 1 mg/L. In general, oligotrophic lakes may need less than 250 mg/m^2/day of oxygen, whereas eutrophic lakes may require twice that amount. Hypereutrophic lakes may require up to 2,000 to 4,000 mg/m^2/day (Jones and Taggart, 2001).

Maintenance Recommendations

Air compressors for hypolimnetic aeration systems should be serviced annually by a qualified service contractor. The aeration lines should be visually inspected throughout the year. The air diffusers will likely need to be replaced according the manufacturers' recommendations or when a sharp drop in performance is observed.

Cost Considerations

<u>Initial Cost</u>

The range of costs for hypolimnetic aeration systems is approximately $500 to $3,000 per surface acre (Jones and Taggart, 2001). This cost is highly variable and will largely depend upon the physical and chemical characteristics of the lake. This cost does not include installation of the aeration system or the installation electrical power to the lake. As a rule of thumb, hypolimnetic aeration systems will generally cost two to three times more than conventional (diffused air) aeration systems.

<u>Maintenance Costs</u>

Annual maintenance costs for compressors can range from less than one hundred to several hundred dollars depending upon the size or horsepower rating. Other maintenance costs include replacing air diffusers according to the manufacturers recommendations or on an as needed basis, and the cost of electricity to run the aerator.

References

Jones, C. W. and J. Taggart, 2001. Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute, in cooperation with the Office of Water, Assessment and Watershed Protection Division, US EPA. Madison, WI.

Lorenzen, M., and A. Fast. 1977. A Guide to Aeration/Circulation Techniques For Lake Management. Corvallis Environmental Research Lab, Oregon, U.S. EPA.. EPA- 600/3-77-004. 125p.

McComas, S. 1993. Lake Smarts – The First Lake Maintenance Handbook. Produced by Terrene Institute for the Office of Water and Office of Wetlands, Oceans and Watersheds, U.S. EPA. Washington, D.C.

New York State Department of Environmental Conservation (NYS DEC). 1990. Diet for a Small Lake – A New Yorker's Guide to Lake Management. Albany, New York.

Olem, H. and G. Flock, ed.s 1990. Lake and Reservoir Restoration Guidance Manual. 2nd edition. EPA 440/4-90-006. Prepared by North American Lake Management Society for U.S. EPA. Washington, DC.

1.3 Liming

Surface waters can suffer from increased acidity due to the effects of acid rain or acid mine drainage. Such acidic lakes may be impacted to the extent that they are no longer capable of maintaining balanced aquatic communities. In this situation, productivity decreases due to the lack of nutrient recycling within the system. Certain species of plankton and algae that form the basis of the aquatic food chain disappear, and many of the larger aquatic organisms, such as fish, become stressed and die.

In nature, the presence of calcium in surface water helps to buffer the effects of increased acidity. However, in calcium-poor or low-alkaline aquatic communities, the natural buffering capacity can quickly be lost with the sudden pulse of acidity associated with a heavy rainfall. As the waters become acidic, aluminum is leached from the surrounding soil and in certain situations becomes highly toxic to fish. Additionally, the increased acidity reduces the calcium concentration, which also intensifies the amount of stress that is placed on the aquatic community. Liming artificially reintroduces calcium into the aquatic system and increases the natural buffering capacity of the water body. Liming also serves as a short-term remedial action aimed at improving the water quality in acidified surface waters, thereby allowing “healthy” aquatic communities to become reestablished.

Applicability

Not all surface waters or lakes are good candidates for liming. Therefore, prior to initiating a lake-liming project, lake managers or owners should ask the following questions:

- What is the present water quality of the lake and contributing watershed with respect to pH and alkalinity? How does that compare with past water quality? Water quality monitoring should be performed before liming is considered.
- Is there now, or has there been, an established fishery?
- If the acidity in the lake is reduced, will there be suitable habitat present in the lake to support aquatic life?
- What is the total surface area and depth of the lake to be treated?
- How quickly does water flow into and out of the lake basin (retention time)?
- Will there be any legal or access issues with adjoining landowners?

The answers to these questions will help determine whether or not a lake is a good candidate for liming. Figure 1.3-1 contains a flow chart showing how to use the answers to these questions as guidelines for determining the need and/or feasibility of conducting a lake-liming project. In addition, the regional PA DEP office must be contacted in the early planning stages of any liming project to discuss permitting issues. A permit from the PA Fish and Boat Commission may also be necessary.

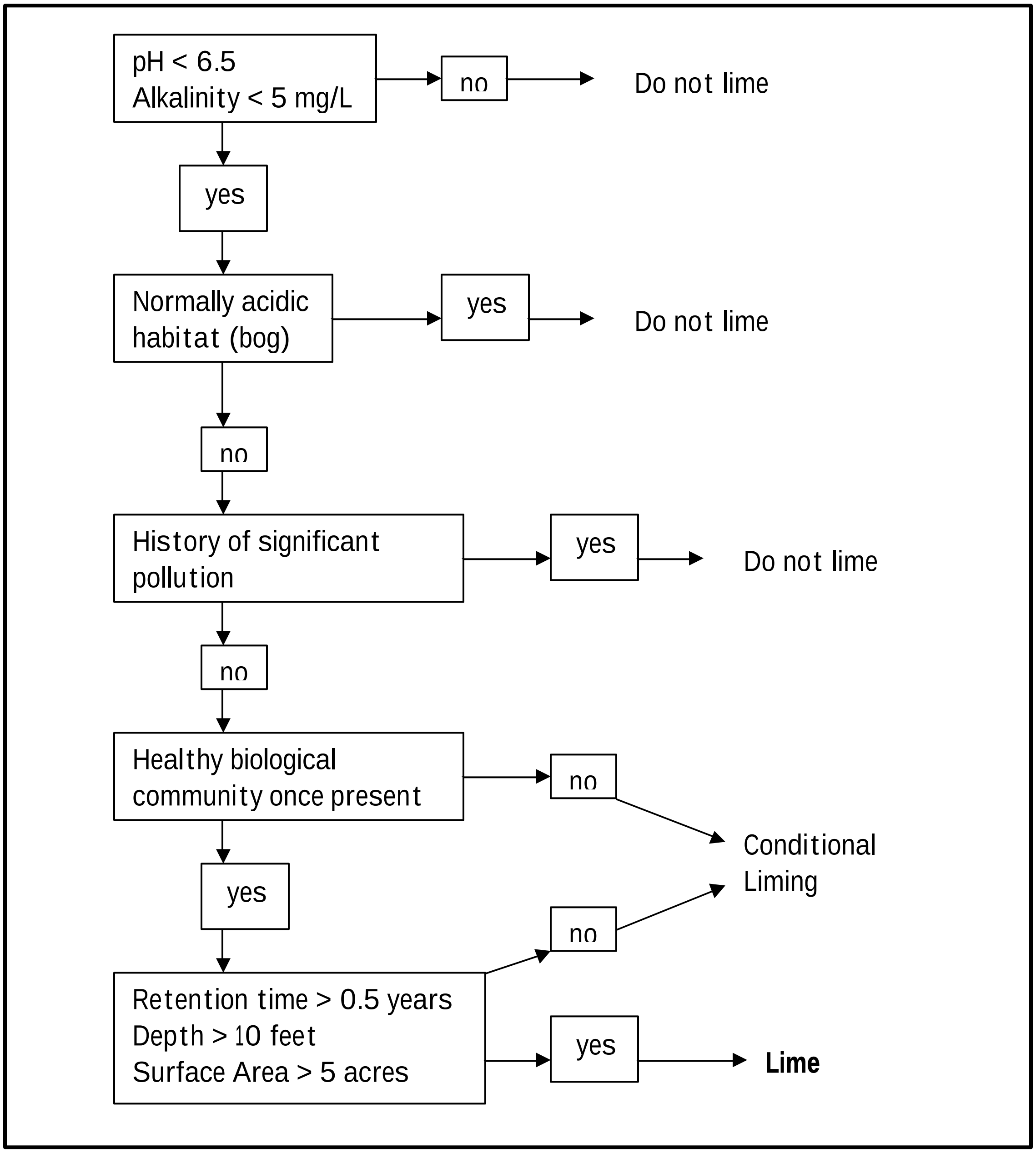


Figure 1.3-1 Flow chart showing specific considerations for evaluating the need for a liming project

Design Considerations

If the results of the feasibility assessment conclude that the lake is a good candidate for liming, and all permits have been approved, the first step in the process is to find a source for the limestone material. The cost of the project will be determined not by the cost of the material, but rather by the transportation costs associated with delivering the material to the site. Therefore, it is important to find a supplier that has good quality material as close to the project site as possible.

Not all limestone is suitable for a lake liming project. Three properties should be taken into consideration when choosing material.

- The calcium content expressed as either $CaCO_3$ or CaO,
- The average particle size of the limestone, and
- The inert materials, besides calcium, that are contained in the limestone.

Since a primary goal of lake liming is to improve the buffering capacity of the lake by increasing the calcium content, material with a higher calcium content will require less to achieve that goal. For example, if 100 tons of limestone has a calcium content of 90 percent, the net result of applying the 100 tons of material to your lake will be 90 tons of buffering capacity. Similarly, if the 100 tons of material has a calcium content of 75 percent, the resulting buffer capacity will be equivalent to 75 tons. Therefore, you would need 115 tons of the limestone with a 75 percent calcium content to achieve the same buffering capacity as 100 tons of limestone with a 90 percent calcium content. In a large-scale lake liming project, the amount of material required to achieve the desired buffering capacity could substantially increase the overall project cost.

A second factor to consider when choosing limestone is particle size. Particle size is directly related to how easily the material will dissolve when placed in water. Course agricultural limestone, although readily available, has a very large particle size and does not dissolve well. Finely ground limestone with an average diameter between 10 and 30 µm is a better choice for lake liming projects. The fine particle size quickly dissolves, providing adequate neutralization of the acidity within the water column. In addition, enough of the material will find its way to the bottom of the lake to provide residual sediment neutralization, which will slow the process of reacidification.

The third consideration in choosing limestone is the composition of inert materials. Various organic substances, phosphorous, aluminum, manganese, mercury, and lead are a few of the inert materials that can be present in limestone. If present in high enough concentrations, these materials can have toxic effects on the aquatic community when they dissolve into solution. Therefore, limestone that has a high calcium content and very few inert materials is best.

Once the limestone has been acquired, it must be applied to the lake surface. The simplest method is to treat the lake in the winter when it is covered with ice. A spreader towed behind a tractor evenly distributes the limestone material across the ice, and when the ice melts the limestone is dispersed throughout the water column.

A second, more commonly used technique is to mix the powdered limestone with lake water as a slurry and dispense it across the lake surface by boat. Although more labor intensive than spreading the material on ice, timing is less critical, and the applicator has greater flexibility to adjust rates according to varying depths and water quality conditions.

Maintenance Recommendations

Once the lake has been treated, it is critical that water quality monitoring continue. At a minimum, pH and alkalinity should be monitored at the surface, mid-depth and immediately above the sediment in the deepest part of the lake. Samples collected within the first few weeks after the liming will provide data that can be used to determine whether the project goals were fulfilled (e.g. pH less than 6.5, total alkalinity greater than 10 mg/L). Subsequent monitoring will help determine when or if additional liming is required to maintain the buffering capacity at the desired level.

In addition to water quality monitoring, it is useful to evaluate the success or failure of the project by recording changes in the biological community. Changes in the species composition and extent of aquatic plant growth in the lake, the presence or absence of amphibians (frogs and salamanders), and the quality of the fishery will all serve as indicators of the success of the project.

Cost Considerations

Project costs will vary depending upon accessibility, travel distance from the supplier to the project site, and differences in local labor costs. Table 1.3-1 provides some guidance on anticipated project costs for the application methods described above.

Table 1.3-1
Summary of Typical Lake Liming Costs

Application Method	Materials (Cost/Ton)	Application (Cost/Ton)
Boat –slurry	$25 - $100	$25 - $250
Tractor - ice	$25 - $100	$25 - $100

References

Brocksen, R. W., M. D. Marcus, and H. Olem. 1992. Practical Guide to Managing Acidic Surface Waters and Their Fisheries. Lewis Publishers, Inc., Chelsea, MI.

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1.4 Alum Treatment

The use of aluminum salts as a lake best management practice (BMP) began in the early 1980s and has since become an effective and efficient method of phosphorus inactivation. Aluminum sulfate (alum) and sodium aluminate are the most prevalent compounds used in sediment phosphorus inactivation treatments. The alum combines with the phosphorus in the lake water, settles to the bottom of the lake, and "seals" the bottom sediments. Once the sediments are "sealed," phosphorus cannot be released and resuspended during anoxic lake conditions. The objective is to reduce the amount of phosphorus available in the lake for algal growth.

A number of salts have been used for lake phosphorus inactivation, including aluminum, calcium and iron. The application of aluminum salts has been the most effective method, in terms of long-term effectiveness. Alum controls the release of phosphorus from sediments through the formation of aluminum hydroxide (Al(OH)3) floc. Aluminum hydroxide forms complexes, chelates and insoluble precipitates with phosphorus. These aluminum complexes and polymers are inert to redox changes in the sediments and effectively trap inorganic and particulate phosphorus from the water column. In lakes with a well-buffered pH, alum is used alone. The addition of sodium aluminate is used to buffer waters that have a low pH and/or buffering capacity. In either case, the treatment is often referred to by the generic term "Alum Treatment."

Two methods of alum treatment are available and commonly practiced where warranted: batch alum treatment and continuous alum treatment. A detailed feasibility study should be performed to adequately evaluate the viability and cost effectiveness of each alum treatment alternative for a given lake or pond. Water quality monitoring should be conducted as part of the feasibility study, including bench-scale laboratory jar tests to determine the application rate of the alum, and in-lake testing of pH and alkalinity. Flow monitoring should also be conducted at the lake before initiation of alum treatment in order to document the flushing rate and determine the necessary frequency of alum application.

As with the addition of any potentially toxic substances to the waters of the Commonwealth, the Pennsylvania Department of Environmental Protection (DEP) and the Pennsylvania Fish and Boat Commission should be contacted during the early planning stages of the project in order to determine what permits might be necessary.

1.4.1 Batch Alum Treatment

Batch alum treatment involves adding a large batch of alum at a given time to bind phosphorus in a lake. Alum is added to the water column to precipitate suspended phosphorus, or directly to the hypolimnion to inhibit phosphorus release from the sediments, or both. This method typically helps to improve water quality in the lake immediately and over a long time period as long as additional phosphorus inputs to the lake are minimized prior to treatment. Studies show that the effects can last 15 years or more in stratified lakes and around 10 years for unstratified lakes (Welch and Cooke, 1999).

Applicability

Batch alum treatment is generally used in lakes that exhibit long retention times with little flushing. It us usually applied to shallow lakes, but has been used in both stratified and unstratified lakes. The advantage of batch alum treatment is that dissolved and particulate phosphorus (including algal cells) are removed from the lake via settling, resulting in an immediate and dramatic improvement in lake phosphorus and chlorophyll a concentrations as well as transparency. This method should be used only when phosphorus loads to the lake (via stormwater or other point or nonpoint sources) are addressed and minimized. Alum can be applied to lakes with one or more inlet streams; however, settling basins may need to be installed at the inlets in order to allow for adequate settling time of the precipitate.

Smaller doses of alum are sufficient to precipitate phosphorus that is suspended in the water column. The disadvantage to small dose alum treatment is that much of the phosphorus-binding capacity of the aluminum may be used up prior to its reaching the sediments. Redistribution of the aluminum floc by wind and water currents may occur prior to settling, resulting in incomplete bottom coverage. Long-term control of sediment release is best accomplished using a larger dose of alum applied directly to the lake hypolimnion. This will reduce the resuspension of phosphorus into the water column from the lake sediments under anoxic conditions. However, if large doses of alum are applied, the potential for elevated aluminum levels and low pH exists. Aluminum can be toxic to aquatic organisms, and low pH can disrupt the aquatic ecosystem. Low pH impacts can be mitigated by the combined use of sodium aluminate and aluminum sulfate. In addition, the increase in lake transparency resulting from the elimination of suspended solids in the water column can increase the amount of aquatic vegetation in a lake.

Poorly buffered lakes, such as mountain lakes that are more seriously affected by acid rain, are not good candidates for alum treatment. This is because aluminum is more toxic to fish and other aquatic life at low pH. However, in well-buffered lakes, most of the aluminum quickly drops out of the water column and remains in the sediment, rendered harmless to aquatic life. In addition, lakes with extremely high nutrient and sediment loads may not be good candidates for alum treatment since the precipitate may be excessive, filling the lake with additional sediment.

Design Considerations

Batch alum is best combined with lake water to form a slurry prior to application. The slurry can then be applied directly to the lake surface through a manifold. Modes of application include modified harvesting equipment, outfitted pontoon boats, and specially designed barges. Suspended, dissolved and particulate matter is precipitated from the water column after application. The precipitated matter sinks to the lake bottom over a period of a few hours to a few days, where it remains inactive, bound to the alum. Alternatively, batch alum can be applied directly to the hypolimnion.

Jar tests are necessary prior to alum treatment to determine appropriate alum dosage for effective phosphorus inactivation and to determine if buffering is required to maintain pH levels. A 2:1 ratio of aluminum sulfate to sodium aluminate should provide adequate buffering to maintain ambient pH, unless the pH is abnormally high because of excessive algal photosynthesis (Jones, et. al., 2001). Sodium hydroxide can also be used for buffering. The recommended dosage for buffered alum is 20 pounds per acre-foot (McComas 1993). One acre-foot is the area of an acre (43,560 square feet), one foot deep.

Permits are required from the Pennsylvania DEP whenever any chemical addition to a body of water is planned. Different permits may be necessary depending on the nature and extent of the project. Contact your regional DEP office to determine which permits are required. Since the ecological implications of alum application to a lake are complex, alum treatment is best accomplished under the direction of a lake professional.

Cost Considerations

The initial costs of batch alum treatment are relatively high, ranging from $500 to $1,000 per acre. The cost range for a hypothetical 100-acre target area over a hypothetical 20-year period is estimated at $50,000 to $200,000 (Jones, et. al., 2001). However, the positive results of the treatment are long-lasting and maintenance costs are fairly nonexistent. Therefore, if it is effective, the overall lake treatment costs may be reduced over the course of several years. Alum treatment is more cost-effective and less ecologically risky over time than other in-lake management strategies such as dredging or frequent algaecide application.

1.4.2 Continuous Alum Treatment

The continuous alum method (also known as alum injection) involves a flow-weighted alum dosing system designed to fit inside a storm sewer manhole. This method is a relatively new in-lake BMP used to reduce phosphorus inputs. Alum treatment of stormwater runoff with this method has consistently achieved a 90 percent reduction in total phosphorus, 50-70 percent reduction in total nitrogen, 50-90 percent reduction in heavy metals, and greater than 99 percent reduction in fecal coliform (Harper et al. 1998). With proper design and operation, continuous alum treatment produces little or no impact on benthic organisms or other aquatic life. Alum treatment systems consistently provide the highest removal efficiencies of any stormwater retrofit alternative and typically require no land acquisition (Herr and Harper, 1997).

Applicability

Continuous alum treatment is typically used in unstratified lakes with short retention times to remove nutrients and sediments from the incoming waters at or near the lake inlets. Alum injection systems are applicable only to lakes where the locations of all the major stormwater inputs to the lake (for example, storm drains) are known. Because of high installation and operation costs, alum injection is best applied to situations where a large volume of water is stored in one area, as in the case of combined sewer overflow (CSO) storage areas at wastewater treatment plants. Alum treatment can also be implemented as a pretreatment step to further reduce turbidity and total suspended solids (TSS). Conventional alum injection treatment systems use continuous dosing to remove nutrients and sediments during both baseflow and stormflow conditions. However, to increase the efficiency and cost effectiveness, alum dosing may be designed to occur only during stormflow conditions when nutrient and sediment concentrations are elevated to problematic levels. Alum dosing may not be necessary or may be significantly reduced during baseflow conditions when nutrient and sediment inputs are generally low.

Continuous alum systems can be extremely cost-effective in areas where land availability around a lake is minimal for more traditional stormwater BMPs, or where the land is prohibitively expensive. Both installation and operation and maintenance costs for alum systems are lower than for traditional stormwater facilities such as retention basins. Nutrient removal efficiencies are similar to removal efficiencies obtained using a dry retention or wet detention basin facility (Harper et al. 1998).

Design Considerations

In a typical continuous alum system, alum is added to the stormwater outfalls on a flow-proportioned basis. Dosage rates, which range from 5 to 10 mg of Al per liter, are determined on a flow-weighted basis during storm events. A variable speed chemical metering pump (injection pump) is typically attached to each incoming stormwater line. Each injection pump is regulated by a flow meter. A separate metering system and storage tank controls the application of a buffering agent if required to maintain desired pH levels. Data from each stormwater flow meter is transformed into a 4-20 mA electronic signal that instructs each metering pump to inject alum according to the measured flow through each individual line. Mixing of the alum and stormwater occurs as a result of turbulence in the inflow line. If sufficient turbulence is not available within the line, artificial turbulence can be generated using aeration or physical modifications. Injection points in the pipes should be 100 feet upstream of the discharge points. The design should incorporate sufficient chemical storage in tanks to minimize the frequency of the need to be refilled.

Conventional continuous alum treatment allows the alum and the nutrient/sediment precipitate, or floc, to flow into the lake and be deposited to the lake bottom. Some recent designs include the use of a floc settling facility to prevent the floc from entering the lake and increasing the sedimentation rate. Certain facilities use automated sump pump units to maintain the settling facility by transporting the floc into sanitary sewer systems for ultimate disposal. Permits are required to pump floc to the sanitary sewer; contact the Regional DEP office for more information. The quantity of sludge produced at a site can be as much as 0.5 percent of the volume of water treated (US EPA, 2002).

Maintenance Recommendations

Operation and maintenance for alum treatment is critical. Routine inspection and repair of equipment, including the doser and pump-out facility, is necessary. A trained operator should be available to regulate the dosage of alum and other chemicals, as well as the flows through the basin. If floc is stored on-site in drying beds, it will need to be disposed of on a regular basis. In addition, any settling basins will need to be dredged periodically to dispose of accumulated floc. Regulatory agencies require continued monitoring of water quality for alum systems, which increases maintenance costs.

Cost Considerations

Estimated construction costs for alum stormwater treatment facilities range from $75,000 to $400,000, depending on the type of system and the number of inlets or outfalls to be treated. Typical operation and maintenance costs for chemicals, power, equipment replacement, and routine inspections range from approximately $5,500 to $27,000 per year (Harper et. al., 1998). If power transmission lines exist in close proximity to the lake, the costs to install power lines to the system are minimal; however, if there are no power lines nearby, line extension needs to be factored into the cost.

1.4.3 References

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Harper, H.H., J.L. Herr, and E.H. Livingston. 1998. Alum Treatment of Stormwater Runoff - An Innovative BMP for Urban Runoff Problems. pp. 205-211.

Herr, J.L.. P. E. and H.H. Harper, Ph.D., P.K, 1997. The Evaluation and Design of an Alum Stormwater Treatment System to Improve Water Quality In Lake Maggiore In St. Petersburg, Florida. Fifth Biennial Stormwater Research Conference Proceedings.
Website: http://stormwater-resources.com/library.htm#New%20Papers.

Jones, C. W. and J. Taggart, 2001. Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute in cooperation with the Office of Water, Assessment and Watershed Protection Division, US EPA. Madison, WI.

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1.5 Chemical Algal Control BMPs

Algal control in lakes and ponds is often a challenging undertaking. Algae are either planktonic or filamentous. Planktonic algae (phytoplankton) are microscopic free-floating aquatic plants. Filamentous algae grow along the lake bottom and often rise to the surface as mats. Algae, unlike higher aquatic plants, acquire nutrients directly from the water column for growth. Algae is not easily harvested and the control of these plants often involves treating the entire lake as opposed to confined lake areas.

High nutrient concentrations are the cause of excessive algae growth. In balanced aquatic systems, algae populations do not reach nuisance proportions because the amount of available nutrients is not sufficient to allow excessive growth. However, when large concentrations of nutrients become available to algae populations, the algae quickly consume the nutrients resulting in excessive growth or "algal blooms".

In healthy lake environments, it is not uncommon for algal blooms to occur immediately following the spring and fall overturn. One should not necessarily become alarmed if the lake experiences these seasonal bursts in algae growth. However, if excessive algae growth occurs throughout the growing season, then implementing one or more of the following chemical algal control BMPs may be considered. In addition to these in-lake algal BMPs, implementation of many of the watershed BMPs outlined in Chapter 2 can help reduce the nutrient loads to the lake, thereby reducing the excessive growth of algae.

Permits are required from the PA DEP and/or PA Fish and Boat Commission whenever any potentially harmful chemical addition to a body of water is planned. Different permits may be necessary depending on the nature and extent of the project. Contact your regional DEP office to determine which permits are required. Since the ecological implications of algal controls are complex, it is best accomplished under the direction of a lake professional.

1.5.1 Algaecides

Algaecides are chemicals applied to lakes to control excessive algal growth. Algaecides restrict algal growth by affecting the individual organism's ability to photosynthesize. Once photosynthesis has been interrupted, the algae are no longer able to metabolize nitrogen and they die. Copper sulfate ($CuSO_4$) is the most widely used algaecide. This chemical has been available as an algal control for many years and is known to many as "bluestone".

Applicability

Algaecides are an effective, inexpensive BMP for controlling excessive algae growth. Results are often seen within days after the treatment and normal activities in the lake can quickly be resumed. In addition, no specific water use restrictions must be observed following the use of these products.

Although algaecides are an attractive, low-cost, quick-fix option for many lakes, they do have some disadvantages. Depending on nutrient concentrations in the lake, algae growth may begin again within days after a chemical algaecide treatment. Therefore, use of chemical algaecides should not be considered a restoration technique, but rather a short-term control for a symptom that has resulted from a much larger lake management problem.

Algaecides have been shown to be toxic to certain fish species. More specifically, species such as trout, grass carp, and koi cannot withstand concentrations of copper that are normally acceptable to other fish species. The potential toxicity of the copper to these species is reduced as water hardness increases.

Additionally, prolonged or excessive use of copper sulfate and/or one of its many formulations can result in the following adverse effects:

- Use of chemical algaecides to treat large areas of excessive algae growth will deplete dissolved oxygen concentrations, which may result in fish kills.
- Over time, copper can accumulate in the sediment, which may adversely affect the health of bottom-dwelling organisms that comprise the lower levels of the aquatic food chain.
- Accumulated copper in lake sediments can increase the cost of dredging projects, since dredged sediments containing copper are considered hazardous materials. Hazardous materials are much more expensive and difficult to dispose of.
- Certain species of blue-green algae can build up a tolerance to copper with prolonged use.

Design Considerations

Normally, copper sulfate is purchased in granular or powder form, although it also available in a variety of different liquid formulations. The powdered or granular form of copper sulfate is the purest form (>99% $CuSO_4$), whereas the liquid formulations consist of lower concentrations of copper sulfate combined with other chemical agents that allow them to persist in the water column for longer periods of time. As with the purchase of any chemical product, it is very important to read the product label to determine exactly what is being applied to the lake. Table 1.5-1 provides a summary of the most commonly used chemical algaecides, information on what algae species they control, and the recommended dosage rate.

Table 1.5-1 Commonly Used Chemical Algaecides			
Chemical Name	**Active Ingredient**	**Controls**	**Dosage**
Copper Sulfate	99% $CuSO_4$	Algae, flagellated Protozoans	0.68–1.36 lbs./acre ft.
Cutrine-Plus (Liquid)	Copper, elemental 9%	Algae (planktonic/filamentous) Chara & Nitella	0.6 gal./acre ft. 1.2 gal./acre ft.
Cutrine-Plus (Granular)	Copper, elemental 3.7%	Algae (planktonic/filamentous) Chara & Nitella	60 lbs./acre
Earthtec	Copper, elemental 5%	Algae (planktonic/filamentous) Chara & Nitella	0.22 gal./acre ft.
Hydrothol 191	Monopotassium salt of endothall, 53%	Algae (planktonic/filamentous) Chara & Nitella	0.6-2.2 pints/acre ft.
K-Tea	Copper, elemental 8%	Algae (planktonic/filamentous) Chara & Nitella	0.7-1.7 gal./acre ft. 1.7-3.4 gal/acre ft.

The type of algae being controlled will determine which chemical formulation is best suited for the specific application. For example, copper sulfate is best suited for control of surface-growing filamentous and planktonic algae, whereas the other copper formulations are better suited for control of bottom growing filamentous or attached algae. The target algae species should be identified prior to purchasing an algaecide so that the chosen algaecide will be most effective. Several good sources of information are available, but one of the most useful references is "Water Weeds and Algae (5th edition)" from Applied Biochemists. The book can be ordered on their website at http://www.appliedbiochemists.com or by calling 1-800-558-5106.

Lake water chemistry can also influence which form of copper sulfate is best suited for use in a given lake or pond. In extremely alkaline lakes with calcium carbonate ($CaCO_3$) concentrations greater than 150 milligrams per liter (mg/l), or in lakes with a high organic content, copper sulfate does not remain suspended in the water column and quickly settles to the bottom where it binds with the sediment. In either of these two situations, a copper sulfate formulation that remains suspended in the water column for a longer time period (e.g. Cutrine or Earthtec) is a better choice.

Application methods for algaecides vary between the different products. One of the easiest ways to apply copper sulfate to a lake is to place the proper amount of chemical in a nylon stocking or burlap bag and drag it around the lake behind a boat. Granular forms of the chemical can be applied using a common broadcast spreader, while the liquid forms are best applied using a mechanical sprayer. An algaecide can be applied either directly to the water surface or immediately below the surface depending upon where in the water column the algae is growing (i.e floating on the surface, suspended, or growing on the bottom). The most important consideration is that regardless of the application method, the longer the copper is in contact with the algae, the better the results.

Cost Considerations

An algaecide is very economical BMP in terms of short-term results. However, over the long term, if multiple applications are necessary, the cost-effectiveness may be reduced. In order to calculate the overall cost of a treatment one must first consider the following:

- The size of the treatment area and cost of chemicals required for the specified dosage,
- The longevity of the treatment determined by the effectiveness of chemical algaecide applied,
- The costs associated with acquiring any necessary permits required to apply the chemicals, and
- Labor charges and fees for professional applicators to apply the algaecide.

Applied at a rate of 0.68–1.36 lbs./acre ft., a copper sulfate treatment will range in cost from $1 to $2 per acre-ft for materials. Liquid copper formulations cost more, ranging from $25 to $50 per gallon, but are much easier to apply. Liquid formulations contain less copper and material costs to treat a surface acre with these formulations will range between $50 and $100.

It is also important to determine whether a professional applicator will be required to apply the algaecide. In Pennsylvania, if the lake is open to the public, the algaecide must be applied by a licensed applicator. Typically, applicators charge a one-time fee to mobilize their equipment, plus an hourly rate to apply the chemical. Regardless of who applies the chemical, a permit must be obtained from the Pennsylvania Fish and Boat Commission prior to application. No fee is charged for the application, but permit approval does take several weeks. Therefore, it is important to apply for the permit well in advance of the proposed treatment.

References

Applied Biochemists. 1998. How to Identify and Control Water Weeds and Algae (5th Edition). Website: http://www.appliedbiochemists.com/.

1.5.2 COLORANTS

As an alternative to algaecides, colorants or dyes can be used as an algal control BMP. Colorants can also inhibit nuisance macrophyte growth. Colorants are often considered a more acceptable BMP than algaecides because they are not commonly viewed as "chemical treatments". Colorants differ from algaecides in that they don't directly affect the algae organism. Instead, colorants consist of a blend of blue and yellow dye specifically designed to screen out portions of the sunlight spectrum (red-orange and blue-violet) required by aquatic plants and algae for growth. Without sunlight, photosynthesis cannot occur and the algae and macrophytes die. Therefore, the use of a colorant as an algae control BMP is often more acceptable than the use of algaecides and creates less controversy among lake users. Because colorants are dyes, there are no specific water-use restrictions associated with their use. In addition, they are not toxic to fish.

APPLICABILITY

Colorants are most effective in lakes with high nutrient concentrations that are two meters deep or greater. If treated early enough in the season, colorants effectively control the early stages of algal growth that occur near the lake bottom, and therefore can potentially provide control throughout the entire season. Since colorants block sunlight throughout the entire water column, they can be used to control both filamentous and planktonic algae. Colorants also dye the lake water a pleasing aqua-blue, potentially enhancing the aesthetic beauty of the water body.

Lakes that have a high flushing rate (short hydraulic residence time) will require repeated applications of the colorant. In this situation, complete shading is not maintained and algae will have the opportunity to grow. Lakes with limited flow or low flush rates require less frequent applications and constant shading is much easier to maintain.

DESIGN CONSIDERATIONS

A number of different products are available for use as colorants. Of these, Aquashade® is the only one registered with the U.S. EPA for use in aquatic environments. Prior to purchasing any other brand of colorant for algae control, it is important to gain approval for use from regulatory agencies.

Colorant application rate is determined based on lake basin volume. In larger waterbodies it is more difficult to determine basin volume; therefore, the use of colorants for algal control is most effective in smaller lakes. Overestimating basin volume will result in adding too much colorant, which will cause the lake water to turn very dark blue to black. If basin volume is underestimated, not enough colorant will be used, complete shading will not occur, and algal growth will be unaffected. In addition, the volume of colorant required to provide complete shading makes it cost prohibitive in larger lakes.

Colorants are available in liquid or solid form. They can be applied to a lake without any specialized equipment. The colorant must be thoroughly dispersed throughout the lake to ensure complete shading.

Cost Considerations

Colorants are very inexpensive to use in terms of treatment success, and are cheaper than other algal control methods. For example, to treat a one-acre pond with an average depth of four feet with Aquashade® would require one gallon of material which would cost between $30 and $50. A similar treatment with an algaecide may cost between $50 and $100. In addition, most colorants do not have to be applied by a licensed applicator. This eliminates additional fees for chemical application. However, it is still important to check with the regulatory agencies (Pennsylvania DEP regional office or Fish and Boat Commission) regarding any specific restrictions or regulations that may pertain to the use of colorants in a particular area.

References

Applied Biochemists. 1998. How to Identify and Control Water Weeds and Algae (5th Edition). Website: http://www.appliedbiochemists.com/.

1.6 Macrophyte Control BMPs

More than 1,100 freshwater aquatic plant (macrophyte) species can be found throughout the United States. Of this total, only 20 to 30 types of aquatic plants may be found in a given lake and only several types may adversely affect desirable lake uses (McComas 1993). Aquatic macrophytes are aquatic vascular plants - meaning they are aquatic plants with conducting cells to transport nutrients and liquid through their stems. Aquatic macrophytes are generally grouped into three classes: emergents (e.g. arrowhead, bulrushes, cattails), floating leaved (e.g. spatterdock, water lilies) and submergents (e.g. pondweeds, watermilfoils, naiads). The typical zonation of aquatic macrophytes in a lake is shown in Figure 1.6-1.

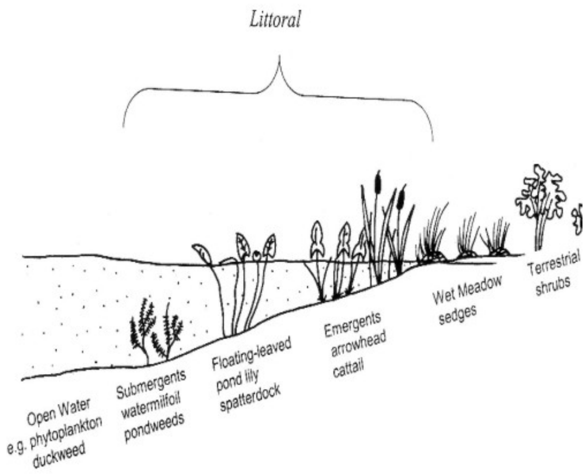

Figure 1.6-1 Littoral vegetation zonation for a typical lake
Source: Jones and Taggart 2001

Nuisance levels of aquatic vegetation can create major problems for lake users. Overabundant macrophytes can interfere with recreation (fishing, boating and swimming) and can adversely affect aesthetics. In extreme cases, dense stands of macrophytes can cover the entire surface and occupy most of the water column (Jones and Taggart 2001). However, there are a number of benefits associated with aquatic plants or macrophytes. These benefits are:

- Macrophytes protect the shoreline from erosion by dampening the force of waves and stabilizing soils.
- Rooted macrophytes provide fish habitat and spawning sites, waterfowl cover and food, and habitat for macroinvertebrates (insects, snails, etc.).
- Many species of macrophytes such as the white water lily and pickerelweed are aesthetically pleasing because of beautiful flowers and interesting forms (Jones and Taggart 2001).

Dense stands of Eurasian Watermilfoil near a boat launch ramp at Pinchot Lake in York County.
Source: Edward Molesky of Aqua-Link, Inc.

The major methods for controlling nuisance levels of aquatic macrophytes can be grouped according to their modes of action. The four major modes of action are physical, biological, chemical and habitat manipulation. Physical controls, which often require the use of specialized equipment to remove or damage all or a portion of the plants, include a wide variety of BMPs such as mechanical harvesting, hydroraking and rototilling. Biological controls involve the stocking of aquatic organisms to consume and damage nuisance stands of aquatic vegetation. Common biological controls are the use of grass carp and aquatic insects. Chemical controls involve the use of aquatic pesticides (herbicides) to kill nuisance aquatic plants. Chemical controls are probably the oldest and most widely used methods of controlling nuisance aquatic plants. Lastly, habitat manipulation involves altering the environment, thereby making the lake less desirable for the growth of aquatic vegetation. BMPs commonly associated with this mode of action are water level drawdown and the use of benthic barriers.

References

McComas, S. 1993. Lake Smarts – The First Lake Maintenance Handbook. U.S. EPA. Office of Water & Office of Wetlands, Oceans and Watersheds. Washington, D.C.

Jones, C. W. and J. Taggart, 2001. Managing Lakes and Reservoirs. N. Am. Lake Management Society and Terrene Inst., in cooperation with Off. Water, Assessment and Watershed Protection Division US Env. Protection Agency, Madison, WI.

Olem, H. and G. Flock, eds. 1990. Lake and Reservoir Restoration Guidance Manual, 2nd Edition. EPA 440/4-90-006. Prep. by N. Am. Lake Management Soc, for U.S. EPA, Washington, DC.

1.6.1 Water Level Drawdown

Water level drawdown is a BMP used to control nuisance aquatic vegetation. This BMP can be used only if the water elevation in a lake can be easily lowered for an extended period of time. In Pennsylvania, water level drawdowns for macrophyte control are beneficial only during the winter months.

Exposed sediments and aquatic macrophytes during a winter drawdown at Shawnee Lake in Bedford County. Source: Edward Molesky of Aqua-Link, Inc.

Water level drawdown exposes sediments to prolonged periods of freezing and drying. Under such conditions, some rooted aquatic plants, including their roots and seeds, are permanently damaged. Permanent damage generally requires two to four consecutive weeks of freezing.

However, some species may be unaffected or enhanced by water level drawdowns (Olem and Flock 1990). The effects of winter drawdown on certain plant species are listed in Table 1.6-1.

Table 1.6-1 The Effect of Drawdown on Selected Plant Species		
Drawdown Effect	**Plant Species**	**Common Name**
Decrease	*Cabomba caroliniana*	Fanwort
	Ceratophyllum demersum	Coontail
	Myriophyllum spp.	Milfoil - most species
	Potamogeton robbinsii	Robbin's pondweed
	Nuphar spp.	Yellow waterlily - most species
	Utricularia spp.	Bladderwort
No change or variable	*Chara spp.*	Muskgrass - most species
	Elodea Canadensis	Elodea
	Typha latifolia	Broad-leaf Cattail
	Valisneria americana	Tapegrass
Increase	*Potamogeton spp.*	Pondweed - most species
	Najas flexilis	Bushy pondweed

Source: NYS DEC 1990

Applicability

Water level drawdown is generally limited to lakes having either a dam structure or some other method for controlling the lake level. Drawdowns are generally performed during the months of November through March in Pennsylvania. Most of the literature strongly suggests that both freezing and desiccation are required for at least two to four consecutive weeks. Wet, cold lake sediments or wet sediments covered by snow may have little impact on the targeted plant species.

Some potential negative impacts that may be associated with this practice are:

- Loss of use of the lake during the drawdown.
- Reduction of populations of benthic macroinvertebrates as food source for fish.
- Dissolved oxygen depletion in the remaining pool of lake water. A fishkill can occur if dissolved oxygen concentrations are severely depleted.

- Reduction in the populations of beneficial macrophytes. However, native plants typically recolonize fairly rapidly.

- Algal blooms related to the release and resuspension of nutrients from exposed sediments.

Design Considerations

It is recommended that a qualified lake professional or aquatic biologist perform an aquatic plant macrophyte survey prior to implementing a water level drawdown. During this survey, macrophytes should be identified and the required depth of the drawdown should be determined.

Water level drawdowns require an approved permit from the Pennsylvania Fish and Boat Commission (PFBC). Copies of the permit application can be obtained from the PFBC website at www.fish.state.pa.us or by contacting PFBC Headquarters at:

Pennsylvania Fish & Boat Commission
1601 Elmerton Avenue
P.O. Box 67000
Harrisburg, PA 17106-7000
Ph: 717-705-7800

Maintenance Recommendations

Water level drawdowns should be implemented once or twice every three years. At this frequency, water level drawdowns will discourage the establishment of resistant plant species, which are often the non-native plants that were the original target of the drawdown (NYS DEC 1990). In addition, annual macrophyte surveys should continue after the drawdown to determine the effectiveness of the practice and the need for additional macrophyte control.

Cost Considerations

Initial Cost

The expense of a water level drawdown is minimal if the water level of the lake can be adjusted via an outlet control structure at the dam. The cost will increase substantially if water must be pumped from the lake. An aerator may need to be installed temporarily if dissolved oxygen levels become severely depleted in the remaining pool of lake water.

Other lake work can be scheduled during the time of water level drawdowns, which will decrease the costs of each project. This work may include installing fish habitat structures, repairing dams and docks, dredging accumulated sediments, and installing benthic barriers.

MAINTENANCE COSTS

The only maintenance costs associated with this lake BMP are the costs of the annual ecological survey.

REFERENCES

Pennsylvania Fish & Boat Commission Website http://www.state.pa.us.

New York State Department of Environmental Conservation (NYS DEC). 1990. Diet for a Small Lake – A New Yorker's Guide to Lake Management. Albany, New York.

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Olem, H. and G. Flock, eds. 1990. Lake and Reservoir Restoration Guidance Manual, 2nd Edition. EPA 440/4-90-006. Prepared by North American Lake Management Society for U.S. EPA. Washington, DC.

1.6.2 BENEFICIAL INSECTS

Both non-native and native beneficial insects have been used to control nuisance rooted aquatic plants (macrophytes) in the United States. Ten different non-native insect species have been imported to the U.S. under quarantine and have received U.S. Department of Agriculture approval for release to U.S. waters. These insects, which include aquatic larvae of moths, beetles (includes weevils) and thrips, have life histories specific to certain host plants. All of these host plants such as alligatorweed, hydrilla, water lettuce and water hyacinth are generally associated with southern waters. Native insects, which include the larvae of midgeflies, caddisflies, beetles (includes weevils) and moths, appear to be promising as aquatic plant management controls in northern states like Pennsylvania. At this time, the native aquatic weevil (*Euhrychiopsis lecontei*) has received most of the attention and is the focus of this section (Jones and Taggart 2001).

Larva on stem of Eurasian watermilfoil. Source: University of Minnesota.

APPLICABILITY

The aquatic weevil (*Euhrychiopsis lecontei*) has been stocked in some lakes of nearby states to Pennsylvania (e.g., New Jersey, Ohio, Vermont) to control nuisance stands of Eurasian watermilfoil (*Myriophyllum spicatum*). It is believed that this species of weevil has been historically associated with northern watermilfoil

(*Myriophyllum sibericum*) and will feed upon the more aggressive, non-native Eurasian watermilfoil if introduced. Native aquatic weevils feed exclusively upon watermilfoil during their larval stages. The life cycle of the aquatic weevil begins when adult weevils lay eggs on the growing tips of watermilfoil plants. The eggs hatch within a week and the larvae begin to feed upon the plant. Eventually, the larvae form pupae in the lower stem of the plants. Adult weevils hatch out and swim to the top of the plants to complete the life cycle. The life cycle of the weevil may go through three instars during a summer. In the fall, adult weevils move to plant litter along the lake margin. In the spring, the adults fly back to the plants and start laying eggs once again.

Design Considerations

If biological control of watermilfoil using weevils is being considered, a qualified lake professional or aquatic biologist should perform an aquatic macrophyte survey of the lake. Based upon this survey, a macrophyte distribution map should be produced and used to develop an aquatic weevil stocking program.

Aquatic weevils are sold commercially for milfoil control. Weevils are usually applied by releasing them from cages or onto individual stems. For good control, the literature recommends approximately one to three weevils per stem (Jones and Taggart 2001). If this biological control method is employed, water level drawdowns must be discontinued in those stocked areas. Any mechanical harvesting and aquatic herbicide treatments should be discontinued as well.

Maintenance Recommendations

Annual macrophyte surveys should continue after stocking to determine the effectiveness of the practice and the need for additional stocking.

Cost Considerations

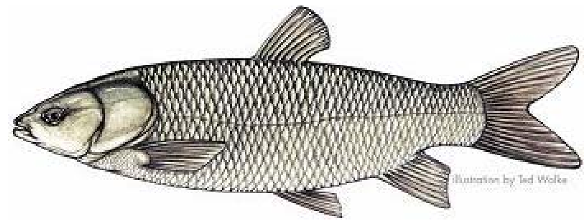
Initial Cost
A typical stocking density for adult weevils is approximately 2,000 to 3,000 adult weevils per acre. The cost per insect is about $1. Other associated costs include the cost of an aquatic macrophyte survey by a qualified lake professional.

Maintenance Costs
The only maintenance costs associated with this lake BMP are the costs of the annual ecological survey, and possible restocking.

References

Jones, C. W. and J. Taggart, 2001. Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute in cooperation with the Office of Water, Assessment and Watershed Protection Division, US EPA. Madison, WI.

1.6.3 Grass Carp



Grass Carp
Source: PA Fish & Boat Commission

Grass Carp (*Ctenopharyngodon idella*), or white amur, was introduced into the United States from East Asia in the 1960s as a potential food fish and to control aquatic vegetation. By 1976, grass carp had been stocked in or spread to (traveling by rivers) 35 to 40 states. Grass carp are voracious feeders on aquatic vegetation, eating many pounds in a single day. They are an option for pond owners as a non-chemical control of aquatic vegetation. However, grass carp are also prolific spawners and fisheries managers view their introduction with caution. Their release into the wild could have devastating effects on aquatic ecology, removing underwater vegetation that other water life depends on for food and cover (PA Fish & Boat Commission website).

In Pennsylvania, introducing grass carp into the state's waters or possessing them without a permit is prohibited. However, a reproductively sterile version of the fish, called the triploid grass carp, is allowed under a tightly regulated permit, available through the Pennsylvania Fish & Boat Commission. The triploid is created by physical alteration of grass carp eggs. The U.S. Fish & Wildlife Service tests each fish before it is sold or stocked to make sure it is sterile. The triploid carp can therefore provide aquatic vegetation control on small waterways without the potential problems of fertile grass carp (PA Fish & Boat Commission website).

The grass carp looks somewhat like the common carp. Its color is olive to silvery-white, and it has large scales that are dark-edged, with a black spot at the base. The fins are clear to gray-brown, and the body is relatively slender and compressed-looking for a carp. Unlike the common carp, grass carp do not have spiny modified rays at the leading edge of the dorsal and anal fins. Grass carp also do not possess barbels around the mouth (PA Fish & Boat Commission website).

Unaltered grass carp are highly fertile. Each female produces one million or more eggs. The eggs must remain suspended in the current for several days before hatching, so grass carp need long stretches of flowing water for successful reproduction. They grow rapidly, to more than 10 pounds in just two years. Grass carp are not readily caught by anglers because they feed almost entirely on aquatic vegetation, algae and some small bottom-dwelling invertebrates. They can grow to 50 pounds or more and about four feet long (PA Fish & Boat Commission website).

Applicability

Grass carp do not consume all types of aquatic plant species equally. Table 1.6-2 provides a list of aquatic plants preferred and non-preferred by grass carp. Therefore, prior to stocking grass carp it is crucial to determine the types and densities of aquatic plants in the lake. For example, it would be nearly impossible to control nuisance levels of filamentous algae and water lilies near a dock or boat launch with grass carp when most of the lake contains large stands of pondweed and naiads.

Table 1.6-2 Aquatic Plants Preferred and Not Preferred by Grass Carp	
Plants Preferred	**Plants Not Preferred**
Pondweeds (*Potamogeton species*)	Filamentous Algae
Common Elodea (*Elodea Canadensis*)	Cattail (*Typha species*)
Coontail (*Ceratophyllum demersum*)	Bulrush (*Scirpus americanus*)
Naiad (*Najas spp.*)	Arrowhead (*Sagittaria species*)
Duckweed (*Lemna species*)	Burreed (*Sparganium eurycarpum*)
Watermilfoil (*Myriophyllum species*)	Watershield (*Brasenia schreberi*)
Bladderwort (*Utricularia species*)	White waterlily (*Nymphaea odorata*)
Water-Stargrass (*Heteranthera dubia*)	

Source: PA Fish & Boat Commission (1997).

Triploid grass carp can be very effective at controlling unwanted aquatic plants. However, subsequent defecation of consumed plant material causes a recycling of nutrients to the water. The reduction in the larger aquatic plants along with changes in water chemistry and nutrient availability can result in phytoplankton (algae) blooms. Therefore, although the larger plants may be controlled or removed, a decrease in water clarity may occur after triploid grass carp introduction (PA Fish & Boat Commission 1997).

Design Considerations

Ideally, triploid grass carp should be stocked at a rate that will allow a gradual decrease in aquatic plant coverage to 20-30% of the pond's surface area. Triploid grass carp are generally available from fish producers in sizes ranging from 8 to 11 inches. The price per fish usually increases with size. Pond owners are advised to purchase triploid grass carp of no less than 8 inches in length. Loss of grass carp to predation (particularly from largemouth bass) can be significantly reduced by stocking triploid grass carp of at least 12 inches in length (PA Fish & Boat Commission 1997).

To obtain the most effective aquatic plant control, triploid grass carp should be stocked during late spring when aquatic plants begin to flourish and when water temperatures are conducive to feeding. The stocking rate can range from 1 to 15 fish per acre depending on the type and density of aquatic plants. It should be noted that the possession, importation and transportation of triploid grass carp is regulated by a permitting process in Pennsylvania. The goal of the permitting process is to ensure the proper use of these sterile fish. The PA Fish and Boat Commission will not approve permits for stocking in excess of 15 triploid grass carp per surface acre of a pond or lake. To promote the prudent use of triploid grass carp and to prevent overstocking, permits to stock triploid grass carp in a specific pond or lake will only be issued every two years (PA Fish and Boat Commission 1997).

Lake outlets must be screened to prevent triploid grass carp escape. An effective screen can be constructed from round steel rods placed horizontally at one-inch intervals on vertical supports. This will prevent triploid grass carp of at least 8 inches in length from escaping.

Fish escapement device installed on outlet structure of a pond in Snyder County. Source: Edward Molesky of Aqua-Link, Inc.

Individuals who wish to stock triploid grass carp in ponds and lakes of five (5) acres or less must complete and submit a Triploid Grass Carp Pondowner Stocking Permit Application along with a $20 permit fee. Lakes greater than five (5) acres in size and instances where there is an increased potential of adverse environmental impacts require an Environmental Inspection Report to be completed in addition to the Triploid Grass Carp Stocking Permit Application. In these cases, a notice of the application will be published in the *Pennsylvania Bulletin* to invite public comment. A qualified biologist, environmental scientist or environmental consulting firm should be retained to complete this report.

The PA Fish and Boat Commission does not conduct routine environmental inspections for the purpose of stocking triploid grass carp; however, a list of environmental inspectors who have presented their credentials to the Commission is available upon request. After receiving a Triploid Grass Carp Stocking Permit, a lake owner can then legally purchase and stock triploid grass carp into their pond. The Commission maintains a list of approved and permitted triploid grass carp suppliers. Copies of the permit application can be obtained from the PFBC website at http://www.fish.state.pa.us or by contacting PFBC Headquarters at:

Pennsylvania Fish & Boat Commission
1601 Elmerton Avenue
P.O. Box 67000
Harrisburg, PA 17106-7000
Ph: 717-705-7800

Maintenance Recommendations

Fish escapement devices should be inspected and cleared of debris on a regular basis. If damaged, fish escapement devices should be repaired immediately.

Lakes should be re-evaluated for supplemental grass carp stockings every 2 to 3 years after the initial stocking. As discussed previously, the goal of the lake owner should be to maintain aquatic plant coverage for approximately 20-30% of the lake's surface area. Therefore, annual aquatic plant surveys should be conducted by a lake professional in order to document changes in plant coverage.

Cost Considerations

Initial Cost

The cost to apply for a Triploid Grass Carp Stocking Permit with the Pennsylvania Fish and Boat Commission is $20. Additional costs include an aquatic plant survey and preparing a Triploid Grass Carp Stocking Permit Application and Environmental Inspection Report by a qualified lake professional. An Environmental Inspection Report is required if the lake is greater than five (5) acres in surface area.

Triploid grass carp ranging 8 to 12 inches in length will cost approximately $12 to $16 per fish.

Maintenance Costs

Maintenance costs are minimal for this lake BMP, and include an annual aquatic plant survey by a lake professional, and periodic re-evaluation of the effectiveness of grass carp stocking.

References

Pennsylvania Fish & Boat Commission Website: http://www.fish.state.pa.us.

Pennsylvania Fish & Boat Commission. Jan. 1997. Pondowner's Guide to the Use of Triploid Grass Carp in Pennsylvania.

1.6.4 Weed Harvesting

Weed harvesting is a physical aquatic plant control method that offers lake managers a means of reducing nuisance aquatic plant growth without the environmental concerns often associated with chemical or biological control methods. This section will briefly discuss three of the most commonly used weed harvesting practices: mechanical weed harvesting, hydroraking and rototilling.

Mechanical Harvesting

Mechanical weed harvesting is very similar in concept to mowing a lawn, if the lawn were underwater. With this method, a cutting blade mounted to the front of a harvester or barge is used to clip off the stems of the aquatic plants below the water surface. As the cut plants float to the surface they are collected on a conveyor and stored on the harvester. When the harvester is full, it returns to the shoreline where it uses the conveyor to unload the harvested plant material onto trucks for transport to a disposal site. An example of a mechanical harvester is shown in Figure 1.6-2.

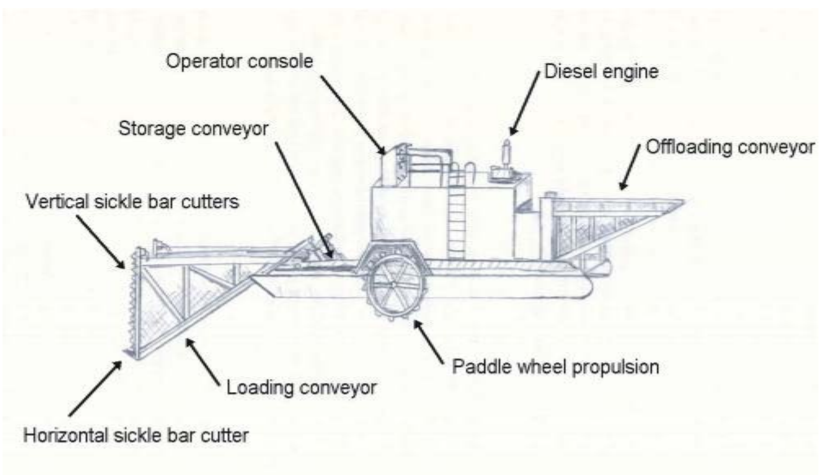


Figure 1.6-2 Mechanical Weed Harvester
Source: EcoSolutions

Applicability

Mechanical weed harvesting is one of the most widely accepted methods for the control of rooted aquatic plants. Harvested areas are immediately available for use without any water-use restrictions, and the ecological effects that sometimes occur following weed harvesting are minor in comparison to the overall benefit to the lake community.

With limited exceptions, mechanical harvesting can be accomplished in almost any lake that is experiencing excessive plant growth. However, mechanical harvesting is best suited for use in six to eight feet of water where the cutter can effectively reach the lower portions of the plant stem. At shallower depths, the harvester is not able to move effectively, often getting hung up on the lake bottom or submerged objects. In deeper water, the plant stems tend to be pushed away from the cutter and the maximum amount of material is not removed on each pass.

Accessibility to the lake is a major consideration in planning the use of a mechanical weed harvester. If access to the lake is limited, mechanical harvesting may not be a practical management consideration. Harvesters are large bulky pieces of equipment, and often times a crane is needed to lift the harvester from its transport trailer and place it in the lake. In addition, plant material collected by the harvester is typically unloaded directly onto trucks at the launch site. Therefore, the launch area should be in close proximity to a roadway and be stable enough to support the movement of heavily loaded vehicles.

Mechanical weed harvesting can have minor negative effects on the lake's fishery. Juvenile fish that become trapped in the harvested plant material are inadvertently removed from the population. When this occurs in successive years, the fish population can become unbalanced. However, this problem can be avoided or at least minimized by controlling when and where specific areas of the lake are harvested.

Another disadvantage is that certain species of plants, especially Eurasian watermilfoil, can become established in new areas of the lake when fragments not collected by the harvester are re-distributed by wind and wave action. This can result in the spread, rather than control, of the nuisance plant species that the weed harvesting program was targeting.

Design Considerations

When developing an effective mechanical weed-harvesting program, prioritization of the areas to be harvested is a major consideration. Heavy use areas such as boating lanes and swimming areas should be given highest priority. A lower priority should be given to areas that are less affected by the presence of heavy weed growth, such as fishing areas that can be used even if weeds are present. Some plant growth is necessary to maintain "healthy" aquatic communities. By no means should all of the aquatic plant life be harvested from a lake. Removal of all of the plant material can and will result in adverse effects to both the biological communities and water quality in the lake. Therefore, care should be taken to harvest only as much of the plant material as necessary to allow unrestricted access to the most heavily used portions of the lake. Aquatic plant mapping should be performed by a qualified lake professional or aquatic biologist prior to harvesting, and in subsequent years in order to determine the effectiveness of this technique.

In conjunction with prioritizing specific areas in the lake to be harvested, it is important to consider the growth periods of the plant species being controlled. Timing the harvesting with the growth periods of the target plant species can reduce the need for multiple cuttings, thereby reducing the overall project costs.

Prior to the start of a mechanical weed harvesting program, arrangements must be made for proper disposal of the removed plant material. Mechanical weed harvesting is a cure for the symptoms caused by excess nutrients entering the lake. These excess nutrients are bound up in the harvested plant material; therefore, it is extremely important that the plant material be disposed of outside of the immediate lake area in a location that will not allow the nutrients released from the decaying plant material to find their way back into the lake. Finding a suitable location will require some research, and may require obtaining permission from outside landowners, but the long-term benefit to the lake will be worth it. Composted aquatic weeds make good organic fertilizer, as long as the proper nutrient management program is in place to ensure that nutrients do not re-enter surface waters.

Usually, no permits are required for mechanical weed harvesting in Pennsylvania. However, as with any project that involves activity within an aquatic resource, it is best to notify the appropriate regulatory agency (regional DEP office, Fish and Boat Commission) prior to starting the program. At the very least, making the agencies aware of the project before it starts will ensure that the project is not shut down because of an unknown concern. In addition, the local County Conservation District should be contacted to determine whether a Sediment and Erosion Control Plan is required for the disposal of the removed plant material.

Maintenance Recommendations

Mechanical weed harvesting is a temporary cure, and repeated cuttings are often required to achieve the level of plant control desired. Depending upon the target plant species, and the level of control that is desired, multiple cuttings within the same season may be required. Annual aquatic plant mapping should continue in subsequent years in order to determine the effectiveness of this practice.

Cost Considerations

Initial Cost

An aquatic weed harvester is a very specialized and expensive piece of equipment to purchase. Depending on the size of the harvester, the cost can range from $50,000 to $150,000. An alternative to purchasing new equipment is seeking out used equipment. Also, many of the manufacturers will lease equipment.

Depending on conditions, approximately one acre of lake surface area can be harvested in a four to eight hour period at a cost of $200 to $500 per day to run the equipment. Labor costs vary, but can range between $25 and $150 per hour depending upon the experience of the operator. A truck/operator to haul the plant material from the project site will range from $40 to $60 per hour.

Maintenance Costs

Periodic maintenance cuttings are almost always required to maintain the desired level of aquatic plant control, with the costs being the same as the initial cuttings. The long-term benefits of a mechanical weed-harvesting program should always be considered in comparison to other aquatic weed management strategies aimed at controlling the "cause" of the problem rather than the "symptoms." Annual costs should include aquatic plant mapping to determine the effectiveness of this technique.

References

New York State Department of Environmental Conservation (NYS DEC). 1990. Diet for a Small Lake – A New Yorker's Guide to Lake Management. Albany, New York.

Olem, H. and G. Flock, ed.s 1990. Lake and Reservoir Restoration Guidance Manual. 2nd edition. EPA 440/4-90-006. Prepared by North American Lake Management Society for U.S. EPA. Washington, DC.

Hydrorakes

Hydroraking is another type of weed harvesting technique. In this method, a large rake fastened to a hydraulic arm is used to reach into the water and pull the plant stems from the lake bottom, as shown in Figure 1.6-3. The plant stems are lifted from the water and placed in a barge or truck, which carries them away from the project area for disposal.

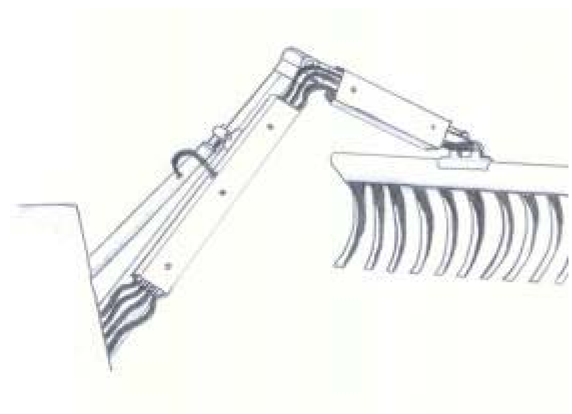


Figure 1.6-3 Hydrorake
Source: EcoSolutions

Applicability

Hydroraking provides immediate, short-term control of nuisance aquatic plant growth. Unlike mechanical weed harvesters that experience restricted mobility in shallow areas, hydrorakes are usually quite mobile in shallow water. In fact, they operate most effectively when they can be positioned immediately adjacent to or just beyond the water's edge. From a stationary position, the plant material is gathered by the rake, picked out of the water, and then unloaded into a nearby truck. As the plant material is removed, the hydrorake is periodically moved along the shoreline until work is completed within the project area. In order for the hydrorake to be utilized most efficiently, trucks should be positioned as close as possible to the hydrorake, so shoreline access is an issue.

When shoreline access is limited and water depth restricts the use of a cutter, the hydrorake can be mounted on the front of a mechanical harvester. The rake is used to remove the unwanted plant material in the same way, but instead of unloading the plant material directly onto a truck, it is first deposited in the harvester. When the harvester is full, it carries the material to shore and uses the onboard conveyor to unload the material to trucks for disposal.

Plant species such as Eurasian watermilfoil that can easily break into small fragments are not easily removed by the rake. These fragments will take root wherever they settle in the lake, allowing the plant to become established at new locations. Therefore, hydroraking is not well-suited for the control of the nuisance plant species that spread via fragmentation.

Design Considerations

Just like any form of mechanical harvesting, hydroraking is a treatment of the "symptom" rather than a cure for the "cause" of the problem. Plants that are removed will grow back, and unless the source of nutrient loading to the lake is eliminated, or an alternative control method is employed, the problem area will have to be continually hydroraked in order to maintain control. Aquatic plant mapping should be performed by a qualified lake professional or aquatic biologist prior to harvesting, and in subsequent years in order to determine the effectiveness of this technique.

Unlike mechanical harvesting which cuts the stems of aquatic plants but leaves the roots, hydroraking removes entire plants and portions of the bottom sediment. Along with the targeted nuisance aquatic species, desirable native plant species may also be removed. After harvesting, the nuisance species may totally displace native species, resulting in an aquatic plant community dominated by undesirable species. Therefore, it is important to identify all of the plant species within the project area prior to hydroraking so that every attempt can be made to avoid removing desirable species. As with mechanical weed harvesting, arrangements must be made for proper disposal of the removed plant material so that the nutrients released from the decaying plant material does not re-enter the lake.

Hydroraking requires permitting because the process not only removes the plants, but also physically disturbs the lake bottom. Before initiating a hydroraking project, the PA DEP regional office should be contacted to find out exactly what type of permits are required. This should be done at least a year before the anticipated start of the project to allow an adequate amount of time for the permit review process, which in some cases can require six months to a year. In addition, the local County Conservation District should be contacted to discuss whether a Sediment and Erosion Control Plan is required for the disposal of the removed plant material.

Maintenance Recommendations

Hydroraking is a short-term, temporary fix for a much larger lake problem. However, a single area will usually not require raking more than once in a season to achieve the desired level of plant control. Ongoing annual or bi-annual maintenance treatments are almost always required to maintain control. Periodic aquatic plant mapping will determine the frequency of treatments.

Cost Considerations

Initial Costs

The cost of the equipment required to conduct a hydroraking project is significantly less than the cost of a mechanical weed harvester. A wire rake can be purchased at your local farm or contractor supply store for $200 to $400. The rake needs to be specially adapted to fit on the end of a hydraulic arm, similar to a backhoe arm for an additional $500 to $1000.

A backhoe can be rented for $250 to $400 per day; weekly or monthly rentals are the most cost effective. A truck/operator to haul the plant material from the project site will cost between $40 and $60 per hour.

Maintenance Costs

Periodic hydroraking is almost always required to maintain the desired level of aquatic plant control, with the costs being the same as the initial treatment. The long-term benefits of a hydroraking program should always be considered in comparison to other aquatic weed management strategies aimed at controlling the "cause" of the problem rather than the "symptoms." Annual costs should include aquatic plant mapping to determine the effectiveness of this technique.

References

McComas, S. 1993. Lake Smarts – The First Lake Maintenance Handbook. Produced by Terrene Institute for the Office of Water and Office of Wetlands, Oceans and Watersheds, U.S. EPA. Washington, D.C.

Rototilling

Rototilling is very similar to hydroraking, except that a tiller, instead of a fixed rake, is affixed to the hydraulic arm. When the tiller is moved across the lake bottom, it chops and dislodges not only the plant stems, but also the plant roots.

Unlike hydroraking, during rototilling the vegetation that is dislodged cannot be collected and removed from the lake without the aid of another device. If the water is deep enough, the dislodged plant material can be collected with the conveyor on a harvester. However, in shallow areas, the material is often collected in a net, and either manually or mechanically removed from the water. The net contents are then unloaded onto a truck for off-site disposal. Therefore, the rototilled areas must be accessible to either a boat or harvester so that the debris can be collected.

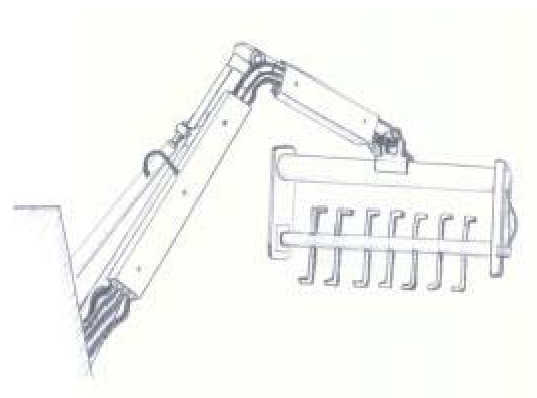


Figure 1.6-4 Rototiller
Source: EcoSolutions

Applicability

Rototilling can be used in many of the same situations as hydroraking. It is most effective and best suited for use in shallow shoreline areas around lakes. The rototiller is usually mounted on a vehicle that has been adapted for muddy shoreline areas. Unlike the mechanical harvester, it does not require a certain water depth for effectiveness.

Since rototilling dislodges the roots of the plant, this technique provides better long-term control than either hydroraking or mechanical harvesting. This technique is best suited to situations where the heaviest weed growth occurs within shallow shoreline areas of the lake, and can provide good control in those areas.

One potential drawback to rototilling is that immediately following the treatment, nutrients that have been bound up in the oxygen-poor sediments may be released. The sudden release of large amounts of nutrients into the water column can result in large algae blooms, which may concern residents living on the lake. In addition, water clarity may decline throughout the lake as the disturbed sediment becomes suspended in the water column.

Design Considerations

Rototilling physically disrupts the biological communities found on and immediately below the surface of the lake sediment. Many of the aquatic invertebrates that are vital to the lower levels of the aquatic food chain live in the sediment, and their life cycles are disrupted by the tilling process. In addition, many fish species spawn in the shallow shoreline areas. In order to avoid destroying their nests, proper timing of rototilling is crucial.

Rototilling requires permitting because of the disturbance of the lake bottom. The PA DEP regional office should be contacted before initiating a rototilling project to determine exactly what type of permits are required. This should be done at least a year before the anticipated start of the project in order to allow an adequate amount of time for the permit review process. In some cases it may take six months to a year before the permit approval is granted. In addition, the local County Conservation District should be contacted to discuss whether a Sediment and Erosion Control Plan is required for the disposal of the removed plant material.

Another potential problem with the rototilling process is that it tends to create even more plant fragments than either hydroraking or mechanic harvesting. Rooted plants such as water lilies, spatterdock, and purple loosestrife, and small shrubs such as water willow and black willow can grow from root or wood stem fragments. These plant species quite frequently reach nuisance proportions within shallow littoral areas of a lake and can easily be spread by rototilling. Therefore, as in any aquatic plant management program, the target nuisance species should be identified and mapped before deciding whether to use this control technique.

Maintenance Recommendations

Although the effects of rototilling are longer lasting than other physical methods of aquatic weed management, it is still considered a short-term, temporary treatment for excessive macrophyte growth. Annual or bi-annual maintenance treatments are almost always required to maintain control. Therefore, just as with the other harvesting techniques discussed in this section, the long-term benefits of this control method in comparison to other management strategies aimed at controlling the "cause" of the problem should be considered. Annual macrophyte mapping by a lake professional or aquatic biologist should be performed in order to document the patterns of plant growth and the need for repeat treatments.

Cost Considerations

<u>Initial Costs</u>

The cost of rototilling equipment is significantly less than a mechanical weed harvester, but more than hydrorake equipment. A hydraulic tilling attachment can be purchased at a local farm or contractor supply store for $500 to $1,000. As with the rake, a special adaptor is required in order to attach the tiller to the end of the hydraulic arm for an additional $500 to $1000.

A backhoe can be rented for $250 to $400 per day; weekly or monthly rentals are most cost effective. Depending on how the dislodged material is collected, an additional labor fee for the rental of a harvester or boat mayl need to be figured into the total project cost. This can range from $50 to $500 per day. Labor costs vary, but can range between $25 and $150 per hour depending upon the experience of the operator. An additional truck/operator to haul the plant material from the project site will range from $40 to $60 per hour.

<u>Maintenance Costs</u>

Periodic rototilling is almost always required to maintain the desired level of aquatic plant control, with the costs being the same as the initial treatment. Annual costs should include aquatic plant mapping to determine the effectiveness of this practice.

References

Jones, C. W. and J. Taggart, 2001. Managing Lakes and Reservoirs. N. Am. Lake Management Society and Terrene Inst., in cooperation with Off. Water, Assessment and Watershed Protection Division US Env. Protection Agency, Madison, WI.

McComas, S. 1993. Lake Smarts – The First Lake Maintenance Handbook. Produced by Terrene Institute for the Office of Water and Office of Wetlands, Oceans and Watersheds, U.S. EPA. Washington, D.C.

1.6.5 Herbicides

Herbicides are chemical formulations used to disrupt the growth of unwanted aquatic plants. Specific herbicides are variable in their effects on plant growth and longevity of control.

Applicability

Most aquatic herbicides are readily available in granular or liquid form from local farm supply stores. Regardless of their form, all chemical herbicides affect the growth of aquatic plants in one of two ways: direct toxicity to the plant, or photosynthesis blocking, which causes the plant to starve.

The use of chemical herbicides is often an important component of aquatic plant management programs, because herbicides provide fast results and often lasting control. After a chemical application, visible changes in the plant community are sometimes seen within a few days; however, for most chemicals, noticeable changes in the plant community are not apparent for at least two to three weeks.

Herbicides can be applied directly to nuisance aquatic plants. Adjusting the method of chemical application provides the versatility to control growth in specific areas. Plants can be treated on the surface, near the bottom, or anywhere in between.

An important, but often overlooked consideration in the use of herbicides for aquatic plant control is notifying and gaining the approval of lake residents. The use of some aquatic herbicides may place temporary restrictions on certain activities in the lake. Everyone who may potentially be in contact with the lake after the treatment must be notified of any water use restrictions. This may entail posting the lake, notifying properties through a community newsletter, or even publicizing the treatment in a local newspaper. It may be impossible to gain approval from all lake residents for herbicide treatment. When herbicide applications will affect large communities, a public meeting may be necessary to address public concerns. Table 1.6-3 shows some commonly-used aquatic herbicides and their corresponding water use restrictions.

Table 1.6-3
Commonly Used Aquatic Herbicides and Their Water Use Restrictions
(Prepared by PA Fish and Boat Commission)

Aquatic Herbicide	Hazard and Label restrictions
Aquathol-K	Do not consume fish for 3 days, No swimming for 24 hours, Do not use for irrigation for 7 to 14 days
Reward or Diquat	Use with little or no overflow, No swimming for 24 hours, Do not use for livestock or irrigation for 14 days
Weedtrine-D	Do not use for irrigation for 7 days, Do not consume fish for 3 days
Hydrothol 191	Do not consume fish for 3 days, No swimming for 24 hours, Do not use for irrigation for 7 to 14 days
Sonar SRP	Restrict use near water supply intakes, Do not use for irrigation for 14 to 30 days
Komeen	Toxic to trout, calculate dosage for upper 1 to 4 feet only
Rodeo	Do not use within ½ mile of water supply
Sonar A.S.	Restrict use near water supply intakes, Do not use for irrigation for 14 to 30 days
Weedtrine II	Do not use for irrigation for 7 days, Do not consume fish for 3 days
Aqua-Kleen Aquacide Navigate	Use with little or no overflow, Apply in spring/early summer

Design Considerations

Prior to conducting an herbicide treatment, it is good practice to hire a lake professional or aquatic biologist to conduct a preliminary survey of the proposed treatment area. The survey would provide baseline information on the plant species composition and coverage within the treatment area, which can later be used to evaluate the effectiveness of the herbicide treatment. At a minimum, the following information should be collected during the preliminary survey:

- The type and coverage of the plant species present,
- Total surface area and average depth of the treatment area,
- Basic water quality parameters including pH, hardness, water temperature, dissolved oxygen and water transparency (Secchi depth).

- Current uses of the water body being treated (e.g. water supply, water contact sports, fishing, aesthetics).

- Type and frequency of the discharge or overflow.

- Name and classification of the receiving stream.

All chemical manufacturers provide a chart or description on the product label that clearly lists plant species controlled and application rates. Application rates for a particular chemical are not the same for all plant species, as shown in Table 1.6-4. Therefore, it is important to be certain that the application rate corresponds with the target plant species. Applying too much or too little of the wrong chemical will result in the failure of the control program.

Herbicide application rates depend upon the size and average depth of the treatment area. Herbicide application rates are expressed as the amount of chemical required to treat a given volume of water and are usually expressed in pounds or gallons per acre-foot. Figure 1.6-5 describes how to calculate these rates when the exact area is known or estimated by measuring the number of square feet within the treatment area.

The timing of an herbicide application can influence the longevity of control. For instance, if an herbicide is applied immediately after the plants begin to emerge, too little of the plant may be affected and re-growth may occur later in the season. Applications conducted after the plants have gone to seed will usually not carry over to the next season because the seeds are unaffected by the herbicide. By understanding the growth habits of the target plant species, the herbicide can be applied when the plant is most vulnerable, thereby increasing the longevity of control.

Table 1.6-4 Summary of Commonly Used Aquatic Herbicides In PA (Prepared by PA Fish and Boat Commission)			
Submerged Aquatic Plants			
Aquatic Herbicide	**Active Ingredient**	**Aquatic Species Controlled**	**Application Rate**
Aquathol-K	Endothall	pondweed, naid,milfoil, coontail	0.6 to 1.9 gal/acre ft
Reward or Diquat	Diquat (35.3%)	pondweed, naid,milfoil, coontail	1 to 2 gal/acre
Weedtrine-D	Diquat (8.53%)	bladderwort, coontail, elodea, naiad, pondweed, milfoil	5-10 gal/acre
Hydrothol 191	Endothall (53%)	naiad,elodea,coontail,pondweed,milfoil	0.7 to 3.4 gal/acre ft
Sonar SRP	Fluridone (5%)	bladderwort,coontail, elodea, naiad, pondweed, milfoil	0.54 to 1.08 lbs/ acre
Komeen	Copper (8%)	milfoil, elodea, pondweed, coontail (NOT an Algaecide)	1.7 to 3.3 gal/acre ft
Emergent and Floating Plants			
Aquatic Herbicide	Active Ingredient	Aquatic Species Controlled	Application Rate
Rodeo	Glyphosphate (53.8%)	cattail, water lily, arrowhead, spatterdock, watershield, purple loosestrife, common reed (Phragmites)	0.75 gal/acre
Sonar A.S.	fluridone (41.7%)	duckweed, watermeal, spatterdock, water lily also coontail, elodea, pondweed, milfoil	< 5 feet 0.16 to 1.25 qt/ acre ft > 5 feet 1.0 to 1.5 qt/ acre ft
Aqua-Kleen Aquacide Navigate	2,4-D (20%- 27.6%)	water lily, spatterdock, watershield also milfoil, bladderwort	150 to 200 lbs/acre 100 to 150 lbs/acre

The method of chemical herbicide application is dependent upon whether the product is granular or liquid. Granular herbicides are typically broadcast across the lake surface using a mechanical spreader fastened to the front of a boat. Since the active ingredient in granular products is chemically bound to an inert substance such as clay, granular products can be dispensed directly from the container without dilution. Liquid herbicides are purchased as a concentrate and must be diluted before application to ensure even distribution of the chemical across the treatment area. Liquid herbicide are typically mixed with water in a holding tank, and either sprayed directly on the plants or dispensed from hoses suspended below the lake surface.

Only herbicides that are registered with the U.S. Environmental Protection Agency (EPA) for use in aquatic systems can be used to control aquatic plants in Pennsylvania. A permit must be obtained from the Pennsylvania Fish and Boat Commission before the herbicide can be applied to any public or private waterway. There is no fee for the permit, but it must be renewed annually. In addition, if the herbicide will be applied to a public waterbody, a licensed applicator must perform the application.

Determination of Acre-Feet to Calculate Total Amount of Herbicide Needed

Acreage Known

If the acreage of the treatment area is known, the number of acre-feet can be determined by multiplying the number of acres by the average depth (average depth = 1/3 of the maximum depth).

(area to be treated) acres x (average depth) feet = (volume) acre-feet

To determine the total herbicide needed:

(volume) acre-feet x (dosage) gal/acre-foot = (total herbicide needed) gallons

Acreage Unknown

If the number of acres is not known, it can be estimated by measuring the number of square feet in the treatment area and dividing by 43,560. The number of square feet in many cases can be closely approximated by multiplying the average width in feet by the average length in feet.

(average width) feet x (average length) feet = (total surface area) square feet

$$\frac{\text{(total surface area) square feet}}{\text{43,560 (square feet in an acre)}} = \text{(total surface area) acres}$$

Figure 1.6-5. Methods for calculating application rate when the acreage of the treatment area is known or estimated. Source: EcoSolutions

Maintenance Recommendations

Herbicides are similar to other aquatic plant control techniques in that they are not a permanent solution for the problem. Therefore, herbicide treatments may have to be performed several times in a single growing season to achieve the desired level of plant control. Long-term weed control almost always requires multi-year treatments and occurs only when the herbicide treatments are performed as part of a lake management plan that involves correcting the cause of the excess plant growth (i.e. excessive nutrients in the lake). Aquatic plant surveys should be performed by a lake professional on an annual basis to document the efficacy of the treatment.

Cost Considerations

Initial Costs

A boat, pump system, and the herbicide are the three major items required to conduct an herbicide treatment. For most applications, a small rowboat will do the job, but with larger treatment areas a motorboat will make the job much easier and more efficient. Flat-bottomed boats between 14 and 16 feet long are the best choice because they are stable and can be maneuvered easily in shallow water. Boats can range in cost from $200 to $5,000 depending on their size, type of motor, and trailer.

A pump system is the second item needed for an herbicide application. A typical system will consist of a gas-powered pump and mixing tank. These components can be purchased separately at a farm supply store, but complete units are available at a lower cost. The unit should be large enough to efficiently handle the required amount of herbicide, but small and light enough to fit into the boat. Suitable pump systems are available that have been adapted for use on ATV's and small tractors. Pump systems range in cost from $250 to $3000.

Herbicide costs are variable, and usually reflect the amount of active ingredient in the product. For example, two one-gallon containers of herbicide may differ in cost by $50. However, one of the products contains 35% of the active ingredient diquat, whereas the other has only 8%. The second product may cost less, but more of it will be required to achieve the same results. Therefore, always compare labels and be prepared to pay between $100 and $500 per acre for the herbicide.

Maintenance Costs

Repeat herbicide applications are almost always necessary to control aquatic plants, unless the source of excessive nutrients causing the abundant plant growth is controlled. Maintenance herbicide applications usually cost the same as the initial applications, although they may not be required in all of the original areas. Aquatic plant surveys should be performed prior to any repeat applications to determine which areas of the lake require treatment.

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1.6.6 BENTHIC MATS

Benthic mats, or bottom barriers, are a very effective physical BMP for controlling rooted aquatic plant growth in small areas. The mats are large sheets of fabric anchored to the lake bottom that prevent sunlight from reaching rooted aquatic plants. Without sunlight, photosynthesis cannot occur and the plants die.

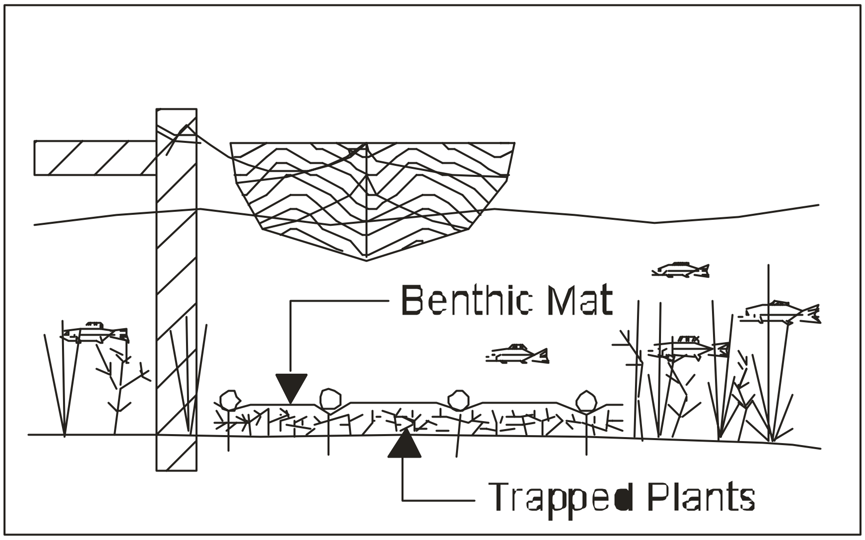

Figure 1.6-6. Benthic Mat
Source: EcoSolutions

In addition to blocking sunlight, the mats also provide a physical barrier that prevents plant growth. Plants trapped below the fabric are not able to grow up through the material and eventually die.

APPLICABILITY

Benthic mats are one of the most ecologically sound BMPs for aquatic plant control. They are non-toxic to the environment, have limited effect on bottom-dwelling organisms and fish, and once installed, have minimal impact on the surrounding habitats. The main disadvantage is that compared to other control methods, benthic mats are expensive. The method is most economically feasible for isolated areas (e.g. around docks) or small stands of invasive plant species. Unlike other aquatic plant management techniques such as harvesting and rototilling, the fragmentation and spread of invasive species in avoided with benthic matting.

Benthic mats work best in small areas and should not be used to cover large areas of the lake bottom. Mats placed in shallow areas around docks, swimming platforms and in swimming areas are easy to install and maintain. Benthic mats can be cut and shaped to control colonies of nuisance plant species without harming adjacent desirable species. If necessary, the mats can be reused and moved to different areas of a lake over the course of a growing season.

Not all lake areas are suited for the installation of benthic mats. Areas with uneven bottoms, steep slopes, large rocks, embedded stumps, or large submerged logs are not good candidates for this control method. It is best to either remove the large rocks, embedded stumps and submerged logs from within the control area, or consider an alternative control technique for those areas. In addition, areas with strong wave action or shallow waters with heavy boat traffic are not well suited to benthic mats.

Design Considerations

Benthic mats are commercially available in a variety of different materials. Typically, the mats consist of a permeable, non-toxic, plastic, nylon, or fiberglass mesh material. Materials such as burlap or canvas should be avoided because they tend to decompose after being submerged for a relatively short period of time.

When purchasing material for use as benthic matting, make sure to consider the method of installation. Most matting material comes on 100 to 150 foot rolls, ranging in width from 5 to 75 feet. The longer and wider the roll, the more difficult the material will be to handle. In addition, if the matting is installed when the lake has not been drawn down, it is helpful to purchase material that is heavier than water. Even heavier material tends to float as it is being installed, but it is much easier to use than lighter materials.

In most cases, no specialized equipment is required to install benthic matting. If the control area is located along boat docks or in shallow portions of swimming areas, two or three people can easily spread and anchor the material as it is rolled out from shore. In deeper water, applying the material to the bottom, spreading it evenly over the control area, and anchoring it in place becomes much more difficult. Divers are often needed to ensure that the barrier is firmly anchored in place and trapped air bubbles are removed. Rebars cut to usable lengths make good anchors.

Timing of installation is very important. If possible, benthic mats should be installed in conjunction with lake drawdowns. If this is not possible, installation should occur early in the season before plant growth becomes heavy. If the installation occurs later in the summer or fall after plant growth has begun, it will be necessary to chemically treat or physically remove the plant material from the control area prior to installing the barrier, which increases the expense and potential impact on desirable plant species. If benthic mats are to be installed in fish spawning areas, installation should only happen after spawning has occurred.

Maintenance Recommendations

Bottom barriers must be cleaned annually to ensure their effectiveness. Accumulated organic material and sediment will provide areas for new plants to become established on the surface of the mats. It is best to remove the mats at the end of the season and store them until the following year. If this is not possible, sediment and debris can be periodically swept from the mat surface.

In addition to cleaning, the mats need to be inspected at least annually for tears in the material and to ensure that they have remained firmly anchored in place. If the matting is torn, it should be replaced. Temporary patches are just that, temporary. Over time, stakes and anchors may come loose or tear free from the edge of the material. By periodically inspecting the mat, a small problem can be prevented from becoming a big one.

Cost Considerations

Initial Costs

The cost to install benthic mats can range from $2,000 to $8,000 per acre (NYS DEC 1990). The wide range in price reflects variations in labor costs associated with the installation. Material costs will vary with regard to the type of matting, but typically range between $0.50 and $1.00 per square foot. Benthic mats are comparatively much more expensive to purchase, install and maintain than other aquatic plant control techniques that provide similar results. For example, the costs for benthic mat purchase and installation are ten times more on average than the cost to chemically treat the same one-acre area with an aquatic herbicide. However, if benthic mat installation can be completed without hiring help or involving divers, the costs can be reduced. Benthic mats are a very ecologically sound management in areas where impacts to non-target species must be minimized.

Maintenance Costs

Maintenance costs are similar to initial labor costs to inspect, remove, and re-install benthic mats. However, if properly maintained, replacement of the mat material should be infrequent.

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1.6.7 Hand Harvesting

Boat full of Eurasian watermilfoil hand harvested from Mountainview Lake, NY
Source: Michael R. Martin, Cedar Eden Environmental

Hand harvesting of aquatic weeds is probably the simplest, most widely-used method for controlling nuisance aquatic plants on a small-scale basis. It involves physically removing plants, stems, and roots using hand tools such as rakes and suction harvesters, or even bare hands. Hand harvesting, or hand pulling, doesn't require a permit, but it does require some knowledge of the plant species being removed. Care must be taken to remove all parts of the plant to eliminate the possibility of regrowth. Hand harvesting is most often used by private lakeshore homeowners around docks and swimming areas, or by trained volunteers as part of an integrated plant management program.

Applicability

Hand harvesting of aquatic plants is best suited for small, high-priority areas such as around docks or water intakes. It can be useful in ecologically sensitive areas where the application of chemical herbicides is prohibited. Hand harvesting is a very selective practice, with little to no impact on any but the target species. It is most effective when used as one facet of an integrated management program that tailors different aquatic plant management techniques to different areas of a lake based on use and plant density. For example, hand harvesting can be performed around the edges of a benthic barrier covering a large invasive aquatic weed infestation, or in areas with smaller, new infestations.

Hand harvesting is less likely to fragment and spread invasive plants than some of the other weed management techniques such as mechanical harvesting or rototilling. Since the plants are removed completely, they are not left to decay and fuel algae blooms. A 50 by 50 foot area can be cleared of aquatic weeds in anywhere from 4.5 to 19 hours, depending on the plant species being removed (McComas 1993). Hand-pulling and suction harvesting are not effective for some plant species, such as hydrilla or water lilies, that have very deep and sturdy root systems.

The major disadvantage to hand harvesting is that it is extremely time consuming. It is only recommended for small areas for this reason. Because of the time involved, hand harvesting can be very expensive, especially if divers and/or suction harvesters are required. However, if volunteer labor is readily available, the costs can be minimized.

Design Considerations

Hand harvesting is done in shallow areas by wading, traveling in a canoe or kayak, or by using a "lake rake" from shore. In deeper water, trained divers are used to remove plant materials. Plants are removed by grabbing the base above the sediments and then following the root system into the sediments to the end. The root base is pulled and the whole plant is removed. Plants are then placed into a dive bag, container, or boat for storage until the puller can return to shore for disposal.

For a larger-scale program, an initial survey of the lake should be performed by a lake professional or aquatic biologist. This professional can then train volunteers or lake association members to spot and remove invasive species. Volunteer weed watchers are invaluable for documenting the spread of invasive plants in a lake, since they know their lake best. Once specific sites are documented, they should be marked using a buoy or emptied and cleaned laundry detergent bottle attached by rope to a brick. These markers are used to help volunteers and hired divers keep track of the areas that need to be harvested.

A larger-scale hand harvesting operation is best accomplished with the aid of trained divers. The divers wear SCUBA or snorkel gear to remove unwanted weeds from deep areas of the lake. A suction harvester can also be used to remove the plants more quickly and efficiently. Suction harvesters are specially-designed hand-dredge machines that vacuum up the unwanted plants, leaving the sediments largely intact. The water and any disturbed sediments are discharged back into the lake. A large pontoon or other open-decked boat is helpful

Hand-harvesting operation at Mountainview Lake, NY, using divers and kayakers to remove milfoil.
Source: Michael R. Martin, Cedar Eden Environmental

for collecting plants and storing divers' air tanks or other equipment. The boat operator acts as a navigator to direct the weed harvesters as well as a safety spotter to keep other boaters away from the divers. It is also helpful to have people with nets – either the boat operator or additional helpers in kayaks – to scoop up any loose plant fragments during harvesting.

To make sure all the plants are removed from the target area, the harvesters should travel in straight lines (using a compass), using systematic grid patterns or transects to cover the entire area. As the divers work, the people in the support boat should mark the treated locations with a buoy or a GPS unit. An accurate location is important since the areas need to be resurveyed a few weeks later. Hand harvesting tends to stir up the bottom sediment. When an area gets too silty to see, harvesters should move on to another area, marking where they stopped so that they can return once the sediment settles.

Plant materials should be disposed of in the same manner as described in Section 1.6.4, Weed Harvesting. It is critical that the removed plant material be disposed in a location away from the lake so that nutrients from the decaying plants do not re-enter the water. Aquatic plants make excellent compost, although their high water content should be balanced in the compost pile by the addition of dry components such as shredded leaves or newspaper.

Maintenance Recommendations

Hand-harvested areas should be re-surveyed several weeks after treatment to ensure that all of the plants have been removed, and that no fragments have taken root. Annual surveys for several years after treatment are necessary to document the success of the treatment and determine the need for additional harvesting.

Hand harvesting alone will never be able to completely control invasive aquatic weeds once they become established in a given lake or pond. However, with vigilant inspections and timely maintenance harvesting, the weeds can be kept to a manageable level and impose minimal impact on the surrounding ecosystem. Frequent small-scale maintenance harvesting can reduce the possibility of large invasive weeds infestations that require more time-consuming and costly management efforts.

Cost Considerations

Initial Cost

The cost of hand harvesting varies widely depending on labor costs, but ranges from $100-$500 per acre including plant disposal (Jones and Taggart, 2001). Individual homeowners may be able to remove weeds themselves for no cost. A "lake rake" costs approximately $100(McComas, 1993). The use of volunteers can decrease costs dramatically, as well. If trained divers or suction harvesters are required, labor costs can be significant. Costs for large-scale operations include the cost of air tanks for the divers, a boat and boat operator, and potential disposal of the removed weeds. These costs can run over $1,000 per acre (Martin 2004). Suction harvesting increases the cost even more, to between $5,000 and $10,000 per acre treated (Jones and Taggart, 2001).

Maintenance Costs

Maintenance costs are the same as initial costs on a per-hour basis. The first year of harvesting will most likely be the most costly due to the amount of time required to remove weeds from the target area. In successive years, the amount of time required for harvesting would most likely be significantly less.

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1.7 Shoreline Stabilization

Severe lake shoreline erosion at Pinchot Lake in York County. Erosion due to wave action and heavy pedestrian foot traffic. Source: Edward Molesky of Aqua-Link, Inc.

The interrelationship between a lake and its shoreline is important. The shoreline zone is the last line of defense against forces that may otherwise destroy a healthy lake. A naturally vegetated shoreline filters runoff generated by surrounding land uses, removing harmful chemicals and nutrients. At the same time, shoreline vegetation protects lake edges from the onslaught of waves and ice during the harsh winter months. The shoreline zone also provides critical habitat for aquatic insects, microorganisms, fish, and other animals, thereby helping to maintain a balance in sensitive aquatic ecosystems. Unfortunately, as lake landscapes are developed, natural shorelines are often damaged or destroyed. Beneficial natural vegetation is cut, mowed, or replaced. In urban and rural environments alike, this leads to eroded shorelines, degraded water quality and aquatic habitat, a decrease in aesthetic value, and a reduction in property values (IEPA & NIPC 1996).

Shorelines can erode from many causes. Natural causes of erosion include currents, waves, ice, and rain. Many human activities may significantly increase the rate of erosion. Some common causes include (IN DNR 1999):

- Removal of natural vegetation for property development or the creation of beaches,
- Improper installation of erosion control structures such as seawalls (retaining walls),
- Increased wave action from watercraft traveling too close to the shoreline,
- Dredging, filling, or construction on or near the shoreline,
- Trampling of banks by human, animal, or vehicle traffic, and
- Inadequate protection against stormwater runoff from roofs, driveways, streets, parking lots, playing courts, and other developed areas.

The three most common methods of stabilizing eroding lake shoreline areas are: establishing lake shoreline buffers, bioengineering, and stone or riprap (IN DNR 1999).

Vegetative Buffers: Vegetative buffers around lakes help protect lakeside properties naturally, effectively, and inexpensively. Erosion can result where vegetation has been damaged or removed by construction, herbicide application, or wave action. Trees offer excellent erosion control because of their deep roots, which bind the soil, and their leaves, which intercept rain before it impacts and erodes the soil. Lower branches of trees may be trimmed to maintain a view of the lake. Trees and shrubs not only hold soil and filter stormwater that may otherwise contaminate the lake, they also provide an aesthetically pleasing screen to protect the privacy of lakefront property owners. Nearshore water plants protect the shoreline against waves and provide excellent fish habitat.

Shoreline vegetative buffer
Source: F. X. Browne, Inc.

Bioengineering: Occasionally, steep bluffs or strong wave energy make it difficult to establish or maintain shoreline vegetation. In these circumstances, property owners may need to utilize innovative structural techniques, such as "bioengineering," to restore shoreline vegetation. Common bioengineering techniques include: planting vegetation on slopes stabilized with blankets made of special, biodegradable fibers; transplanting trees into stone or riprap (known as "joint planting"); planting freshly cut willow limbs in the ground (known as "willow staking"); and laying interlocking blocks with gaps designed to promote plant growth. Bioengineering can cost more than either vegetation or riprap alone. However, bioengineering methods can effectively protect highly vulnerable shorelines less expensively and more aesthetically than seawalls (retaining walls). Unlike a solid seawall, bioengineering also maintains the valuable shoreline habitat and increases in strength over time as the plants grow. Because of the

Bioengineering project using fiber roll revetment at Verona Lake, NJ Source: F. X. Browne, Inc.

complexity of these techniques, the assistance of a professional is usually necessary to attain satisfactory results.

Stone or Riprap: Large stones placed on top of gravel or a filter blanket will stabilize gradual to moderately sloped lakeshores by holding soils and dissipating wave action. The size of the stones and width of the stone layer required to effectively protect a shoreline depend on the wave height, shoreline slope, fetch (extent of open water near the shore), and distance between the high and low water lines. Where underwater beaches reach the shoreline, pea gravel (small rounded stones about 1/4 inch in diameter) will provide more stability than sand. Large stones provide a rocky, more natural-appearing shoreline than riprap. Stones provide some habitat value, particularly if vegetation is allowed to grow up through them. Variations in depth along the shoreline provide diverse habitat for different species of plants and animals. Fish, turtles, crayfish, and other animals look for food, lay their eggs, and protect their young among shoreline vegetation and gaps in the rocks.

Riprap stabilizing a lake shoreline
Source: F. X. Browne, Inc.

Under the most severe conditions, eroding lake shoreline areas can be stabilized with concrete or sheet pilings (retaining walls). In some cases, a combination of the above methods may constitute the most effective design for protecting the shoreline and providing wildlife habitat. With any shoreline protection or construction project, a design which does not take the existing lakeshore conditions into consideration may fail and cause a bigger and more expensive erosion problem than originally existed.

Applicability

Of the above stabilization methods, vegetative buffer strips are most inexpensive and the least complex to install. The benefits of buffer strips are well documented and include (IEPA & NIPC 1996):

- Runoff filtering - As runoff from adjacent land passes through a buffer, pollutants and sediment are removed by filtration and settling in the dense network of plants. Soluble pollutants, including nutrients, are taken up through plant roots or consumed by microorganisms in the soil. Native plants, particularly prairie vegetation, have much denser, deeper root structures than conventional turfgrass, which greatly improves the infiltration of surface runoff into the ground. Depending on the width and characteristics of the buffer, as much as 70 to 95 percent of incoming sediment, and 25 to 60 percent of incoming nutrients and other pollutants can be removed from the runoff.

- Shoreline stabilization - Natural buffers that extend down to the water's edge can be very effective in preventing shoreline erosion. In contrast to conventional turfgrass (which is shallow-rooted and intolerant of flooding), natural riparian vegetation has dense, deep root systems that firmly anchor shoreline soils. These native plants are also able to withstand the extended periods of inundation that are common around lakes and reservoirs. Native vegetation is especially useful in bioengineering techniques as a low-cost alternative to conventional engineering solutions such as riprap or seawalls.

- Preservation of fish and wildlife habitat - Many aquatic organisms, particularly insects, spend substantial portions of their life cycles in upland environments. Buffers provide a critical transition zone between upland and aquatic/wetland habitats. Depending on their widths, buffers also can shield sensitive species, particularly birds, from potentially disruptive activities occurring on adjacent land uses.

- Noise screening - Beyond protecting wildlife uses, buffers can also preserve the quality of lake recreational uses by filtering out the noise associated with certain types of adjacent land uses. Forested buffers, in particular, can effectively intercept noise from adjacent highways and industrial operations.

- Preservation of aesthetic values – Lakeside property owners often have varying opinions about what constitutes "appropriate" shoreline landscaping. However, most will agree that "natural" is better than "artificial." Even a narrow buffer can enhance the view across a lake. Forested buffers can effectively screen the clutter of surrounding urban developments.

The establishment of vegetative buffers along shoreline areas is applicable to lakes throughout Pennsylvania. If lake shoreline erosion is moderate to severe, the banks may need to be regraded and restabilized using either bioengineering or structural (stone or riprap) bank stabilization practices.

For more information on specific bank stabilization practices, refer to Section 2.7, entitled Streambank Stabilization. Many of the watershed best management practices in this section are also applicable to lake shoreline stabilization projects. Section 2.8, entitled Riparian Corridor Restoration, includes useful information on native plant species that work well in buffers. The remainder of this section focuses on shoreline stabilization using vegetative buffers.

Design Considerations

Vegetative buffers used for shoreline stabilization vary depending on the lake setting. A buffer may include forest or wetland vegetation. It may be twenty-five feet wide around a small urban pond, or hundreds of feet wide along a pristine rural lake. However, there are some basic criteria that apply to all lake shoreline buffers (IEPA & NIPC 1996):

- Buffer width - any width of natural vegetation will provide some benefits; however, a 25-foot minimum width is most often recommended. Wider buffers (50 to 100 feet) should be established for larger or more sensitive lakes.

- Buffer intrusions - while a continuous, uninterrupted buffer is preferable for protection of water quality and habitat, some flexibility may be needed to provide access to beaches, piers, and other lake areas. Access typically is provided via a mowed footpath. Less intrusive pedestrian access could be provided via a stepping stone trail. Paving through a buffer is discouraged.

- Buffer vegetation - it is recommended that buffers be planted with native species that are indigenous to the particular location. Buffer vegetation should also reflect local needs and conditions. For example, a forested buffer is useful if noise screening is desired, but it may not be appropriate if local residents prefer an unobstructed lake view.

Installation of a vegetative buffer typically begins with the removal of existing, undesirable vegetation. Planting should begin with wetland species at or below the normal water elevation and should proceed up the shoreline slope with water-tolerant and upland species. While buffer vegetation is being established, mowing and/or selected use of approved herbicides may be necessary to control the spread of aggressive, nonnative plants.

Planting native vegetation rated for the proper climatological zone and site conditions will improve the chances of seedling survival. Incorporating wildlife-resistant, salt-resistant, flood-tolerant, shade-tolerant, and/or disease-resistant plantings can be helpful, depending on the location and function of a given buffer. Buffers may require repellants or fencing to protect trees, shrubs, and grasses from wildlife damage (beavers, muskrats, nutria, whitetailed deer, etc.).

Maintenance Recommendations

Once the buffer is well established (typically within 1-3 years), maintenance will involve occasional mowing to control weeds and maintain native plant diversity. If certain noxious weeds need additional control, the limited use of approved herbicides may be appropriate in localized areas. Use of fertilizer is not necessary and should be avoided in the buffer strip (IEPA & NIPC 1996). Some seedling mortality is expected; however, woody plants should be replanted within a row if more than 3-4 consecutive seedlings have died. Reseeding should occur if large bare patches are observed. During the life of the riparian buffer, tree seedlings will begin to compete with each other. In order to maintain an optimal growth rate, trees should be pruned and trimmed regularly.

Cost Considerations

Initial Cost

The initial cost for establishing a lake shoreline buffer will vary considerably and largely depend upon the width of the buffer desired, the type and size of the plants selected, and the density at which the plants are installed. As a rule of thumb, the costs for establishing a lake shoreline buffer may range from $5 to $25 per linear foot (IN DNR 1999). In some cases, funding from the Pennsylvania Conservation Reserve Enhancement Program (CREP) can be used for buffer plantings (USDA 2003).

Maintenance Costs

Maintenance costs will be minimal and may include costs for mowing grass areas; purchasing and applying approved herbicides to control noxious weeds; purchasing and installing nuisance wildlife control measures, and purchasing and installing any supplemental plant materials on an as needed basis.

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1.8 Dredging

Dredging involves the removal of accumulated sediments from lakes, ponds, and reservoirs. Dredging can be an appropriate and highly-effective in-lake treatment strategy when sediment accumulation is a significant management concern. There are several potential undesirable consequences of excessive sedimentation in freshwater lakes and reservoirs. Sediment accumulation contributes to lake eutrophication by aggravating internal phosphorus loading and resuspension under anoxic conditions, and by providing nutrient resources for rooted vascular aquatic plants. By reducing water depth and increasing light availability, sediment accumulation may also dramatically increase the available habitat for rooted vascular aquatic plants. Sedimentation may reduce water depth to levels that significantly impair recreational activities such as swimming and boating. The reduction in total water volume may also result in a marked increase in water temperature and a reduction in dissolved oxygen concentration and deep water habitat. Excessive sedimentation can also clog water supply intakes for drinking water reservoirs.

Excessive sedimentation can stimulate the growth of nuisance aquatic plants. Source: F. X. Browne, Inc.

Two commonly-used methods exist for dredging freshwater lakes and reservoirs. These include mechanical dredging, during which material is manually removed with heavy equipment such as bulldozers and clamshell diggers, and hydraulic dredging, during which dredged material is "sucked" out of the lake using a device called a cutterhead.

Mechanical dredging can be performed with or without lowering the lake water level. When the lake water level is lowered, sediment can be excavated using bulldozers and other heavy construction equipment. Cranes with clamshell buckets can operate from the shoreline or from a barge to remove sediment without lowering the lake water level. Once the sediment is excavated, it is loaded onto trucks and hauled to the disposal site. If the sediment is not sufficiently dewatered at the lake, watertight trucks must be used for transportation. Hauling sediment with

Mechanical dredging: Using a track hoe to remove sediments from a dewatered lake basin. Source: F. X. Browne, Inc.

high water content increases the project cost by increasing the volume of material that must be transported.

Hydraulic dredging: A typical dredging barge equipped with a cutterhead dredge. Source: F. X. Browne, Inc.

Hydraulic dredging involves the removal of accumulated sediment through the use of a vacuum-like dredge and pumping system. Prior to hydraulic dredging, a dredging barge is unloaded from a trailer into the lake. The barge is equipped with a cutterhead, which dislodges sediment from the bottom of the lake. The sediment mixes with water and is pumped as slurry from the barge to a nearby disposal site via a pipeline. Disposal of hydraulically dredged sediment requires either the construction of a sedimentation basin at the disposal site or requires that mechanical dewatering equipment be used to remove water from the dredged material. If mechanical dewatering equipment is used, the dredging rate must be comparable to the dewatering rate, or else a holding basin must be constructed for the sediment slurry. In general, mechanical dewatering is more costly than constructing a disposal basin; however, if a disposal site is not available near the dredging site, dewatering may be the only option. Hydraulic dredging may be hindered by the presence of large rocks, trees, and other debris in the sediment.

Once the material is removed from the lake, it is transported by dump truck or by pipeline to a suitable disposal site. There, the material is left to dry for several weeks or months and subsequently revegetated. If dredged spoils are contaminated, regulatory agencies may require that the sediment be “capped” with clean fill or taken to a landfill. Nutrient-rich dredged soils can sometimes be used as agricultural fertilizer or as a soil amendment for restoring brownfield areas. If the sediment is used as fertilizer within the lake’s watershed, a Nutrient Management Plan should be developed in order to ensure that the sediments are not washed back into the lake.

Dredging design and permitting usually takes at least a year to complete. The first step in the design process involves conducting a dredging feasibility study. The dredging feasibility study includes a bathymetric survey, which measures unconsolidated sediment and water depth. This information is used to then calculate sediment volume, as shown in Figure 1.8-1. In addition to the bathymetric survey, sediment testing may be required by regulatory agencies to determine suitable disposal alternatives. Usually at least one sediment sample is collected to determine the grain size distribution and organic content of the sediment. Sediment samples may also need to be tested for hazardous materials. Land use within the watershed is analyzed to identify industrial or hazardous waste sites that are potential sources of sediment contamination. Also, if the lake has been treated with chemical algaecides, the sediments may be contaminated with copper. Finally, sediment disposal and lake drawdown options as well as permitting feasibility considerations are investigated. Once all the information is collected, a dredging design plan is developed that includes the recommended type of dredging (hydraulic or mechanical), equipment needed, and recommended disposal site, as well as potential permits, funding, and timelines for the project.

Following the initial design process, engineering plans and permit applications are prepared by a professional engineer. Permit application review may take several months. Once all the permits have been secured, bids are prepared, a dredging contractor is selected, and the construction contract is awarded. For most lakes and reservoirs, the actual removal of material requires several months. Full restoration of the disposal area may take several years.

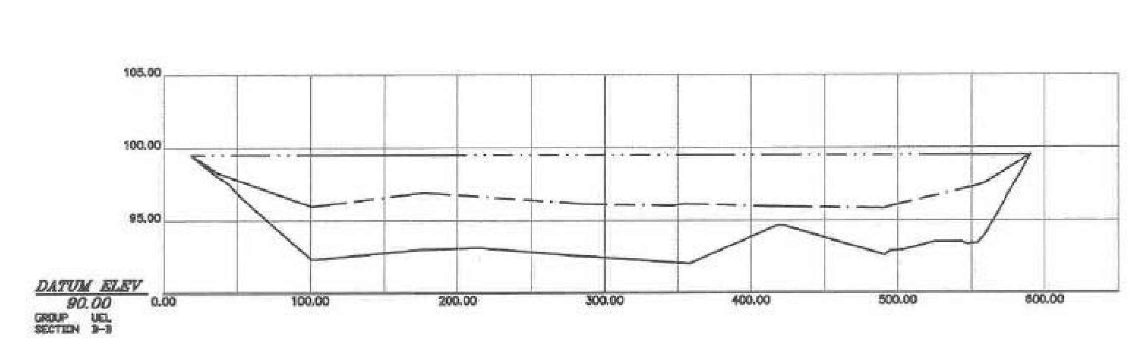


Figure 1.8-1 Cross section diagram showing water level (top line), existing unconsolidated sediment level (middle line), and proposed dredging depth (bottom line) for a lake dredging project.
Source: F. X. Browne, Inc.

Applicability

Depending on the extent and impact of sedimentation, dredging can be used to remove all or a portion of the accumulated sediments in a particular waterbody. Spot dredging is often used as a cost-effective alternative to whole-lake dredging where the impact of sediment accumulation is restricted to certain areas (e.g. near water supply intakes, swimming areas, boat launches, etc.).

Although dredging can be quite expensive, it remains a frequently exercised lake management option in the US, probably because it is really the only method of removing significant quantities of accumulated sediment and because it is highly effective in achieving its objective. Often, dredging is viewed as an acceptable and unavoidable maintenance requirement, rather than as an elective management practice. While dredging is an effective management technique that often produces immediate and significant improvements in resource quality, it is highly disturbing to a lake's biological communities and ecological functions. This may be of limited concern in highly-impacted systems such as urban reservoirs, but can be extremely damaging to high-quality natural lakes with delicate ecological systems and diverse native aquatic plant communities.

Because dredging treats only the symptom or end result of excessive sediment loading, dredging is a classic example of an “end of pipe solution”. Dredging frequency can be significantly decreased through the implementation of watershed-based sediment reduction strategies. If internal phosphorus loading is the primary reason for dredging, some type of phosphorus inactivation, such as bulk or continuous alum treatment, may be a more cost-effective and less disturbing management option.

Design Considerations

Major design considerations for dredging projects include dredging method selection, sediment disposal site selection and minimization of environmental impacts. It is important to recognize that many of these issues are interrelated and need to be simultaneously considered during the dredging design process.

Dredging Methods

Most freshwater lakes and reservoirs are dredged either mechanically or hydraulically. Choice of dredging method is based on a number of interrelated factors including:

- Sediment characteristics
- Disposal site availability and location
- Lake characteristics including water depth, shoreline accessibility, and ease of drawdown
- Timing restrictions
- Regulatory concerns
- Cost

Dredging projects are sometimes designed using multiple methods, which are determined during the design process. This approach allows dredging contractors more flexibility when bidding the project, which can help to reduce project costs.

Mechanical dredging is often the selected method of dredging when the waterbody can be easily drained. This is often the case with many small recreational reservoirs. Mechanical dredging is also the method of choice where suitable proximate disposal sites for hydraulic dredging (see below) are not available. Mechanical dredging is also the preferred option when the sediment contains significant quantities of rock, debris or other large material that could damage a hydraulic dredge. Mechanical dredging requires the availability of a staging area adjacent to the lake that can be used to load dredged sediment onto dump trucks.

Hydraulic dredging has a lesser impact on shoreline areas than mechanical dredging and is usually more cost effective. Additionally, hydraulic dredging does not require a lake drawdown permit. One potential negative impact of hydraulic dredging is the resuspension of lake sediments by the cutterhead dredge, although this is a temporary impact. Generally, however, the biggest drawback of hydraulic dredging is the proximity of a suitable disposal site. Hydraulic dredging typically requires at least three feet of standing water. Thus, it may be difficult to dredge tight coves and shoreline areas using a hydraulic dredge.

Sediment slurry inflow into a sediment disposal basin for a hydraulic dredging project.
Source: F. X. Browne, Inc.

Hydraulic dredging: return water effluent following sediment removal in a sediment disposal basin
Source: F. X. Browne. Inc.

Hydraulic dredging: mechanical dewatering equipment used to dewater sediment slurry in place of a sediment disposal basin
Source: F. X. Browne. Inc.

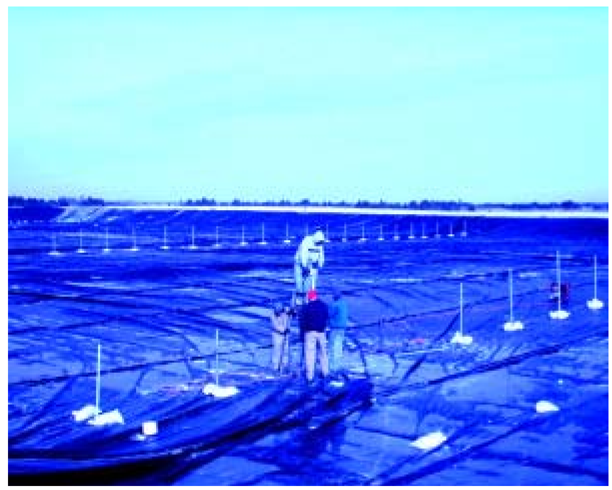
Sediment Type and Quality

Sediment characteristics and quality influence the selection of dredging method and disposal site. The most important sediment characteristics are particle size and organic matter content. Silt, clay, and sand sediments are suitable for mechanical or hydraulic dredging, while gravel and cobble are more suited for mechanical removal. It may be more difficult to dispose of large material such as sand, gravel, or cobble than silt and clay because they are less desirable for re-use. Rock material may be disposed of at a quarry, while sand material can sometimes be used for dune restoration or beach amendments. Material high in organic matter may cause odor problems at the disposal site and may be difficult to settle in a dewatering basin. Material low in organic matter may require the addition of fertilizer before reuse as a seeding or planting medium.

Depending on historical land uses in the surrounding watershed, sediments may sometimes be contaminated with heavy metals, pesticides, volatile organic compounds, or other hazardous chemicals. Contaminated sediments pose much more difficult and costly disposal issues since they must be trucked to a hazardous waste landfill. Typically, lake sediments are tested for hazardous materials during the dredging feasibility study if the watershed land use indicates the potential for sediment contamination.

Disposal Site Selection

Disposal site selection and availability is a critical dredging design consideration. When sediment is contaminated and the lake is located in highly developed urban areas, suitable disposal sites close to the dredging site may be difficult, or impossible to locate. In these instances, project designers must find creative, cost-effective sediment disposal solutions.



Hydraulic dredging: Installing a geosynthetic liner for a sediment disposal basin. Source: F. X. Browne, Inc.

Minimizing environmental impacts associated with sediment disposal greatly simplifies the permitting process and will avoid public controversy. In general, sediment disposal sites should not contain wetlands, high quality forests, or other significant natural habitats. Groundwater recharge areas, steep slopes and floodplain areas present significant regulatory and environmental issues and should also be avoided if possible.

Public use areas, such as parks or recreational areas, pose significant drawbacks for sediment disposal. The dredging disposal process will inevitably disrupt normal use of these areas and may create odor problems, safety hazards, and public fears concerning exposure to contamination (whether or not these fears are actually justified).

In addition to general disposal site guidelines, disposal site guidelines specific to each dredging method must be considered. For example, for hydraulic dredging, the disposal site must be located close to the dredging site (ideally within 0 to 1,500 ft) in order to be cost effective. Also, the disposal site must be large enough to include an adequate dewatering basin. The depth to bedrock or groundwater in the dewatering basin area must allow for excavation to the required basin depth. The disposal site must provide for inflow and outflow pipelines from the dredging site to the disposal site. If possible, the pipeline route should not cross major roads or utilities. Ideally, the disposal site should be higher in elevation than the dredging site and should slope towards the dredging site. This will allow the return water to flow via gravity back to the lake.

Inflow pipeline from a hydraulic dredging operation discharging dredged material into the disposal basin. Lake Lily, NJ. Source: F. X. Browne, Inc.

For mechanical dredging, material is physically removed rather than pumped from the lake. Therefore, disposal sites can be loaded onto trucks for disposal much farther away from the dredging site. To be cost effective, disposal sites for mechanical dredging projects should be located within 10 miles of the project site. However, using a disposal site close to the dredging site can dramatically lower project costs. Reusing the dredged sediment for fertilizer or fill can also decrease costs. Drainage and site accessibility are also key considerations in selecting an appropriate disposal site for a mechanical dredging project.

Environmental Impacts

Dredging can be an effective management tool, but it can have significant negative environmental consequences, both within the lake and at the sediment disposal site. State and federal regulations require that the environmental impacts associated with various dredging alternatives be carefully evaluated. Regulations may place restrictions on the extent, method, and timing of dredging to minimize environmental impacts. Also, permanent impacts to wetland and submerged aquatic vegetation must be compensated with active mitigation efforts (e.g., wetland creation).

All dredging projects cause disturbance to the lake bottom, which can lead to significant mortality of benthic macroinvertebrates, amphibians, reptiles, and plants. Proper timing can help to reduce impacts to migratory birds, hibernating animals, and fish spawning. In general, dredging is most detrimental to aquatic life in the spring and least detrimental in late summer/early fall. Reducing the total dredging period by extending the daily hours of construction and dredging rate can mitigate total environmental impact.

The desiccation and possible freezing of the lake bed during the extended drawdown required during most mechanical dredging projects is a significant disturbance to plant and animal communities within the lake. A comprehensive fish salvage and restocking plan should be developed if a complete drawdown is proposed. Access to the lake should be carefully considered to minimize impacts to shoreline habitats and riparian areas. Construction staging should reduce movement of heavy equipment across the lake bottom.

A fish salvaging operation prior to lake drawdown for a mechanical dredging project. Source: F. X. Browne, Inc.

Hydraulic dredging can produce localized increases in turbidity that can be detrimental to aquatic life. Extraction of sediment using suction-based methods can be particularly damaging to hibernating animals, such as turtles, if performed during the winter. Sediment dewatering basins must be well designed to provide acceptable return water effluent quality.

Environmental impacts at the disposal site can also be significant. Disposal sites with significant environmental resources (e.g., wetlands, forests, groundwater recharge areas, etc.) should be avoided. State and federal regulatory authorities will usually strongly discourage or prohibit use of such area for sediment disposal. Proper management of stormwater runoff at the disposal site is critical for minimizing environmental impacts. Drying sediment generates significant quantities of runoff that can pose a threat to nearby waterways if proper erosion and sediment control measures are not employed.

Maintenance Recommendations

Required maintenance for most dredging projects is minimal. After dredging is complete, the disposed sediments may require several months to fully dry. Regularly spaced trenches that traverse the disposal site may speed up the drying process. Vegetating the site may also reduce drying time and is critical for controlling erosion and sediment pollution.

Ideally, no dredging project should have to be repeated. Identifying and controlling sediment sources and inputs to the lake such as streambank erosion and agricultural runoff should be implemented to prevent further degradation to the lake.

Cost Considerations

Dredging costs vary greatly according to type and amount of material, dredging method, disposal site location, sediment contamination levels, season, location within the state, and a variety of other factors. A review of previous dredging projects designed by F. X. Browne, Inc., as shown in Figure 1.8-2, indicates that per cubic yard removal costs vary from approximately $9 for large projects (greater than 200,000 cubic yards) to approximately $150-200 for small projects (1,000-2,000 cubic yards). Costs for projects ranging from 10,000 – 250,000 cubic yards of sediment removed averaged approximately $16 per cubic yard.

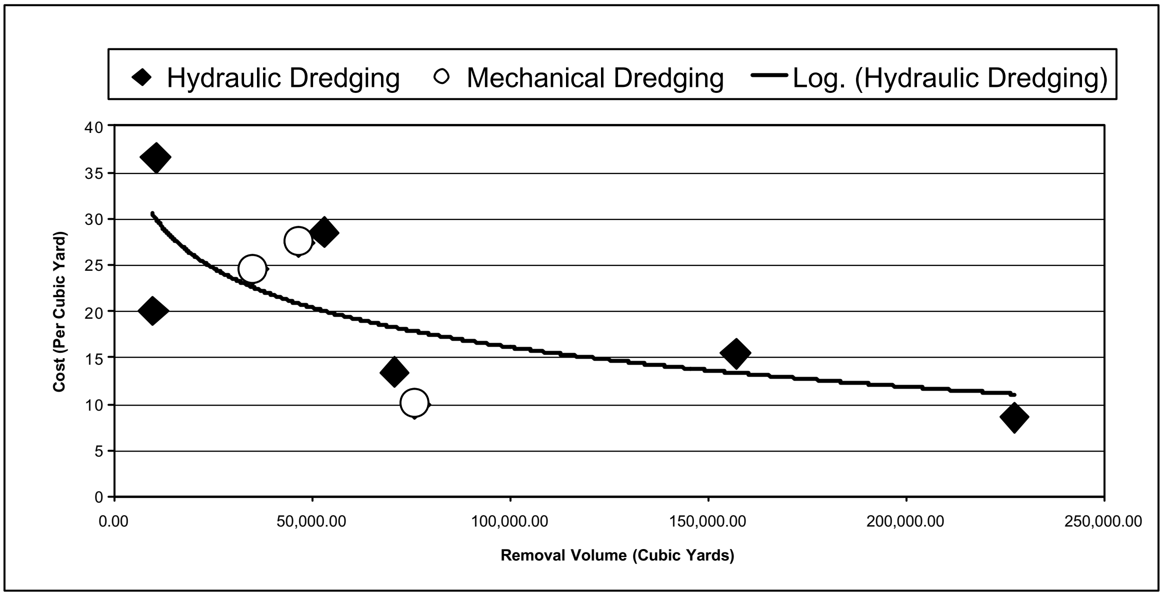


Figure 1.8-2. Unit Cost (2001 Dollars) vs. Removal Volume For Selected Lake Dredging Projects (1984-2001) Source F. X. Browne, Inc.

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1.9 Fishery Management

Fishery management is often overlooked as part of a lake management plan. The quality of a lake's fishery often indicates the overall "health" of the aquatic system. Healthy fish populations reflect balanced lake ecosystems. The primary goal of any lake management plan is to create a balanced ecosystem, and fishery management should be a key part of developing a management plan. In addition, fishing tends to be a very popular lake use, and therefore many lake users consider the health of the lake's fishery to be of primary importance.

1.9.1 Water Quality Monitoring

Water is the largest component of a lake ecosystem. Identifying and understanding how water quality influences a lake's fishery is the first step in the development of a good fishery management plan.

Applicability

Fish obtain oxygen for respiration from the water column in the form of dissolved oxygen, so poor water quality can influence the amount of oxygen available. Heavy sediment loads, decaying plants, and chemical pollutants can all reduce the amount of oxygen available to fish. Over time, reduced oxygen concentrations will stress the fish. If low oxygen persists, death may occur.

Nitrogen and phosphorus concentrations in a lake will influence the base levels of the aquatic food chain, which are the primary food source for juvenile fish. Low levels of nutrients within a lake translates to low productivity, and usually results in fewer, smaller fish. High nutrient concentrations foster higher productivity, which can lead to excessive plant growth and more frequent algae blooms.

The chemical characteristics of lake water can affect fish health. For example, lakes with low pH do not maintain good fisheries because the low pH causes aluminum to be released from the soil in the surrounding watershed and lake sediments. Aluminum binds to the surface of fish gills, reducing the fish's ability to absorb oxygen from the water column. This can lead to suffocation and death.

Design Considerations

Water quality monitoring is essential when developing a lake management plan. Most, if not all, of the physical and chemical characteristics of the lake and surrounding watershed can be identified through routine monitoring. Routine monitoring parameters should include pH, dissolved oxygen, temperature, and nutrients (total phosphorus, nitrate and ammonia nitrogen). In a lake or pond these samples should be collected from at least one mid-lake location and at both the inlet and the outlet. Water samples should be collected at least once during the spring, summer, and fall. Monthly monitoring during the growing season (May through October) is preferred.

Maintenance Recommendations

Once a fishery management program has been initiated, it is important to continue monitoring water quality. Water samples should be collected from the same locations at approximately the same time of year. This will allow comparisons to be made between water quality data collected from season to season. Subtle changes in water quality will influence fish health and affect the overall quality of the fishery. Identifying changes in water quality that could affect the health of the fishery early on can prevent the need for expensive restocking or major habitat improvements in the future.

Cost Considerations

Initial Costs

In comparison to other fishery management practices, water quality monitoring can be very inexpensive. Basic sampling equipment would include a pH meter, conductivity meter, Secchi disk, thermometer and several water test kits (dissolved oxygen, nitrate nitrogen, total phosphorus). The price and quality of this equipment will vary, but all of the equipment listed above can be purchased for $500 to $700.

Maintenance Costs

With proper care, the field meters and sampling kits should last for years. Each field kit contains enough chemical reagents to perform approximately 50 tests. Replacement reagents will be required, costing from $30 to $50. Reagents should be replaced at the start of each sampling year to ensure freshness.

1.9.2 Physical Habitat Assessment

Along with monitoring water quality, it is also important to asses the physical habitat in a lake or pond when managing a lake's fishery. Physical habitat generally refers to specific habitat features that fish use in the lake for spawning, hunting prey, and hiding from larger predators. This would include natural features such as aquatic vegetation, submerged trees and logs, and large boulders. Other less obvious or overlooked natural habitat features include sudden changes in topography along the lake bottom, inlet and outlet areas, underwater springs, and shoreline irregularities. Artificial or human-made structures such as docks, log cribs, brush piles, and rubble reefs also provide physical habitat and should be included as part of the physical habitat assessment.

Applicability

Knowledge of the type and extent of fish habitat available in the lake will help determine whether habitat is limiting the quality of the fishery. If suitable habitat is not available for all life stages of the fish species being managed (i.e fry, juvenile, and adult), the quality of the fishery will decline.

Design Considerations

All habitat types should be evaluated during the assessment, including aquatic plant growth. This may require hiring a professional to accurately identify and map the plant species growing in the lake. However, with some training, volunteer monitors can become familiar enough with the aquatic plant types in a given lake to complete the assessment on their own. A basic aquatic plant assessment involves identifying and mapping the exact location and extent of individual plant species and type (i.e. emergent, submerged, floating) on a scaled map of the lake so that changes in coverage and species diversity can be monitored, as shown in Figure 1.9-1.

LEGEND

1. *Decodon verticillatus*
2. *Peltandra virginica*
3. *Myriophyllum* spp.
4. *Ceratophyllum demersum*
5. *Sparganium* sp. and *Decodon verticillatus*
6. *Decodon verticillatus*, *Sparganium* spp., and *Iris versicolor*
7. *Pontederia cordata*
8. *Sparganium* spp. and *Peltandra virginica*
9. *Decodon verticillatus* and *Ludwigia Palustris*
10. *Sparganium* spp.
11. *Decodon verticillatus* and *Sparganium* spp.
12. *Decodon verticillatus*, *Myriophyllum* spp., *Peltandra virginica*, *Sparganium* spp., *Pontederia cordata, Iris versicolor*, *Ceratophyllum demersum*, and *Potamogeton natans*
13. *Nuphar luteum*, *Lemna* spp.
14. *Lythrum salicaria*

Dashed lines denote channel, open water

Scale: 1" = 250

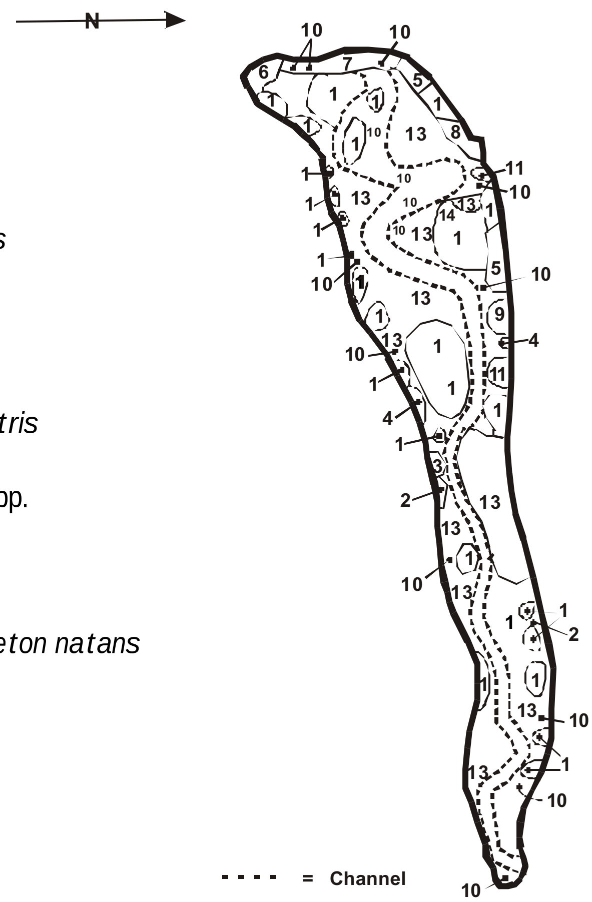


Figure 1.9-1 Example of an aquatic plant map. Source: F. X. Browne, Inc.

In addition to plant habitat, other physical habitat features should be identified on the habitat assessment map. Features such as rock piles, spawning areas and submerged logs should be clearly identified on the map so that their contribution to the overall habitat in the lake can be evaluated.

If available, the assessment should also include a bathymetric map, or map showing the lake topography, so that habitat provided by changing features in the lake bottom is documented. A simple way to create a bathymetric map is to use a weighted line and portable GPS unit to measure the depth and document the location of the measurement at various locations throughout the lake. The GPS unit will record the distance from a known location on the lake (i.e. dock, outlet, inlet) where the depth measurement was taken, which can then be easily recorded on a base map. GPS units can be purchased from most sporting goods or retail stores for less than $200, and with a little practice are quite easy to use. Using a GPS will also help relocate the sampling points or habitat features in the lake so that they can be monitored again in the future. A bathymetric map is also helpful when making other management decisions requiring information about acreage and depths in the lake.

Maintenance Recommendations

Re-evaluation of the physical habitat may be necessary if fishery management is a significant component of the lake management plan. Physical habitat characteristics do not change rapidly, so a re-assessment of the physical habitat should only need to be performed every two to three years.

Cost Considerations

The cost for a preliminary habitat assessment by a consultant will range between $2,000 and $5,000 depending upon how extensive the survey is and the amount of baseline information such as mapping that is already available. Once the initial assessment has been completed re-assessment costs will be much less ranging from $1,000 to $2,000 per assessment. Volunteers can perform a habitat assessment for much less by purchasing their own equipment (i.e. GPS unit, sounding line, or fish finder) for $200 to $500 and developing a map on their own. If this option is chosen, some professional training is recommended.

1.9.3 Fish Surveys

Fish populations in a lake are surveyed with various types of nets or electro-fishing equipment. Gill nets can be suspended from floats in the deeper portions of the lake. Seines are used to corral and trap fish against the shoreline in shallow water. Trap nets are positioned to intercept migrating fish along the shoreline. Electro-fishing is conducted by professional fishery biologists, and involves the use of specialized equipment that attracts and temporarily stuns the fish so they can be collected and sampled. The sampling technique best suited for a given lake will depend on the type of habitat to be sampled and the type of information needed to address the management concerns.

Applicability

A fishery survey yields length, weight and fish population data needed to accurately evaluate the quality of a lake's fishery. Ancillary information gained from individual sources may be biased and may only provide information on the fish species of most interest to the group or individual. Nets and electro-fishing equipment collect all sizes and species of fish providing a better picture of the overall fishery.

Design Considerations

Written goals and objectives of the fishery management plan will dictate the amount of sampling required. If the primary goal is to identify fish species found in the lake, several hours of electro-fishing or seining the shoreline may be sufficient. However, if the management goals involve evaluating the condition of the fishery, then a more extensive sampling program with multiple sampling efforts at different times of the year is ideal. Sampling intensity will also depend on the types of habitat found in the lake. Lakes with a variety of habitat types (i.e. deep water, shallow shoreline areas, and extensive weed growth) will require several different sampling methods to collect the necessary data.

Electroshocking at a Pennsylvania Lake
Source: Renea Ruffing, PA Sea Grant

Fishery sampling equipment is expensive and requires specialized training for proper use. Permits from the Pennsylvania Fish and Boat Commission are required for all types of fish sampling. Nets greater than four feet in length must be permitted with the Fish and Boat Commission and special regulations apply to how they are used. Contracting a professional biologist that has the proper equipment and experience is recommended. Volunteer labor can be used to help with the sampling to reduce costs.

In Pennsylvania, as in many states, a collector's permit must be obtained from the Fish and Boat Commission prior to performing a fish survey. Collector's permits are required to ensure that the survey is performed in accordance with current statewide regulations, and assures that the Fish and Boat Commission is notified of the activity.

Maintenance Recommendations

If fishery management is a major component of a lake management plan, fish surveys should be performed annually. However, if fishery management is not a primary interest, survey data need only be collected once with additional surveys conducted if the quality of the fishery suddenly changes.

Cost Considerations

Initial Costs

In Pennsylvania, a collector's permit can be acquired for $50 with an additional $10 for each technician assisting with the sampling. Additionally, each individual listed on the permit must have a valid Pennsylvania fishing license.

Typically, the consultant will assess an initial fee of between $150 and $500 for equipment mobilization. A three-member sampling crew consisting of a project scientist and two technicians costs $150 to $200 per hour.

1.9.4 Fish Habitat Enhancement

The two primary types of fish habitat enhancement are natural and artificial. Planting shoreline areas with native emergent plant species or stabilizing steep shoreline areas with trees and shrubs are examples of natural enhancements. Artificial enhancements include building rock cribs, pallet structures, and brush piles, liming, raising pH and alkalinity, and the installation of an aeration system to increase the amount of oxygen-rich water available in the lake basin.

Applicability

Building Fish Spawning Structures
Source: PA Fish and Boat Commission

Not all lakes provide suitable habitat for the type of fishery that is trying to be maintained. Certain fish species and different life stages of fish require specific habitat and without it a good fishery cannot be established or naturally maintained. When this occurs, habitat enhancements such as rubble piles, brush piles, and pallet cribs can be used to create conditions that will improve the quality of the fishery.

Even in lakes where natural habitat features are abundant, water quality issues can prevent fish from utilizing available habitat. Low pH, reduced oxygen concentrations, and high nutrient concentrations can all result in a poor quality fishery. In these situations, enhancements to improve water quality such as liming, installation of aeration systems, and installation of stormwater management devices can improve the quality of the fishery.

Design Considerations

Fish habitat preferences are determined by age, time of year, and species. Habitat enhancement devices such as rubble reefs, rock piles, or pallet reefs should be placed where they will best meet the needs of the target fish species. Prior to installing artificial structures, one should learn about and understand the different habitat preferences of the target fish species. A good source of information on the different types of enhancement devices and where they should be located is the Pennsylvania Fish and Boat Commission Adopt-A-Lake Program. This program provides information on and assistance with the installation of habitat enhancement devices that have proven to be effective throughout Pennsylvania. Visit the Environmental Services section of the Fish and Boat Commission website at http://www.fish.state.pa.us/, or call the Fish and Boat Commission Habitat Management Section at 814-359-5185 for more information.

When constructing artificial structures, it is important to ensure that the materials used to construct the structures are free of contaminants that could potentially harm the aquatic environment. Pallets and used tires can be used to construct artificial structures, but should be cleaned prior to placement to avoid introducing oil, grease and any other potentially harmful substance to the lake. Pressure treated lumber should never be used to construct artificial structures since it may contain arsenic, a potentially deadly chemical.

Porcupine crib habitat structure installation
Source: PA Fish and Boat Commission

Lake liming and the installation of aeration systems to improve water quality and the extent of available fish habitat should be thoroughly evaluated before they are used as a habitat enhancement technique. These techniques could pose potential side effects could cause other lake management problems such as excessive plant growth and algal blooms. Without forethought, a solution for one problem could lead to other types of problems.

Cost Considerations

Costs associated with habitat enhancement projects are directly related to the extent of enhancement that will be performed. Artificial structures can be constructed from recycled materials at no cost. Artificial structures do not have to be constructed from elaborate materials; fish will live in an old abandoned shoe just as well as in a log crib constructed out of quality pine. Creativity can help keep project costs at a minimum.

1.9.5 Bio-manipulation

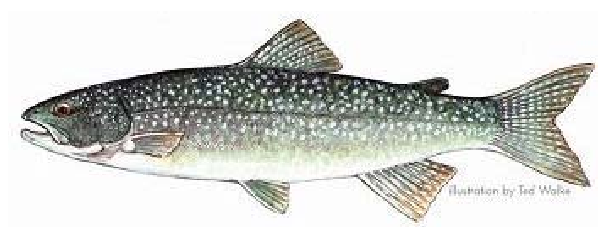
Bio-manipulation refers to the introduction or removal of an aquatic species with the intent of creating a more balanced ecosystem in the lake.

Applicability

The survival of juvenile fish is highly dependent upon the abundance of phytoplankton and zooplankton as a food source. In low productivity lakes where nutrients are lacking, planktonic organisms are not abundant and thereby limit the growth and survival of juvenile fish. To improve the survival of juvenile fish, lakes are sometimes mechanically fertilized to increase algae and phytoplankton growth, which in turn improves the survival of the juvenile fish.

Fish populations often become stunted when the major predator species is unable to consume enough of the prey species to keep a population in balance, or there is an inadequate number of prey species to support the nutritional requirements of the larger predator species. In such situations where the population has become unbalanced, supplemental stockings can bring the fishery back into balance by increasing the number of prey or predator species.

Declining water quality or poor habitat often allows undesirable species or “rough fish” to become the dominant species in a fishery. Once the water quality or habitat conditions have been improved, physically removing the undesirable species from the population can provide more desirable species with the opportunity to regain dominance and improve the quality of the fishery.



Lake Trout
Source: PA Fish and Boat Commission

Design Considerations

Bio-manipulation requires a good understanding of the ecology of the fish species that are being managed. Therefore, intentionally altering the biological community should only be performed under the guidance of a knowledgeable aquatic ecologist. The effects of introducing a new species, removing an undesirable species, or supplementing the number of existing species can potentially result in long-term adverse affects to the biological community. Therefore, bio-manipulation should only be considered when the interactions of the biological community are fully understood.

Maintenance Recommendations

The effects of bio-manipulation projects should be monitored annually. This will allow adequate time for the manipulation to take effect and to determine whether alterations need to be made to the program in order to prevent a further decline in the quality of the fishery.

Cost Considerations

It is difficult to estimate the cost of a bio-manipulation project since such projects usually involve a combination of techniques. For example, a fish removal project may involve the use of the chemical rotenone and sampling equipment similar to that used during a fishery survey. Therefore, the cost of the project could be equal to the combined cost of both these types of projects and will cost several thousand dollars. The cost of a fishery survey should be included in the cost of any bio-manipulation project.

Supplemental stocking of prey species such as fathead minnow or shiners could cost less than $100 per acre, whereas the supplemental stocking of predator species such as largemouth bass could cost as much as $500 to $1,000 per acre depending upon the size of the fish that are stocked.

Lake fertilization is the least expensive of the bio-manipulation techniques that have been discussed ranging in cost from $30 to $50 per acre.

1.9.6 Fish Stocking

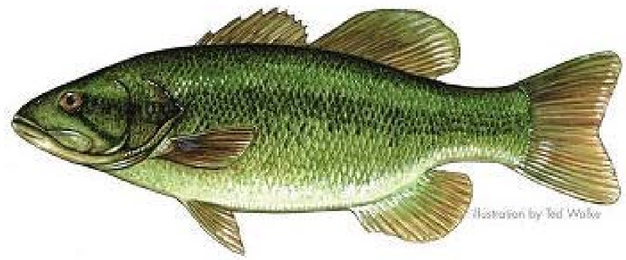
Of all the fishery management techniques, fish stocking is probably used most often. The desired species of fish are purchased from a hatchery and put in to the lake to supplement the existing fish population.

Applicability

Fish stocking is an important management tool when a lake receives heavy fishing pressure and the natural fish population is unable to maintain an adequate number of fish to meet the demands of fishermen. Large numbers of legal-sized fish are stocked on a regular basis so that the population is replaced as quickly as they are removed. This is commonly referred to as a "put-and-take" fishery.

Supplemental stockings can also be performed when the results of a fishery survey indicate that certain size classes of fish are missing from the population. With this type of stocking, fish of a specific size are introduced in limited numbers to bring the population into balance. The goal of this type of stocking is not to provide fish to be harvested, but rather to correct a situation such as an abundance of fish that are all the same length.

Although not very common, a new species is sometimes introduced into a lake through stocking programs. Certain species of fish are more desirable to anglers, and if that species is not present, lake managers are often asked to stock it in the lake. Introducing new species into a lake can be risky to the natural population, especially if the lake already has a well-established fishery.



Largemouth Bass
Source: PA Fish and Boat Commission

Design Considerations

Prior to stocking fish of any species into a lake, it is important to know the condition of the existing fishery. This is not as critical if the lake is being managed as a “put-and-take” fishery. However, if the goal is to establish a self-sustaining fishery, introducing large numbers of the wrong size fish to the population can disrupt the natural balance of the fishery.

A second consideration in stocking is whether or not the lake can support more fish. Poor water quality, lack of habitat, and an insufficient number of prey can limit existing fish populations. Stocking fish could put more stress on the population and do more harm than good.

The size of the stocked fish depends on the management goal and budget. Fish can be purchased as fry, fingerlings, yearlings, or adults. Fry are an inch in length, fingerlings are about the size of a finger, and yearlings are one-year old fish. Adult fish have reached maturity and are available in a variety of different sizes. Fingerlings are usually the best choice when large numbers of fish are required. Fish of this size class are less vulnerable to predation than fry, but less expensive than either yearling or adult fish.

Stocking rates vary between species and certain fish combinations are better than others. Typical fish combinations include bass and sunfish, walleye and perch, and trout and pike. Stocking rates for each of these species are dependent upon the size of the lake and condition of the existing fishery. Stocking the wrong quantity or species of fish can destroy the fishery. Therefore, it is best to consult a professional fishery manager during the decision making process.

Maintenance Recommendations

Maintenance stockings should not be performed if the fishery can sustain itself. However, if maintenance stockings are required to preserve balanced conditions they should be performed annually. If maintenance stockings are not required, adding a few trophy-size fish to the population at the beginning of each season will not harm the natural balance and will help keep the fishermen interested in the management program.

Cost Considerations

The cost of stocking fish will depend on the species, size, and transportation costs. These costs will vary from region to region. Some species of fish are only available at certain times of the year. Therefore, make sure to confirm fish availability with the hatchery. Table 1.9-1 provides an example of the prices and recommended stocking rates for fish species typically stocked in Pennsylvania lakes and ponds.

Table 1.9-1
Fish Prices & Stocking Rates
(Source: Fish Haven Farm, LLC)

Species	Stocking Rate**	Size	Retail Price*
Largemouth Bass	100/acre	1”-2”	$70 per 100
		2”-4”	$85 per 100
		6”-8”	$3.00 each
Channel Catfish	200/acre	3”-5”	$70 per 100
Walleye	50/acre	5”-7”	$195 per 100
Yellow Perch	300/acre	3”-5”	$75 per 100
Rainbow Trout	300/acre	2”-3”	$50 per 100
		6”-8”	$140 per 100
		8”-10”	$180 per 100
Crappie	200/acre	3”-5”	$95 per 100
Fathead Minnow	20lbs/acre	1”-3”	$10 per pound

*This price does not include delivery.
**Actual rate should be determined based on the current, or pre-stocking fish population (by species). Rates presented are for new ponds or restoration of lost fisheries in existing lakes or ponds (i.e. due to dredging, fishery restoration, etc.).

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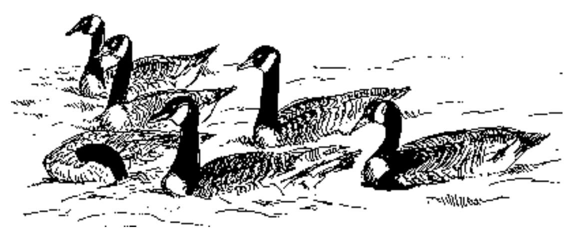
1.10 Nuisance Wildlife Control

In a perfect world, humans and wildlife would coexist without much interaction. However, as humans continue to convert wildlife habitat into human habitat, problems inevitably occur. While many people enjoy the presence of wildlife, certain animals have the potential to threaten other wildlife populations, the environment in which they live, agriculture and aquaculture industries, and human health and safety. Non-native species can be especially problematic since they often have no natural predators and can damage existing ecosystems. In situations where wildlife species become troublesome or compete with man's economic or health interests, the animals are called pests. Most wildlife species have the potential to become pests. Many species of wildlife do not cause physical damage, but can be considered nuisances merely by their presence in a particular location.

This section focuses on nuisance wildlife in lake and riparian environments. Issues concerning waterfowl, beavers, muskrats, deer, and other native wildlife are addressed, as well as control of non-native species. Problems resulting from the presence of these animals along with solutions regarding their control are presented.

1.10.1 Nuisance Waterfowl: Swans, Ducks, and Geese



"Nuisance" waterfowl refers to large flocks of waterfowl, primarily Canada geese, that congregate on the shores of lakes and other water bodies. While migratory populations of Canada geese have been on the decline since 1985 in Pennsylvania, nonmigratory, or resident populations, have been increasing, and in some areas are considered a nuisance.

Management Problem

While small populations of waterfowl are natural in lake environments, high concentrations of waterfowl are unnatural and bring negative consequences. When flocks of geese or other waterfowl no longer migrate, it becomes a problem in developed areas. The availability of suitable habitat on golf courses, parks, and residential lawns has made migration unnecessary for birds in many areas of Pennsylvania. These areas, which were once mere stopovers, become permanent homes for the birds. Although most people enjoy seeing the birds, and some even feed them, the potential harm to lake water quality can be serious. The waterfowl may overgraze vegetation upon which other fish and wildlife species depend for food and shelter. The excessive bird feces contribute nutrients to the water that can lead to algae blooms, accelerated eutrophication, depleted dissolved oxygen levels, and high bacteria levels in the water. In addition, frequent entering and exiting the water by the waterfowl can erode shorelines and increase siltation and nutrients to the waterbody. These problems have a negative impact on the ecological balance of the waterbody, and can threaten other native species.

In public areas, excessive waterfowl populations increase the chances of swimmers contracting swimmer's itch, also known as "Duck itch." Waterfowl droppings can carry a parasite that causes this uncomfortable rash in humans, and the likelihood of infection increases when the waterfowl population is large. The aesthetic problems with excessive bird droppings are also an issue.

Geese and swans defend their nests and young aggressively. Humans that venture too close to nests and/or young are likely to be attacked.

Management Recommendations

A range of options is available to discourage nuisance resident waterfowl populations, some more palatable to bird lovers than others. The most important first step is to stop all waterfowl feeding. Sometimes a township ordinance is necessary to stop waterfowl feeding. It is important that a public education campaign accompany any anti-feeding ordinances to stimulate public interest, participation, and support.

The key to controlling nuisance flocks of ducks, geese, or swans is promptness and persistence. Deterrents can include physical barriers that exclude the waterfowl from the lake or prime waterside areas. Deterrents can also be visual (flapping objects, fake predators) or audio (dogs, loud noises). Breeding can be minimized via egg addling. Birds can be gathered up and moved during the molting period. Some park and municipal managers have been known to scare off nuisance waterfowl by shining lasers into their eyes at night. Many managers have resorted to gassing or shooting the birds, which is only allowed by state or federal permit, and is a last resort. Some of the other management techniques require permits as well, so it is best to check with the Pennsylvania Game Commission before undertaking any waterfowl management program. An integrated approach, involving multiple strategies, is often the best way to manage nuisance waterfowl.

One of the most effective ways to discourage waterfowl from congregating around a lake is to allow vegetation to grow up along the shoreline. Most large waterfowl prefer not to walk through long grasses or sedges to enter the water, so by maintaining a shoreline buffer area, the birds will look for another home. Planting vegetation along the water edges less palatable to the birds, such as tall fescue (*Festuca arundinaceae*) pachysandra (*Pachysandra terminalis*), and periwinkle (*Vinca minor*), will reduce grazing.

Cost Considerations

The cost of nuisance waterfowl management can vary greatly depending on the size of the site and the extent of the problem. Some parks and public agencies spend thousands of dollars a year in attempts to eradicate nuisance waterfowl, and usually the efforts must be continued on a long-term basis. Visual deterrents are the most inexpensive of the management techniques, but they rarely control nuisance populations by themselves. If permits are involved with the management process, this can increase costs considerably. If an overall restoration plan is being undertaken at the lake, planting a vegetative buffer is the most cost-effective solution since it would serve a dual purpose: deterring waterfowl and improving water quality.

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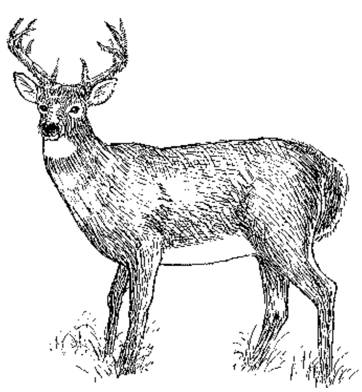
1.10.2 White-Tailed Deer



Before European settlement in Pennsylvania, Pennsylvania had an estimated 8 to 10 white-tailed deer (referred to as deer in this section) per square mile. In the early 1900's, the Pennsylvania habitat was ideal for deer populations. Most of the forestland that was clear-cut in the 1800s regenerated into young forestland. The thick stands of young trees and shrubs provided the perfect food and cover for deer. Deer were also brought in from other states, such as Michigan and Kentucky, to restock a population that had been seriously over hunted by the end of the 1800's. As a result, Pennsylvania's deer population grew rapidly in the 1900's. Today there are approximately 30 deer per square mile in Pennsylvania, or 1.5 million deer. Deer are an important part of Pennsylvania's economy. Tourists enjoy watching deer at wildlife centers or along roadsides. Revenues from hunting are critical to the welfare of many small businesses and communities. Deer are also an important part of the forest ecosystem, helping to maintain healthy and diverse forest habitats. However, when they become so abundant as to alter forest ecosystems and cause property damage in suburban areas, they become a nuisance.

In the report, “Deer Management: Taking the Next Step Forward,” (2002) the Pennsylvania Game Commission (PGC) outlines a plan to return the Pennsylvania deer population to a more natural ecological state. The report states that “Of all the things that could increase the number and size of bucks in our deer herd and improve our breeding ecology, nothing would do it as dramatically - and be accepted by hunters - as changing our antler restrictions.” The PGC believes that allowing more does and fewer young bucks to be harvested would restore a more natural breeding population. Deer populations and density goals based upon habitat, along with hunter success rates, are used to gauge how many hunting permits should be issued. In 2003, regulations aimed at increasing the survival of yearling bucks allowed hunters to shoot only bucks with 3 or 4 points to an antler, depending on location. In the long term, the PGC feels that hunters will likely see more and larger bucks than in the past. The PGC is also participating in several deer population studies, including a Forest Restoration Area Study, in order to assess the relationship between deer numbers and hunting practices.

Deer Herd Source: Pennsylvania Game Commission

Despite the attempts by the PGC to reduce the deer population in the Commonwealth, deer are found in populated areas with increasing frequency. Deer population control in suburban areas has become a somewhat controversial subject in Pennsylvania as well as other areas of the US. Many residents enjoy seeing the animals and oppose hunting and other lethal efforts at controlling the population. Others are continually frustrated by deer eating their gardens and posing driving risks. Regardless of the options being considered for deer management, public education about the available options and the negative environmental effects of deer overpopulation is critical.

Management Problem

White-tailed deer are only a nuisance when overpopulation is an issue. In residential areas, deer destroy gardens and ornamental trees, and tend to cause automobile accidents. While an over population of deer may not directly impact a lake environment, damage to the forests within a watershed may have indirect negative consequences on lake environments. Large populations of deer can over-browse

Source: Pennsylvania Game Commission

riparian buffers, especially newly restored buffers with tender young trees, therefore reducing their effectiveness. In addition, deer prefer to feed on new forest growth, causing the forests to revert to single-aged stands with only a few species able to survive the deer's winter feeding frenzy. Over the long term, this can lead to depletion of understory plants and wildflowers, as well as the birds and other animals that feed on them or require them for shelter. Very excessive numbers of deer can erode streambanks where deer trails and crossings are established, and contribute nutrients to streams via their feces.

Management Recommendations

There is no one easy solution to the problem of deer overpopulation, and the first step in developing a management plan should be to assess the current status of the deer population via monitoring studies or infrared surveys. The next step in deer management is a public education campaign, and a restrictive ordinance prohibiting deer feeding. Feeding deer encourages population growth beyond the capacity of the area, causing a high level of dependency, diseases due to improper diet, and death by starvation. The ordinance should prohibit residents from feeding deer under any circumstances. Another concern with deer feeding is the potential spread of Chronic Wasting Disease at feeding stations. While the disease is not currently known to exist in Pennsylvania, several states, including neighboring New York State, have already banned deer feeding statewide.

Deer feeding on residential lawn. Source: SWMNGA

Encouraging hunting in overpopulated areas, is one of the more effective ways to manage deer overpopulation. Besides hunting, which may not be an option in more population-dense areas, trained sharp-shooters or controlled archery organizations (such as the Quality Deer Management Association) can be hired under special permit to cull the deer population in defined areas. These experienced hunters can reduce localized populations in a short period of time, often at night when their activities are less disturbing to local residents. The deer meat is often donated to local food pantries.

If lethal deer control methods are not applicable or preferred, several non-lethal deer control methods exist. Repellants (via odor or taste, such as bonemeal) and fencing can be effective techniques for site-specific deer damage problems; however, these methods will not decrease damage on a watershed scale. In residential areas, damage can sometimes be reduced by planting yard vegetation that is unpalatable to deer. However, when deer densities are high or natural foods are limited, deer may browse on species they otherwise would not eat. Visual or audio deer deterrents are commercially available, as are special highway warning reflectors to discourage deer from entering roadways in front of cars at night. Deer birth control products are being developed but are currently prohibited by the Pennsylvania Game Commission. One other non-lethal deer control method is capture and relocation. This method is very time-consuming and expensive, however, and is not effective for large populations.

Cost Considerations

Hunting is the most cost-effective way to reduce deer overpopulation since it entails no cost on the part of the property owner. Some bowhunting organizations will cull deer herds on a property for free or for a very low cost in exchange for the chance to hunt on private land, the opportunity to improve the deer herd, and the venison. Deer repellents and deterrents can be inexpensive, but are not feasible on a large scale. Fencing can be very expensive, since deer can jump very high and fences must be tall. Fencing is not feasible on a large scale, but may work to protect individual trees, parks, or yards.

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1.10.3 Beaver, Muskrat, and Nutria

Beaver, muskrat, and nutria are all aquatic mammals in the rodent family. All three are vegetarians, and all three have a tendency to modify lake and wetland habitat. This tendency is the primary cause of conflict between the animals and humans.

Beaver Dam

Beavers are the largest North American rodents, and are best known for their unique dam building ability, which enables them to modify their habitat to meet their needs. In some instances, beaver dams have a positive effect on an environment; they may stabilize creek flow, slow runoff, and create ponds that benefit fish and other wildlife. However, in other situations, a beaver's modification of the environment may be more damaging than beneficial. Muskrats are smaller than beavers, but they may also modify wetland habitat. The habitat modifications can benefit a wide variety of wildlife, but can cause damage to human-made structures and wetland or riparian vegetation.

Nutria

Nutria are large, semi-aquatic rodents native to South America that were first imported to the United States in 1899. They resemble beavers or muskrats but differ by having long, round tails and webs between the inner four toes of their hind feet. Populations were once kept in check through trapping; however, as the price of their pelts fell, little economic incentive existed to continue trapping them. A tremendous increase in the nutria population resulted. While it is believed that nutria do not currently inhabit Pennsylvania, populations are known to exist in Maryland, and it is possible that nutria may soon become an issue in Pennsylvania.

Management Problem

Most of the damage caused by beavers is the result of bank burrowing, dam building, tree cutting, or flooding. Beavers can weaken levees or earthen dams by burrowing into the banks, which may cause them to collapse during periods of high water. Beavers cut trees along the water's edge to build their dams and lodges; this can damage riparian buffers and creates a nuisance to shoreline homeowners who value their trees. In addition, beaver dams can block creeks, drainage ditches, culvers and spillways, causing adjacent lands and roads to be damaged by flooding and erosion.

Muskrats also cause damage by burrowing into the banks of earthen water retaining structures (i.e. dams and dikes) and lead to serious leakage problems or even loss of stored water. The burrows along the shoreline can represent erosion problems. In addition, large populations of muskrats can eat excessive amounts of aquatic vegetation, making the habitat less suitable for other wildlife.

Problems associated with nutria also involve burrowing into lake dams, levees, or watershed structures. Even small numbers of nutria can devastate wetland vegetation through intense feeding. The destruction of wetland vegetation has many negative consequences including impacts to other wildlife.

Muskrat burrow

Management Recommendations

Beavers

Beaver management options vary depending on the primary source of damage. If loss of trees is the main problem, heavy-gauge fencing with a mesh opening of no more than 2-inch x 4-inch can be installed around the base of the tree, six inches away from the trunk and extending to a height of four feet. In situations where beaver dams are blocking culverts and threatening roads, a strong woven wire fence can be staked 10 to 15 feet in front of the culvert, which physically prevents the beavers from accessing and plugging the culvert. Factors such as water depth, topography and wetland substrate need to be assessed before placing a fence in front of a culvert.

In situations where beaver dams have altered water flows, a water level control device (WLCD) may be effective in reducing flooding to a tolerable level for landowners while maintaining suitable beaver habitat. A WLCD is any device inserted through a beaver dam to drain water from the flowage. Plastic perforated pipes, wooden boxes with mesh bottoms, perforated aluminum culverts and culverts made from layers of mesh are variations of WLCDs. A WLCD minimizes the sound and motion of running water so that it is less noticeable to the beavers. Ideally, beavers should be able to continue their activities but not plug the device.

Sometimes, breaching of beaver dams is necessary as an interim measure to relieve flooding until other control measures are implemented. This is not an effective long-term control option, however. Breaching must be done on a regular basis because the beavers will rebuild the dam each night. If the nuisance beaver activity is severe, hunting or trapping may be an option. All wildlife is protected in Pennsylvania, and therefore all hunting and trapping activities are regulated by the Pennsylvania Game Commission.

Muskrats

Muskrats are very prevalent in Pennsylvania lakes, ponds, and wetlands. For this reason, barriers to prevent burrowing offer the most practical management solutions for muskrats. A properly constructed riprap filter and filter layer will discourage burrowing into human-made water control structures, as will heavy wire fencing laid flat against the slope and extending above and below the water line. Another option is to dig a trench extending lengthwise along the structure about three feet below water level, and fill the trench to one foot above water level with concrete.

If erosion damage to natural streambanks from muskrat burrows is the primary concern, backfilling, or "mud-packing," the burrows may be an option. This simple, inexpensive method involves placing one or two lengths of metal stove or vent pipe in a vertical position over the entrance of the den. The mud-pack is a 90 percent earth/10 percent cement combination mixed with water until a slurry or thin cement consistency is attained. Making sure that the pipe connection to the den does not leak, the mud-pack mixture is then poured into the pipe until the burrow and pipe are filled. The pipe is removed and dry earth is packed into the entrance. All entrances should be plugged with well-compacted earth and re-vegetated.

Trapping or hunting muskrats is a last-resort option, since it is likely that other muskrats will return wherever suitable habitat exists. The effectiveness of any trap is determined by the trapper's knowledge of muskrat habits, as well as proper trap selection and placement. All wildlife in the state of Pennsylvania is protected, and therefore all hunting and trapping activities are regulated by the Pennsylvania Game Commission.

Nutria

Once nutria populations become established over a large area, control can be difficult, so the potential problems caused by nutria should be addressed as soon as nutria populations are documented in a lake. The same management methods described for muskrat control may be applied to nutria problems.

Cost Considerations

Most of the physical control measures described above require very inexpensive materials available at any hardware store or home center. Management of aquatic rodents involves more time than money, as frequent inspections and repairs to dams and other structures may be necessary. All installations require regular maintenance to ensure their effectiveness. On the other hand, repair of streambanks, riparian buffers, or dams can be extremely costly, so it is best to address any potential aquatic rodent problems as soon as they become apparent. The installation of a water level control device at a culvert or modification of a beaver dam, including breaching or removal, may be considered a regulated wetland activity and may require a permit from the Pennsylvania Department Of Environmental Protection.

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1.10.4 Sea Lamprey

Sea lampreys are predaceous, eel-like fish found in coastal regions of both sides of the Atlantic Ocean. Although they are native to the Susquehanna and Delaware River Basins, the sea lamprey has had a devastating effect on Great Lakes and Lake Champlain fisheries where it is not native. It is estimated that sea lampreys entered the Great Lakes through the Welland Canal in 1921. Sea Lampreys contributed greatly to the decline of whitefish and lake trout in the Great Lakes before control measures were implemented. Since 1956, the governments of the United States and Canada, working jointly through the Great Lakes Fishery Commission, have implemented a successful sea lamprey control program.

Sea lamprey

Management Problem

Sea lampreys are parasitic pests. Lacking jaws, they attach to fish with their suction mouth and teeth, and use their tongue to rasp through a fish's scales and skin so they can feed on its blood and body fluids. A single sea lamprey can destroy up to 40 lbs. (18 kgs.) of fish during its adult lifetime. Sea lampreys are so destructive that, under some conditions, only one out of seven fish attacked will survive. Sea lampreys prey on all types of large fish, such as lake trout, salmon, rainbow trout (steelhead), brown trout, whitefish, yellow perch, burbot, walleye, and catfish. Since these are mostly larger game species, the sea lamprey has had a negative impact on recreational and associated economic opportunities in the Great Lakes region, including Lake Erie in Pennsylvania.

Management Recommendations

A sea lamprey attached to a fish.

Currently, the primary method to control sea lampreys involves the use of a lampricide called TFM that kills sea lamprey larvae in streams with little or no impact to other fish. About 175 Great Lakes streams are treated at regular intervals with lampricide to kill larval sea lampreys. Another promising management technique is the use of barriers to block the upstream migration of spawning sea lamprey. Barriers have eliminated lampricide treatment on some streams and reduced the stream distance requiring treatment on others. Newer barrier designs include velocity barriers that take advantage of the lampreys' poor swimming ability; electrical barriers that repel sea lampreys during the spawning run without risk to other fish or animals; and adjustable-crest barriers that can be inflated during the spawning run and then deflated to allow other fish to pass during the rest of the year. Other management strategies include the release of sterile male lampreys into the breeding population, and trapping lamprey. Overall, the sea lamprey control program has been tremendously successful. Ongoing control efforts have resulted in a 90 percent reduction of sea lamprey populations in most areas of the Great Lakes.

Cost Considerations

Despite the success of the TFM lampricide, it is a costly control method. The Great Lakes Fishery Commission has moved toward reducing its use by relying more heavily on other management methods. A more integrated approach to sea lamprey management is more effective and less costly.

References

Great Lakes Information Network. Invasive Species in the Great Lakes Region. http://www.great-lakes.net/envt/flora-fauna/invasive/invasive.html.

Great Lakes Fishery Commission. Sea Lamprey Control. http://www.glfc.org/lampcon.htm.

Lake Champlain Basin Program. "Nonnative Aquatic Nuisance Species: Sea Lamprey." Website: http://www.lcbp.org/nuissum.htm#lamprey.

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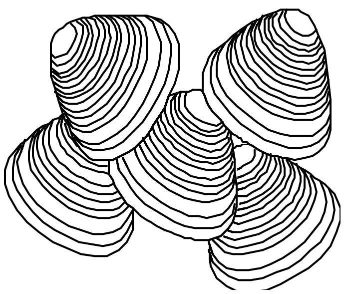
1.10.5 Mollusks: Zebra Mussel and Asian Clam

Zebra mussels

Both zebra mussels (*Dreissena polymorpha*) and Asian clams (*Corbicula fluminea*) are non-native mollusks that are currently wreaking havoc on Lake Erie and other lakes and rivers in Pennsylvania. Zebra mussels are native to western Russia, near the Caspian Sea. They were first discovered in the Great Lakes in 1988. Zebra mussels quickly spread to all the Great Lakes, and within one year they colonized nearly every firm object in Lake Erie. The Asian clam is a small freshwater bivalve mollusk that originated from Southeast Asia. First introduced on the west coast of North America around 1924, by the 1970s, the clam occupied most of the Mississippi Basin, the Gulf Coast and eastern United States. Its presence has been documented in many of the major rivers of Pennsylvania including the Ohio, Delaware, Monongahela, and Schuykill Rivers.



Asian clams

Management Problem

Zebra mussels

Zebra mussels cause problems by clogging water intake structures, such as those used by power plants and city treatment plants. Since 1989, some facilities located on Lake Erie have reported large reductions in pumping capacity and occasional shutdowns caused by encrusted zebra mussels. Zebra mussels can also clog boat motors, unprotected docks, breakwalls, boat bottoms, and engine outdrives. Zebra mussels can also damage submerged historical resources and impact tourism by covering beaches. In addition to their negative effects on human recreation and industry, zebra mussels can alter the natural environment by encrusting and outcompeting native mollusks, and by filtering particulate matter from the water, including phytoplankton and some small forms of zooplankton. Each adult zebra mussel can filter about one liter of water per day. Since these microscopic plants and animals are the base of the food chain, the long-term consequences of removing them from the environment is still unknown.

Asian Clams

Asian clams also cause problems with human industry. The Asian clam is a serious biofouler of raw water intake pipes, affecting power and water suppliers and other industries. Asian clams are drawn into intake pipes, and the live animals, empty shells, and body tissues obstruct water flow through condenser tubes, valves and service water systems. Buoyant dead clams can clog intake screens. Nuclear service water (fire protection) systems are most vulnerable.

Management Recommendations

Zebra Mussels

Physically scraping or hand removal is a somewhat effective and low-cost control method for zebra mussels. However, depending on existing populations, physical methods may very time consuming and the removal rate may not match the reproduction rate. In addition, the early life stages of the zebra mussel are very minute and not clearly visible to the naked eye. Total elimination is unlikely but populations can be significantly reduced through the removal of adult zebra mussels.

Currently, the only existing zebra mussel controls designed to protect vulnerable mechanical water supply systems are removal, exclusion filters and chemical treatment. Liquid sodium hypochlorite (bleach) has been used for years to control corrosion, scale, and lead buildup in pipes. This chemical has been found to be effective in controlling zebra mussels within water intake valves. Consultation with a qualified professional is recommended before using the chemical treatment since side effects to other organisms and other health hazards may result.

There are no known, environmentally-sound methods for completely eliminating zebra mussels from a waterbody once they have become established. Therefore, like many invasive species, the best control method is to prevent introduction into a new environment. Education campaigns are essential for public awareness and preventing spread. Several excellent fact sheets and brochures have been developed to explain zebra mussel identification and prevention. Refer to the reference section for more information.

Signs should be posted at susceptible waterways instructing visitors to remove any visible mussels from boats, trailers, and accessory equipment (anchors, centerboards, trailer hitch, wheels, rollers, cables, and axles) before leaving the water access area. All livewells, bilge water, and transom wells should also be drained and bait buckets emptied on land before leaving the water access area. Since zebra mussel veligers (immature larvae) are often invisible to the naked eye, it is important to wash boats, tackle, downriggers, and trailers with hot water after returning home and before entering any new water body. Hot water should be flushed through the motor's cooling system and other boat parts that normally get wet. If possible, the boat and equipment should be allowed to dry for three days before entering another body of water.

Asian Clam

There are several ways to minimize the impact of Asian clams on power planst, water suppliers or industries. Mechanical regulation involves using screens and traps to prevent mature clams from entering the water systems and to remove clam bodies and shells. This method is effective for dealing with older clams. Thermal regulation involves heating the water in the intake pipes to temperatures exceeding 37º F, but this is not feasible for many existing water systems. Chemical regulation involves applying small concentrations of chlorine or bromine to kill the juvenile, and in some cases, adult Asian clams. This is a very effective control method; however, state and federal environmental regulatory agencies are becoming increasingly restrictive regarding the amount of chemicals that can be discharged from a facility. The current trend is to search for more environmentally-sound, yet cost-effective and efficient treatment methods, and thus move away from the use of chemicals altogether.

Like many invasive species, the best control method is to prevent its introduction into a new environment. The same precautions outlined above for the prevention of zebra mussel spread also apply to Asian clams.

Cost Considerations

By far the most cost-effective means of dealing with invasive mollusks is prevention. Public education campaigns are fairly inexpensive, especially considering the wealth of existing materials available. Typically, the cost of a two-sided color brochure is about $0.80-$1.50 apiece, depending on the size and colors. Usually lower rates are available for printing in bulk. The cost of excluding or removing invasive mollusks from water intake pipes or other structures can be thousands of dollars.

References

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Great Lakes Science Center. 2000. Fact Sheet: Zebra Mussels Cause Economic and Ecological Problems in the Great Lakes. US Geological Survey.
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Lake Champlain Basin Program. 1998. Fact Sheet: Zebra Mussel. http://www.lcbp.org/zmfs.PDF.

Minnesota Sea Grant. 2002. Zebra Mussel ID Card.
Website: http://www.seagrant.umn.edu/exotics/zmid.html.

Pennsylvania Department of Environmental Protection. 2001. “Zebra Mussel Fact Sheet.” http://www.dep.state.pa.us/dep/deputate/watermgt/Wqp/WQStandards/Facts/fs2007.htm .

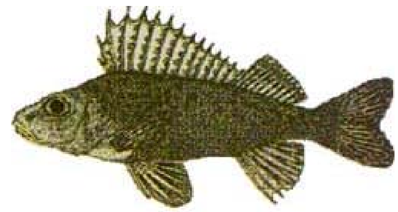
Pennsylvania Fish and Boat Commission. 2001. Poster: "Pennsylvania's 10 Least-Wanted Aquatic Nuisance Species."http://sites.state.pa.us/PA_Exec/Fish_Boat/so2001/leastpostr.pdf.

Pennsylvania Sea Grant. 2002. Fact Sheet: Zebra Mussels.
Website: http://www.pserie.psu.edu/seagrant/communication/fact/fs12.html.

The United States Environmental Protection Agency, Office of Water. "Invasive Species." http://www.epa.gov/owow/invasive_species/intro.html.

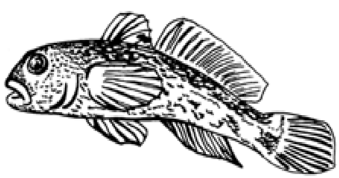
1.10.6 Non-Native Fish: Eurasian Ruffe and Round Goby

Non-native fish species can cause ecological problems when outside of their home ranges. The Eurasian ruffe (*Gymnocephalus cernuus*) is a small but aggressive fish species native to Eurasia. It was introduced into Lake Superior in the mid-1980s in the ballast water of an ocean-going vessel. A member of the perch family, an adult ruffe can grow to about five to six inches long, rarely exceeding 10 inches. The ruffe has not yet been documented in Lake Erie. However, the ruffe's ability to move from lake to lake in ships' ballast will make it difficult to prevent the fish from expanding its range to the lower great lakes.



Eurasian ruffe

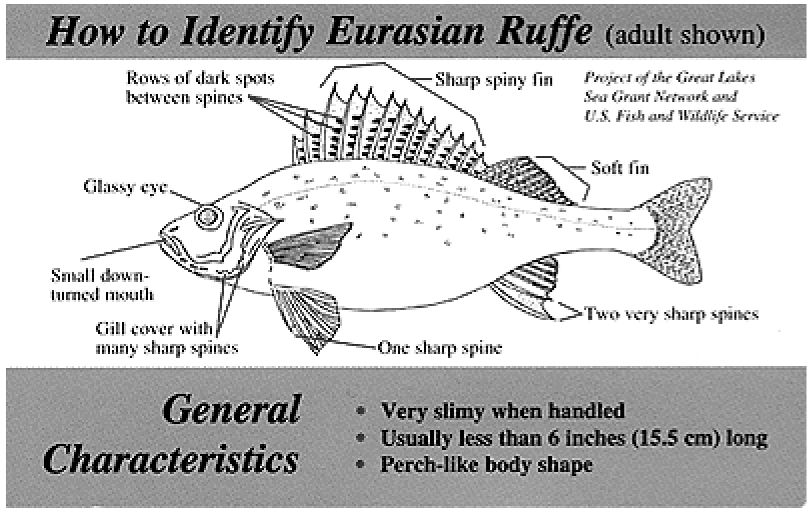
The round goby (*Neogobius melanostomus*) is a bottom-dwelling fish that has great potential for causing impacts on Great Lakes fisheries. Originally the round goby was introduced into the St. Claire River in 1990, probably via contaminated ballast water of transoceanic ships. It has since spread throughout the Great Lakes, including Lake Erie, and to many rivers, including the Mississippi watershed. Round gobies look similar to native sculpin, but can be distinguished by the fused pelvic fins on the underside.



Round goby

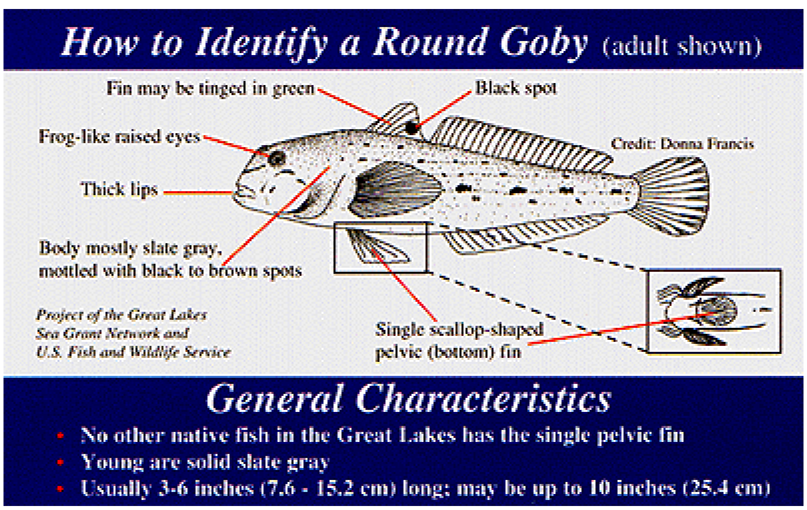
Management Problem

Explosive growth of Eurasian ruffe populations has the potential to seriously disrupt the delicate predator/prey balance vital to sustaining a healthy fishery. The ruffe grows and reproduces very quickly, out-competing other fish with similar diets and feeding habits. Because of this, walleye, perch, and a number of small forage fish species are seriously threatened by the continued expansion of the ruffe's range.



Source: Pennsylvania Sea Grant

Round goby are out-competing native fish in the Great Lakes Basin because they are aggressive, voracious feeders that can forage in total darkness. The round goby takes over prime spawning sites traditionally used by native species, competing for habitat and changing the balance of the ecosystem. The round goby is already causing problems for other bottom-dwelling Great Lakes native fish like mottled sculpin, logperch and darters. Round goby can also survive in degraded water conditions, and spawn more often and over a longer period than native fish.



Source: Pennsylvania Sea Grant

Another concern regarding the round goby is the bioaccumulation of contaminants in their flesh. The diet of round gobies consists predominately of zebra mussels (unfortunately, they don't eat enough zebra mussels to deplete the population), which filter particulate matter often containing pollutants from the water. A direct transfer of contaminants may occur when gobies are eaten by sport fish. This in turn may lead to more restrictive fish consumption advisories for sport fish. Sport fish found to prey on gobies include smallmouth bass, rockbass, walleye, yellow perch and burbot.

Management Recommendations

Like most invasive species, the best control method for the Eurasian ruffe or round goby is to prevent introduction into a new environment. While research into control methods such as disruption of breeding behaviors is ongoing, at the moment no viable after-the-fact management technique exists for either fish. Public education campaigns are essential for creating awareness and preventing the spread of non-native fish in Pennsylvania. Several excellent fact sheets and brochures explain how to identify and prevent the spread of the Eurasian ruffe and round goby, as listed in the reference section. Signs should be posted near at-risk waters that explain how to identify the Eurasian ruffe and round goby. Anglers should be encouraged to empty all bait buckets on land, and to never dump live fish from one water body into other waters. If a Eurasian ruffe or round goby is found, the fish should not be thrown back alive. To enable biologists to track the spread of the invasive fish, up-to-date information on new sightings is needed. New sightings can be confirmed only by identification of a captured fish, dead or alive. Occasionally, unknowing bait dealers will sell non-native fish. If a non-native fish is seen being sold as bait, the Pennsylvania Sea Grant office, Fish and Boat Commission, or Department of Environmental Protection should be notified immediately.

Cost Considerations

Currently, the only means of managing the Eurasian ruffe or round goby is prevention. Public education campaigns are fairly inexpensive, especially considering the wealth of existing materials available. Typically, the cost of a two-sided color brochure is about $0.80-$1.50 apiece, depending on the size and colors. Usually lower rates are available for printing in bulk. The cost to the fisheries industry, as well as to the ecological balance of Pennsylvania lakes, could be immeasurable if these non-native fish become widespread.

References

Great Lakes Information Network. Invasive Species in the Great Lakes Region. http://www.great-lakes.net/envt/flora-fauna/invasive/invasive.html.

Marsden, J.E. and D.J. Jude, 1995. "Round Gobies Fact Sheet 065." Illinois Natural Historic Survey and University of Michigan. http://www.sg.ohio-state.edu/PDFS/PUBLICATIONS/FS/FS-065.pdf.

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Pennsylvania Sea Grant. 2002. Fact Sheet: Eurasian Ruffe.
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Pennsylvania Sea Grant. 2002. Fact Sheet: Round Goby.
Website: http://www.pserie.psu.edu/seagrant/communication/fact/fs11.html .

Pennsylvania Sea Grant. 2002. Round Goby Watch.
Website: http://www.pserie.psu.edu/seagrant/communication/other/other1.html

Pennsylvania Sea Grant. 2002. Ruffe Watch.
Website: http://www.pserie.psu.edu/seagrant/communication/other/other6.html.

The United States Environmental Protection Agency, Office of Water. "Invasive Species." http://www.epa.gov/owow/invasive_species/intro.html.

1.10.7 Nuisance Wildlife Control Contact Information

For assistance with wildlife control issues contact:

Pennsylvania Wildlife Services
(Division of Animal and Plant Health Inspection Service, US Department of Agriculture)
(908) 735-5654
Email: janet.l.bucknall@aphis.usda.gov
Web site: http://www.aphis.usda.gov/ws

Pennsylvania Game Commission
Wildlife Management
(717) 787-5529
(refer to PALMS directory for phone numbers of regional offices)
Web site: http://www.pgc.state.pa.us /

For assistance with zebra mussel control issues contact:

Pennsylvania Department of Environmental Protection
Office of Water Management
(717) 787-9637
Web site: http://www.dep.state.pa.us/dep/deputate/watermgt/watermgt.htm

For assistance with exotic species control issues contact:

Pennsylvania Sea Grant
(814) 898-6420
Web site: http://www.pserie.psu.edu/seagrant/seagindex.htm

Pennsylvania Department of Agriculture
(717)-787-4737 Web site: http://www.pda.state.pa.us/

1.11 Boat Operation and Maintenance

A growing awareness of environmental impacts associated boating use has led to stricter boating laws and regulations. All boat owners and operators have a responsibility to protect fragile ecosystems from the impacts of boating use. Proper boat operation and maintenance are important best management practices for protecting lakes and ponds from environmental damage.

1.11.1 Boat Operation

Obeying No Wake Zones

Boat wakes contribute to shoreline erosion due to wave action and can stir up bottom sediments. Stirring up sediments causes the water to become turbid or cloudy, damaging sensitive fish gills, making it difficult for fish and aquatic insects to breathe, see, and feed properly, and reducing sunlight penetration into the water column that is essential for submerged aquatic vegetation. Boaters should avoid causing wakes and propeller disturbances by reducing boat speed before reaching “no wake zone” buoys in shallow or constricted areas.

Proper Fueling

Gas dissolves slowly in water, forms toxic slicks and eventually accumulates on particles in lake sediment. When the sediment is disturbed, toxic contaminants are released, which can be detrimental to aquatic plants and animals. When fueling on or near water, boaters should avoid topping off fuel tanks to prevent gasoline or diesel fuel from entering surface waters. Boats should include a fuel/air separator or whistle in the fuel tank vent line to prevent fuel leakage.

Sewage Disposal and Fish Wastes

All boaters must observe state and federal laws for proper wastewater disposal on boats. In Pennsylvania, all recreational vessels with installed toilet facilities must have an operable marine sanitation device (MSD) onboard. A MSD consists of either holding tanks, portable toilets, or approved waste treatment devices. Disposing of wastewater in a properly maintained pump out station upon returning to shore is also required by law, and will help keep disease-carrying bacteria and nutrients out of the lake. Similarly, fish wastes should be discarded at a suitable facility. Dumping fish wastes into surface waters is illegal in some areas, is unsightly, and can contaminate the water with bacteria and nutrients. Fish wastes can be recycled on land as excellent compost for gardens.

Bilge Water Disposal

Boaters should dispose of bilge water in a proper container at designated disposal site. Bilge water has a tendency to collect oil drippings from the engine. In addition, bilge water may contain invasive plants and animals that can be spread to other water bodies. Never pump contaminated bilge water overboard.

Hitch-hikers (Exotic and Invasive Species)

Many parasites and exotic and invasive species of plants and animals are spread from one body of water to another on boats and trailers. Exotic and invasive species have a detrimental effect on native species and cause habitat degradation. Before leaving the boat launch, boaters should drain live-wells, and clean all mud and plant debris from the boat, trailer, motor, bilge, propeller, and anchors as well as clothes and fishing gear to prevent the spread of exotic species. Thoroughly wash all of these items away from the lake with hot water. Preferably, the boat and equipment should be allowed to dry out for a long time period before entering another waterbody since some parasites may live as long as ten days out of water.

1.11.2 Proper Boat Maintenance

Routine Engine Service

All boat engine maintenance should be performed on dry ground. Drip pans or trays should be used when changing fluids or working on engines or changing motor oil, and the ground should be covered with a tarp to catch spills. One quart of oil can contaminate up to two million gallons of water. As a safe alternative, carbohydrate-based oils, such as soy oils, should be used as a substitute for petroleum-based oils. Motors should be kept finely tuned to increase fuel efficiency, reduce fuel consumption, and avoid discharging pollutants into waterways.

Extra caution is needed to avoid spills from boats that use liquid antifreeze. Antifreeze sinks in water and settles to the sediment where it does not readily degrade. Even in low doses, ethylene glycol (the chemical component of antifreeze) is hazardous to humans, animals, and aquatic life. A low-toxic antifreeze containing propylene glycol is a safe alternative. Antifreeze, transmission fluid, lead acid batteries, used oil, and used oil filters, and their containers should be recycled at an approved recycling facility. Never mix waste fluids, and never pour hazardous chemicals on the ground, in open water, or down drains.

Boat Painting

Toxic agents, such as metals, pesticides, biocides, and antifouling agents associated with paints can accumulate in sediment, aquatic plants, and animals and can remain persistent in aquatic environments for years. When repainting a boat, marinas that use a closed-loop hull-blasting system to remove old paint should be sought. Boat owners re-painting boats themselves should work at dry locations well away from open water. A sealed area such as a garage is preferred. A tarp should be spread on the ground to collect paint chips and debris. Dustless vacuum sanders will prevent the spread of airborne particles. Paints containing toxic metals such as copper, mercury, arsenic, or pesticides should be avoided. Instead, environmentally friendly boat paints that contain vinyl, silicone, Teflon, or organic ingredients such as cayenne pepper should be used. When the job is complete, paint cans and paint chips should be properly disposed. Applying slick bottom wax regularly to paint surfaces will reduce paint chipping and flaking and extend paint life.

Boat Cleaning

Most cleaning products, including household detergents and soaps, act as dispersants, contain mercury, and accumulate in sediment. They are toxic to aquatic plants and animals, impair breathing of fish, and reduce oxygen in the water. For this reason, boats should never be cleaned in the water, but rather in a dry location well away from open bodies of water. Phosphate-free, biodegradable cleaning agents should be used, as described in Table 1.11-1. Nutrients such as phosphorus and nitrogen contribute to algae blooms and other nuisance plant growth. Excessive algae and plants can harm fish and limit boating and other water recreation activities. Cleaners that emulsify or contain ammonia, chlorine, caustic soda, surfactants or potassium hydroxide should be avoided. These cleaners can be toxic to fish and other aquatic organisms. Non-toxic bilge cleaners and bilge pillows that digest hydrocarbons should be used rather than detergents or degreasers to clean the bilge. Boat engines should be steam-cleaned in a dry work area. Boats should be kept covered with a reusable canvas cover or plastic tarp when not in use to reduce the number of cleanings required.

Table 1.11-1
List Of Commonly Used Household Products And Environmentally-Friendly Alternatives

Harmful Products	Environmentally-friendly Alternatives
Bleach	Borax or hydrogen peroxide
Chrome cleaner	Apple cider vinegar to clean, baby oil to polish
Copper cleaner	Half of a lemon dipped in salt
Degreasers	Citrus or water-based products
Drain cleaner	Boiling water and plunger
Fiberglass stain remover	Baking soda paste and scrub pad
Locker top cleaner	Vinegar and water
Paint stripper	Physical removal
Scouring powders	Baking soda and scrub pad
Shower cleaner	Baking soda, scouring cloth, and lemon juice
Window cleaner	Vinegar, lemon juice, and warm water
Wood polish	Olive oil or almond oil
Wood stains and finishes	Water-based products of shellac or tung oil

References

Boat Maintenance Fact Sheet. 2001. National Clean Boating Campaign.
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Canadian Coast Guard, "Protecting the Aquatic Environment: A Boaters Guide".
http://www.ccg-gcc.gc.ca/obs-bsn/pubs/pme/main_e.htm .

Ohio Department of Natural Resources, "Boating and Environment".
http://www.deq.state.mi.us/documents/deq-ead-p2-marina-boating.pdf

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1.12 Aquatic Exotic and Invasive Plant Management

A plant species is considered exotic or non-native when it is either accidentally or intentionally introduced into areas where it does not naturally occur. If habitat conditions are suitable, the newly introduced species quickly becomes established and competes with native species for habitat. Both native and non-native species are considered invasive when they spread rapidly and displace other species. Not all exotic species are invasive, and not all invasive species are exotic. When invasive species spread and out-compete other native species, habitat diversity is lost and overall habitat quality declines. In aquatic systems, this can result in poor water quality, declining fisheries, and loss of recreational use.

1.12.1 Integrated Pest Management Plans (IPMs)

Exotic and invasive species are best monitored and controlled through the development of Integrated Pest Management Plans (IPMs). IPM plans prevent or control the spread of exotic species and the growth of invasive species using multiple methods coordinated with respect to timing and application rates. An effective IPM plan includes an understanding of the biology of the target species when designing control methods.

The first step in developing an effective IPM plan involves an assessment of the affected area. During the assessment, an inventory of both native and non-native plant and animal species found is performed. For aquatic plants, this involves mapping the areal extent of the plant species within the lake. The mapping helps to determine the species diversity in the lake and to identify target species for control.

Once the initial assessment is completed, specific control techniques are considered. The goal of an IPM plan is to maintain species diversity, protect non-target species, and maximize the health and use of the aquatic resource. The development of the IPM plan should take into account:

- An analysis of all the applicable control methods for the target species,
- Anticipated project costs,
- Longevity of the proposed control method,
- Permits required for the proposed control method,
- Disposal of any waste material (i.e dead plant material) generated during the project,
- Secondary effects of the control method on non-target species, and
- Acceptance of the control method by lake users.

An effective IPM plan will often combine several different treatment methods in managing the target species. For example, some areas of the lake with heavier invasive species infestations may be treated with herbicide, while smaller infestations in other areas may be controlled with a benthic barrier. A citizen's Weed Watch program could round out the program. Or, different treatments may be employed at different times of the year depending on the timing of plant emergence or the life cycles of other non-target species.

When managing invasive aquatic plants, it is rarely possible to completely eradicate the target species. However, it is possible to manage plant growth at a level that does not interfere with desired lake uses. Reasonable goals for the project should be thoroughly discussed in the IPM plan. The number of treatments required and the amount of time before results are expected should be clearly outlined. If successive years of treatment are necessary to achieve the desired results (which is usually the case), it should be stated as such. It is better to set realistic project goals than to overestimate the potential success of the project to satisfy the desires of project participants. An IPM program will quickly fail if the project partners lose interest or become frustrated by unexpected results.

Finally, the IPM plan should include a monitoring program to evaluate the effectiveness of the plan and determine the need for future management. The monitoring program should be conducted in the same manner as the initial assessment and should begin immediately upon completion of the project. If the project will be implemented over several years, monitoring should take place at the end of each project year.

1.12.2 Exotic and Invasive Species Prevention

Of all the exotic and invasive species control options available, prevention is by far the most effective. Preventing non-native species from establishing within a lake or pond can save significant amounts of time, money, and headaches. Learning to identify potential invasive species as well as their biological traits and preferred habitats is critical. The following practices can increase the chances of avoiding exotic and invasive plant establishment:

- Remove any visible mud, plants, fish or animals before transporting boats and equipment from one body of water to another.

- Drain water from boats, motors, trailers, live wells and bilges before leaving the area.

- Clean and dry anything that comes into contact with the lake water (equipment, clothing, dogs, etc.).

- Never release plants, fish or animals into a body of water unless they came out of that body of water.

- Always dispose of unused bait at a dry location on land or in the trash.

- Never dip a bait bucket into a lake or river if it has water in it from another waterbody.

- Frequently clean recreational equipment with high pressure hot water (104º F) on dry land and well away from any bodies of water. Dry everything for at least three to five days before reuse in another water body.

- Avoid planting seed mixtures and ornamental aquatic plants that may contain exotic or invasive species.

- Report sightings of invasive or aquatic plants to the Pennsylvania Sea Grant (814) 898-6420, the Pennsylvania Fish and Boat Commission (814) 474-1515 or the Pennsylvania Department of Agriculture (717) 772-5209.

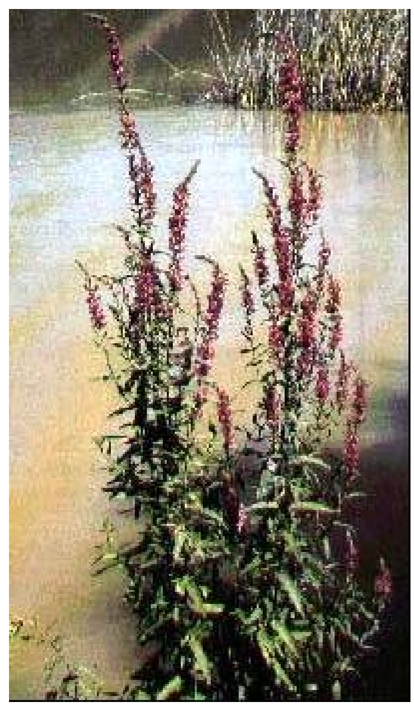
1.12.3 Exotic and Invasive Plant Species in Pennsylvania Lakes

The following sections briefly describe some of the more common exotic and/or invasive aquatic species found in Pennsylvania. Along with a description of each species, the most commonly used control methods for that species are discussed. General aquatic weed management techniques are more thoroughly discussed in Section 1.6 of this handbook.

Emergent Aquatic Plants

Purple Loosestrife (Lythrum salicaria)

Purple Loosestrife is an exotic and invasive perennial plant native to Europe. The plant grows up to 2 meters (6.5 feet) tall, with a thick stem, opposite or whorled spear-shaped leaves, and spikes of purple flowers blooming from July to September. Purple loosestrife grows quickly, forming dense stands and displacing native grasses, sedges, and other more nutritional herbaceous species. Purple loosestrife reproduces by seed; one flowering plant can produce an estimated two million seeds per year. Purple loosestrife is also known to spread vegetatively through underground root systems.



Purple loosestrife
Source: Colorado Weed Management Association

Pulling entire young plants before they set seed can mechanically control small infestations. Larger infestations are more effectively controlled with approved herbicides containing glyphosate. Depending on application rates and location, pesticide applicators permits may be required, so check with the Pennsylvania Department of Environmental Protection or Fish and Boat Commission before spraying. Plants should be sprayed late in the growing season as they are preparing for dormancy. Although mechanical and chemical treatments are effective at controlling small infestations, biological control agents are better for achieving long-term control of large infestations. Currently approved biocontrol species include a root-mining weevil (*Hylobius transversovittatus*) and two leaf-feeding beetles (*Galerucella calmariensis* and *Galerucella pusilla*). These insect species, native to Europe, have been carefully tested and have been shown to effectively target purple loosestrife without damaging native plants.

Common Reed (Phragmites australis)

Common reed is a native but invasive, tall, grass-like, perennial plants that reach heights of 4 meters (13 feet) and form dense and extensive colonies. Common reed has broad, flat leaves with feathery flowers at the top of the plant. Seed set occurs during fall and winter. Common reed also forms dense clones through underground rhizome growth. These dense, monotypic communities displace other plant species, decrease biodiversity, and alter natural wetland functions.

Common reed
Source: The Nature Conservancy

Control of common reed is often difficult, time-consuming, labor intensive, and costly. Mechanical techniques such as cutting and burning have been used with limited success, since such methods do not remove underground rhizomes. Chemical herbicides are an effective but very costly control. A combination of mechanical removal and spot treatment with a chemical herbicide may be more effective. Researchers have recently begun investigating the potential for biological control of this plant.

Floating-Leaved and Submerged Aquatic Plants

Hydrilla (Hydrilla verticillata)

This submersed, rooted, perennial aquatic plant species is native to Eurasia, Africa, and Australia, and is designated as a federal noxious weed. Hydrilla forms dense beds that extend from the substrate to the top of the water column, sometimes reaching heights greater than 20 feet. Leaves are small and pointed in whorls of four to eight, with leaf margins distinctly saw-toothed. A similar species, native to Pennsylvania, is common waterweed (*Elodea Canadensis*), which has leaves in whorls of three with finely toothed leaf margins. Hydrilla reproduces prolifically via the regrowth of stem fragments and by auxiliary buds. The plant quickly out-competes native submerged aquatic vegetation and chokes the water body, inhibiting boating, fishing and other recreational uses.

Hydrilla
Source: Mike Naylor, MD DNR

Mechanical weed harvesting provides temporary hydrilla control and creates open areas for boating. However, due to the plant's ability to grow from stem fragments, harvesting can actually spread the infestation, providing only short-term control. Systemic herbicide applications can provide more long-term control. Triploid grass carp are an herbivorous fish that can be used to control hydrilla. A permit from the Pennsylvania Fish and Boat Commission is necessary to introduce grass carp to a particular waterbody.

Brazilian Elodea (Egeria densa)

Brazilian Elodea
Source: WA State Dept. of Ecology

Brazilian elodea is a submerged aquatic, mat-forming plant thought to have been introduced to North America by disposing aquarium contents in lakes and ponds. Like hydrilla, the thick mats choke out native plants and interfere with boating, swimming, and fishing. Brazilian elodea is a bushy plant with finely-toothed, green leaves arranged in whorls of four to eight.

Like hydrilla, Brazilian elodea can rapidly regrow from stem fragmentation, eliminating mechanical harvesting as an effective control. Better control is achieved by systemic herbicide applications. Triploid grass carp are also effective, since older grass carp find Brazilian elodea highly palatable and preferable to other plants.

Eurasian Watermilfoil (*Myriophyllum spicatum*)

Mats of Eurasian watermilfoil in Cayuga Lake, NY
Source: Robert L. Johnson, Cornell University

Native to Eurasia, Eurasian milfoil grows in water depths of 0.5 meter to 4 meters (1.5 to 13 feet), and has leaves in whorls of four with 14-24 pairs of leaflets. Small reddish flowers rise above the water on spikes, blooming from July to August. Eurasian milfoil is easily mistaken for northern or spiked water milfoil (*M. sibiricum* or *M. exalbescens*) which is native and endangered in Pennsylvania. Northern water milfoil has fewer leaflets (5-12 pairs) than that of Eurasian water milfoil. Other similar native plants include bladderwort (*Utricularia sp.*), and coontail (*Ceratophyllum sp.*). Careful identification is necessary.

Large harvesting equipment for larger areas and hand rakes for light infestations can provide relatively inexpensive Eurasian milfoil control. However, results with these methods are temporary since Eurasian milfoil spreads by fragmentation. Other mechanical or physical control options include water level manipulation, water colorants or floating cover devises to reduce light penetration, and physical benthic barriers. Contact or systemic herbicides, especially those containing Fluridone, are also effective. A native aquatic weevil (*Euhrychiopsis lecontei*) has shown promise in controlling Eurasian milfoil in smaller lakes and ponds. A combination of methods may be the best approach.

Curly-leaf pondweed (*Potamogeton crispus*)

Curly-leaf pondweed is a submersed, rooted perennial aquatic plant native to Europe. The plant has slightly flattened stems and reddish-green, toothed, wavy-edged leaves. Curly-leaf pondweed reproduces by winter buds, or turions, which enable the plant to grow under ice and snow. Curly-leaf pondweed is often the first plant to emerge in the spring. Once established, curly-leaf pondweed spreads by seeds and rhizomes. Dense colonies forming in

Curly-Leaf Pondweed
Source: Virginia Tech

the spring can restrict boating and dock access into the early summer months. Growth of this plant declines in mid summer to early fall, as the plant enters a dormant state.

Control methods are similar to those used for hydrilla and Brazilian elodea. Over the long term, reducing nutrient inputs from the surrounding watershed will help control the growth of curly-leaf pondweed.

Water Chestnut (*Trapa natans*)

Water Chestnut
Source: N. Droege, Invasive Plant Council of New York

Water chestnut is an annual aquatic plant originating in Europe, Asia, and Africa. Now found in many North American lakes and ponds, water chestnut prefers nutrient rich, slow moving waters where it forms dense floating mats that severely limit light penetration through the water column. Water chestnut is known to reduce dissolved oxygen levels in the lake, which can increase the potential for fish kills. Water chestnut has intervals of feathery leaves along its submerged stem that can reach 3 meters (10 feet) in length. The plant is anchored by fine roots in the substrate. Rosettes of saw-toothed, triangular, floating leaves are found at the water's surface connected to an inflated petiole, which provides buoyancy. After pollination of its four-petaled white flowers in June, a fruit is formed with four half-inch barbed spines that can cause painful wounds if stepped on. Water chestnut not only spreads via the floating, spiny fruit but also by detachment of the rosette.

Extreme care should be taken in utilizing control techniques for water chestnut, not only because of the sharp fruit, but also because plant parts are easily dislodged and spread through mechanical and manual techniques. Any plant removal should be done before seed set in July. Careful mechanical harvesting, or hand-harvesting are the best methods for control. Control may take several years to achieve since the fruits can remain viable for up to 12 years.

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Chapter 2: Watershed BEST MANAGEMENT PRACTICES

2.1 Introduction

A Lake and Its Surrounding Watershed
Source: USDA NRCS

Lakes are often described as a reflection of their surrounding watersheds. Many lake problems are linked directly to watershed activities such as changes in land use or land management activities. For example, the water quality of a natural lake, which is nestled in scenic Pocono Mountains, seriously deteriorated in the late 1980's. Water quality degradation was attributed to heavy timber harvesting and land development activities that occurred from 1980 through 1986. In another example, the water clarity of a drinking water supply reservoir in York County significantly improved after implementing a variety of watershed best management practices. Many of these practices targeted high sediment and nutrient loadings from agricultural lands. These and other examples illustrate the importance of watershed management as an integral component of lake management and restoration.

Pollutants that are transported or discharged to streams or lakes are classified as either point or nonpoint sources. Point sources come from a distinct source like a pipe or outlet structure. Point sources include wastewater treatment plants and industrial facilities. The Pennsylvania Department of Environmental Protection regulates point source discharges via permits under the National Pollution Discharge Elimination System (NPDES). Conversely, nonpoint sources are diffuse sources of pollution that do not originate from a single. Nonpoint source pollutants are generally dissolved or dislodged from lands in the watershed during storm events. These pollutants are transported to streams or lakes via overland runoff or groundwater seepage. Nonpoint source pollution has a much broader definition and essentially encompasses everything not classified as point source pollution.

Some watershed BMPs target the lake's immediate shoreline, and others target nonpoint sources of pollution in more distant areas of the watershed. The primary causes of nonpoint source pollution that occur in Pennsylvania are briefly described in the remainder of this section. Information in this section was taken from the U.S. EPA document, Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls (1997, EPA/841-B-96-004).

The major categories of nonpoint source pollution in Pennsylvania watersheds include:

- Agriculture
- Urbanization
- Removal of Streamside Vegetation
- Timber Harveting
- Construction
- Hydromodification
- Mining

Agriculture

The primary nonpoint source pollutants associated with agriculture are nutrients, sediment, animal wastes, salts and chemicals. Also, agriculture activities can directly adversely impact stream water quality and habitats. These activities include planting crops too close to streams and allowing livestock direct access to riparian areas.

Nitrogen and phosphorus are the two major nutrients from agricultural land that degrade water quality. Nutrients are applied to agricultural land in several dfferent forms and come from various sources, including commercial fertilizer, manure from animal production facilities, municipal and industrial treatment plant sludge and/or effluent applied to agricultural lands, legumes and crop residues, irrigation water. Atmospheric deposition can be a significant source of nutrients in some areas as well.

Increased sediment loadings to surface waters can result from land disturbance and clearing for agricultural operations and from stream bank erosion due to increased instream flows. Sediment loss and runoff are especially high if rain or high winds occur during soil disturbance.

Animal waste includes the fecal and urinary wastes of livestock and poultry; and the process water, feed, bedding, litter, and soil from confined animal facilities. Runoff water and process wastewater from confined animal facilities can contain oxygen-demanding substances including nitrogen, phosphorus, and other nutrients, organic solids, salts, bacteria, viruses, and other microorganisms, and sediment.

Large amounts of salt can be added to agricultural soils by irrigation water that has a natural base load of dissolved mineral salts from groundwater or surface water sources. Irrigation water consumed by plants is lost to the atmosphere by evaporation, and the salts in the water remain and concentrate in the soil. Salt accumulation leads to soil dispersion, soil compaction, and possible toxicity to plants and soil fauna.

Agricultural chemicals including pesticides, herbicides, fungicides, and their degradation products can enter ground and surface waters in solution, in emulsion, or bound to soil colloids. Some types of agricultural chemicals are resistant to degradation and persist and accumulate in aquatic ecosystems. Normal application to agricultural fields is a major source of pesticide contamination of surface water and ground water. Other sources are atmospheric deposition, drift during application, misuse, and spills, leaks, and discharges associated with pesticide storage, handling, and disposal.

In addition, some agricultural activities such as planting crops too close to streams and allowing livestock direct access to riparian areas can adversely impact stream water quality and habitats. Livestock grazing can degrade cover vegetation on pasturelands, resulting in erosion, loss of plant diversity, and adverse impacts on surface waters. Cattle with access to streams or lakes trample riparian vegetation and disturb shoreline soils, leading to bank erosion. They alter riparian vegetation species composition through selective grazing. Grazing animals also add fecal contamination to streams and ponds (U.S. EPA 1997).

Urbanization

The major runoff pollutants from urban areas are sediment, nutrients, oxygen-demanding substances, road salts, heavy metals, petroleum hydrocarbons, pathogenic bacteria, viruses, and toxic chemicals. These are generated directly from the use of insecticides, road salts, and fertilizers, and indirectly from wastewater, automobile exhaust, oil drippings from trucks and cars, brake lining wear, and various other urban activities.

In urban areas, pervious, vegetated land is converted to impervious, unvegetated land. Impervious areas such as rooftops, roads, parking lots, and sidewalks may cover 35 percent or less of the land area in lightly urbanized areas to nearly 100 percent of the land area in heavily urbanized areas. Imperviousness results in increased stormwater runoff volumes and altered hydrology. Urban stormwater runoff carries increased pollutant loadings to surface waters, typically without treatment.

In addition to increased stormwater volumes, stormwater runoff is delivered to surface waters from impervious areas much more quickly than from vegetated areas, which can result in scouring of streambeds and increased sediment loadings to surface waters. When combined with the increased runoff velocities during spring snowmelts and rain-on-snow events, floods can occur more frequently and with greater severity in urbanized areas. Major snowmelt events in urban areas can produce peak flows with as much as 20 times the volume of baseflows (U.S. EPA 1997). The high velocity of stormwater flow in urban areas allows little infiltration and groundwater recharge.

Removal of Riparian Vegetation

Loss of riparian vegetation is attributed to land conversion for farmland or drainage, forest harvesting, channelization, creation of impoundments, irrigation diversions, ground water pumping, and overgrazing (U.S. EPA 1997). This loss of streamside plants adversely impacts aquatic habitat, the stability of streambanks and stream water quality.

Riparian vegetation serves as a source of energy and in-stream habitat for aquatic organisms. The biological communities in streams depend on energy inputs from these outside sources. The primary source of energy and nutrients in small, low-order streams is organic debris (i.e., leaf litter) deposited from riparian vegetation. When riparian vegetation is removed, this source of energy and nutrients is reduced or eliminated. Denuded stretches of streams and rivers are left with sunlight as the only source of energy. Trees along rivers and streams shade and cool the water, providing essential habitat for coldwater fish. Other essential inputs to rivers and streams, such as woody debris that provides microhabitats for fish and invertebrates, and plants that provide food and shelter for aquatic animals and wildlife, are also lost when streamside vegetation is removed.

Riparian vegetation protects streambanks from erosion due to flowing water. Increases in erosion, turbidity, and sedimentation usually result when vegetation is removed. Riparian vegetation filters nutrients and sediment as water passes through it, protecting floodplains and improving water quality for downstream users. Degraded water quality, increased severity of flooding, loss of wildlife habitat, increased stream temperatures, and increased expense to purify water for public uses are some of the consequences of the removal of riparian vegetation.

Timber Harvesting

Sediment, organic debris, nutrients, and silvicultural chemicals are typical pollutants associated with forest harvesting operations. Timber harvesting operations can degrade water quality in waterbodies with forest land drainage in several ways. Construction of forest roads and yarding areas, as well as log dragging during harvesting, can accelerate erosion and sediment deposition in streams. Removal of overstory riparian shade increases stream water temperatures. Harvesting operations sometimes leave slash and other organic debris to accumulate in streams, which depletes dissolved oxygen and alters instream habitats. Fertilizer applications contribute excessive nutrients to aquatic habitats and accelerate eutrophication. Pesticide applications increase organic and inorganic chemical concentrations in waterbodies, and adversely affect wildlife.

Construction

Runoff from construction sites is by far the largest source of sediment in developing urban areas. Soil erosion accounts for over 90 percent of sediment loss in urbanizing areas, where most construction activities occur. Uncontrolled construction site sediment loads on the order of 35 to 45 tons per acre per year have been reported. Loadings from undisturbed woodlands are typically less than 1 ton per year.

The variety of pollutants present at construction sites and the severity of their effects depend on the nature of the construction activity, the physical characteristics of the construction site, the proximity of surface waters to the nonpoint pollutant source, and the extent of measures used to contain the pollutants.

Many potential pollutants are associated with construction activities. Petroleum products used during construction include fuels and lubricants for vehicles, power tools, and general equipment maintenance. Asphalt paving can be particularly harmful since it releases oils for a considerable time period after application. Solid waste on construction sites includes trees and shrubs removed during land clearing and structure installation, wood and paper from packaging and building materials, scrap metal, sanitary wastes, rubber, plastic, glass, and masonry and asphalt products. Chemical pollutants, such as paints, acids for cleaning masonry surfaces, cleaning solvents, asphalt products, soil additives used for stabilization, pollutants in wash water from concrete mixers, and concrete-curing compounds, can also be used on construction sites and carried in runoff.

Hydromodification

Hydromodification includes channel modification (channelization) and stream flow alteration. Channel modification refers to river and stream channel engineering for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration. Straightening, widening, deepening, or relocating existing stream channels and other practices that change the depth, width, or location of waterways are examples of channel modification. Channel modification typically results in more uniform channel cross-sections, steeper stream gradients, and reduced average pool depths. Stream flow alteration is hydromodification activity that results in either an increase or a decrease in the usual supply of fresh water to a stream, river, or estuary. Flow alterations include diversions, withdrawals, and impoundments. Levees and dikes are also flow alteration structures.

Channel modification deprives wetlands of enriching sediment, changes the ability of natural systems to both absorb hydraulic energy and filter pollutants from surface waters, increases transport of suspended sediment to coastal and near-coastal waters during high-flow events, increases instream water temperature, and accelerates the discharge of pollutants. Hydromodification often diminishes the suitability of instream and riparian habitat for fish and wildlife through reduced flushing, lowered dissolved oxygen levels, interrupted life cycles of aquatic organisms, and loss of streamside vegetation.

Mining

Numerous pollutants are associated with coal mining. Acid mine drainage from coal mining contains sulfates, acid (low pH), heavy metals, ferric hydroxide or "yellow boy," and silt. The metals released from mining activities include silver, arsenic, copper, cadmium, mercury, lead, antimony, aluminum, magnesium, and zinc.

Three types of mines are created for coal extraction. Drift or slope mines are driven into valley walls to expose coal. Shaft mines are driven perpendicular to the ground. These mines must be pumped continuously to extract infiltrating water, and when abandoned they fill with water. Surface mining extracts coal from the surface after overlying soil and rock have been removed.

Surface mines leach metals and acids as seeps or springs, and they can have flows of up to 500 gallons per minute. Abandoned, self-draining underground mines and coal mining refuse piles are the worst potential sources of acid mine drainage. Contamination from deep underground mines can continue for 800 to 3,000 years as all of the exposed acidic materials from the mines slowly leach pollutants to ground waters. Acid mine drainage from surface mines is also a problem but is more controllable.

The effects of acid mine drainage can be devastating. In severely affected streams, ferric hydroxide, aluminum precipitates, and magnesium precipitates blanket stream bottoms, smothering fish eggs, and covering gills and body surfaces. Once a stream's acid-neutralizing capacity has been depleted by acid mine drainage, the acidity begins to alter the biota. Fish are absent from streams with a pH less than 4.5 standard units, and vascular plants are lacking in streams with a pH less than 4.0 standard units.

Approximately 11,990 miles of streams are reported to be degraded by acid mine drainage in Pennsylvania, West Virginia, Ohio, Kentucky, Maryland, Indiana, Illinois, Oklahoma, Iowa, Missouri, Kansas, Tennessee, Virginia, Alabama, and Georgia. The worst acid mine drainage pollution is in Pennsylvania and West Virginia and some areas of southeastern Ohio. Pennsylvania alone has 7,800 abandoned or inactive underground mines below the water table; an estimated one billion gallons of acid mine drainage flows to surface waters from these mines per day.

Watershed Best Management Practices (BMPs)

Lake management requires a thorough understanding of the lake as well as its surrounding watershed. This understanding is frequently gained by performing a Phase I Diagnostic-Feasibility Study that incorporates watershed nonpoint sources, as discussed in Chapter 1. Under most circumstances, the success and cost-effectiveness of implemented lake BMPs are maximized when nonpoint source pollution from the surrounding watershed is reduced.

Table 2.1-1 provides a list of watershed BMPs that are discussed throughout the remainder of Chapter 2. This table provides additional information regarding pollutant type (point vs. nonpoint) and the major nonpoint source category for each of the BMPs. It should be noted that mining BMPs are not addressed in this document. These best management practices were beyond the scope of this document. For information on mining BMPs, refer to the Pennsylvania Department of Environmental Protection (DEP) Bureau of Abandoned Mine Reclamation website at http://www.dep.state.pa.us/dep/deputate/minres/bamr/bamr.htm.

Table 2.1-1
Watershed Best Management Practices

Best Management Practice	Pollutant Type	Major Nonpoint Source Category
Environmental Planning	Point/Nonpoint	Multi-category
Stormwater Management BMPs	Nonpoint	Urbanization
Agriculture BMPs	Nonpoint	Agriculture
Forestry Management	Nonpoint	Timber Harvesting
Streambank Stabilization and Restoration	Nonpoint	Hydromodification Removal of Streamside Vegetation
Riparian Corridor Restoration	Nonpoint	Removal of Streamside Vegetation
Terrestrial Exotic Plant Management	Nonpoint	Removal of Streamside Vegetation
Construction Erosion and Sedimentation Pollution Control	Nonpoint	Construction
Dirt and Gravel Road Management	Nonpoint	Construction, Timber Harvesting
Septic Systems and Wastewater Management	Nonpoint/Point	Urbanization

2.2 Environmental Planning

Environmental planning refers to the practice of requiring the use of BMPs for new development and changes in land use. One may actually view "environmental planning" as a BMP. Environmental planning, or resource-based planning, is an effective preservation and protection tool for lake and watershed management. It is well documented that changes in land-use represents one of the greatest impacts on water resources. However, numerous, easily-implemented BMPs exist to prevent degradation of these natural resources. The old adage, "an ounce of prevention is worth a pound of cure," applies to environmental planning practices.

Pennsylvania is a Commonwealth, whereby municipalities are charged with regulating activities within their borders to best meet the needs and desires of local citizens. The nature of this type of small-scale regulation makes good and active planning essential, as the state and county governments have very little regulation over many important issues and activities related to watershed protection. Sound environmental planning will not correct past degradation of resources, but will help to prevent future losses and promote "sustainability" of local land and water resources.

Environmental planning most commonly focuses on municipal ordinances, or regulations, which serve as the primary guidance for activities within a municipality. Ordinances are discussed in greater detail in the following section. One particular type of ordinance establishes an Environmental Advisory Council (EAC), whose primary function is environmental planning and enforcement of environmental provisions related to existing municipal ordinances. EACs are extremely beneficial to municipalities and are discussed below in greater detail.

2.2.1 Ordinances

An ordinance is a statute or regulation that is enacted by a municipality, such as a township, borough, or city. Traditionally, ordinances have been very specific in meeting the goals of individual municipalities. More recently, however, multi-municipal planning has been used to streamline local regulations across watershed areas and improve use and enforcement.

Most municipalities in Pennsylvania have both Zoning Ordinances and Subdivision and Land Development Ordinances (SALDOs). Zoning Ordinances shape the overall development trends in a municipality by targeting different areas within the municipality for different types of growth (e.g. commercially developed areas vs. residentially developed areas). The SALDO outlines specific, detailed requirements for development standards within each zoning district. Both Zoning Ordinances and SALDOs generally contain provisions that protect environmental resources, but neither is designed specifically for such purpose.

In many cases, both the Zoning Ordinance and the SALDO can be revised to provide even greater protection for natural resources. Common revisions include specific legal language for the definitions of different resources, and revisions to the methodologies by which they are evaluated and shown on site plans. Many "stand-alone" ordinances have been developed in recent years that are specifically designed to target the conservation, preservation, and protection of natural resources. Common stand-alone ordinances are listed below.

Natural Features Conservation – Preserves interesting geological features (rock outcrops, steep slopes, ledges/cliffs, escarpments, boulder fields, glacial erratics, etc.), protects wild flora and fauna, protects significant trees, protects against surface and groundwater pollution, protects against soil erosion and sedimentation, protects wetlands, and protects surface water resources.

Stormwater Management - Establishes standards and regulations for the management and discharge of the quantity, quality, velocity, and direction of stormwater runoff from land development projects and other construction activities. The goals of the ordinance include the following:

- Provide protection to downstream property owners, control soil erosion and sedimentation and protect the public general health, safety and welfare.
- Reduce artificially induced flood damage to public health, life, and property.
- Minimize increases in stormwater runoff rates and volumes
- Minimize the deterioration of existing water courses, culverts, bridges, dams and other structures that would result from increased rates of stormwater runoff; to induce water recharge into the ground wherever suitable infiltration, soil permeability, and geological conditions exist
- Prevent increases in nonpoint source pollution.
- Maintain the integrity and stability of stream channels for their biological functions as well as for drainage, conveyance of floodwater, and other purposes.
- Control and minimize soil erosion and the subsequent transport of sediment.
- Minimize public safety hazards at any stormwater detention facility constructed pursuant to subdivision or site plan approval.
- Maintain high water quality in all streams and other surface water bodies; J) to protect all surface water resources from degradation.
- Protect groundwater resources from degradation.

- Encourage the use of smart site design principles and techniques.

- Maximize the use of biological technologies for the treatment of stormwater quantity and quality.

Riparian Buffer Conservation - Establishes minimal acceptable requirements for the design and preservation of buffers to protect streams, wetlands, and floodplains; to protect the water quality of watercourses, reservoirs, lakes, and other significant water resources; to protect riparian and aquatic ecosystems; and to provide for the environmentally sound use of watershed land resources.

Steep Slopes - Regulates the use intensity in areas of steeply sloping terrain to limit soil loss, erosion, excessive stormwater runoff, degradation of surface water, and to maintain the natural topography and drainage patterns of the land.

Open Space Preservation - Protects the natural, historic, and community resources by promoting open space preservation.

Noxious Weed Control - Encourages the control of noxious or invasive vegetation to reduce the amount of natural irritants and pollens in the air, prevent any noxious weeds from spreading, and improve the aesthetic quality of the municipality. It is important to include provisions for maintaining buffers in riparian and drainage areas so that the ordinance is not misinterpreted, resulting in removal of vegetation in such areas.

Natural Landscaping - Promotes the use of native vegetation, including native grasses and wildflowers, in managed yards and landscapes to preserve and restore natural plant communities and discourage the colonization of noxious weeds. This ordinance is often implemented in conjunction with the Noxious Weed Control ordinance.

Forest Conservation – Provides for the conservation, protection and planting of trees to maintain forested areas. Designed to accomplish the following:

- Stabilization of soil by the prevention of erosion and sedimentation,

- Reduction of stormwater runoff and the potential damage it may create.

- Removal of pollutants from the air and the generation of oxygen.

- Creation of buffers and screens against noise pollution.

- Control of drainage and restoration of denuded soil subsequent to construction or grading.

- Creation of protected environments for birds and other wildlife.
- Creation of shade and shelter for people, mitigating heat islands.
- Protection and enhancement of property values.
- Conservation and enhancement of the municipality's physical and aesthetic appearance.
- Protection of the public health and safety, as well as the general welfare of the people.

GROUNDWATER PROTECTION - Protects public health and safety by minimizing contamination of shallow/surficial aquifers, and preserving and protecting existing and potential sources of drinking water supplies. This is accomplished through both public education and public cooperation, as well as by creating appropriate land use regulations in addition to those currently imposed by existing zoning districts or other municipal regulations. (USEPA, 2004)

SURFACE WATER PROTECTION - Ensures the adequate protection of current or potential public water supply reservoirs. The establishment of these regulations is intended to protect public health, insure the availability of safe drinking water, and prevent the degradation of the water supply in the reservoirs through the regulation of land uses and development within the reservoir drainage areas. (USEPA, 2004)

VERNAL POOL PROTECTION – Protects vernal pools as important wildlife habitat from direct and indirect impacts of development and other land-use changes.

SHORELINE PROTECTION - Protects important surface water resources within a municipality. This ordinance is designed to maintain safe and healthful conditions of the water body; to prevent and control water pollution; to protect fish spawning grounds; to protect aquatic life, bird and other wildlife habitat; to protect buildings and lands from flooding and accelerated erosion; to protect archaeological and historic resources; to protect wetlands; to control building sites, placement of structures and land uses; to conserve shore cover, and visual as well as actual access points to water; to conserve natural beauty and open space; and to anticipate and respond to the impacts of development along shoreline areas. Provisions of this ordinance may best be melded into the

Shoreline protected by riparian buffer
Source: Wisconsin DNR

municipal zoning ordinance, rather than as a separate stand-alone ordinance. (Wisconsin DNR, 2004)

The concept of ordinances is simple, but the actual tailoring and adoption process is quite involved and should be directed by a qualified professional. Before formal adoption, an ordinance must be approved by the municipality's solicitor as well as the governing authority, and must complete a public comment process.

Cost Considerations

Ordinance development costs, including revision and enactment, will vary according to the municipality and situation. A professional consultant may be required to adequately review and revise existing ordinances. Adoption of pre-designed ordinances, however, may be very inexpensive if obtained from a reliable source, especially if that source is willing and able to assist in the process. Other municipal costs may include internal review, legal advertising in newspapers, public meetings, and solicitor review fees.

Websites with information on model ordinances:

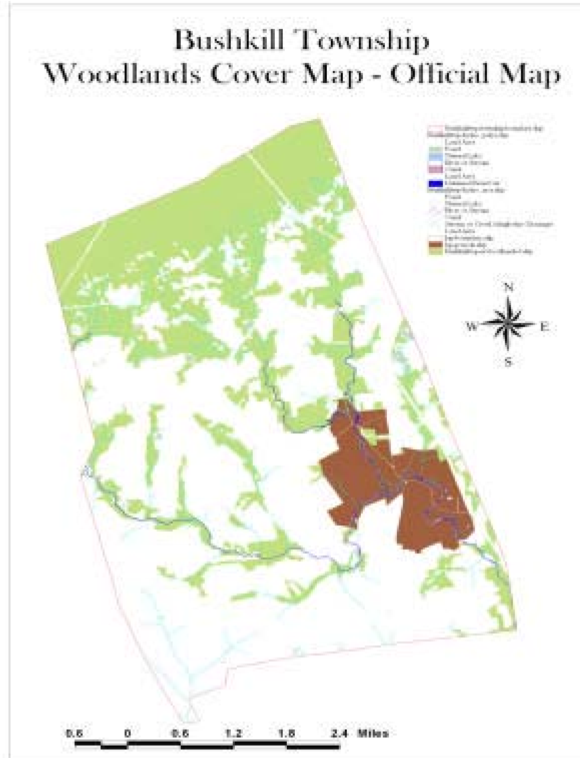
EPA model ordinances - http://www.epa.gov/owow/nps/ordinance/
Center for Watershed Protection – http://www.cwp.org/pubs_download.htm
Smart Communities Network - http://www.sustainable.doe.gov/greendev/codes.shtml
Sustainable Communities - http://www.celdf.org/scm/ord.asp
Stormwater Manager's Resource Center - http://www.stormwatercenter.net/

2.2.2 Environmental Advisory Councils (EACs)

An Environmental Advisory Council (EAC) is a valuable asset to any municipality interested in preserving and improving its environmental resources. An EAC is comprised of three to seven community residents that are appointed by locally elected municipal officials. An EAC is typically outlined in an ordinance designed to advise the municipality on the protection, management, and use of natural resources. EAC members are citizens of their community who volunteer their time and energy to provide the elected officials, the planning commission, and the park and recreation board with the information they need to make sound environmental decisions. EACs are strongly integrated with local government and can serve as effective liaisons between the elected officials and the community.

EACs play a critical role in the management and stewardship of natural resources within Pennsylvania. The Commonwealth grants significant regulatory power to municipalities, and EACs can be particularly effective in shaping development and implementing meaningful programs that protect and preserve local resources. EACs focus specifically on environmental issues and they find the means, including funding and volunteers, to address concerns and better the environmental quality of their communities. In many instances, EACs partner with neighboring municipalities to address problems on a larger scale. EACs have been formed for a variety of reasons, depending on the needs of the municipality and the interests of the members.

Watershed protection has become important to many EACs interested in maintaining the quality of water resources including lakes, rivers, and streams. For example, the Durham Township EAC of Bucks County secured $84,000 from the Pennsylvania Department of Conservation and Natural Resources (DCNR) and the US Environmental Protection Agency and organized over 700 volunteer hours to develop a Conservation Plan for the Cooks Creek Watershed. This plan was approved by DCNR and will be placed on the Pennsylvania Rivers Registry. The funding also provided stream monitoring equipment and set up a GIS database for use in future plans and ordinances.



Development of Geographic Information Systems (GIS) database mapping was part of an Environmental Resource Inventory (ERI) by the Pennsylvania Environmental Council during their reestablishment of an EAC in Bushkill Township. The EAC worked with the township supervisors to highlight the value of the riparian woodlands and mapped them on the official map used for planning purposes in the township.

Some other typical projects implemented by EACs include:

- Streambank stabilization
- Riparian buffer planting
- Greenways and trail plans
- Recycling programs
- Open space plans
- Historical research
- Resource cataloguing (GIS based)
- Invasive plant management
- Stormwater outfall monitoring
- Water quality monitoring
- Newsletter articles
- Educational presentations
- Ordinance work
- Sponsor local workshops
- Stream identification signs

EACs are extremely valuable for assisting the municipal planning commission in reviewing proposed development plans to ensure that regulations/ordinances are being followed and that on-site resources are being preserved or protected. An EAC can enhance the aesthetic aspects of a community and also assist in heightening community pride, education, and appreciation for local natural resources.

To establish an EAC, contact the EAC Network (see contact information listed below) and request a copy of The EAC Handbook, a comprehensive guide to establishing and maintaining an EAC. The EAC Network can provide sample EAC ordinances and project ideas. For useful EAC tools, links, and slideshows highlighting various projects, visit the EAC Website at http://www.eacnetwork.org. To become acquainted with the local government, attend local municipal meetings and talk to members of the governing body about the value of EACs. Talk to friends and neighbors who might be willing to serve on an EAC and think about possible projects that would benefit the community. By establishing an EAC, a municipality takes positive steps towards preserving the environment for all residents, now and in years to come. (Linder, 2003)

Contact Information

EAC Network
HTTP://WWW.GREENWORKS.TV/EAC/INDEX.ASP
Jeanne Barrett Ortiz - 215 563-0250;
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117 South 17th Street, Suite 2300
Philadelphia, PA 19103-5022
800-322-9214
http://www.pecpa.org/

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2.3 Stormwater Management BMPs

Stormwater runoff originates from rain or snowmelt that flows over land rather than percolating into the soil or evaporating. Stormwater runoff increases when land becomes developed and impervious surfaces (e.g., parking lots, roads, buildings and rooftops) replace forest and vegetated land. As more and more development occurs, the volume of stormwater runoff increases because the infiltration capacity of the land is decreased. When this happens, stormwater runoff reaches the receiving stream or river faster, and the velocity of the stream or river increases.

When stormwater runoff velocity increases, it picks up soils laden with nutrients and other pollutants from construction sites, developed areas, roads, and farms, and carries these pollutants into nearby waterbodies. Stormwater runoff from developed areas typically contains concentrated levels of pollutants. The pollutants include suspended solids from eroded soils, metals from buildings, pipes and other structures, and nutrients from animal droppings, vegetative matter, fertilizers, and other debris. The increased velocity of stormwater over impervious surfaces causes more pollutants to reach surface waters since there is less opportunity for natural infiltration of stormwater and filtration of pollutants to occur.

Stormwater runoff can negatively affect water quality, aquatic biota, and stream temperatures. Once stormwater pollutants are introduced to streams and lakes they can cause many water quality problems. Sediments clog the gills of fish and smother newly-laid fish eggs and other aquatic life. Sediments also muddy the water. This reduces the amount of penetrating sunlight, which in turn will affect water temperature and the growth of animals and plant life. In addition, sediments often carry chemicals such as phosphorus, nitrogen and toxins which further pollute the water by increasing the amount of undesirable aquatic plant and algae growth in the water. Excessive stormwater runoff also increases the amount of water in streams, resulting in flooding and streambank erosion.

Recognizing the problems created by increased stormwater runoff, engineers, planners and developers are now incorporating stormwater Best Management Practices (BMPs) into developments to reduce on-site runoff. Traditionally, stormwater management entailed draining runoff away from a developed site as quickly as possible. More recently, stormwater management philosophy has evolved toward stormwater treatment through on-site structures designed to blend into the community landscape. Stormwater BMPs are now designed to treat runoff water quality and volume as well as peak flow rate.

Four major stormwater management principles are recommended to control stormwater runoff (F. X. Browne, Inc. 2003):

- Reduce Site Runoff
- Maximize use of Natural Drainage
- Provide Pre-treatment of Runoff
- Treat the Water Quality Storm

Most existing stormwater management facilities are designed to treat large storms that occur infrequently (i.e. every 2, 25 or 100 years). They were not designed to treat the smaller, more frequent storms, nor were they designed to address water quality. The "water quality storm" is defined as the type of storm that accounts for 70 to 90 percent of the average annual rainfall in a given region. Designing stormwater BMPs to accommodate the water quality storm will provide much better pollutant removal over time than treating only large storms. Please refer to the Pennsylvania Handbook of Best Management Practices for Developing Areas (PACD 1998, or later edition) for specific formulas for calculating the water quality design storm in the five rainfall regions of Pennsylvania.

Whenever possible, stormwater should be infiltrated into the ground, either through natural drainage structures and vegetated surfaces, or through stormwater BMPs. On-site infiltration not only reduces the velocity and volume of stormwater entering surface waters, it also recharges groundwater directly at the site.

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2.3.1 Water Quality Swales and Channels

The term "swale" refers to a series of vegetated, open channels designed specifically to provide for the conveyance and water quality improvement of stormwater runoff for a specified water quality volume. As stormwater runoff flows through the channel, it is slowed and filtered by vegetation and/or a subsoil matrix. Additional treatment can be achieved by infiltration into the underlying soils. Swale design variations include the grassed channel, dry swale and wet swale. The specific design features and treatment methods differ, but all improve upon the traditional drainage ditch. Each incorporate modified geometry and other design features to allow the swale to convey and treat stormwater runoff while reducing flooding and erosion potential.

Grassed swales can be used in commercial or industrial settings.
Source: F. X. Browne, Inc.

Applicability

Swales are most useful for small drainage sites with low channel velocities. They can be used in most developed areas, and are particularly useful along roads and highways due to their linear nature. Typically, swales are designed to convey runoff from the 2-year storm without causing erosion; however, swales should also have the capacity to safely pass larger storms (typically a 10-year storm). Contaminated “hot spot” runoff should not be directed into swales due to the likelihood that the pollutants will infiltrate into the groundwater. Swales are a good treatment practice for watersheds with coldwater streams since swales do not pond water for long periods of time. Ponded water in traditional drainage ditches is subjected to warming by the sun, which in turn increases the temperature in receiving waters. In some cases, check dams (small dams along the ditch that trap sediment, slow runoff, and reduce the longitudinal slope) can be incorporated into the swale design to enhance pollutant removal or infiltration. Although grassed swales cannot treat a large drainage area, they are often an effective retrofit option for a single site.

Design Criteria

Individual grassed channels should generally treat drainage areas of less than five acres, with relatively flat slopes (i.e., less than 4% slope). Larger drainage areas and steeper slopes can lead to high velocities, which increases the erosion potential and decreases the treatment capability. Grassed channels can be used on most soils except highly impermeable soils. A small forebay should be located upstream of the channel to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river run gravel) can also be used to pretreat runoff that enters the sides of the channel. Only native vegetation should be planted in open swales in order to maximize long-term survival. Vegetation species should be able to withstand both wet and dry conditions. Table 2.3-1 lists recommended grass species for open channels.

Table 2.3-1
Common Grass Species For Open Channels

Plant Species	Notes
Bermuda grass (*Cynodon dactylon*)	Not for wet swales
Big Bluestem (*Andropogon gerardii*)	
Creeping Bentgrass (*Agrostis palustris*)	
Red Fescue (*Festuca rubra*)	Not for wet swales
Redtop (*Agrostis alba*)	Not for wet swales
Smooth Brome (*Bromus inermis*)	Not for wet swales
Switch grass (*Panicum virgatum*)	

Three design variations of the grassed channel are described below. Designs should have a trapezoidal or parabolic cross section with relatively flat side slopes (generally flatter than 3:1).

Grassed Channel

Grassed channels can be easily retrofitted to traditional roadside stormwater ditches, usually with existing soil underneath. Grassed channels should be broad and shallow in order to maximize water contact with the vegetation and soil surface. The bottom of the channel should be two to six feet wide, with the side slope ratio greater than or equal to 3:1. The critical slope should range from one to four percent. If the longitudinal slope exceeds 4 percent, log or rock check dams should be installed approximately every 50 feet (15 meters).

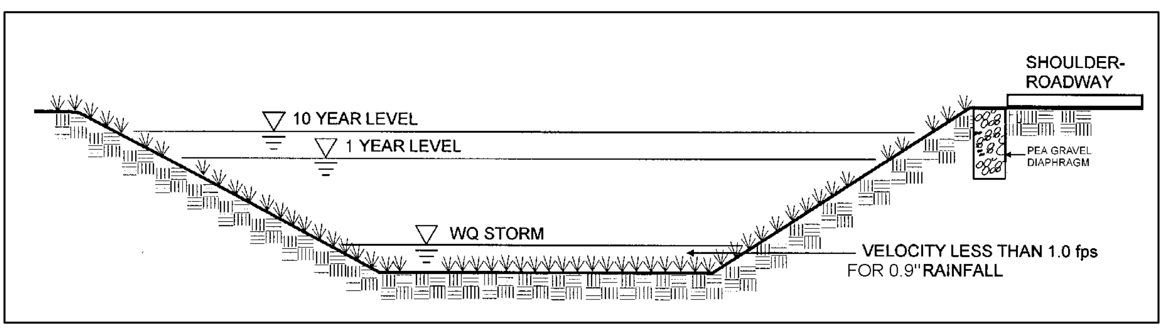

Figure 2.3-1 Cross section view of a grassed channel
Source: Center for Watershed Protection

Dry Swale

Dry swales are grassed channels designed to maximize stormwater infiltration. The existing soils should be replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system consisting of a gravel layer over a perforated pipe should be installed under the soil bed. The bottom of the channel should be two to eight feet wide, with side slopes of 2:1 or flatter. Check dams can also be included. Dry swales can be used to treat hotspot runoff since they generally don't intersect the groundwater.

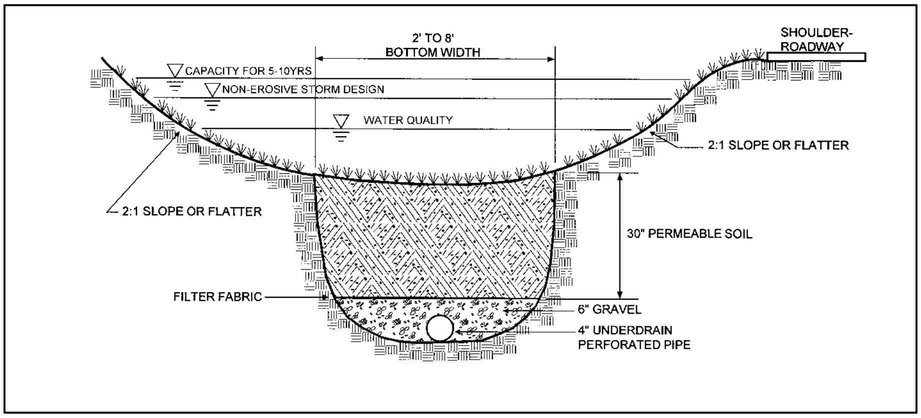

Figure 2.3-2 Cross section view of a dry swale
Source: Center for Watershed Protection

Wet Swale

Wet swales are designed with a shallow permanent pool. They should incorporate wetland vegetation into the design, similar to a constructed wetland cell. They usually intersect the groundwater, and therefore should not be used to treat hotspot runoff. The bottom of the channel should be two to eight feet wide with a side slope of 2:1 or flatter. Check dams can be included in the design.

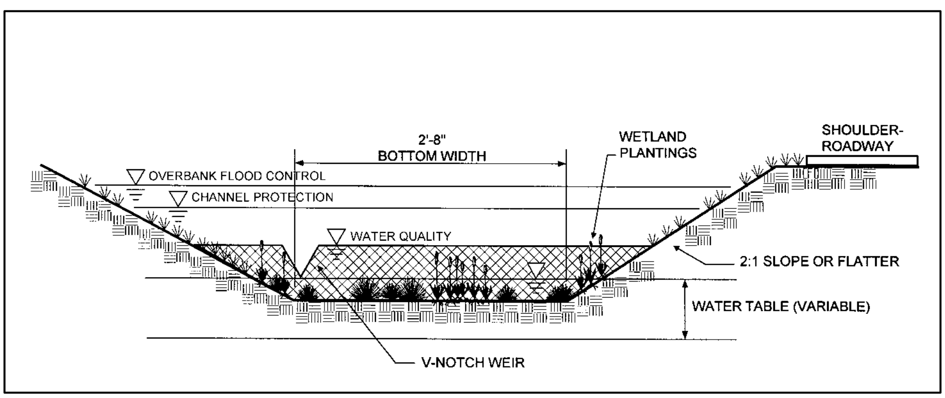

Figure 2.3-3 Cross section view of a wet swale
Source: Center for Watershed Protection

Maintenance Recommendations

During and immediately after construction, it is important to stabilize the channel until the vegetation becomes established, either with a temporary grass cover or with natural or synthetic erosion control products. After vegetation establishment, the most critical maintenance activity for most types of grassed swales is regular mowing to maintain a grass height of 3-6 inches. The swale should be inspected periodically for erosion problems or poor establishment of plant species. These problems should be corrected immediately by re-planting, or planting an alternative species. On a semi-annual basis, the pea gravel diaphragm should be inspected for clogging, and any trash and debris that accumulates in the forebay or swale should be removed. The sediment should be removed from the bottom of the swale once it has accumulated to 25 percent of the original design volume. Sediment in the forebay should be removed every five to seven years, or as needed.

Cost Considerations

Initial Costs

Typically, grassed swales cost less to construct than curb, gutters, and underground pipe. The cost of a traditional grass swale typically ranges between $16 and $49 per linear meter ($5 and $15 per linear foot) depending on local conditions, swale dimensions, and the degree of internal storage (i.e., check dams) provided (Schueler, 1992). The cost of dry swales is higher than a typical grassed or wet swale due to the underlying soil and drainage system installation. Dry swales cost approximately $5.50 per cubic foot of storage (SMRC, Bioretention Fact Sheet).

Maintenance Costs

Maintenance costs for grassed channels are low, since the primary maintenance activities are mowing and trash removal. One source (SWRPC, 1991) estimates the annual cost of maintaining a grassed swale at between $1.90 and $4.10 per linear meter ($0.58 and $1.25 per linear ft).

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2.3.2 Sand Filters

Sand filters are structural devices that treat runoff from the water quality storm and return the treated stormwater through an underdrain back to the main conveyance system. Sand filters are usually two-chambered structures; the first chamber is for settling, and the second chamber is a filter bed filled with sand or other filtering media, as shown in Figure 2.3-4. As stormwater flows into the first chamber, large particles settle out. In the second chamber, finer particles and other pollutants are adsorbed as stormwater flows through filtering media, and pollutant concentrations in stormwater are reduced to acceptable levels.

Applicability

Sand filters are typically used to treat runoff from small impervious areas with low sediment loading such as rooftops, parking lots and urban areas with drainage areas up to 5 acres. Sand filters are applicable for most land uses. They are good candidates for retrofits and highly urban areas since they require a small area (two to three percent of the impervious drainage area), and for contaminated stormwater hotspots. Sand filters can be used on sites with any soil type, with up to about six percent slopes. However, they require a significant drop in elevation (about five to eight feet) to allow runoff flow through the filter. Sand filters can be used in unique conditions where many other stormwater management practices are inappropriate, such as karst topography. In general, surface sand filters are not recommended where high sediment loads are expected, since the sediment will clog the filter. Design modifications may be necessary in cold regions since sand filters will freeze and no filtering will occur. Sand filters cannot control floods, and generally are not designed to protect stream channels from erosion or recharge the groundwater.

Design Criteria

Sand filters are best used in small drainage areas. Sand filters generally consist of four basic design components (NJ DEP 2000):

- An inflow regulator that diverts the stormwater into the system and bypasses exceeding flows.
- A pretreatment system that settles out coarse sediments.
- A sand filter bed.
- An outflow structure that returns filtered effluent back to the stormwater conveyance system and handles flows that exceed system capacity.

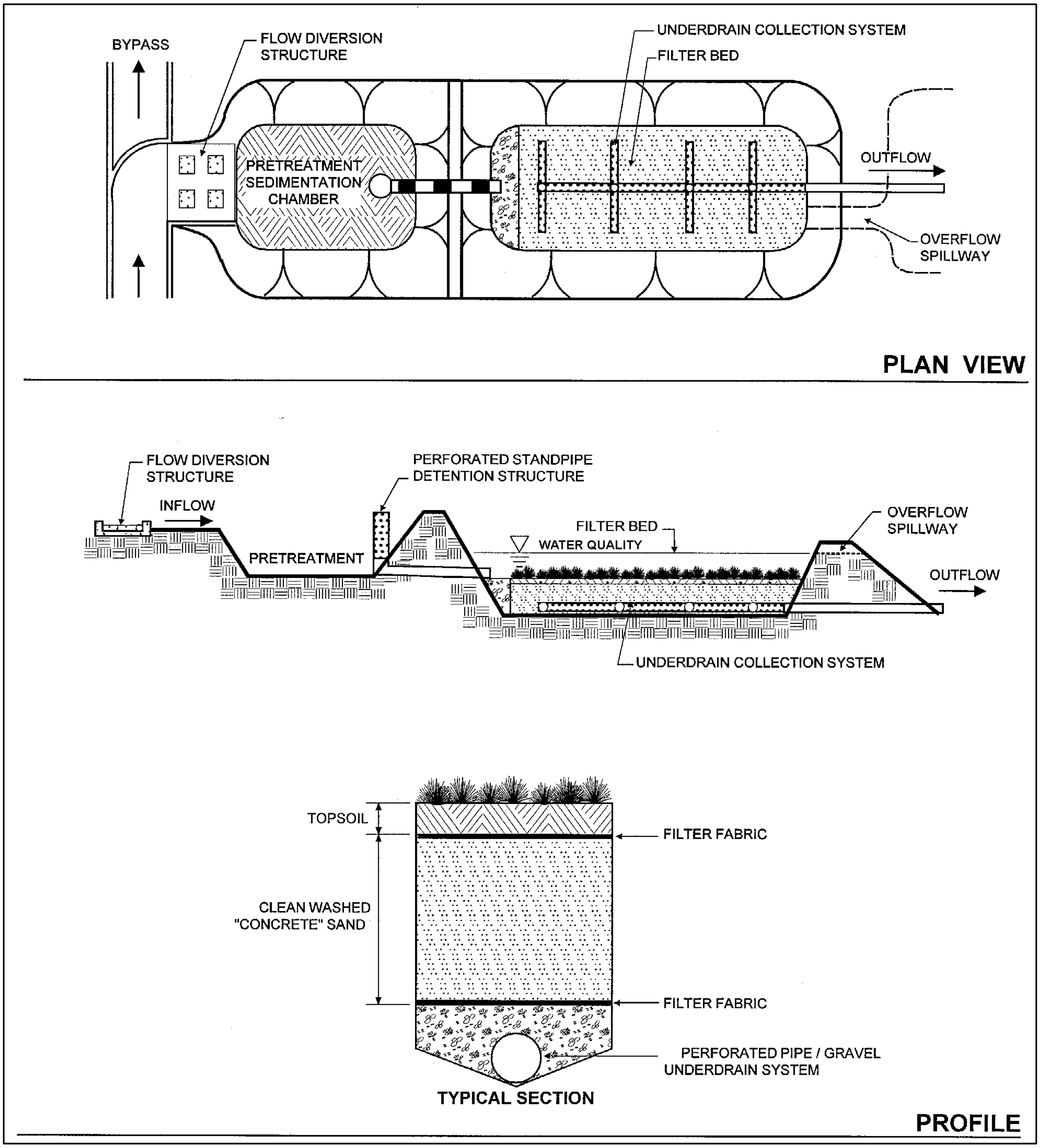

Figure 2.3-4 Typical Sand Filter
Source: Center for Watershed Protection

Sand filtration basins should be designed to empty completely in 24 hours or less. A sand bed depth of 18 inches (450 mm) is recommended. The top of the sand filter bed, overflow weirs, multiple orifices, and flow distribution slots must be constructed completely level to ensure adequate distribution of design flows. At least two feet of vertical separation should exist between the bottom of the filter and the seasonally high groundwater table, unless a waterproof liner is used. This prevents both structural damage to the filter and possible groundwater contamination. Underground sand filters should always be constructed completely watertight, especially if used over extremely sensitive groundwater conditions or where the runoff contains a high level of pollutants.

Allowance should be made for settling after initial construction. No runoff should be allowed to enter the sand filter bed until the upstream drainage area is completely stabilized and site construction is complete. One observation well should be installed for every 50 feet (15.25 meters) of sand filter length. The observation well should consist of perforated PVC pipe, 2 to 4 inches (50 to 100 mm) in diameter. The facility must be designed such that the settling basin is easily accessible for required maintenance. Provisions should be made for the removal, disposal, or re-use of sediment (both from the sedimentation basin/chamber and the sand bed).

There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and the Multi-Chamber Treatment Train (MCTT). The surface sand filter is the original sand filter design, where both the filter bed and the sediment chamber are above ground. The underground sand filter is a modification of the surface sand filter, where all of the filter components are underground. Both of these designs are intended to be offline, treating only the water quality design storm (PACD 1998). In a perimeter sand filter, flow enters the system through grates, usually at the edge of a parking lot. All flows in a perimeter sand filter enter the system on-line, but larger events bypass treatment by entering an overflow chamber. Organic media filters are essentially the same as surface filters, with the sand media replaced or supplemented with another medium such as peat or compost. The increased cation exchange capacity achieved by increasing the organic matter is intended to enhance pollutant removal for many compounds. The MCTT filter uses a combination of the above filter designs in a series of chambers. This practice achieves high pollutant removal rates, but can be prohibitively expensive.

Maintenance Recommendations

During the first year following construction, the sand filter observation well should be monitored monthly and after large storm events to document the rate of filter dewatering and sediment buildup following a storm. The inlet and filter surfaces should be cleared of debris and sediment monthly. Filter strips should be mowed periodically and kept clear of grass clippings. Annual inspections and maintenance should be performed for damage, erosion, sediment clogging, or vandalism.

Over time, a layer of sediment will build up on top of the filtration media, inhibiting the percolation rate. This sediment can be scraped off during dry periods with steel rakes or other devices. (Idaho DEQ, 2001). striating the surface layer of the media can restore the design permeability of the filtration media once sediment is removed. Replacement of the sand media should not be necessary for at least five years, but will likely be required after 10 or 20 years.

Cost Considerations

Initial Costs

According to Brown and Schueler (1997), the typical cost of sand filter installation ranges between $2.50 and $7.50 per cubic foot of stormwater treated, with an average cost of about $5 per cubic foot of stormwater treated. (This estimate includes approximately 25 percent contingency costs beyond the construction costs). These costs vary considerably depending on the filter design, site characteristics and labor costs in the region. Underground and perimeter sand filters consume no surface space, and are relatively cost-effective in ultra-urban areas where land is at a premium. Surface sand filters are less expensive to build than underground or perimeter sand filters, but they do utilize land area. Retrofitting a large area with sand filters is more expensive than using stormwater BMPs such as constructed wetlands, since sand filters treat only small areas and would require many filters.

Maintenance Costs

Annual costs for maintaining sand filter systems average about 5 percent of the initial construction cost (Schueler, et. al. 1992). Maintenance costs are incurred for inspections and periodic replacement of the gravel layer, filter fabric and top portion of the sand.

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2.3.3 BIORETENTION SYSTEMS

Bioretention systems are stormwater BMPs that treat stormwater runoff from impervious surfaces using native plants and soil conditioning measures. Bioretention systems are modeled after the biological and physical characteristics of an upland terrestrial forest or meadow ecosystem, and typically consist of a shallow depression planted with vegetation, as shown in Figure 2.3-5. Sources of runoff are diverted into bioretention system directly as overland flow or through a stormwater drainage system. The natural vegetation, such as trees, shrubs, and grasses, filters pollutants from the runoff. Soil in the biotetention system consists of a mixture of sandy and loamy soils that promote infiltration and water storage for uptake by native vegetation.

Bioretention effectively removes nutrients and suspended solids from runoff and reduces peak flow rates, peak velocities and total runoff volume. Bioretention also facilitates groundwater recharge by using the physical and biological processes of adsorption, filtration, infiltration, volatilization, ion exchange and decomposition. The vegetation in bioretention systems improves water quality while improving landscape value and providing protection from the sun and wind. During storms, runoff ponds on top of the mulch and soil, eventually filtering through. Typically, the filtered runoff is collected in a perforated underdrain and returned to the storm drain system, although this is not always necessary depending on soil conditions.

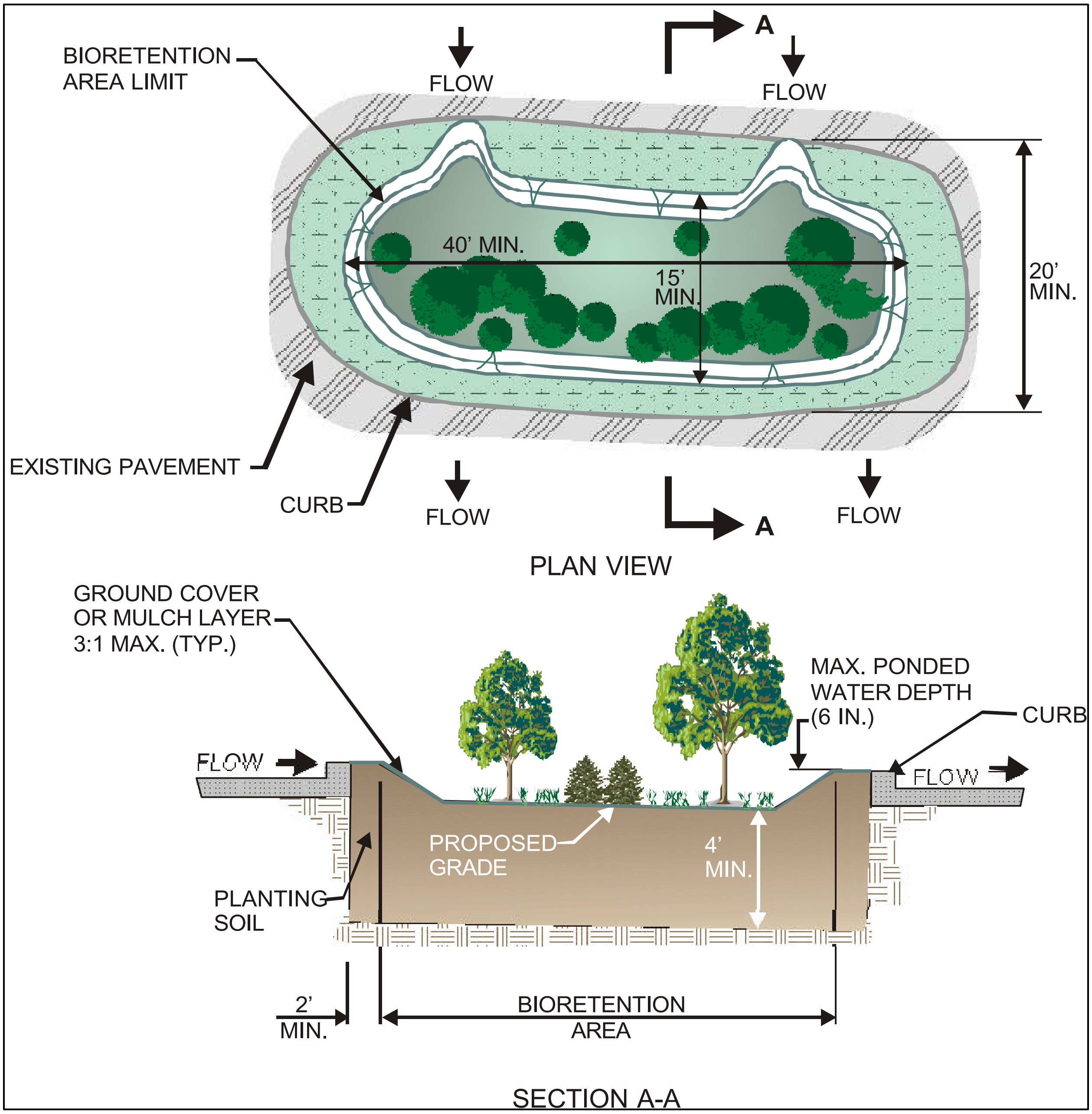

Figure 2.3-5 Typical Bioretention System
Source: F. X. Browne, Inc.

Applicability

Bioretention systems can be used in commercial or residential developments, and are particularly applicable to sites where aesthetics are an issue. Bioretention areas can be located in median strips, in parking lot or cul-de-sac islands, or adjacent to parking lots, and therefore are ideal in urban situations or retrofits. Bioretention systems can be used to treat stormwater hotspots as long as an impermeable liner is placed at the bottom of the filter bed. Bioretention systems should only be used to treat small drainage areas (five acres or less) to prevent clogging.

Bioretention systems are most effective when sited close to the source of runoff and the runoff is received as sheet flow. They are most appropriate for small drainage areas of 0.25 to 1 acre, and should be placed throughout the development site to provide localized treatment of stormwater runoff. Alternatively, a bioretention system can be constructed directly in a drainage channel or swale, or incorporated into larger stormwater systems that use multiple treatment methods.

Source: Maryland Department of the Environment

Bioretention systems are particularly well-suited for retrofits or urban areas where available land area for stormwater management systems is scarce. Bioretention systems should have a means to divert excess runoff that cannot be infiltrated into the soil, temporarily ponded, or evapotranspirated by the plants. Runoff that exceeds the water quality design storm should safely bypass or flow over the bioretention area.

Design Criteria

Bioretention areas are best applied to relatively shallow slopes (usually about 5 percent or less). They should be designed to fully drain the ponded water in less than 72 hours. Bioretention systems should not be used where the underlying soil stratum is unstable or where the water table is within six feet of the land surface. They should not be installed in areas where large mature trees would need to be removed. A 12 to 18 inch sand bed and 10 inch gravel underdrain equipped with perforated PVC conduit should be constructed underneath the planting bed. A catchbasin, inlet, or overflow channel should be located slightly above the shallow ponding limit, in order to reduce the risk of damage to the plantings during heavy storms. A gravity drain should be included so that the bioretention facility can be drained for maintenance purposes. Maintenance access should be incorporated into the facility design.

The bioretention area should be a minimum of 10 to 15 feet wide and 40 feet long. Bioretention systems should include a 20 to 25 foot wide pretreatment grassed filter strip to accommodate incoming velocities and remove coarse sediments. A pea gravel diaphragm can be used for sediment removal, to decrease runoff velocity, and to evenly distribute incoming flow. A shallow ponding area should be included to temporary storage of the water quality design storm (PACD 1998) and allow particle settling. This area should be a maximum of six inches deep. The planting bed should consist of 10 to 25 percent clay soil, 30 to 55 percent silt, and 35 to 60 percent sand. Soil pH should range from 5.5 to 6.5 standard units. Planting soil mix should be three to four feet deep. A two- to four-inch bark mulch layer should be applied over the surface of the planting bed to retain moisture and provide additional filtration.

The vegetation for the bioretention system should be designed by a wetland scientist. The planting plan should simulate a forest-shrub community of primarily upland species. Three distinct wetness zones should be incorporated into a properly built bioretention system, and plants must be selected and placed appropriately. Trees should dominate the perimeter zone. A well-planned bioretention basin will feature a diverse mixture of wetland plants. Native species should be planted whenever possible since they are best suited to climatic, light, and soil conditions. Avoid the use of any invasive plants, native or otherwise. Species that have been used successfully in bioretention areas and are commercially available are preferred. Using plant common forage plants will help create wildlife habitat; however, it is important to avoid plants that could be decimated by wildlife such as deer. A diversity of plants is best to reduce the risk of loss from pests or disease. Above all, the plants must be able to withstand the pollutant concentrations in the stormwater, and tolerate some fluctuation in the water level of the bioretention basin. A list of plant species suitable for bioretention systems, including their soil and light requirements, is provided in the Prince George's County, MD Low Impact Development Bioretention Manual (2002), which can be found on the Internet at www.goprincegeorgescounty.com/Government/AgencyIndex/DER/PPD/LID/pdf/plant_list.pdf.

Maintenance Recommendations

After construction, bioretention systems should be inspected monthly until vegetation is sufficiently established. Vegetation should be watered every day for two weeks following planting. Damaged vegetation should be replaced as soon as possible. Bioretention systems should be inspected twice per year or after large storms to ensure that they are functioning properly, to inspect for dead or distressed vegetation, to remove debris, and to unclog surface drains. The filter strip should be mowed at least monthly during the growing season. The bioretention area should be pruned and weeded as necessary to maintain aesthetic appearances. Annual soil tests for pH changes and toxic pollutants should be conducted. Lime should be applied as necessary based on soil test results. Every two to three years, the entire bioretention area should be re-mulched. If bare spots appear before that time, spot mulching should be adequate.

Cost Considerations

Initial Costs

According to Brown and Schueler (1997), the cost of bioretention systems is fairly expensive; approximately $6.80 per cubic foot of water storage. The US EPA (1999) estimates the cost of a bioretention area in Prince George's County, MD at approximately $500. The cost estimate includes the cost for excavating 0.6 to 1 meters (2 to 3 feet) and vegetating the site with 1 to 2 trees and 3 to 5 shrubs. The cost of retrofitting a site was estimated at $6,500 per bioretention area. The higher costs for retrofitting are attributed to the demolition of existing concrete, asphalt, and existing structures, and the replacement of fill material with planting soil.

When evaluating the costs of bioretention systems, consider that the bioretention system often replaces an area that would likely be landscaped anyway. Thus, the true cost of the bioretention area may be less than the construction costs reported above.

Maintenance Costs

Maintenance costs for bioretention areas are similar to normal landscaping maintenance costs, and therefore may be fairly negligible.

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2.3.4 Wet ponds

Wet ponds (also known as stormwater ponds, retention ponds, or wet extended detention ponds) are stormwater retention basins designed to retain a permanent pool of water, as shown in Figure 2.3-6. This is accomplished by constructing an embankment or excavating a pit. The ponds provide long-term storage of stormwater runoff for mechanical settling of algae and fine suspended sediments, as well as biological treatment and removal of nutrients for water quality improvement. Wet ponds provide aesthetic and recreational benefits as well as fire protection and irrigation water supply. Wet ponds may also be used for flood and downstream erosion control through the use of multi-stage outlets.

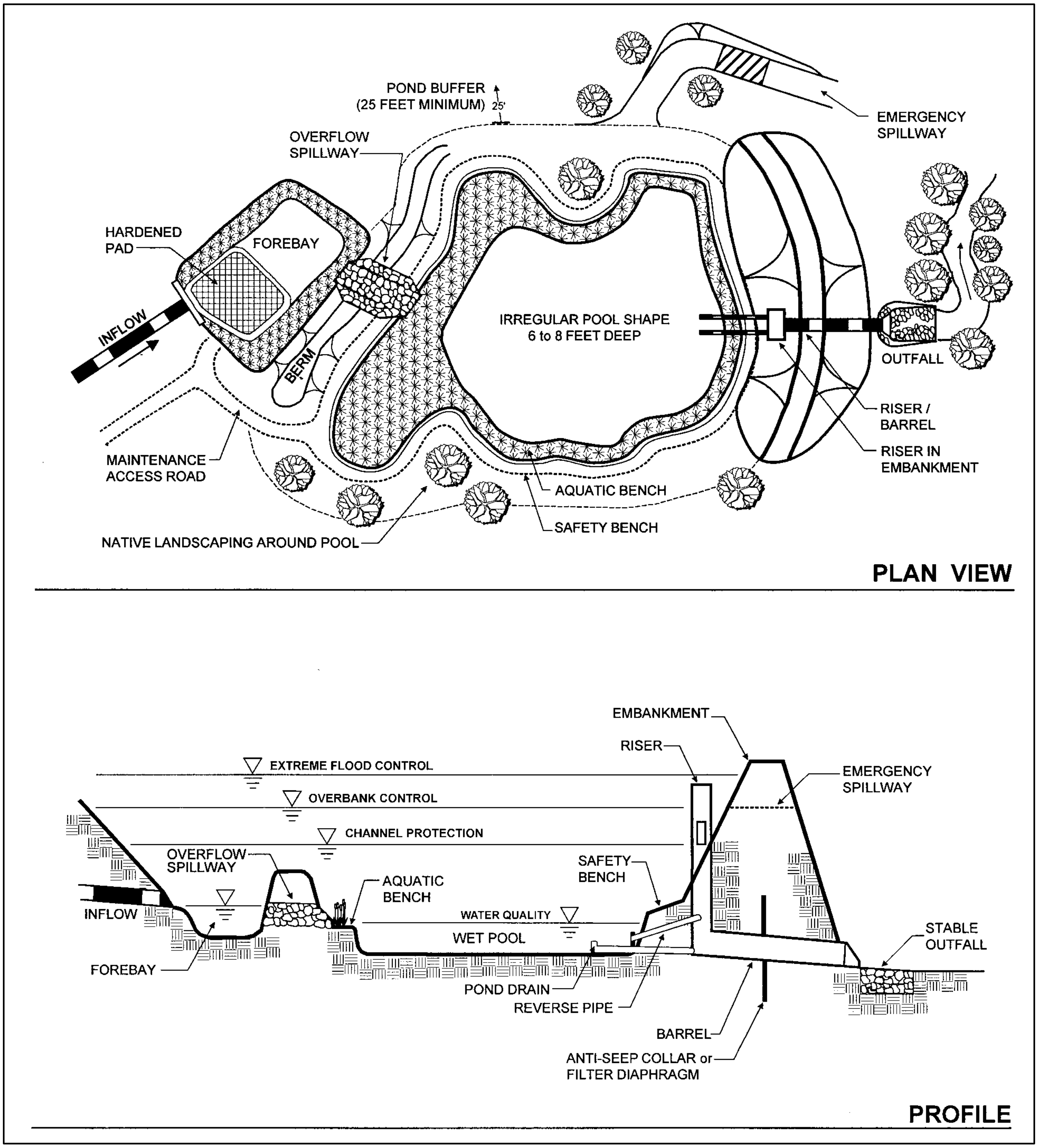

Figure 2.3-6 Typical Wet Pond
Source: Center for Watershed Protection

Applicability

Wet ponds are among the most cost-effective and therefore most widely used stormwater BMPs. They are frequently used in residential and commercial areas where nutrient loadings are high. They can be installed in virtually any soil type, and unless they receive hotspot runoff, depth to groundwater is not a concern. Wet pond basins require moderate to large drainage areas, usually greater than 20 acres, in order to maintain a permanent pool. This may restrict their use in ultra-urban areas. Wet ponds can be used for stormwater retrofits, most commonly as a modification to a dry detention pond that has been designed for flood control in the past. Alternatively, new wet ponds may be installed in streams or in open areas as a part of a comprehensive watershed retrofit plan.

A limitation of wet ponds is the potential for water temperature to increase in the permanent pool during the summer months. If the nearby receiving waters are ecologically sensitive to temperature change, the wet pond overflow cannot be directed into them. Wet ponds must be specially designed in cold regions due to freezing of the pond, inlets, and outlets, and the increase in potentially contaminated runoff due to melting snowpack in the springtime. Also, wet ponds may cause some public safety concerns due to the large amount of open water and steep sides and the potential for mosquito breeding. In public areas, access may need to be restricted by sturdy fencing. Warning signs for deep water and potential health risks should be used wherever appropriate. Signs should be placed so that at least one is clearly visible and legible from all adjacent streets, sidewalks or paths.

Design Criteria

In order to maintain a permanent pool, a reliable source of runoff or ground water must be available. While there is no minimum slope requirement, sufficient elevation drop must exist from the pond inlet to the pond outlet to ensure water flow through the system by gravity. Wet ponds should always be designed with a length to width ratio of at least 1.5:1. In addition, the design should incorporate features such as underwater berms designed to create a longer flow path through the pond. Combining these two measures ensures that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system.

A wet pond in Fairfax County, VA
Source: Fairfax County DPWES

The mean depth of the pool is obtained by dividing the storage volume by the pool surface area. The pool should be shallow enough to avoid thermal stratification and deep enough to minimize algal blooms and resuspension of previously deposited materials by major storms and wind generated disturbances. At a minimum, the volume of the wet pond must be equal to the runoff volume generated from the water quality storm. An average depth of three to six feet is usually sufficient to maintain the pool environment. The minimum pool surface area is 0.25 acres; four acres of contributing drainage area is needed for each acre-foot of storage.

A ten-foot wide and one-foot deep bench around the perimeter of the pool promotes the growth of aquatic vegetation and reduces the potential safety hazard to the public. Aquatic plants provide some pollutant removal, and help stabilize the soil at the pond edge, enhance habitat, and improve aesthetic value. The water level of the permanent pool should be maintained at about one foot above the bench. A sediment forebay (typically about 10% of the volume of the permanent pool) should be installed near the inlet structure to promote sediment deposition in an easily accessible area.

Native vegetation buffers should be planted and maintained around the pond perimeter to protect banks from erosion and provide some pollutant removal before runoff enters the pond by overland flow. Access points must be incorporated into the wet pond design to allow for maintenance of both the forebay and the main pool. In addition, ponds should include a drain for pond or forebay drawdown to enable periodic sediment removal. A reverse-slope pipe, or a weir outlet with a trash rack should be included at the pond outlet to prevent clogging. To maintain dissolved oxygen levels, control mosquito breeding, and prevent stagnation, a sufficient regular inflow of water (either surface or ground water) is necessary. A fountain or solar powered aerator may be used for water oxygenation. Once the wet pond becomes naturalized with vegetation, predators such as dragonflies and frogs will help control the mosquito population.

Several wet pond design variations exist, including wet extended detention ponds and pocket ponds. A wet extended detention pond detains stormwater above the permanent pool and releases it over 12 to 48 hours. Wet extended detention ponds have similar pollutant removal capabilities to traditional wet ponds, and consume less space. Pocket ponds are designed to drain smaller areas than traditional wet ponds, and the permanent pool is maintained by intercepting the groundwater. Pocket ponds accomplish less pollutant removal than traditional wet ponds, but are useful in areas where space is at a premium.

Maintenance Recommendations

After installation, the wet pond should be inspected monthly to determine proper function and sedimentation accumulation rates. After the first year, the structure should be inspected annually for damage, vandalism, sediment clogging, inlet and outlet scouring, dead or distressed vegetation, and erosion or bank undercuts. Repairs should be made as needed. Side slopes should be mowed monthly and debris should be removed from inlet and outlet structures. Sediment should be removed from the forebay approximately every five to seven years. The permanent pool should be dredged every 20 to 50 years, as needed. Depending on the area of contributing drainage, the removed sediment may contain hazardous materials such as pesticides and petroleum products, in which case the cost of sediment disposal could be significant. Nuisance waterfowl sometimes congregate in and around wet ponds. See Section 1.10 of this handbook for a description of nuisance waterfowl management options.

Cost Considerations

Initial Costs

Wet ponds are relatively inexpensive stormwater practices. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment of a ponds system may be spread over a relatively long time period. Construction costs range considerably. A study by Brown and Schueler (1997) estimated typical construction costs at $45,700 for a 1 acre-foot facility, or $232,000 for a 10 acre-foot facility. Wet ponds require a generally large continuous land area, and are difficult to "squeeze" into marginal land. However, in addition to water resource protection benefits of wet ponds, wet ponds may provide an economic benefit by increasing property values in the surrounding area.

Maintenance Costs

The annual cost of routine maintenance for a wet pond is typically about 3 to 5 percent of the construction cost.

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2.3.5 Constructed Wetlands

Constructed stormwater wetlands are designed wetland systems that temporarily store stormwater runoff in shallow pools, as shown in Figure 2.3-7. These pools support conditions suitable for the growth of wetland plants, which filter stormwater runoff. Other BMP components, such as sediment forebays and micropools, may be used in connection with the wetland structure. The purpose of a constructed stormwater wetland is to allow the particulate pollutants in stormwater runoff to settle, allow for the biological uptake of pollutants by wetland plants, and to lower peak discharges for downstream flood control.

Constructed stormwater wetlands have relatively low maintenance costs once the site is established as a miniature self-contained ecosystem. They provide high pollutant removal efficiency as well as providing aesthetic and recreational benefits.

Some disadvantages of constructed wetlands include relatively high construction costs and larger land requirements in comparison to other BMPs. Pollutant removal efficiencies may be lower until the vegetation is well established, and seasonal variations in treatment and pollutant removal efficiencies may occur, especially in cold regions.

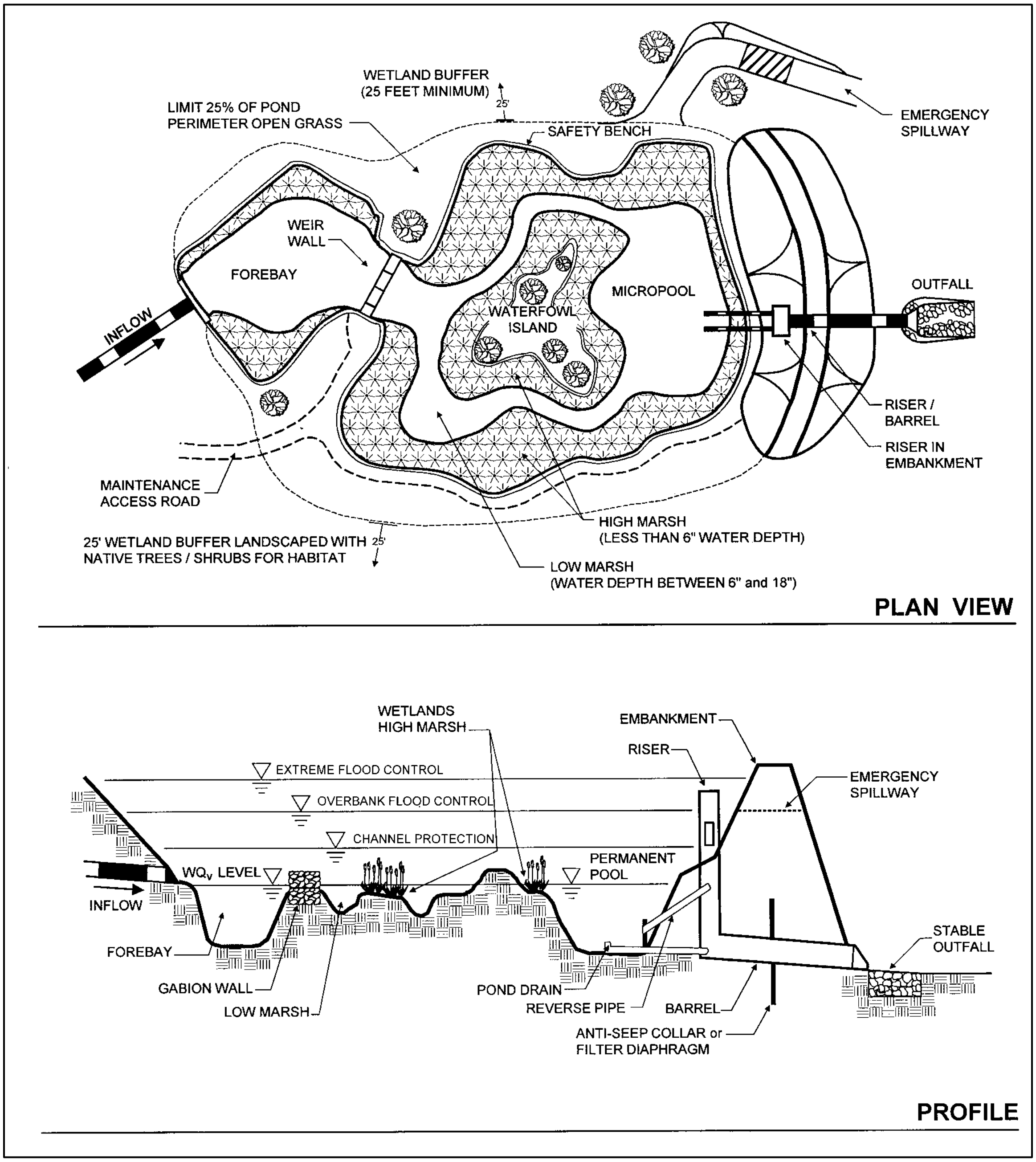

Figure 2.3-7 Typical Constructed Stormwater Wetland
Source: Center for Watershed Protection

Applicability

Constructed stormwater wetlands typically require at least 10 acres of contributing drainage area. However, pocket type wetlands may be appropriate for smaller sites if sufficient ground water flow is available. Wetlands need sufficient drainage area or baseflow to maintain a shallow permanent pool. When retrofitting an entire watershed, stormwater wetlands have the added advantage of providing both educational and habitat value.

Constructed stormwater wetlands should not be located within natural wetland areas. Engineered stormwater wetlands differ from restoration wetlands in that they do not have the full range of ecological functions of natural wetlands. Constructed stormwater wetlands are designed specifically for flood control and water quality improvement purposes. Constructed wetlands draining to coldwater streams have the potential to negatively impact the cold water system due to thermal warming in the wetland pool. If an exceptional coldwater environment is downstream from a constructed wetland, potential thermal impacts should be considered.

Constructed wetlands can be used to treat contaminated runoff (stormwater “hotspots”) as long as groundwater is not impacted. Designers must ensure that runoff pollutants do not accumulate in aquatic organisms living in or near the wetland. At sites where bedrock is close to the surface, high excavation costs may reduce the feasibility of constructed stormwater wetlands.

Design Criteria

According to Schueler et. al. (1992), pollutant removal in constructed wetlands tends to increase as the stormwater wetland to watershed ratio increases. The wetland surface area should be at least one percent of the contributing drainage area. Ideally, stormwater wetlands should be sized to capture and treat 90 percent of all runoff-producing storms. Sufficient elevation drop from the inlet to the outlet (generally about three to five feet) is required to ensure that hydraulic conveyance is achieved by gravity. In karst topography, the bottom of constructed wetlands should incorporate an impermeable liner to prevent groundwater contamination or sinkhole formation and to help maintain the shallow pool. The wetland should be located to take advantage of the existing topography of the site.

A complex internal structure of microtopography – flats, shoals, islands, and pools – can be used to increase the amount of surface area in the wetlands. High surface area to volume (SA/V) ratios increase sedimentation, adsorption, microbial activity, and uptake of pollutants by algae. It is best to allocate as much area as possible to shallow depths to promote sheetflow. Greater flowpaths can be achieved by making the wetland longer than it is wide. This helps prevent "short circuiting.”

Constructed wetlands should be designed with varying depth zones, as described below and as shown in Figure 2.3-7:

- Deepwater zone: Ranges from 1.5 to 6 feet deep. Supports little emergent vegetation, but may support submerged or floating vegetation. Can be further broken down into forebay, micropool and deepwater channels. The deepwater zone is intended to provide areas for sediment settling.

- Low marsh zone: Ranges from 18 to 6 inches below the permanent pool. Suitable for the growth of several emergent wetland plant species. Intended to increase the stormwater runoff retention time and contact area.

- High marsh zone: Ranges from 6 inches below the pool up to the permanent pool. Will support a greater density and diversity of emergent wetland species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone, and provide increased nutrient uptake.

- Semi-wet zone: Areas above the permanent pool that are inundated on an irregular basis and support wetland plants. Semi-wet zones provide additional retention area for larger storms.

Medium-fine texture soils (loams and silt loams) are best to establish vegetation, retain surface water, permit groundwater discharge, and capture pollutants. An impermeable liner may be required at sites where infiltration is too rapid to sustain permanent soil saturation. The use of "wetlands mulch" enhances the diversity of the plant community and speeds establishment of vegetation. Wetlands mulch is hydric soil that contains vegetative plant material. This mulch can be obtained from wetland soils removed during dredging or from natural wetlands that are permitted for filling. A drawback to using constructed stormwater wetland mulch is its unpredictable content.

Constructed stormwater wetland treat parking lot runoff at F. X. Browne, Inc., main office in Lansdale, PA
Source: F. X. Browne, Inc.

Each stormwater wetland should have a "pondscaping plan". This plan should include hydrological calculations (or water budgets), a wetland design and configuration, elevations and grades, a site/soil analysis, estimated depth zones, and a map of the wetland plants used in the design. When choosing wetland plants, consider the prospects for success more than the specific selection. Native species should be planted whenever possible since they will likely be the best suited to climatic, light, and soil conditions. Avoid the use of any invasive plants, native or otherwise. Priority should be given to species that are commercially available and known to succeed in constructed stormwater wetlands. Planting common forage species will help create wildlife habitat. If wildlife damage is a problem, deer- and pest-resistant species should be used. A diversity of plants should be incorporated to reduce loss from pests or disease. Incorporating plant species with varying root depths will provide better pollutant removal.

Each stormwater wetland should be designed with a separate, four to six foot deep cell near the inlet to act as a sediment forebay. This forebay should have a capacity of at least 10 percent of the total treatment volume and a direct and convenient access for cleanout. Safety ledges should be constructed on all basins with a permanent pool of water deeper than 2.5 feet (Revised Manual for New Jersey: Best Management Practices for Control of Nonpoint Source Pollution from Stormwater, 2000).

In front of the outlet, a four to six foot deep micropool having a capacity of at least 10 percent of the total treatment volume should be constructed to prevent outlet clogging. A bottom drain pipe with an inverted elbow to prevent sediment clogging should be installed for complete draining of the stormwater wetland and for emergency or maintenance purposes. Adequate access to the forebay and micropool must be provided. Designers should provide shade around the channel at the wetlands outlet to prevent warming.

Variations of constructed wetlands include shallow marsh wetlands, extended detention wetlands, pond/wetland systems, pocket wetlands, and gravel based wetlands. The designs differ in the volume of deep pool, high marsh, low marsh, and extended detention above the wetland surface. These variations are briefly described below.

Shallow Marsh Constructed Wetland

In the shallow marsh constructed wetland, most of the wetland volume is in shallow high marsh or low marsh zones. The only deep areas of the design are the forebay at the wetland inlet and the micropool at the outlet. Shallow marshes are typically designed with sinuous pathways to increase retention time and contact area. One disadvantage of the shallow marsh design is that since the pool is shallow, a large amount of land is typically required for storage of the runoff volume.

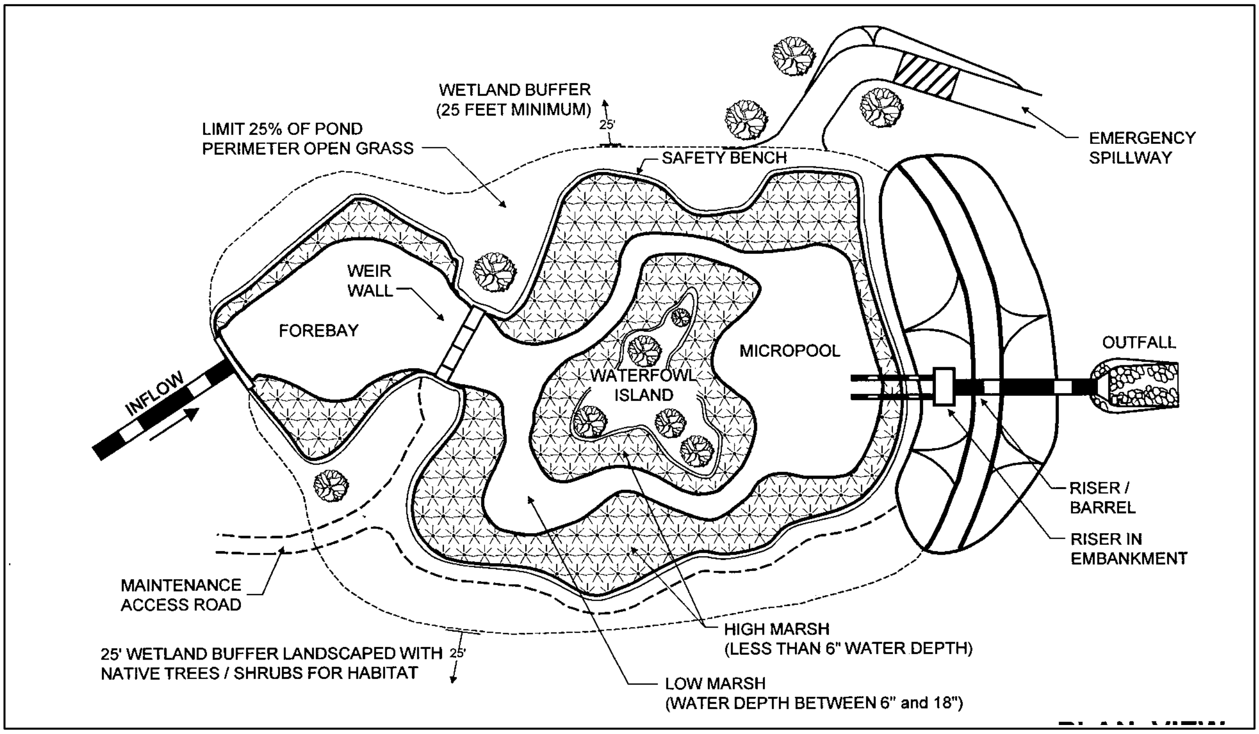

Figure 2.3-8 **Plan view of a shallow marsh wetland**
Source: Center for Watershed Protection

Extended Detention Constructed Wetland

An extended detention constructed wetland is designed with more storage above the surface of the marsh than a shallow marsh constructed wetland. Stormwater is temporarily ponded in the extended detention zone for 12 to 24 hours. Therefore, the extended detention wetland can treat a greater volume of stormwater in a smaller space than the shallow marsh wetland design. Extended detention wetlands provide a greater degree of downstream channel protection. Plants that can tolerate both wet and dry periods should be planted along the shoreline of an extended detention wetland.

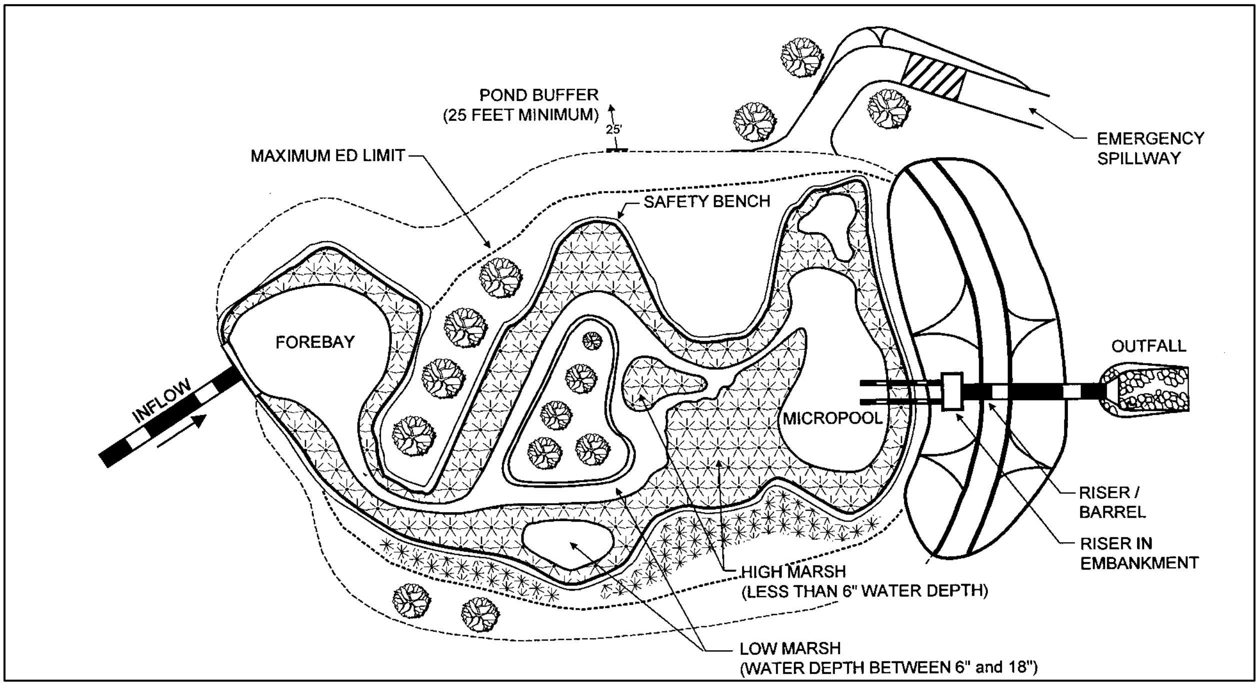

Figure 2.3-9 Plan view of an extended detention constructed wetland
Source: Center for Watershed Protection

Pond/Wetland System

The pond/wetland system combines a wet pond and a shallow marsh. Stormwater runoff flows through the wet pond into the shallow marsh. The wet pond reduces the velocity of runoff entering the system. The shallow marsh provides additional treatment of the runoff, especially soluble pollutants. This design requires less surface area than a shallow marsh constructed wetland because much of the pond is relatively deep (i.e., six to eight feet). Pond/wetland systems generally achieve a higher pollutant removal rate than other constructed stormwater wetland designs.

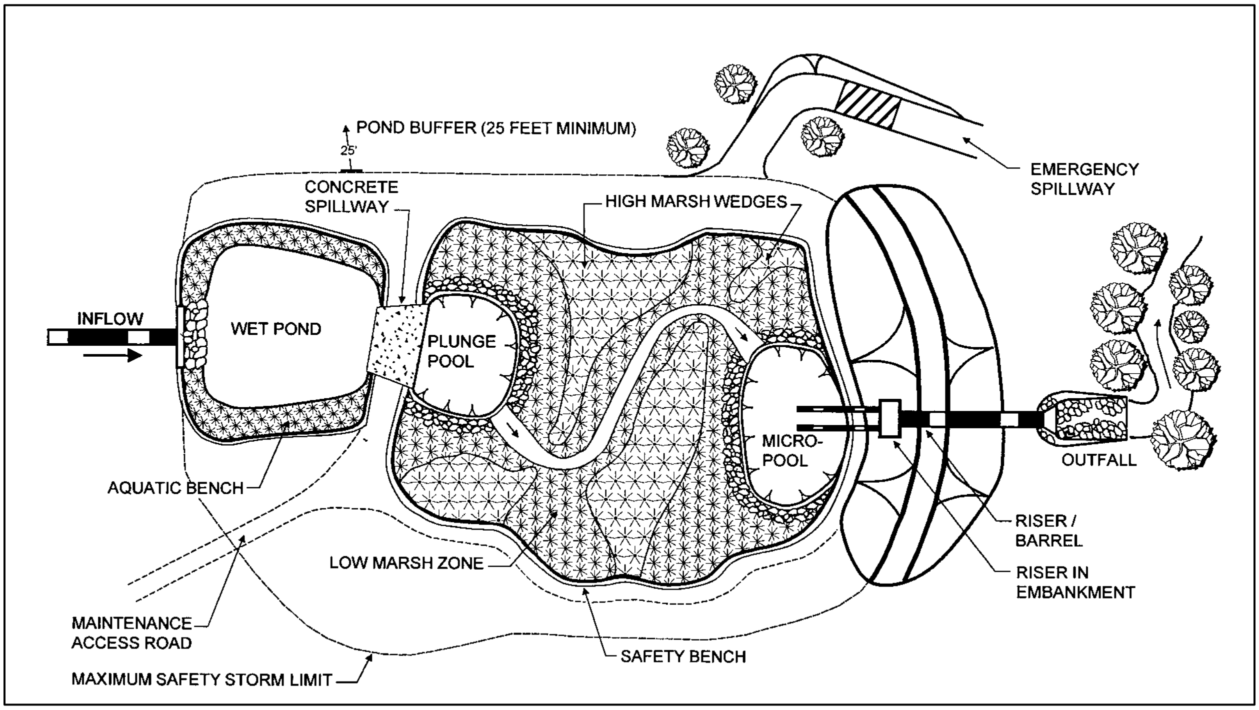

Figure 2.3-10 **Plan view of a pond/wetland system**
Source: Center for Watershed Protection

Maintenance Recommendations

Constructed stormwater wetlands require frequent, although inexpensive, routine maintenance. In contrast, conventional detention pond stormwater systems require infrequent routine maintenance that involves expensive sediment removal. The newly constructed stormwater wetland should be inspected monthly to ensure proper functioning; quarterly inspection should be adequate after the first year. In spring following wetland construction, dead or distressed vegetation should be replaced to maintain at least 50 percent surface area coverage. Quarterly inspections should include an invasive plant survey, as well as inspection for damage, vandalism, erosion, or scouring. Side slopes should be mowed and debris removed from the inlet and outlet structures, as needed. The constructed wetland should be monitored for sediment accumulation, which should be removed from the forebay and micropool every five to seven years, or as needed. The entire pool volume should be dredged when the plants become choked with sediment, the pool becomes eutrophic, or the pool volume becomes significantly reduced, about every 20 to 50 years.

Cost Considerations

Initial Cost

Constructed wetlands are fairly expensive, but they treat a large land area, eliminating the need for multiple BMPs. According to Brown and Schueler (1997), estimated construction costs are $57,100 for a 1 acre-foot facility and $289,000 for a 10 acre-foot facility. Wetlands require a large amount of land area compared to other stormwater management practices. Where land value is high, stormwater wetlands may be infeasible.

Maintenance Costs

Annual cost of routine maintenance is typically about three to five percent of the construction cost. However, since constructed wetlands are a long-term treatment practice, costs can be spread out over time. In addition, constructed wetlands may increase property values in certain areas.

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2.3.6 Porous Pavement

Porous pavement (also known as pervious or permeable paving) refers to patios, walkways, driveways, fire lanes, and parking areas constructed using specific materials that allow stormwater to infiltrate into the underlying soil. These materials include pervious interlocking concrete paving blocks, porous asphalt, concrete grid pavers, perforated brick pavers, and compacted gravel. The porous pavement surface is typically placed over a highly permeable layer of open-graded gravel and crushed stone, as shown in Figure 2.3-11. The void spaces in the aggregate layers act as a storage reservoir for runoff and the evaporation of infiltrated water is minimized. Porous pavement is most effective for reducing stormwater volume, reducing peak surface runoff rates, and improving the groundwater recharge characteristics of developed sites. Porous pavement has the potential to be a highly effective stormwater treatment practice; however, proper maintenance is critical for optimum efficacy.

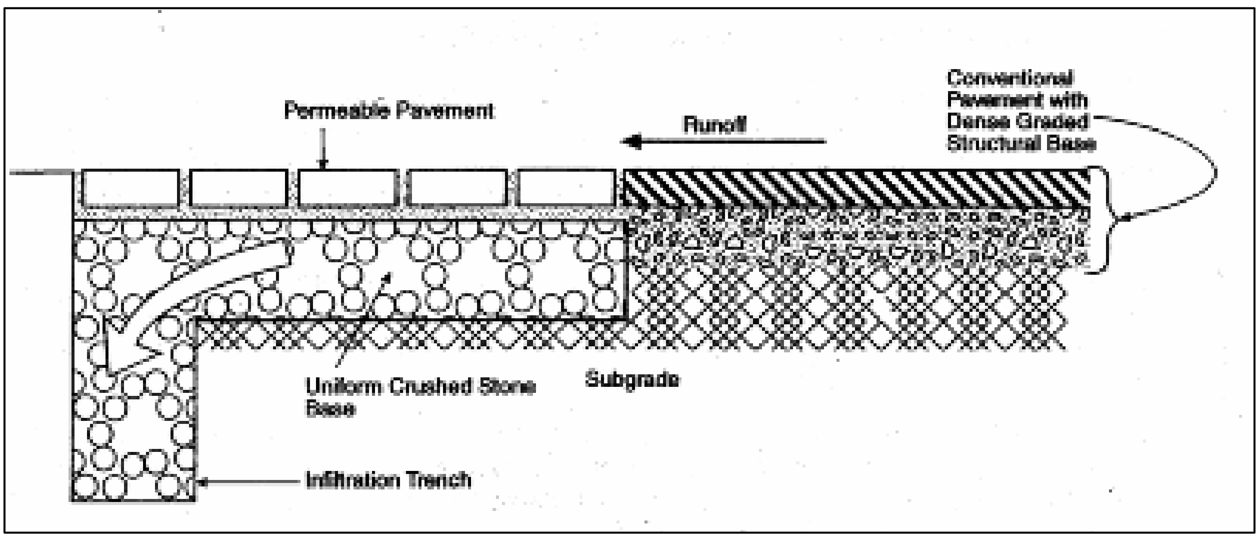

Figure 2.3-11 Typical Porous Pavement System
Source: Pennsylvania Handbook of Best Management Practices for Developing Areas

Variations of porous pavement include porous asphalt or concrete, and pervious paving systems. Porous asphalt and pervious concrete are similar in surface appearance to traditional pavement and are applied using conventional techniques. They are manufactured without "fine" materials and incorporate void spaces to allow infiltration, which differs from traditional pavement.

Porous concrete allows stormwater to rapidly infiltrate

Pervious paving systems have open spaces between the paving stones to allow infiltration

Pervious pavers are concrete interlocking blocks or synthetic fibrous grid systems with open areas designed to allow grass to grow within the void areas. Some pervious pavers use gravel in the void areas. Pervious paving systems can be used as inlets and covers for infiltration trenches and underlying drainage systems.

Applicability

The ideal application for porous pavement is a low traffic or overflow parking area. Porous pavement systems work well in highly urban areas since no extra land area is required. Porous pavement can be used to treat large drainage areas. The systems require moderately pervious soil with a depth to the seasonal high water table or bedrock of greater than 3 feet below grade. Porous pavement has been used successfully at sites underlain by karst bedrock where other methods of groundwater recharge would not be recommended because of the risk of sink hole formation. Porous pavement is not applicable where the potential for contaminated surface runoff exists, because the contaminated stormwater will infiltrate directly into the soil and enter the groundwater. For the same reason, porous pavement should not be installed in highly pervious sand or gravel that is directly connected to aquifers. Porous pavement works best when the up-gradient drainage area is minimized. One strategy is to alternate impervious and pervious paving areas. Porous pavement can be easily retrofitted onto existing paved areas during resurfacing.

Porous pavement systems are prone to clogging by suspended solids and should not be used in areas receiving significant amounts of sediment or mud tracked onto the surfaces during wet weather. Care must be taken not to damage the pavement with snowplows in cold climates.

Sand cannot be applied to the surface during the winter for fear of clogging the pores. However, when installed properly, less sand and salt are required for porous pavement than for traditional pavement during icy conditions. When snow melts on the surface of porous pavement, it tends to infiltrate rather than form ice (Miller 1989, Cahill Associates 1993). Similarly, greater pore space below the pavement provides room for freezing and thawing, leading to fewer potholes.

Design Criteria

Porous paving systems should be designed to treat the water quality design storm (PACD 1998). For optimum performance, percolation of runoff through the porous paving system should be complete within 48 hours. Water should be conveyed through the surface of the pavement to a stone reservoir, and infiltrated into the ground through the bottom of the reservoir. A geosynthetic liner and sand layer should be placed below the stone reservoir to prevent clogging and to maintain a flat bottom. Runoff from adjoining areas should be prevented or minimized by grading the surrounding landscape away from the site, or by installing trenches to collect the runoff. If the subgrade materials are not adequately permeable, percolation can be enhanced by interconnecting the paving base with an infiltration trench.

Engineers and contractors familiar with porous pavement systems should be used for the design and construction, since improper installation can lead to high failure rates. To prevent clogging, porous pavement should not be installed until all disturbed areas have been completely stabilized and all ground preparation and earthwork has been completed. Roof downspouts can be directed onto the porous pavement; however, the volume of the paving base should be increased and leaves and roof litter should be filtered prior to release. A perimeter overflow edge can be constructed to intercept runoff from the paving if the porous surface becomes clogged. The perimeter overflow edge should connect directly into the base layer of the paving.

Maintenance Recommendations

Proper maintenance is critical to a functional porous pavement system. The system should be inspected monthly and after large storms to remove debris and ensure that sufficient infiltration has occurred. The area should be kept clean of sediments that clog the system by vacuum sweeping at least three to four times a year. Upgradient land areas should be seeded and mowed frequently to reduce sediment washing onto the paving surface. Vegetation planted between the pavers should be mowed periodically and woody vegetation removed. If interlocking pavers with gravel are used, vegetation should be removed from the open cells with a low-dose herbicide that does not persist in the environment. In cold climates, snow removal methods should include plowing, but no more sand or salt than necessary.

Cost Considerations

Initial Costs

Initial costs of porous pavement may be competitive or somewhat higher than conventional materials. Since the same raw materials, mixing and application equipment are used, costs should not be higher for porous material. However, contractors may initially charge higher prices for jobs involving unfamiliar formulas or techniques. Planning, testing, and engineering fees may also be higher, but are often offset because other types of stormwater drainage such as storm drains may not be necessary. Porous pavement costs range from $2 to $3 per square foot, depending on the design (Center for Watershed Protection, 1998; Schueler, 1987). Since no extra land is required, costs can be lower than other BMPs in areas where land values are high.

Other, less easily quantified benefits include: groundwater recharge to local water supplies of up to one million gallons per acre per year (Miller, 1989); increase in sewage treatment plant capacity due to elimination of combined sewer overflow problems; and reduction in downstream flooding damage. Although these benefits are not included in construction costs, their economic and social values can be significant.

Maintenance Costs

Maintenance costs for porous pavement (i.e. vacuum sweeping) can be high if a community is not already equipped to perform this operation. The average annual maintenance program for a porous pavement parking lot costs approximately $200 per acre per year ($4,942 per hectare per year). This cost assumes four inspections each year with appropriate jet hosing and vacuum sweeping treatments.

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2.3.7 Extended Detention Basins

Extended detention basins are designed to detain stormwater runoff from the water quality design storm for some minimum duration (e.g., 24 hours), which allows sediment particles and associated pollutants to settle out (PACD 1998). Traditional detention ponds collect stormwater from large rain events and provide the required detention but very little treatment. Extended detention basins are constructed with small pools at the inlet and outlet of the pond and incorporate vegetation and increased flow paths to enhance soluble pollutant removal, as shown in Figure 2.3-12.

Extended detention basins are typically used for flood control and water quality improvement. Extended detention basins may be either "wet" or "dry," above ground (ponds) or below ground (tanks or vaults). A wet pond, as the name implies, maintains a permanent pool of water for runoff treatment purposes and incorporates wetland vegetation for soluble pollutant removal. In contrast, a dry facility detains water for a short period of time to allow pollutants to settle, but dries out completely between storms.

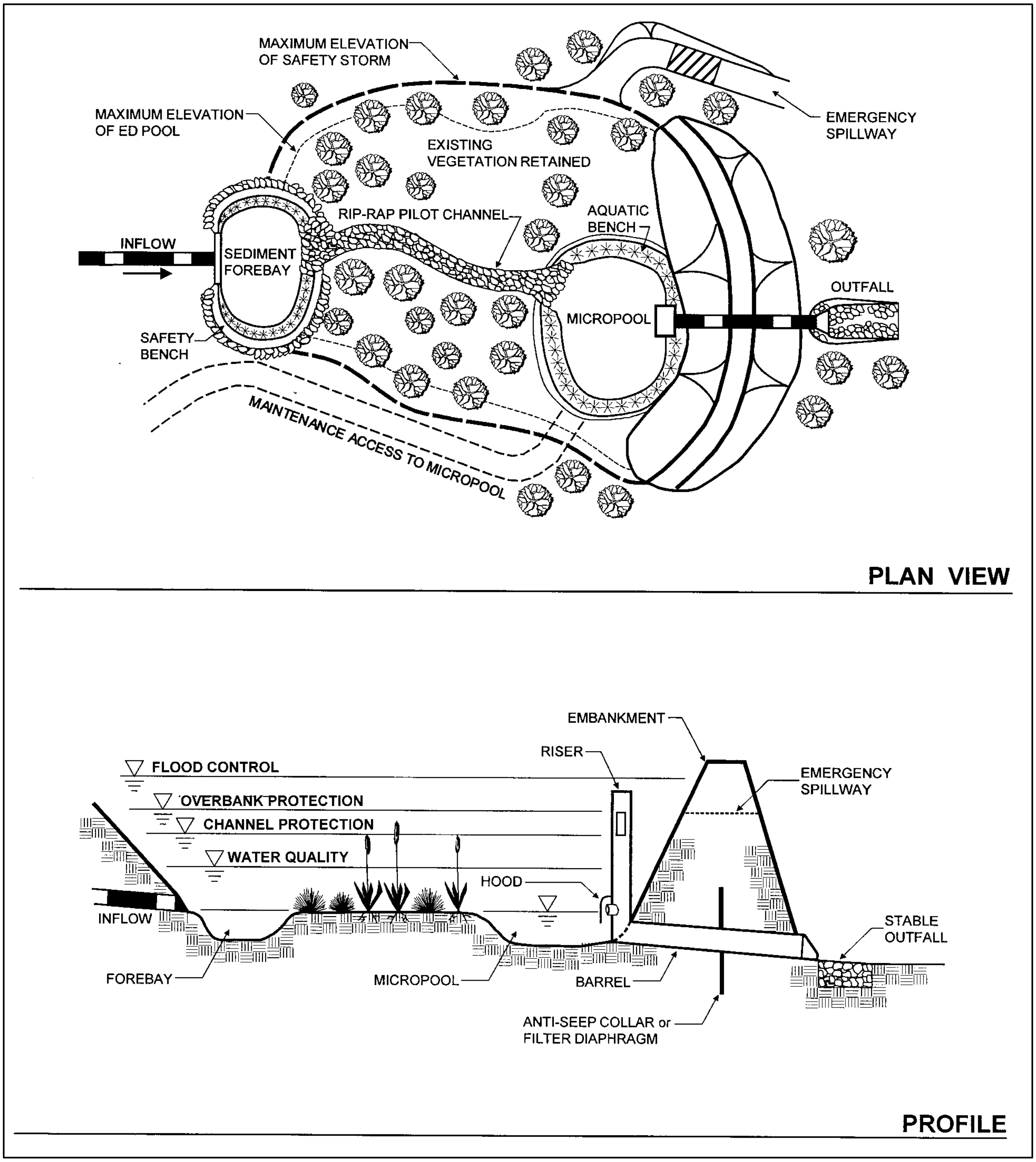

Figure 2.3-12 Typical Extended Detention Basin
Source: Center for Watershed Protection

Applicability

Extended detention basins are among the most widely applicable stormwater treatment practices since they have few restrictions as long as sufficient land area exists. Existing stormwater detention basins can be retrofitted for extended detention and improved outflow water quality by modifying the outlet structure. In general, extended detention basins should be used at sites with a minimum drainage area of ten acres. Extended detention ponds can be used on sites with slopes up to about 15 percent.

Extended detention basins are applicable in residential, industrial, and commercial areas where the amount of impervious surface is relatively high and sediment, heavy metals and hydrocarbons are the target pollutants. However, they provide limited effectiveness in removing soluble pollutants such as nutrients, fertilizers, and pesticides unless they include wetland areas. The bottom of the detention basin should not intersect with the groundwater table, especially in residential areas where mosquito breeding habitat or safety is a concern. If used to treat hotspot runoff, the basin should be lined to protect groundwater from hazardous contaminants.

Design Criteria

Detention time is the most critical parameter in extended detention basin design. The detention time determines the basin volume for a given design storm and the extent of pollutant removal. A minimum detention time of 24 hours provides adequate settling of sediment and pollutants. Detention basin size is determined by the runoff volume to be detained over a specified period of time to enhance water quality. A typical extended detention basin ranges from three to twelve feet deep. Depth is often limited by ground water conditions or by the need for positive drainage from excavated basins. The extended detention basin should be sized to accommodate the runoff generated by the water quality design storm, at a minimum (PACD 1998). In a dry detention basin, no more than 10 percent of the total runoff volume from the design storm should remain after 24 hours, and within 72 hours the basin should be completely evacuated. Higher detention volume may be needed in cold climates to treat the large amount of spring melt runoff.

Typical extended detention basin
Source: Center for Watershed Protection

Detention basin designs may vary considerably, depending on site constraints or community preference. An extended detention basin should include a sediment forebay designed to contain about 10 percent of the treated water volume. The treatment pond length to width ratio should be at least 1.5:1. The pond bottom should have a 2 percent slope and a low flow channel from inlet to outlet to allow complete drainage. A micropool at the outlet can prevent resuspension of sediment and outlet clogging. The extended detention basin should include adequate access to the forebay and micropool for maintenance. Conduit outlet protection must be included at all inflow and outflow points. An overflow device must be installed to bypass flows over or around the restrictor system.

Extended detention basins should include a vegetated buffer around the pond, and incorporate plants within the detention area that can withstand both wet and dry periods. The side slopes of dry ponds should be relatively flat to reduce safety risks. Fencing and signage can be placed around the detention basin, if necessary, especially when located within a residential area where children are likely to play.

Maintenance Recommendations

Extended detention basins should be inspected monthly and after large storms during the first year to ensure proper function. Thereafter, annual inspections and inspections after large storms are adequate to survey damage and erosion, remove debris, and monitor sediment accumulation. Sediment should be removed from the forebay and micropool areas every five to seven years. Sediment should be removed from the pond area when the pond volume has decreased by 25 percent, or every 20 to 50 years.

Cost Considerations

Initial Costs

Dry extended detention ponds are the least expensive stormwater treatment practices, on a cost per unit area treated. Brown and Schueler (1997) estimated typical construction costs at $41,600 for a 1 acre-foot pond and $239,000 for a 10 acre-foot pond. Extended detention basins require relatively large continuous areas; they can't be "squeezed in" to unusable land like filters or swales. Thus, they may be more costly where land values are at a premium. Extended detention basins are long-lived facilities (typically longer than 20 years), however, so the initial investment may be spread over a relatively long time period.

Maintenance Costs

Estimated annual cost of routine maintenance is typically three to five percent of the construction cost (Schueler, 1992). Traditionally, detention basins tend to detract from the value of adjacent properties due to the lack of aesthetic character and potential for breeding mosquitoes. However, a regularly scheduled mowing program of bottoms, side-slopes and embankments and attractive native plantings should help reduce these perceptions. A properly designed extended detention basin that completely evacuates stormwater within 72 hours is not a concern in terms of mosquito habitat, especially with native plants to attract predatory insects that eat mosquito larvae.

References

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2.4 Agricultural Best Management Practices

Nonpoint source pollution from agricultural runoff can be a significant source of lake nutrient (phosphorus and nitrogen) and sediment loadings. Pollutant loadings from agricultural land uses can be reduced through the implementation of both traditional and innovative agricultural BMPs. Some agricultural BMPs address cattle and other grazing animals and their impact on erosion. Others target crop farming practices or waste storage. Examples of agricultural BMPs include:

- Crop Residue Management
- Grassed Waterways
- Contour Farming
- Contour Stripcropping
- Crop Rotation
- Terraces and Diversions
- Grazing Management
- Barnyard Runoff Management
- Exclusionary Fencing
- Stream Crossings
- Spring Development
- Animal Waste Storage Facilities
- Nutrient Management Plans

Each of the above agricultural BMPs is discussed in detail in the following sections.

Source: USDA NRCS

2.4.1 Crop Residue Management

Crop residue management is the planned use of crop residue to protect the soil surface (PA Conservation Partnership 1999).

Applicability

Crop residue in a field
Source: USDA NRCS

There is a direct relationship between the amount of tillage done and the amount of crop residue left on the surface after planting. The most effective method to maximize surface residue is to use no-till planting. Many of today's producers use complete cropping systems with no tillage at all. This maximizes the residue amounts accumulated on the surface through a complete crop rotation. Continuously maintaining soil cover levels of 50 to 75 percent tends to improve the effectiveness of no-till systems and soil quality. Other producers combine no-till and reduced-till practices with the use of a moldboard plow. These combinations will increase the amount of crop residue when compared to the singular use of a moldboard plow. Continuous use of a moldboard plow represents maximum tillage and the smallest amount of surface residue left to protect the soil and build soil organic matter (PA Conservation Partnership 1999).

The benefits of crop residue management are (PA Conservation Partnership 1999):

- Increased water absorption
- Reduced volume and velocity of surface runoff
- Improved soil moisture from mulching effects
- Improved biological activity from populations of earth worms, night crawlers and other forms of soil life

Design/Maintenance Considerations

The following should be considered when implementing this best management practice (PA Conservation Partnership 1999):

- Use complete no-till systems whenever possible or combine no-till with other systems that increase residue on the surface.

- Reduce the number of tillage passes.

- Select tillage methods that leave more residue. Chisels and field cultivators with straight points or sweeps will maximize surface residues as compared to disks and equipment with twisted shanks.
- Operate tillage tools at shallower depths (3- 4 in.) to increase residue and save fuel.
- Perform fall tillage only when necessary and when the surface is left rough with residues over 50 percent. If tillage leaves low residue amounts, consider planting a winter grain for cover.
- Use cover crops to supplement low residue crops such as soybeans and vegetables or to replace removed residue.
- Spread all residue evenly at harvest.
- Chop corn stalks in the spring just prior to planting to allow the soil to warm more quickly or only when more even distribution is necessary to protect the soil.
- Fall chopping provides better winter soil protection.
- No-till planting into corn stalks helps retain surface residue for two years.
- Surface applied manure in no-till systems can supplement surface cover especially when bedded manure is used.

Cost Considerations

The cost for crop residue management is highly variable and ultimately depends upon the machinery needed (PA Conservation Partnership 1999). Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania' Natural Resources.

2.4.2 Grassed Waterways

Grassed waterways are natural or constructed swales designed to prevent water from concentrating as it runs off a field (PA Conservation Partnership 1999).

Applicability

Grassed waterways slow runoff water and guide it from the field preventing gully erosion. Before establishing grass, one must know the watershed, which is the land draining into the waterway. Waterways with large drainage areas or steep slopes should be carefully designed and constructed (PA Conservation Partnership 1999).

Source: USDA NRCS

The benefits of grassed waterways are (PA Conservation Partnership 1999):

- Improved water quality
- Reduced erosion
- Improved field conditions
- Provides an outlet for terraces or diversions

Design Considerations

The local NRCS or conservation district office should be contacted in order to determine whether major land shaping is needed. Smaller waterways on gentle slopes can be shaped and seeded by the farmer. Charts are available to help landowners design and lay out their waterways (PA Conservation Partnership 1999).

Maintenance Recommendations

Proper maintenance will protect the investment in a grassed waterway. The following tips will help keep it functioning properly (USDA NRCS).

- Lift implements out of the ground as you cross the waterway.
- Bring crop row patterns perpendicular to the waterway where possible. If the waterway is firm, use it as a turn area. Don't plant end rows along the sides of the waterway unless using no-till planting.
- Mow and fertilize periodically to maintain proper grass height and plant density.

- Inspect the waterway frequently for areas that are eroding and need reseeding. Repair problems immediately. Small depressions and gullies can be filled with stones.
- Maintain the width of the grassed waterway when tilling and planting surrounding fields.
- Herbicide applications should NOT be applied within the waterway.
- Don't use the waterway as a road. Vehicle tire tracks can become gullies.

Cost Considerations

The estimated cost for installing grassed waterways is $2.10 per linear foot (PA Conservation Partnership 1999) or $480 per acre (USDA NRCS). Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

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2.4.3 Contour Farming

Contour farming involves conducting tillage, planting and harvesting operations as near to the natural land contour as practical to reduce soil erosion, protect soil fertility, and limit water runoff. Crop row ridges (usually 1-3 inches high) built by tilling and/or planting on the contour create hundreds of small dams parallel to the slope. These ridges or dams slow water flow and increase infiltration, which reduces erosion.

Contour farming
Source: USDA NRCS

Applicability

Contour farming is most effective on tilled fields because tilling results in larger, more numerous ridges. Contour farming can be combined with high residue tillage or no-till systems with small grains/forages. Contour farming is most effective on moderate slopes of three to eight percent. The practice works best on short slopes, or on longer slopes with cropland terraces (PA Conservation Partnership 1999).

DESIGN CONSIDERATIONS

When implementing contour farming, the following factors should be considered (PA Conservation Partnership 1999). Farmers should request assistance from NRCS or their local conservation district to establish a contour system.

- The shape and steepness of the land should determine the contour row pattern. In land with uniform, gentle slopes, contouring should start from a single contour baseline near the middle of the slope, resulting in well-rounded, gentle lines for farming operation.

- On more rolling land, several baselines and point rows will be needed to retain conformance close to the contour.

- Deviation from the contour should not exceed a four percent row grade for a minimum distance of 150 feet. This amount of variance is allowed on fields with irregular slopes or rolling topography.

- Grassed waterways should be consructed in areas where runoff concentrates, especially in deep or narrow concentrated flow areas that drain more acres.

- In some instances, row direction cannot meet the minimum guidelines for contour farming due to extremely irregular slopes. In these instances, a practice referred to as cross-slope farming may be used. Because cross-slope farming results in a greater deviation from the contour, grassed waterways are more critical in areas of concentrated water flow.

MAINTENANCE RECOMMENDATIONS

For ease of planting, farmers should keep strip widths consistent from year to year. It is helpful to establish a narrow, permanent strip of grass along each key contour line to avoid having to lay out new lines every year (USDA NRCS).

COST CONSIDERATIONS

The estimated cost for implementing contour farming is $3 per acre. This estimate includes the time, machinery, and labor to lay out or outline contour strips (USDA NRCS). The actual cost for implementing this practice will depend largely upon local site conditions, labor costs, and other factors. Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or County Conservation District office.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania' Natural Resources.

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2.4.4 Contour Stripcropping

Contour stripcropping is a system of alternating strips of close-growing crops with strips of grain crops (such as corn, soybeans or oats) in a field. By alternating crops in strips that follow the contour of the land, water runoff and soil erosion are greatly reduced, and both water and air quality are improved. Traditionally, stripcropping involved alternating strips of row crops with strips of either small grain or hay. Today, strips with high levels of residue on the surface (greater than 50 percent) may be used as substitutes for alternate hay or small grain strips.

Contour stripcropping
Source: USDA NRCS

Applicability

When land is very irregular or rolling and contour strips cannot be used, either field strips or contour farming may be more appropriate. When field strips are used on irregular land, they are less effective in controlling soil erosion and retaining surface runoff for absorption into the soil because they deviate more from the contour. The use of field strips may also require more grassed waterways because the rows will lead water toward swales or drainage ways. Contour farming would be more effective in these instances, but would result in uneven width fields with some short rows (PA Conservation Partnership 1999).

Design Considerations

Contour strips are generally even widths although uneven widths may improve "farmability" in areas with rolling or irregular topography. Uneven width correction strips may also be used. Strip widths generally range from 90 to 120 feet, based on the land slope and cropping system being used. The following should be considered when implementing this best management practice (PA Conservation Partnership 1999):

- Contour strips are generally established by running a contour baseline somewhere near the middle of the slope. After the base contour line is run, even-width strips will be measured until the field is finished or the contour line is too far from the contour.

- For contour strips to be effective, strips of hay, small grain or heavy residue must be alternated with strips of row crop or crop with low residues.

- When all strips have similar crop or residue cover, they provide no additional protection against sheet and rill erosion. They do provide the flexibility to use tillage on alternate strips.

- Stripcropping may be combined with conservation tillage and residue management as well as the use of hay and small grains in rotation.

- Stripcropping is commonly supported by grassed waterways and diversions.

- Contour stripcropping may reduce the potential for gully erosion.

Maintenance Recommendations

Sediment accumulations along the upslope edge of protected strips may need to be smoothed or redistributed to maintain uniform sheet flow along the strip boundary. When headlands/end rows are in permanent cover, renovate as needed to keep ground cover above 65 percent. No-till renovation of headlands/end rows is recommended. Maintain full headland/end row width to allow turning of farm implements at the end of a tilled strip to double back on the same strip. Keep strip widths consistent from year to year.

Cost Considerations

The estimated unit cost for implementing contour stripcropping is $6 per acre, including time, machinery, and labor to layout or outline strips (USDA NRCS). The actual cost for implementing this practice will depend largely upon local site conditions, labor costs, and other factors. Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or County Conservation District offices.

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Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania' Natural Resources.

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2.4.5 CROP ROTATIONS

Crop rotation is the practice of planned alternation of different crops on the same field. The benefits of crop rotations are (PA Conservation Partnership 1999):

- Improved soil nutrient balance
- Improved soil quality
- Reduced threat of insects or diseases
- Reduced soil erosion
- Reduced use of pesticides

APPLICABILITY

Crop rotations may be a simple 2-year rotation of corn and soybeans, or an 8-year rotation of 4 years of silage corn and 4 years of hay. It could include a mixture of crops such as corn, small grain, soybeans and forages spread over 6-8 or more years. Crop rotations are typically used on most cropland in Pennsylvania (PA Conservation Partnership 1999).

Cover Crop as part of a Rotation
Source: USDA NRCS

DESIGN CONSIDERATIONS

The following should be considered when implementing this best management practice (PA Conservation Partnership 1999):

- Consider alternating grass and legume crops since legumes add nitrogen to the soil.

- Rotations offer more alternatives for weed, insect and disease control as they reduce the risks commonly associated with a monoculture such as continuous corn.

- Alternating high and low residue-producing crops is helpful when using no-till or reduced tillage. If crops are planted into high levels of residue from the prior crop, a cover crop may not be necessary after harvesting.

- Crop rotations may need to be modified from time to time due to weather conditions, economics or needed crop management strategies. Sometimes residue is removed contrary to the plan. That removal can be offset by using a cover crop to replace the removed residue. Cover crops can also protect soil if a low level of residue was produced.

- If a low residue crop is used to replace a high residue one, a cover crop may be used or the crop should be no-tilled to retain as much residue as possible.

- The use of hay and pasture, especially when it includes a grass or grass/legume mix, can further reduce soil loss as well as improving soil health.

Maintenance Recommendations

For crop rotations which include hay (meadow) the rotation can be lengthened by maintaining the existing hay stand for additional years. Switch crops to maintain perennials in the rotation, if necessary. Be careful of herbicide carry over to avoid crop failures.

Cost Considerations

Crop rotation is a best management practice that does not require any initial capital for its implementation. Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania's Natural Resources.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). N.D. A Conservation Catalog for Pennsylvania.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Iowa. Core 4: Conservation Choices.
Website: http://www.ctic.purdue.edu/Core4/CT/Choices/Choices.html.

2.4.6 Terraces and Diversions

Terraces and diversions are earthen channels that intercept runoff on slopes (PA Conservation Partnership 1999). Terraces and diversions transform long slopes into a series of shorter slopes to reduce the rate of runoff and allow soil particles to settle out. The end result is cleaner water that is carried off the field without causing erosion.

Applicability

Terraces are cross-slope channels that control erosion on cropland and are usually constructed so crops can be grown on the terrace. They handle areas of concentrated flow where ephemeral gullies may form. There are two types of terraces. Storage terraces collect water and store it until it can be absorbed into the soil or released to stable outlet channels or through underground outlets. Gradient terraces are designed as cross-slope channels to collect runoff water and carry it to a stable outlet like a waterway.

The Use of Terraces
Source: USDA NRCS

Diversions are cross-slope channels that are permanently vegetated with grass. They are used on steeper slopes where a terrace would be too expensive or difficult to build, maintain or farm. Diversions can also be used on non-cropped land to protect a farmstead or barnyard from runoff water.

Terraces and diversions are most effective when used in combination with other practices such as crop residue management, contour farming, crop rotation, and field borders. (PA Conservation Partnership 1999).

Design Considerations

The following should be considered when implementing these best management practices (PA Conservation Partnership 1999):

- Terraces and diversions must generally fit the contour of the land. Deviations from the contour must be limited and are used only when necessary to obtain good alignment.
- If terraces or diversions are planned to outlet into a grassed waterway, the waterway should be fully vegetated before the terraces or diversions are built.

- Terraces should be cropped parallel to the terrace channel and ridge. Care must be taken to maintain the ridge height by not straddling the ridge top with planting or tillage equipment.

Maintenance Recommendations

Diversions should be mowed and fertilized to maintain a vigorous sod cover over the entire channel and ridge. Rodents, burrowing animals, weeds, brush and trees in the practices should be controlled. Tillage, planting, and herbicide applications should be conducted parallel to and outside the diversion. Vehicle traffic should not cross over a terrace or diversion unless a roadway is designed and built as part of the practice. Any sediment build-up in the channel should be removed to maintain the required water-holding capacity. Eroded or settled sections of embankment or intakes should be removed.

Cost Considerations

The estimated costs for installing gradient and storage terraces are $375 and $600 per acre protected. The estimated cost for diversions is $2.10 per linear foot (PA Conservation Partnership 1999). Cost sharing may be available for these practices. For more information, contact the local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservatin of Pennsylvania's Natural Resources.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Iowa. Core 4: Conservation Choices. Website: http://www.ctic.purdue.edu/Core4/CT/Choices/Choices.html.

2.4.7 Grazing Management

Grazing management is the designed harvesting of forages by a grazing or browsing animal. The benefits of grazing management are (PA Conservation Partnership 1999):

Source: USDA NRCS

- Increased profits from reduced feed costs
- Improved quality of life
- Improved animal health and productivity
- Improved food and cover for grazing animals
- Improved water quality and quantity
- Reduced soil erosion and improved soil condition

Applicability

The use of a managed grazing system allows grazed pastures to rest and forages to replenish their energy reserves. A well-managed and maintained grazing system allows very little, if any, soil erosion. Water quality is protected both on the farm and downstream. In addition to improving the land, many social and economic benefits are derived from a prescribed grazing system. A prescribed or planned grazing system incorporates one or more grazing options such as fenced paddocks and achieves effective forage utilization to enhance the animal's performance. Grazing options are managed to improve or maintain the health and vigor of selected plants for a stable and desired plant community and to help the producer achieve specific goals (PA Conservation Partnership 1999).

Design/Maintenance Considerations

The following should be considered when implementing this best management practice (PA Conservation Partnership 1999):

- Tailor paddock sizes so available forage is utilized in three days or less. This limits the re-grazing of new growth.
- Rest paddocks long enough for forage plants to replenish energy reserves.
- Establish and maintain the desired plant species by tailoring the grazing plan to utilize plants as well as allow for their regrowth.
- Limit forage utilization to prevent overgrazing and the depletion of forage stands, which leads to soil erosion.
- Provide an adequate supply of clean water for grazing livestock.
- Design and install proper fencing and watering systems as key components to a proper functioning grazing system.

Cost Considerations

The estimated costs for grazing management is $220 per acre. This cost includes the cost of fencing materials and a charger (PA Conservation Partnership 1999). Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania's Natural Resources.

2.4.8 Barnyard Runoff Management

Barnyard runoff management reduces the amount of runoff water from barnyards, feedlots or other animal concentration areas and keeps it from affecting nearby surface waters or underlying groundwater (PA Conservation Partnership 1999). The benefits of grazing management are (PA Conservation Partnership 1999):

- Increased profits from reduced feed costs
- Improved quality of life
- Improved animal health and productivity
- Improved food and cover for grazing animals
- Improved water quality and quantity
- Reduced soil erosion and improved soil condition

Applicability

The first step in planning barnyard runoff control is to evaluate existing practices, including livestock management and manure handling and collection. This evaluation will help identify problems that could cause pollution of surface or groundwater, contamination and/or animal health problems. The Pennsylvania Farm-A-Syst worksheet for Barnyard Conditions and Management is a good self-evaluation tool to help farmers through this process. It is available from the local cooperative extension and conservation district offices.

Source: USDA NRCS

All livestock operations are required to follow the minimum requirements in the Pennsylvania Department of Environmental Protection Manure Management Manual to keep contaminated runoff out of surface waters. Some producers are subject to additional requirements and permits may be required (PA Conservation Partnership 1999).

Design Considerations

The most cost-effective action in correcting barnyard runoff problems is to "keep clean water clean." The following practices may be appropriate depending upon the existing site conditions:

- A diversion up-slope of the barnyard to exclude the clean water.

- Roof runoff management including gutters or drip-line drains that connect to underground outlets.

- Water control structures including storm drains, surface inlets or culverts.

- Subsurface drainage to remove clean groundwater.

The first step in the design process is to evaluate the barnyard type and frequency of use. Designs should always provide adequate room for the intended uses. If cows are confined in an outside holding area prior to milking, the area should be paved and provide about 15 square feet per cow. In barnyards or exercise lots where the livestock will be held for more than a couple of hours at a time, provide about 75 square feet per cow on a paved surface or 350 square feet per cow on bare earth.

If a rotational exercise lot system is used, the sacrifice lot should be about the same size as an unpaved exercise lot and a minimum of three vegetated lots should each provide about 2,200 square feet per cow.

The barnyard shape and dimensions should be adjusted to provide a uniform surface for comfortable cow traffic and easier manure scraping. Access to manure storage, spreader loading and other traffic should also be considered. The final surface should be firm and able to withstand the intended use. If milk trucks or silage wagons will drive through the barnyard, stronger paving will be needed. The choice of surface material should be based on the expected intensity of use, the equipment that will be cleaning the barnyard, and the cost. Concrete costs are twice as much as a bare earth surface, and rolled stone is about half the cost of concrete. Durability, repair and replacement costs should also be considered.

The manure-laden runoff from the barnyard should be collected and directed to storage or treatment facilities. Curbing should be installed along the lower portion of the barnyard to direct the runoff to a collection or storage tank, or temporarily store the runoff on a portion of the barnyard where the solids can settle out before the water is released to a vegetated filter area or constructed wetland.

Maintenance Recommendations

Improved facilities can improve herd health and water quality, but management is critical to keeping the facilities working as intended. All improved barnyards require routine scraping of manure. Barnyards that drain to storage facilities do not need as much management as those that depend on treatment systems. To keep excess solids out of treatment facilities, farmers may need to operate and clean screen boxes, settling tanks, and pumps, and scrape the barnyard more frequently. Any leaks or seepage in fences or storage facilities should be repaired immediately.

Cost Considerations

The estimated costs for barnyard runoff control is $3 per square foot. This cost includes concrete curbs, roof gutters and a collection tank and is based on a 5,000 square foot barnyard (PA Conservation Partnership 1999). Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania's Natural Resources.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Iowa. Core 4: Conservation Choices.
Website: http://www.ctic.purdue.edu/Core4/CT/Choices/Choices.html.

2.4.9 Exclusionary Fencing

Exclusionary fencing is installed to prevent livestock access to environmentally sensitive areas on a permanent or limited basis. The benefits of fencing are:

- Improved water quality
- Reduced streambank destabilization and soil erosion
- Reduced overgrazing and soil erosion
- Reduced injuries of livestock by eliminating access to dangerously steep-sided streambanks
- Reduce health risks to livestock by providing alternative, clean source of water (off-stream water source)

Applicability

Fencing limits the accessibility of livestock to environmentally sensitive areas such as riparian buffers, streams and wetlands. Fencing installed along riparian areas often requires the implementation of other practices such as protected stream crossings and off-stream watering systems. Also, fencing is an integral component of grazing management practices. A wide variety of fences have been developed for

Source: USDA NRCS

livestock containment or exclusion. Fencing material and construction quality should be designed and installed to assure the fence will meet the intended purpose and longevity requirements of the project. The standard fence is constructed of either barbed or smooth wire suspended by posts with support structures (USDA NRCS Practice Code 382).

Design Considerations

The following should be considered prior to installing this best management practice (USDA NRCS Practice Code 382):

- For ease of maintenance, avoid as much irregular terrain as possible.
- Wildlife movement needs should be considered.
- State and local laws may apply to boundary fences.
- Consider livestock handling, watering and feeding requirements when locating fences.
- Install off-stream watering systems if necessary.
- Consider soil erosion potential and feasibility of fence construction when planning fences on steep or irregular terrain.

Additional information including designs and construction specifications are available at the local USDE NRCS and county conservation district offices.

Maintenance Recommendations

Fences should be repaired as necessary. Off-stream watering systems may need to be removed in the winter and reinstalled in the spring.

Cost Considerations

The estimated costs for exclusionary fencing is $1.20 per linear foot. This is the typical cost for a 4-strand barbed wire fence with wooden posts (USDA NRCS). Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). N.D. A Conservation Catalog for Pennsylvania.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). Practice Code 382. Website: www.ftw.nrcs.usda.gov.

2.4.10 Protected Stream Crossing

Protected stream crossings are installed for one or more of the following purposes (MD NRCS Practice Code 728):

- To reduce streambank and streambed erosion by providing a stable area to cross.
- To improve and/or protect water quality from sediment, nutrients and organic wastes by exclusion of animals from the stream channel and providing a controlled crossing (access).
- Protect the stream from adverse hydrologic and hydraulic impacts.

Applicability


Source: USDA NRCS

This practice may be applied to all land uses where an intermittent or perennial watercourse exists, and a permanent or temporary crossing is needed for livestock, people, and/or equipment. Stream crossings protect the soil, vegetation, water, or other natural resources from uncontrolled access to the watercourse by livestock or human activities. This practice may be applied as part of a grazing land resource management system, where access is needed from one grazing area to another grazing area, and where movement of equipment between areas is necessary for pasture maintenance (MD NRCS Practice Code 728).

Design Considerations

Stream crossings can be fords, culverts or bridges. Factors to consider when selecting the type of crossing are (MD NRCS Practice Code 728):

- Purpose and planned use of the crossing – All types of crossings can be suitable for providing a stable access across a stream channel. When crossings will be frequently used by large numbers of livestock or vehicles, or when livestock are expected to congregate in the stream, use culverts or bridges to provide a dry and stable access and protect water quality. Crossings planned for equipment only can usually be of any type. Livestock crossings require further evaluation. Consider the type and number of livestock, and the distance between pastures and water sources when locating crossings. Also consider animal health and safety issues. Livestock may avoid bridge crossings that are narrow and high above the stream bottom. Livestock may slip on snow covered or icy fords.

- Channel geometry - Deep and/or narrow channels are well suited for bridge or culvert crossings. Where a channel has a shallow depth and/or large width, a ford crossing may be more suitable.

- Size of watershed - Large watersheds with high rates of runoff are better suited for fords, bridges or large culverts where reduction in the channel size is minimized. If the crossing is to be permanent, such structures should be designed by a professional.

- Type of watershed - Watersheds prone to debris blockages require large openings to pass sediment and debris. Bridges, fords or large culverts are suitable for these conditions. Small culverts or multiple culvert crossings may block and cause damage to the crossing and surrounding areas.

Identify and evaluate other constraints such as management options, economic feasibility, access, state and federal regulations, or cost-share program requirements. If permits or approvals are required before construction of the crossing, consider the amount of time that will be needed to complete the process. Consider the need for additional conservation practices to protect the resource base in and adjacent to the stream corridor. Supporting practices may include riparian forest buffers, filter strips, fences, spring developments, watering facilities, critical area plantings, and streambank and shoreline protection measures.

Additional information including designs and construction specifications are available at the local USDE NRCS and county conservation district offices.

Maintenance Recommendations

Fallen trees, stumps, and debris above and below the stream crossing that might cause turbulence in the stream and increase chances of flooding should be removed. However, leaving such natural items in safe areas can provide excellent aquatic habitat. If the stream crossing is no longer needed, it should be removed. Structural damage to the crossing should be repaired, and any erosion of the streambanks should be stabilized with rip-rap or vegetation.

Cost Considerations

The cost for installing protected stream crossings is highly variable and largely dependent upon the type of crossing selected (ford crossing, culvert, bridge), site specific factors (e.g., dimensions and characteristics of the stream, size of watershed) and whether any other best management practices are required as noted above. Other associated costs include the preparation of design plans and permit applications plus any applicable permitting applications fees. Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Maryland Natural Resources Conservation Service (MD NRCS). Practice Code 728. Website: www.ftw.nrcs.usda.gov.

2.4.11 Spring Development

Spring development refers to improving springs and seeps by excavating, cleaning, capping, or providing collection and storage facilities (USDA NRCS Practice Code 574). The purpose of the practice is to improve distribution of water for livestock, recreation and wildlife. The practice can also apply to irrigation when the quantity and quality are suitable for irrigating crops.

Applicability

Spring development involves cleaning and/or enlarging the discharge opening of the spring. Other components that might be needed are a collection device to channel the water, a spring box to provide a small amount of storage and serve as a sediment trap, and a connection point for an outlet pipe(s). The outlet pipe(s) may then lead to a storage facility such as a trough or tank (USDA NRCS Practice Code 574).

Source: USDA NRCS

The benefits of spring development are:

- Improved stream water quality
- Reduced streambank destabilization and soil erosion
- Reduced injuries of livestock by eliminating access to dangerously steep-sided streambanks
- Reduced health risks to livestock by providing alternative, clean source of water

Design Considerations

Spring developments should be planned, designed, and constructed in compliance with Federal, State and local laws and regulations. An investigation of site conditions, including soil borings, should be made. Water quality should be determined to the extent required for the intended purpose. Water quantity should be measured from existing flows to determine if the development will meet the specified requirements. Impacts to existing wetland functions should also be assessed (USDA NRCS Practice Code 574).

The three major types of springs that can be developed for alternative water sources are fracture (tubular) springs, perched (contact) springs, and artesian springs. These three types of springs along with other components (collection system, spring box and outlet) that may be required for spring development are briefly discussed below.

Fracture (tubular) springs: This type of spring is associated with cavernous rock. If water issues from rock fractures, the individual openings can be cleaned and enlarged to improve flow. The water from these individual openings should be collected by tile or perforated pipeline or by a gravel-filled ditch. The collection works should be constructed at an adequate distance below the elevation of the openings to permit free discharge. If water issues from a single opening, the opening should be cleaned or enlarged. A collection system is usually not required. If a spring box or sump is used, it should be installed at a low enough elevation that water yield is not restricted (USDA NRCS Practice Code 574).

Perched (contact) springs: Perched or contact springs occur when an impermeable layer lies beneath a water-bearing permeable layer. Collection trenches should be used to intercept and divert flows from the water-bearing formation (USDA NRCS Practice Code 574).

Artesian springs: Artesian springs normally occur at a fissure or break in the impervious stratum. The water source is an underlying pervious water-bearing layer positioned so that the water surface elevation (water table) is always above the outlet point of the spring. Remove obstructions, clean or enlarge joints or fractures, or lower the outlet elevation as needed to improve flow. Sumps or spring boxes can be used. Free outlet discharge or minimum restriction to the spring flow is required to protect and maintain yield (USDA NRCS Practice Code 574).

Collection systems: If a collection trench is used, the trench should be excavated so that it extends into the impervious layer. The minimum length of the trench should be based on site conditions, preferably the entire length of the water-bearing outcrop. A cutoff wall should be constructed along the downstream side of the trench to ensure that the flow enters the collection system. The cutoff wall may be constructed of plastic sheeting, well-tamped clay, masonry, concrete, or other impervious materials. The collection system should consist of subsurface drainage tubing or perforated pipe not less than 4-inch diameter, wood box drain, or another suitable manufactured system. Surrounding the collector with geotextile fabric or a sand-gravel filter is recommended. Crushed rock or gravel backfill, at least one foot thick, may be used as a collection system if site conditions warrant, in lieu of other materials. Sand, gravel, and crushed rock should be composed of clean, hard, durable particles (USDA NRCS Practice Code 574).

<u>Spring boxes:</u> Spring boxes should be made of plastic, concrete, or other durable material, with a tight access cover and impervious floor. A "shoebox" type access cover or manhole attachment with gasket is recommended for tightness. The box floor can be omitted if the underlying material is stable and impervious. Spring box overflows, if needed, should meet the requirements in NRCS Conservation Practice Standard: Trough or Tank, Code 614 (USDA NRCS Practice Code 574).

<u>Outlets:</u> The outlet pipe from a spring box should be placed not less than six inches above the floor, to provide a sediment trap. The spring outlet pipe should be at the same elevation or lower than the collector pipe outlet to prevent reduced spring flow. The intake to the outlet pipe should be screened and attached to the box with a watertight connection (USDA NRCS Practice Code 574).

Additional information including designs and construction specifications are available at the local USDE NRCS and county conservation district offices.

Maintenance Recommendations

All collection systems and outlets should be cleaned out regularly. Spring boxes and collection systems should be inspected regularly and kept free of debris.

Cost Considerations

A typical cost for spring development is about $1,200 (Sheffield). This cost may vary significantly depending upon local site conditions. Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Sheffield, Ronald. Developing Off-Stream Water Sources. Biological and Agricultural Engineering, North Carolina State University.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). Practice Code 574. Website: www.ftw.nrcs.usda.gov.

2.4.12 ANIMAL WASTE STORAGE FACILITIES

A manure storage facility contains manure and/or wastewater until it can be used in a controlled manner (PA Conservation Partnership 1999). Manure storage helps farmers make optimum use of manure nutrients while protecting water quality. Proper storage allows manure to be: (1) managed as a useful resource rather than something without value and (2) applied to fields under the right conditions (PA Conservation Partnership 1999).

Manure Storage Tank
Source: USDA NRCS

APPLICABILITY

Several types of storage facilities exist, including earthen or lined ponds, above ground or in ground tanks, containment under livestock confinement facilities, and open or roofed stacking facilities. The type of storage facility should be selected based on the type of livestock operation, manure handling system, and method of field application. Other design considerations include topography, soil conditions and the depth to groundwater and bedrock (PA Conservation Partnership 1999).

The benefits of constructing and utilizing animal waste storage facilities are (PA Conservation Partnership 1999):

- Improved water quality
- Improved animal health
- Better utilization of manure for crops
- Improved aesthetics
- Improved relationships with neighbors

DESIGN CONSIDERATIONS

Manure can be pumped, flushed, scraped and hauled, or pushed directly into a storage facility or transported by gravity via a flow pipe. The means of loading depends on the type of manure, how it's handled in the barn, how far it must be moved and the elevation difference from the livestock housing to the storage facility (PA Conservation Partnership 1999).

Manure handling should follow the Nutrient Management Plan outlined for the particular farm. The following should be considered prior to installing this best management practice (PA Conservation Partnership 1999):

- Make sure the manure storage structure is sized appropriately to handle the amount of manure produced during the planned storage period.

- The structure should be constructed in order to accommodate existing farm equipment.

- Divert clean runoff from surrounding areas away from the storage facility. Include buffer zones of vegetation around the structure to filter any runoff and to improve the appearance.

- If manure is stored as a stackable solid, it should be protected from precipitation.

- Consider wind direction and odors when selecting a storage location.

- Storage facilities should be fenced for livestock and human safety. Signs should warn about drowning and hazardous gases.

All manure storage facilities should be designed by engineers. Manure storage facilities must meet State requirements as stated in the Pennsylvania Manure Management Manual. In some cases, additional permits may be required. Designers should be familiar with these requirements (PA Conservation Partnership 1999). Additional information including designs and construction specifications are available in the local USDE NRCS and county conservation district offices.

Maintenance Recommendations

Storage periods should be determined from the Nutrient Management Plan. The manure storage facility should be emptied at least twice a year and applied whenever possible to growing crops according to the plan. Any leaks or seepage from the facility should be repaired immediately, as should damage to fences or other containment structures.

Cost Considerations

The estimated cost for manure storage is $0.20 per cubic foot (PA Conservation Partnership 1999). This cost includes an earthen pond with fence. Conversely, on a per head basis, the cost for manure storage ranges from $100 per cow for earthen ponds to $1,000 per cow for above ground tanks (USDA NRCS). Cost sharing may be available for this practice. For more information, contact the local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania's Natural Resources.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). A Guide to Environmentally Sound Practices for Wisconsin Farmers.

2.4.13 Nutrient Management Plans

Nutrient management is the planned use of organic and inorganic materials to provide adequate nutrients for crop production while protecting water quality (PA Conservation Partnership 1999). Nutrient management plans are developed to help producers apply the proper rate and type of inorganic and organic sources of nutrients at the proper time. These plans are prepared by properly trained individuals involved in agribusiness or private consulting and, in some instances, conservation district staff or representatives from other agencies.

Applicability

A nutrient management plan will help a producer maximize the use of nutrients available on the farm and can reduce the need for purchased nutrients. Nutrient management plans need to be written according to the Pennsylvania Department of Environmental Protection Manure Management Manual. In some cases, plans must be written by a certified Nutrient Management Specialist and may fall under Pennsylvania's Nutrient Management Act, referred to as Act 6 (PA Conservation Partnership 1999).

Spreading liquid hog waste
Source: USDA NRCS

The benefits of developing and implementing nutrient management plans are (PA Conservation Partnership 1999):

- Improved water quality
- Maximized use of existing organic and inorganic nutrients for plant growth
- Reduced need and cost for some purchased nutrients
- Improved water quality
- Improved balance of soil nutrients

Design Considerations

The following should be considered to improve the efficiency of manure applications according to prepared nutrient management plans (PA Conservation Partnership 1999):

- Use soil nitrate testing, plant tissue tests, credits for past manure applications and nitrogen credits from legumes to estimate nitrogen application rates.

- Set realistic crop yield goals for the farm. Consider soil type and other conditions, which impact yields.

- Obtain soil tests every three years to determine recommendations for Nitrogen (N), Potassium (K) and Phosphorus (P).

- Do not use application rates, which continuously build up P and K.

- Calibrate manure and fertilizer spreaders so materials can be accurately applied.

- Nutrient management may be successfully implemented in no-till systems.

- Apply manure as close as possible to the time it is needed by plants.

- Apply manure uniformly just as fertilizers are applied.

- Apply manure on fields of low fertility first.

- For fall or winter applications, spread manure according to the following priorities: (1) Live perennial and annual crops, (2) Heavy surface residue such as corn stalks or small grain, (3) Low residue crop with cover crop established, (4) Low residue crop without cover crop and (5) Bare soil (application of manure or other source of nutrients is not recommended).

- Avoid spreading manure on steep slopes until just prior to tillage or planting. Avoid spreading manure immediately adjacent to streams or open water, immediately up-slope from sinkholes, and when rutting or soil compaction may occur.

- Nutrient management should be used in conjunction with other practices to adequately address soil erosion and water quality concerns.

Additional information about this best management practice is available at the local USDA NRCS and county conservation district offices.

Maintenance Recommendations

Field soils should be tested once every two to four years according to State recommendations. Manure and other organic waste should be analyzed for nutrient content before field applications. It is important to e stablish a winter cover crop if there is a possibility of excess nitrogen leaching.

Cost Considerations

The estimated initial cost for preparing a nutrient management plan is $7.50 per acre (PA Conservation Partnership 1999). Cost sharing may be available for this practice. For more information, contact your local USDA NRCS or county conservation district offices.

References

Pennsylvania Conservation Partnership. 1999. A Conservation Catalog – Practices for the Conservation of Pennsylvania's Natural Resources.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Iowa. Core 4: Conservation Choices. Website: http://www.ctic.purdue.edu/Core4/CT/Choices/Choices.html.

2.5 Forest Management

Forest management can significantly benefit the quality of lakes and ponds. Forest management plans provide guidelines for projects aimed at improving water quality throughout the watershed. These plans can be as simple as establishing management practices to preserve existing forests, or can involve more complex practices such as planned timber harvests, establishing conservation easements to protect vital resources, or developing complete reforestation plans. Since all of these practices will affect downstream water quality, a forest management plan should be included in a lake management plan.

Applicability

In lake management, the focus is typically placed on forests immediately surrounding a lake. However, it is important to consider forest resources within the entire watershed. Any activity within the watershed can directly affect the quality of a lake. This is especially true in lakes and ponds that are fed by streams and other sources of direct runoff. Good forest management plans identify significant resources and potential management problems within the watershed. The plan then provides suggestions for best management practices (BMPs) that will protect or improve the resource, while providing solutions for problem areas. Protecting sensitive areas, improving existing resources, and finding solutions for problem areas will result in better downstream water quality and fewer concerns for the lake manager.

Design Considerations

The first step in developing a forest management plan is to establish the watershed boundary for the lake. This requires a U.S.G.S. 7.5 minute topographical quadrangle of the area. The topographic quadrangle map must show all of the streams that flow into the lake. Sometimes this may require purchasing several adjoining quadrangles until the entire drainage area is shown on the maps. Topographic quadrangles are available from the United States Geological Survey, from local sporting good stores, or as a free download off the internet at http://library.usgs.gov/maplinks.html.

Watershed boundaries are delineated or outlined by drawing a line along the ridges and saddles connecting the topographically highest points around the lake. The watershed boundary begins and ends at the outlet of the lake, and includes all of the streams that flow into the lake. The shape encircling the lake in Figure 2.5-1 represents the lake watershed boundary.

On the watershed boundary map, all forested areas are shown in green. Typically, these areas extend beyond the lake property boundaries to include the entire watershed. Involving all of the residents in the watershed with the development of a forest management plan can be challenging. However, all the residents and stakeholders should be given the opportunity to become involved early in the planning process. This will ensure that everyone has the opportunity to express their concerns and will make developing and implementing a final plan much easier.

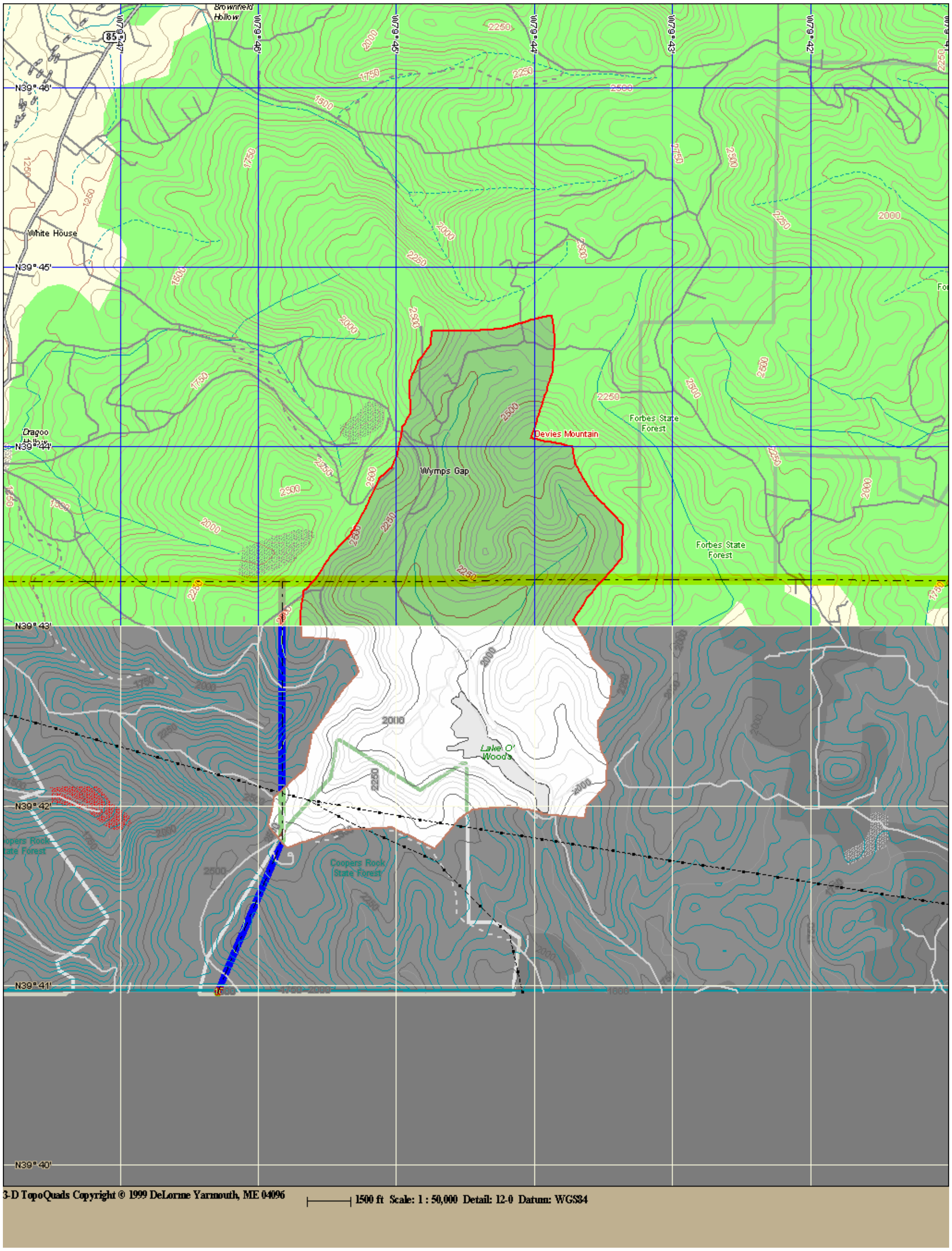

Figure 2.5-1: Watershed Boundary drawn on 7.5 minute USGS topographical map. Source: EcoSolutions

Important characteristics to include in forest management plans are major forest associations, canopy and understory species components, dominant and co-dominant species, age classes, and a general assessment of the forest's health. Forest stand delineations are field surveys that should be performed by forestry professionals or other qualified natural resource specialists.

Historical aerial photographs should be used to gain background information on stand locations prior to conducting fieldwork. Aerial photos also provide indisputable information on land-use changes that have occurred over time (i.e. past timbering, mining, and development). Poor access and uncooperative landowners can sometimes make aerial photos the only way to assess specific properties in a watershed.

Information that can be gained in an aerial photograph review includes:

- Proximity of forest areas to streams, wetlands, and other waterbodies.
- Current timber harvesting practices.
- Identification of current land-use practices having either detrimental or positive effects on existing forests.
- The age of individual forest stands (i.e. early successional, mature)
- The economic and resource potential of specific forest stands within the watershed (this may require an evaluation by a forestry professional).

Once it has been determined what forest resources are present, specific goals and objectives for the forest management plan need to be developed. Items to consider when formulating the goals and objectives for the plan include:

- What is the intended use of the forest?
- Is the forest size adequate?
- Do the existing forests benefit the lake or pond?
- Is wildlife habitat preservation a concern?
- Is the forest a source of income?
- Are aesthetics and/or recreational uses of the forest planned?

Answers to these types of questions will help establish goals for the management plan. Forest management goals can include items such as increasing water quality and quantity to the lake, creating buffers to provide or improve wildlife habitat, or gaining revenues from timber harvesting for other lake improvement projects.

The objectives of the forest management plan should clearly outline the steps to achieve the specific goals. This should include who will conduct certain portions of the project, a list of what types of permits will be required, a description of anticipated results, and a specific time frame for completing the project. A clear understanding of how a specific goal will be achieved can help minimize the cost of the project, ensure that the end result will be achieved, and minimize frustration while completing the project.

The following forest management practices may be included in the forest management plan to protect or enhance the water quality of the lake or pond.

<u>Forest Buffers:</u> Forest buffers are used to provide screening or protection between different land-use activities. Buffers along streams and shorelines provide benefits such as filtering sediments and pollutants, providing wildlife corridors, providing erosion control, and reducing water temperature. A minimum 30-ft. forest buffer along a stream or lake shoreline is sufficient, but a 100-foot buffer is ideal on gently sloping areas with slope grades of 0-19%. The buffer width should be increased on slopes exceeding a 20% grade and on highly erodible soils.

Buffers protect streams
Source: USDA Forest Service

<u>Streambank Fencing:</u> Streambank fencing can reduce streambank erosion in pastures. Fencing is placed approximately 20 feet from the streambank to keep livestock from entering the stream and trampling the streambanks. Stabilized stream crossings through fenced areas provide access to adjacent fields and protection for the stream banks in the unfenced areas. Unforested land between the fence and stream channel can be planted with native trees and shrubs to further stabilize the banks and provide wildlife habitat. Financial and technical assistance for this type of project is available through the U.S. Fish and Wildlife Service, and other state and federal agencies. More information on stream fencing and crossings is provided in Section 2.4 of this Handbook.

<u>Timber Harvesting:</u> Timber harvesting can improve or reduce the forest quality depending on the methods used, and the care taken during timbering operations. The occasional cutting of trees for firewood does not have a drastic effect on forest ecosystems or forest health. However, large scale timber operations, when performed irresponsibly, can have a drastic negative effect on forest ecosystems and forest health. Large scale timber harvests should be carefully planned by an accredited forestry professional.

Three common timber harvesting practices include clearcutting, selective harvest, and non-selective harvest. Clearcutting involves the removal of all trees within an area, regardless of tree size, resulting in an open area. The disadvantage of clearcutting is accelerated erosion and increased runoff, and a decrease in wildlife habitat for interior forest species such as bear, turkey, and bobcat. However, as long as a sufficient seed bank is present or stump sprout growth potential exists, clearcutting can be beneficial to species adapted to thick early successional growth such as ruffed grouse, deer, and many song birds. Clearcutting should only be done on relatively level topography, well away from streams and wetlands, and on low erodible soils.

Selective harvest involves cutting specific sizes and types of trees from the forest stand. This timber harvesting technique is good if the goal of the management plan is maximum financial gain. Tree species and age class diversity can be preserved through non-selective harvest since non-selective timber harvesting methods do not target particular species and/or age classes. However, selective harvesting enhances shrub and other low-quality tree growth that will have little wildlife value and will cause a non-uniform appearance in the stand.

If timber harvesting is part of the forest management plan, careful planning is necessary to protect adjacent streams, wetlands, and other bodies of water from erosion and sedimentation. Timber harvesting can increase water runoff and soil erosion, and is classified as an "earth disturbance" practice because of disruption of the forest floor and soil. While timber operations are exempt from federal NPDES Stormwater regulations, an Erosion and Sediment Control Permit is required for earth disturbances of 25 acres or more. In addition, every logging operation, regardless of amount of earth disturbance, requires an Erosion and Sediment Control Plan (E&S plan). This E&S Plan does not need regulatory approval, but must be onsite at all times so that the County Conservation District or Pennsylvania Department of Environmental Protection can review it if necessary. Some municipalities have ordinances that require the E&S Plan to be approved by the County Conservation District for logging or any other earth disturbance project. Landowners should contact the County Conservation District or the Pennsylvania Department of Environmental Protection to obtain information on laws and regulations governing timber harvest operations.

Logging Road Maintenance: Logging roads through forested areas should be permanently stabilized once the timber has been removed. Although these roads are intended for use only during the logging operation, they are often used long afterwards by ATV's and other off-road vehicles. Roads should be built with a maximum slope of 10 percent parallel to the existing contour to avoid creating steep inclines. Avoid building roads on poorly drained and highly erodible soils (consult the county soil survey). Natural obstacles such as springs, wetlands, and streams should be avoided, and a vegetated buffer should be maintained between the road and any water resources. Where stream crossings are necessary, the roadway should be positioned in a gently sloping area perpendicular to the channel.

Bridge on a logging road
Source: USDA Forest Service

The disturbed soil on newly graded logging roads is easily dislodged and highly erodible, and proper road drainage minimizes erosion. Water control structures used to convey surface water away from logging roads include culverts, broad-based dips, and waterbars (often referred to as "thank-you-ma'ams"). Pipe culverts are expensive but are preferred for roads with heavy traffic. Open-top box culverts are used in place of pipe culverts on roads with relatively light traffic. Broad-based dips are used to convey broad areas of sheet flow across a road, while waterbars are an inexpensive means of conveying water off a descending logging road or skid trail. Regardless of the methods used, an area of undisturbed forest should be maintained between the outfalls or discharge points of these structures and adjacent streams or other bodies of water to allow sufficient filtering of sediments.

Log Landing Maintenance: Log landings are open staging areas where logs are temporarily stockpiled until they are removed from the site. Heavy equipment used to load the logs compacts soil, limiting water absorption, and increasing runoff. To prevent sediment from reaching streams, wetlands, and other bodies of water, the landings should be located on relatively flat terrain and well away from these resources. Where runoff from adjacent slopes flows toward the landing, diversion ditches can be placed around the uphill perimeter to divert flow around the area. Once stabilized, abandoned log landings make good food plots for wildlife when planted with forage grasses and berry producing shrubs.

Reclaimed log landing, Klamath River Basin
Source: Pat Higgins, Kier Assoc. 1999

Wildlife Habitat: Food plots can be designed and maintained within existing fields or created within the interior of a forest. Plot size can vary, but ½ to 1 acre areas are the most successful. Once timbering has been completed, the soil within the food plot is tilled, seeded, and stabilized with straw mulch. The type of seed used in the plot will vary, but many commercially prepared mixtures are available at farm supply stores and mail order catalogues.

Tree tops left after timbering provide excellent shelter for a variety of wildlife species including small mammals, birds, amphibians, and reptiles. Consider leaving dead trees standing, as long as they don't pose any threats to people or property. The dead trees provide shelter and a food source for insects, mushrooms, and other types of fungi. Hollow trees also provide dens for raccoons, fox, bear, and squirrels in upland areas, and for wood ducks along water bodies. Dead trees with large limbs and open canopies along shorelines provide observation and nesting areas for great blue herons and raptors such as bald eagles and osprey. Small mammals use logs as raceways across the forest floor and ruffed grouse use logs as drumming platforms during the spring to attract mates. Partially exposed logs lying within lake or pond provide loafing areas for turtles and ducks. Brush piles provide habitat for birds and small mammals such as rabbits. The small mammals in turn are food for predators such as fox and coyote.

Cost Considerations

The cost of developing a forest management plan can be reduced through volunteer support. A professional forester does not need to be involved in every step of the process, but should be contracted to do the forest stand delineation. State foresters can help with this process for little or no cost through the PA Forest Stewardship Program or CIP (Conservation Incentives Program). A typical forest management plan can cost $10,000 to $20,000 when professional foresters complete most of the work.

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http://forestry.about.com/gi/dynamic/offsite.htm?zi=1/XJ&sdn=forestry&zu=http%3A%2F%2Fwww.usabmp.net%2F

2.6 Stream Restoration

Introduction

The term stream restoration encompasses a wide range of BMPs that enhance the physical state of a stream channel. Stream restoration can be used to achieve a variety of specific management objectives including reducing nutrient and sediment loading, improving fish habitat, enhancing recreational and aesthetic values, improving flood control, and restoring ecological function. Stream restoration projects range in complexity from simple planting projects that require limited design and permitting and can be implemented by volunteers to large-scale stream realignment projects that involve extensive engineering and must be implemented by professional contractors.

Denuded riparian buffer and cattle grazing have caused severe channel erosion along this section of the South Branch Tunkhannock Creek, Lackawanna County, PA. Source: F. X. Browne, Inc.

Stream restoration BMPs generally fall into one of three categories, which are addressed in more detail later in the chapter:

Streambank stabilization refers to structural measures such as boulders and concrete, and nonstructural measures such as plantings designed to stabilize eroding streambanks.

In-stream habitat enhancement involves the placement of various structures in the stream channel that are designed to deflect or alter streamflow to enhance in-stream habitats.

Natural channel design is used to restore the natural form and pattern of channels that have been severely destabilized by land use changes, channelization, piping or dredging.

Stream restoration projects often use native wildflowers which provide excellent erosion control, habitat, and aesthetic value.

Designing a stream restoration project involves assessing the nature and extent of the problem, establishing specific project objectives, and evaluating design constraints (e.g., construction access, funding availability, environmental regulations, landowner cooperation). In the early stages, the project designer defines the general approach and type of restoration that will be used (e.g., streambank stabilization, in-stream habitat enhancement, natural channel design, or some combination of the three). Detailed design procedures typically include collecting, processing, and synthesizing environmental data, comparing site data with design criteria for various BMP options, and determining specific design specifications for selected BMPs.

Site assessment is a critical first step in a successful stream restoration design. A thorough site assessment involves collecting a range of information concerning the project site. The site assessment is used to diagnose and characterize the impacts to the stream channel and banks. The site assessment also allows the project designer to evaluate construction logistics, potential regulatory issues, aesthetic and structural concerns, and environmental characteristics and constraints such as soil type, soil moisture, and shading. A variety of established procedures exist for conducting qualitative and quantitative site assessments including:

- Natural Resources Conservation Service - Stream Visual Assessment Protocol
- Environmental Protection Agency – Rapid Bioassessment Protocol Habitat Inventory.
- Dave Rosgen’s Level I-IV Geomorphic Classification and Assessment
- Vermont Stream Geomorphic Assessment Protocols

Depending on the complexity of the stream restoration project, a more detailed site survey may be needed. Detailed data and mapping of channel bed, bank, and floodplain topography and geomorphology, channel material size, soil type, and existing landscape features such as trees, wetlands, structures, utilities, bridge, and roadways are often obtained during a detailed site survey. This information is used to guide the design process, to develop hydraulic and geomorphic computer models of the stream, and to prepare engineering plans for the project.

Permitting for stream restoration projects varies widely depending on the scope, objective, and extent of the project. Most projects involve the approval of an Erosion and Sediment Control

Plan with the appropriate County Conservation District. Some type of permit from the Pennsylvania Department of Environmental Protection is also required. For larger projects, NPDES (National Pollution Discharge Elimination System) and U.S. Army Corps of Engineers permits may be needed. Because projects vary in complexity, the Pennsylvania Department of Environmental Protection should be contacted during the initial planning stages of any stream restoration project in order to determine what permits will be required for the specific project.

Construction of simple stream restoration projects can often be accomplished using donated materials and volunteer labor. More complex projects that involve the use of heavy equipment usually require a professional contractor and/or construction manager. An environmental consultant or engineer can be very useful for many types of stream restoration projects to assist with project design and permitting. Construction of stream restoration projects is usually most effective in the fall, when low flow conditions and cool weather are conducive to in-stream work and installation of planting and seeding projects, and animal breeding seasons are less likely to be disrupted.

2.6.1 Streambank Stabilization and Soil Bioengineering

The term "streambank stabilization" encompasses a diverse set of techniques used to remediate streambank erosion problems. In general, streambank stabilization projects are implemented to meet one or more of the following objectives:

- Reduce sediment and nutrient loading due to bank erosion
- Protect land or structural resources from bank erosion
- Enhance streamside recreational and aesthetic values

Increasing interest in streambank stabilization over the last 10-15 years has led to a rapid proliferation of design approaches and techniques. In general, these techniques are classified as either structural or soil bioengineering techniques.

Structural techniques consist of highly rigid methods that utilize concrete, stone, or other man-made material to armor the streambank. Examples of structural streambank stabilization techniques include rip-rap, stone walls, and gabion baskets.

An integrated biostructural streambank stabilization project along the East Branch Wallenpaupack Creek, Pike County, PA
Source: F. X. Browne. Inc.

Soil bioengineering methods, by contrast, use various combinations of living and non-living natural materials to restore eroding streambanks. Soil bioengineering efforts strive to restore naturalized bank conditions and habitats while providing erosion and sediment control. There are also hybrid techniques that combine soil bioengineering and structural elements. These techniques are often referred to as ***biostructural stabilization*** methods.

Soil bioengineering and biostructural methods often involve the use of dormant live material. Dormant live material consists of cuttings of native shrubs and plants that are harvested after the onset of dormancy (i.e., after the leaves have fallen off). This material is used in a variety of forms including cuttings or whips, stakes, twigs, and posts.

Where applicable, soil bioengineering is favored over structural methods for most applications. The primary reason for this preference is that soil bioengineering techniques provide multiple ecological benefits including riparian habitat creation, pollutant filtering, natural aesthetics, and erosion control. Most structural methods, by contrast, provide limited benefits beyond erosion control. Furthermore, because structural methods often essentially lock the streambank in place, some practitioners argue that these methods tend to shift erosion problems to unprotected downstream areas. Soil bioengineering tends to be significantly less expensive than structural methods, making it the only feasible stabilization option for many watershed groups. Often, trained volunteers can effectively install all or part of a soil bioengineering project.

Although soil bioengineering has become increasingly popular, it does have significant limitations. First, soil bioengineering is not effective in high velocity and shear stress situations. Second, because soil bioengineering techniques involve living plants, they are subject to less than optimal performance depending on environmental conditions (e.g., drought, soil contamination), plant stock quality, and disease. Soil bioengineering is often ineffective when the bank cannot be graded to provide a suitable planting slope and where heavy shade, dry conditions, or poor soil quality prevent the rapid establishment of vegetation. Finally, soil bioengineering often requires on-going maintenance and occasional repair. A good designer must take a careful inventory of site conditions, project objectives, and logistical constraints to select the appropriate combination of stabilization methods for any given site.

In the next sections, detailed design guidelines are presented for several common bioengineering and biostructural stabilization methods, as outlined in Table 2.6-1. These guidelines should be used in conjunction with detailed site data to select appropriate treatments.

Table 2.6-1
Summary of Streambank Stabilization Practices

Treatment Type	Velocity/ shear stress tolerance (1=low)	Requires grading	Light limitation	Bank region	Cost (1 = low)	Volunteer installation potential	Heavy equipment required
Live stakes	2	Yes	High	Middle, upper	1	Full	No
Live fascines	2	Yes	High	Middle, upper	2	Full	Mechanical trencher
Dormant posts	3	Yes	High	Toe	3	Partial	Hydraulic auger
Vegetated geogrids	4	No	Medium	Toe, middle, upper	5	Partial	Excavator
Branch packing	2	No	Medium	Middle, upper	1	Full	No
Live cribwalls	4	No	Medium	Toe, middle, upper	5	Partial	Excavator
Rootwads	4	No	Low	Toe	3	No	Excavator
Native seeding and planting	2	Yes	Medium	Middle, upper	1	Full	No
Boulder toe	5	No	Low	Toe	5	No	Excavator
Tree revetments	3	No	Low	Toe. Middle	3	Partial	No
Fiber roll revetments	1	No	High	Toe	3	Full	Mechanical trencher

Many bioengineering and biostructural stabilization methods lack quantitative design criteria that allow the sizing and specification of various design elements to match hydraulic variables such as shear stress and velocity. Instead, most design guidance is qualitative in nature and is based on “lessons learned” from various successful and failed installations of a particular stabilization practice. The lack of well-defined design criteria places great value on the personal experience and judgment of the designer. It also highlights the importance of active monitoring and maintenance of the site after installation.

Although specific quantitative design criteria for bioengineering or biostructural projects may be difficult to determine, several general design criteria should be considered, including:

- The bank toe (where the bank meets the channel) is often the most critical stabilization location because it is subject to the most stress during flood events.

- Game deterrent measures are critical whenever native planting or seeding is used. Whenever possible and practical, game-resistant varieties should be chosen.

- Monitoring and maintenance of newly installed sites increases project success. At a minimum, visual inspection of installation areas should be performed following major storm events.

- Because bioengineering treatments often depend on vegetation to provide stability, they are most susceptible to failure immediately following installation.

- Bioengineering and biostructural stabilization methods are usually ineffective in actively downcutting channels (straighter stream channels with fast-moving water, where most of the erosive action takes place along the river bottom rather than along the sides of the channel). This is a common feature of streams in rapidly urbanizing areas.

- Flanking, which occurs when erosion continues around and behind a stabilization practice, is a common cause of failure of streambank stabilization practice. To prevent flanking, stabilization treatments should always begin and end at stable bank locations.

- Undermining, or erosion below a streambank stabilization practice, is another common mode of failure, particularly in fine-grained channels that have deep scouring depths. Toe stabilization practices must be sufficiently entrenched into the streambed to resist undermining.

Live Stakes

Description

Live staking consists of inserting dormant shrub and tree cuttings into a streambank, as shown in Figure 2.6-1. Stabilization is achieved through the development of root structures over time.

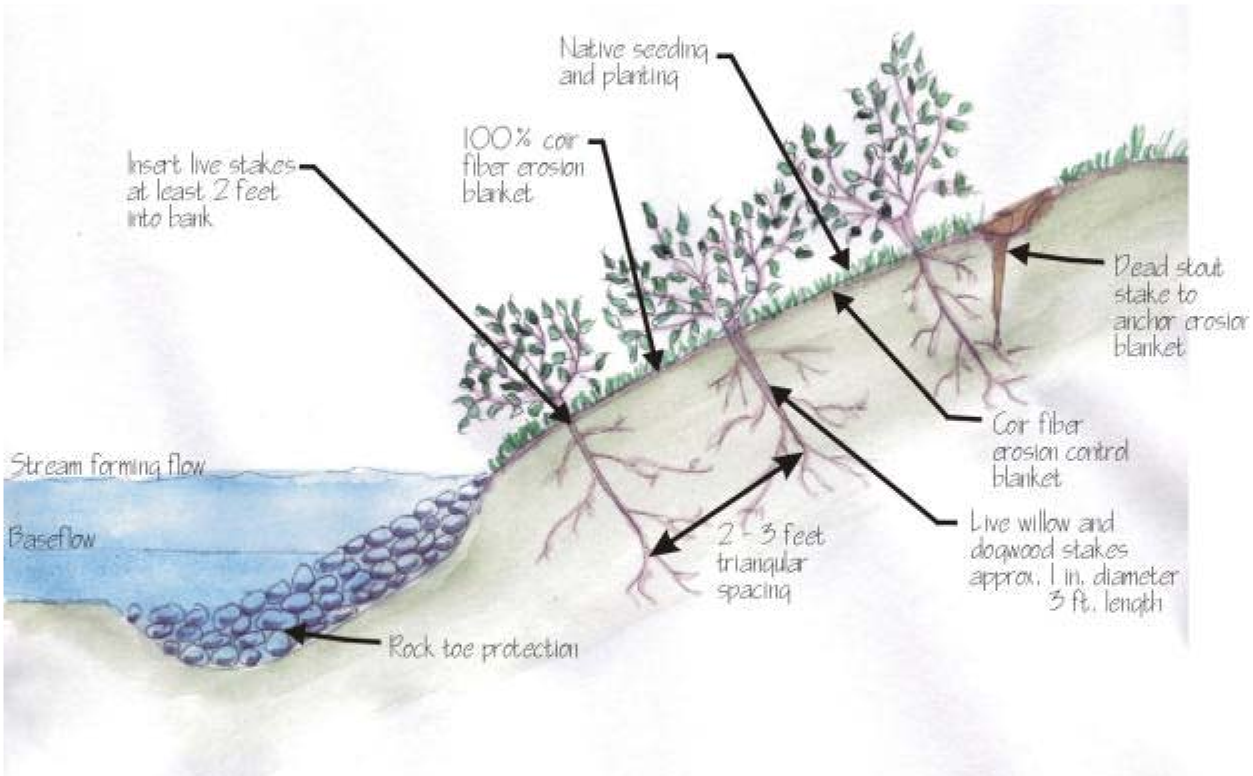

Figure 2.6-1 Live stake installation
Source: F. X. Browne, Inc.

Applicability

Live staking is often used in conjunction with other soil bioengineering techniques (e.g. branch packing, live fascines) as part of an integrated treatment system. Live stakes provide modest erosion control in the middle portions of a streambank. Live staking cannot provide the structure needed for stabilizing banks that are exhibiting mass wasting or rotational failure. Live staking is ineffective for toe stabilization because of the high shear stresses in this region. It is also ineffective near the top of the bank because of lack of moisture availability. Live staking is less effective in shady areas, although some shade-tolerant species such as common elderberry can be used for high-shade applications.

A shipment of live stakes for a streambank restoration project
Source: F. X. Browne, Inc.

Close-up of first year growth on a native willow live stake
Source: F. X. Browne, Inc.

Live staking should not be used if the stream velocity exceeds 4 feet per second or if shear stress exceeds 1 lb./ft. Deer browse, lack of moisture, lack of sunlight, and continued bank erosion are the most common cause of failure. Live stake survival is generally poor in gravel and cobble-dominated bank material. Soils should have a significant loam composition for optimum results. Results can be enhanced by installing native seeding mix between the live stakes.

Design Considerations

Live stakes are usually native shrub willows and dogwoods that grow rapidly in near-saturated conditions. The stakes are approximately 0.5 to 1 inch in diameter and 2-3 feet in length. Stakes are inserted to a depth of 2/3 their length. Staking most often occurs in parallel rows spaced 3-4 feet apart. Spacing in adjacent rows is offset and spacing of individual stakes within a given row is approximately 3-4 feet.

A two-man crew installs live stakes along the Vermillion River, Dakota County, Minnesota
Source: Dakota County Soil and Water Conservation District

Maintenance Recommendations

Live stake installations should be inspected annually for poor growth and/or stake mortality. Widespread mortality may indicate that all or part of the site is not appropriate for live stake installation. Occasional, random incidences of mortality within an otherwise successful application may occur as a result of improper installation, diseased or damaged stock, or local anomalies in environmental conditions and should be replaced with fresh stakes. Achieving 75% survivorship after three years is a good indication of a successful live staking. Game deterrent fencing must be maintained if nuisance wildlife is a known threat.

Cost Considerations

Live staking can be installed by well-trained volunteers and inexpensive equipment (e.g. planting bar, sledge hammer). Approximately 8.5-14.5 stakes can be installed per labor hour (Sortir, 1997). In many instances, stakes can be obtained free of charge from existing plants near the project site (this often requires talking to local landowners to identify a good source). Live stakes may be purchased from various local nurseries for approximately $1 per stake for a 3-foot stake. Coir fiber erosion blanket costs average $1.50 to $2.00 per square yard.

Live Fascines

Description

Live fascines, also called wattles, are bundles of live material that are placed in a series of shallow trenches parallel to the streambank, as shown in Figure 2.6-2. Live fascines usually consist of native shrub willow and dogwood bundles. Stabilization is achieved through the development of root structure over time.

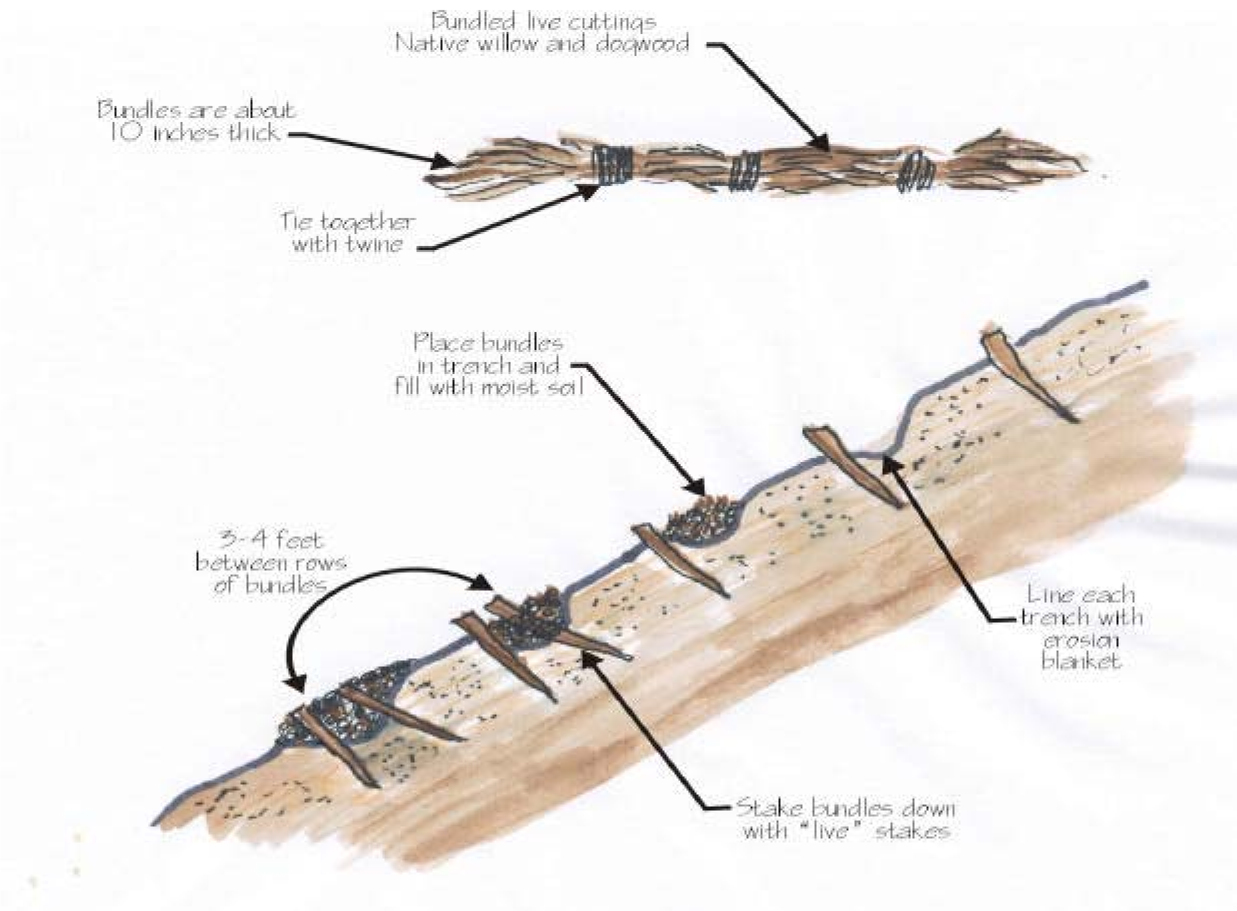

Figure 2.6-2 Live fascine installation
Source: F. X. Browne, Inc.

Applicability

Live fascine bundles awaiting installation
Source: F. X. Browne, Inc.

Live fascines are primarily used to prevent the development of rills and gullies on the surface of streambanks, particularly in situations where the length of the bank slope is long and/or significant sources of surface runoff flow over the bank. Fascine rows break up the slope into smaller segments, eliminating the potential for the migration of gullies and rills. The fascines also help to trap sediment that is carried in overland runoff before it reaches the stream.

Live fascines generally do not provide deep stabilization of an eroding soil profile and are often best used in conjunction with other stabilization methods such as live staking or native seeding and planting. Live fascines, like other live material-based stabilization methods, are most effective in sunny areas. Because they are installed in shallow trenches, live fascines tend to be more susceptible to drought and should not be located in upper bank areas that don't maintain moisture throughout the growing season. Live fascines are not effective toe stabilization techniques and should be used primarily in the middle portions of streambanks.

Design Considerations

Preparing live material bundles for a live fascine installation. Note the erosion blanket-lined trench awaiting bundle placement.
Source: Dakota County Soil and Water Conservation District

Most designers use 8 to 10 inch diameter bundles. Individual cuttings in the bundles are typically 6-8 feet long and 0.25-0.5 inches thick. Bundles are tied together with twine or wire, with the cuttings randomly oriented. The trench into which the bundles are placed should be made large enough for packing loose soil upslope and downslope of the bundle. The trench is typically lined with coir fiber erosion blanket. Bundles are partially covered with loose soil and staked down with hardwood stakes (3 foot length). These specifications are standard for most designs. The NRCS Engineering Field Handbook (1996) recommends certain guidelines for determining the spacing of live fascine rows based on soil type and bank slope; as shown in Table 2.6-2.

Table 2.6-2 Live Fascine Spacing			
Slope steepness	Soils		
	Erosive (feet)	Non-erosive (feet)	Fill (feet)
3:1 or flatter	3 - 5	5 - 7	3 – 5 *
Steeper than 3:1 (up to 1:1)	3 *	3 - 5	**

* Not recommended alone.

** Not a recommended system.

Source: Engineering Field Handbook, Part 650, Chapter 16, Streambank and Shoreline Protection, December 1996

Maintenance Recommendations

Live fascine growth should be carefully monitored, especially during the first growing season. Areas of poor growth should be identified and analyzed for possible causes such as poor soil or improper installation. Failure of an entire row or series of rows may indicate that live fascines are not an appropriate stabilization technique for the site.

Cost Considerations

Live fascine installation can be accomplished with trained volunteer labor. Approximately 3.5-8 linear feet can be installed per labor hour (Sortir, 1997). A Ditch Witch® or similar mechanical trenching device is recommended for the preparation of the trenches. Rental rates for mechanical trenchers range from $90-150 per day. Manual preparation of the trenches is possible but very labor intensive. Preparation of bundles from loose live cuttings is also quite labor intensive. Finding a local source of free live material can dramatically cut costs. Ready-to-install live fascine bundles are commercially available. Costs (in 2003 dollars) range from $5-9 per linear foot of bundle for a 6-12 inch bundle. Coir fiber erosion control blanket costs average $1.50 to $2.00 per square yard.

Dormant Posts

Description

A completed dormant post planting along the South Branch Tunkhannock Creek five months after installation
Source: F. X. Browne, Inc.

Dormant posts are large live stakes installed at the base of an eroding streambank to prevent toe erosion. Dormant posts are usually shrub willow and dogwood species. Posts are large, and usually installed using a hydraulic auger attachment on a small excavator.

Applicability

Dormant posts are typically used as a method of stabilizing the toe area of a streambank. Posts are typically installed in rows below the bankfull elevation. The lower row of posts often extends into the baseflow of the stream. Like most live material-based methods, dormant posts perform best in sunny areas. Because of the large size of dormant posts, deer browse is usually not a problem. Since the posts are installed at the base of the bank, moisture is rarely a limiting factor. Installation can be difficult and high mortality can be a problem in stony or rocky soils. Since posts often extend five or more feet into the soil, depth to bedrock is an important site consideration. Dormant posts should not be installed where active channel incision (downcutting) is occurring.

Design Considerations

A completed dormant post stabilization system along Teedyuskung Creek, PA
Source: Pike County Conservation District

Dormant posts are usually a variety of shrub dogwood or willow species. Posts range from 6 to 10 feet in length, and from 4 to 6 inches in diameter. Larger posts are typically used in more severe situations and on larger streams, although no specific design criteria exist. Posts are typically inserted up to 2/3 of their length into the existing streambank. Posts are most commonly installed in rows spaced 3 to 4 feet apart. Individual spacing of posts within rows ranges from 3 to 4 feet. The first row of posts is usually placed about one foot into the low flow channel beyond the bank toe; subsequent rows are added until the bankfull elevation is reached.

Protection of the bank between posts is critical and is best achieved using durable long-term coir fiber erosion blanket installed prior to installation of the posts. Randomly-placed boulders may also be used.

Because dormant posts are installed deeply into the soil, they can inflict great damage to the bank and channel if they are pulled from their holes during flooding events. Therefore, dormant posts should not be used unless detailed hydraulic modeling of expected shear stress is first performed. If expected near bank shear stress exceeds 1 lb. / sq ft., dormant posts should not be used.

Maintenance Recommendations

Frequent monitoring should be conducted of dormant post installation to evaluate plant survivorship and vigor. It is not uncommon for the lowest row of posts to experience significant mortality. Significant mortality in other rows may indicate poor installation, poor soil conditions, excessive shading, or poor stock. The cause of the mortality should be assessed before replacing posts. The toe section of the slope should be closely monitored for on-going erosion. If erosion is observed, additional, more structural toe protection and/or flow deflection may be needed to provide long-term toe stability.

Cost Considerations

As with most live material, dormant posts can often be obtained free of charge if local sites exist and landowner permission can be obtained. If posts are not locally available, they can be purchased from native nurseries. Costs vary depending on the size of the post, but average around $12 per post for 6 foot posts that are 4-6 inches wide. Installation typically requires renting a hydraulic auger attached to a bobcat or small excavator, which costs about $200 per day. Using this method, approximately 75-100 posts can be installed per day. Coir fiber erosion control blanket costs average $1.50 to $2.00 per square yard.

Vegetated Geogrids

Description

Vegetated geogrids consist of a series of rock and soil lifts that are wrapped with erosion blanket or geotextile. Live cuttings are placed between adjacent lifts, as shown in Figure 2.6-3.

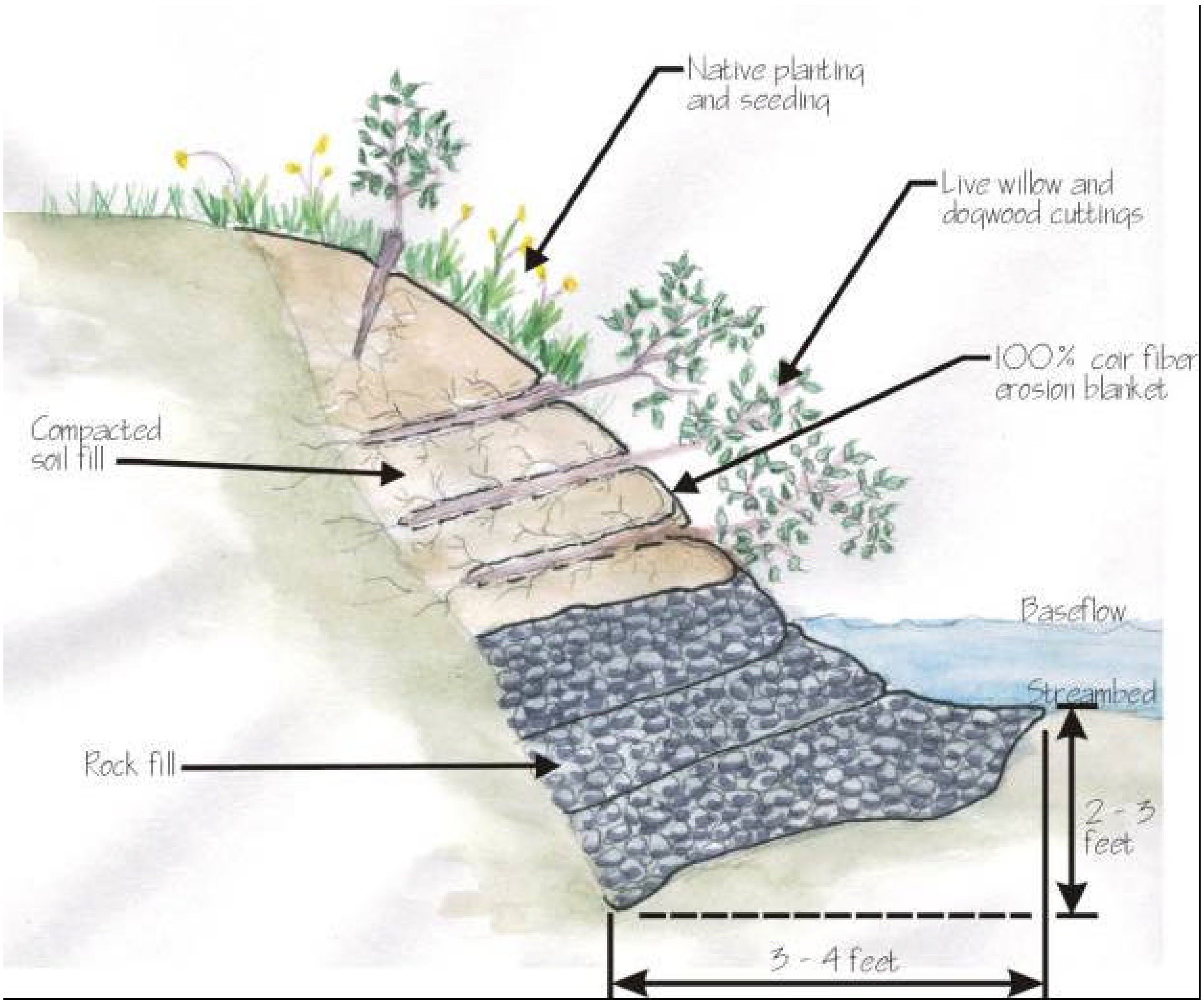

Figure 2.6-3 Vegetated geogrid installation
Source: F. X. Browne, Inc.

Applicability

Vegetated geogrids are used to rebuild scoured-out portions of streambanks or to rebuild a stable bank profile in situations where bank grading is not practical. Vegetated geogrids are an excellent method of establishing a naturally-vegetated streambank on relatively steep slopes.

Vegetated geogrids require significant amounts of labor, fill material, and live material and, as a result, can be fairly costly. Geogrids can be used in high shear stress locations if properly designed. They should not be installed in locations where active channel incision (downcutting) is occurring.

Design Considerations

Most geogrid systems are built on a rock filled trench foundation. The first two above-ground lifts are usually also rock filled rather than soil filled. The size of the rock for the foundation and base lifts is usually dependent upon expected near-bank shear stress and/or velocity. A variety of procedures ranging from simple to complex allow the designer to calculate rock size based on shear stress and/or velocity data.

First year growth on willow and dogwood cuttings used in a vegetated geogrid installation on the East Branch Perkiomen Creek, Bucks County, PA
Source: F. X. Browne, Inc.

As with other live material-based methods, vegetated geogrids work best in sunny areas. Native shrub willow and dogwood species are typically used between lifts. Elderberry should be considered for shadier applications. Individual cuttings vary between 0.25 and 0.5 inches in diameter. Individual cuttings are usually stacked between lifts to create a 4-8 inch layer of cuttings. 100% coir fiber extended term erosion blanket is typically used to form the soil wraps. Two layers of erosion blanket and/or chicken wire can be used to strengthen the lifts. The face of each soil lift is seeded with a native grass and wildflower seed mix.

A newly completed vegetated geogrid installation on the Vermillion River, Dakota County, Minnesota
Source: Dakota County Soil and Water Conservation District

Maintenance Recommendations

If designed properly, vegetated geogrid systems require minimal maintenance. Newly installed systems should be routinely inspected after large storm events to check for evidence of scour or undermining. Survivorship and overall growth of the live material layers should be assessed. Additional live material can be added to the system if needed by installing live stakes (see live stake description, above).

Seed establishment should be checked regularly, and areas of poor germination should be reseeded as needed.

COST CONSIDERATIONS

Vegetated geogrids are typically expensive compared with other bioengineering techniques. A professional contractor is required for the installation, although volunteers can assist with the construction of the soil lifts. Professional contractors may charge $100 per linear foot or more for geogrid construction, depending on the height of the bank. Costs can be reduced considerably if volunteers are used.

BRANCH PACKING

DESCRIPTION

Branch packing involves stabilizing small scour areas using layers of compacted soil and live cuttings, as shown in Figure 2.6-4.

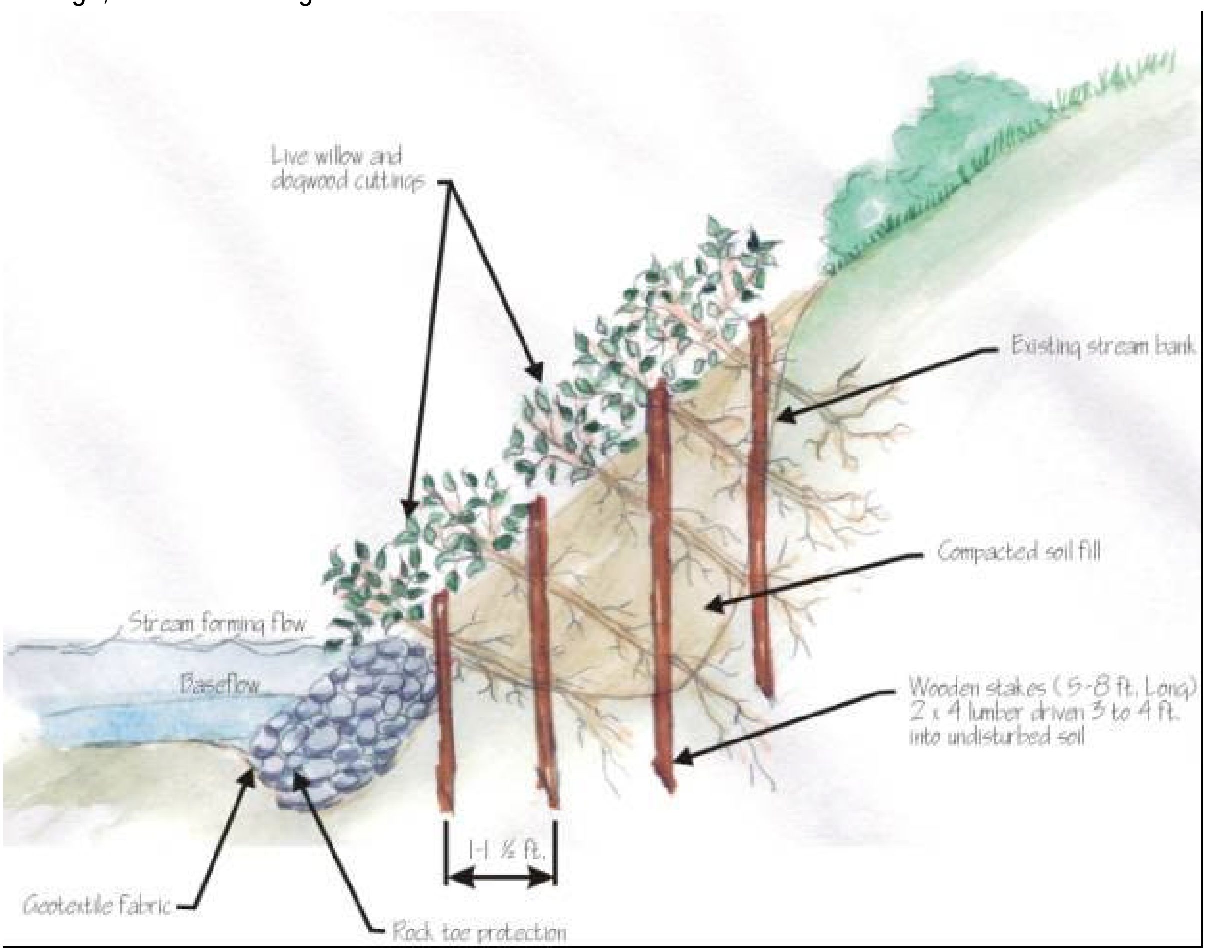

Figure 2.6-4 Branch packing installation
Source: F. X. Browne, Inc.

Applicability

Branch packing is typically used to repair small scour areas on the middle and upper areas of streambanks. As with other bioengineering treatments, branch packing works best in sunny locations where soil remains moist throughout the growing season. Branch packing is not typically used to stabilize large stretches of streambanks. It is most often used to "patch" localized scour areas. Branch packing should not be used for toe stabilization.

Volunteers use branch packing to repair a scoured bank along Cooks Creek, Bucks County, PA. Source: F. X. Browne, Inc.

Design Considerations

The branches are typically shrub willow and dogwood cuttings that range from 0.25 to 0.5 inches in diameter. The treatment is constructed by placing alternating layers of compacted soil (approximately 1-foot thick) and branch cuttings (2-4 inches thick) until the entire scour area is filled. Long hardwood stakes (4-5 feet long) are driven vertically through the branch and soil layering. The surface of the treatment is then seeded using native wildflower and grass species and covered with a coir fiber erosion blanket.

Maintenance Recommendations

Branch packing installations should be monitored frequently, especially after large storm events. The installation area should be visually inspected for signs of erosion. Adequate live cutting survivorship and seed germination is critical to treatment success. If needed, additional live material can be added to the system by installing live stakes (see live stake description, above). Areas of poor seed germination should be reseeded.

Cost Considerations

Because branch packing is most often applied to relatively small areas, it can usually be installed using volunteer labor. Installation costs are under $20 per linear foot.

Live Cribwalls

Description

Live cribwalls are log-cabin like wall structures composed of railroad ties or timbers and filled with stone and soil. Cribwalls are then planted with live material, as shown in Figure 2.6-5.

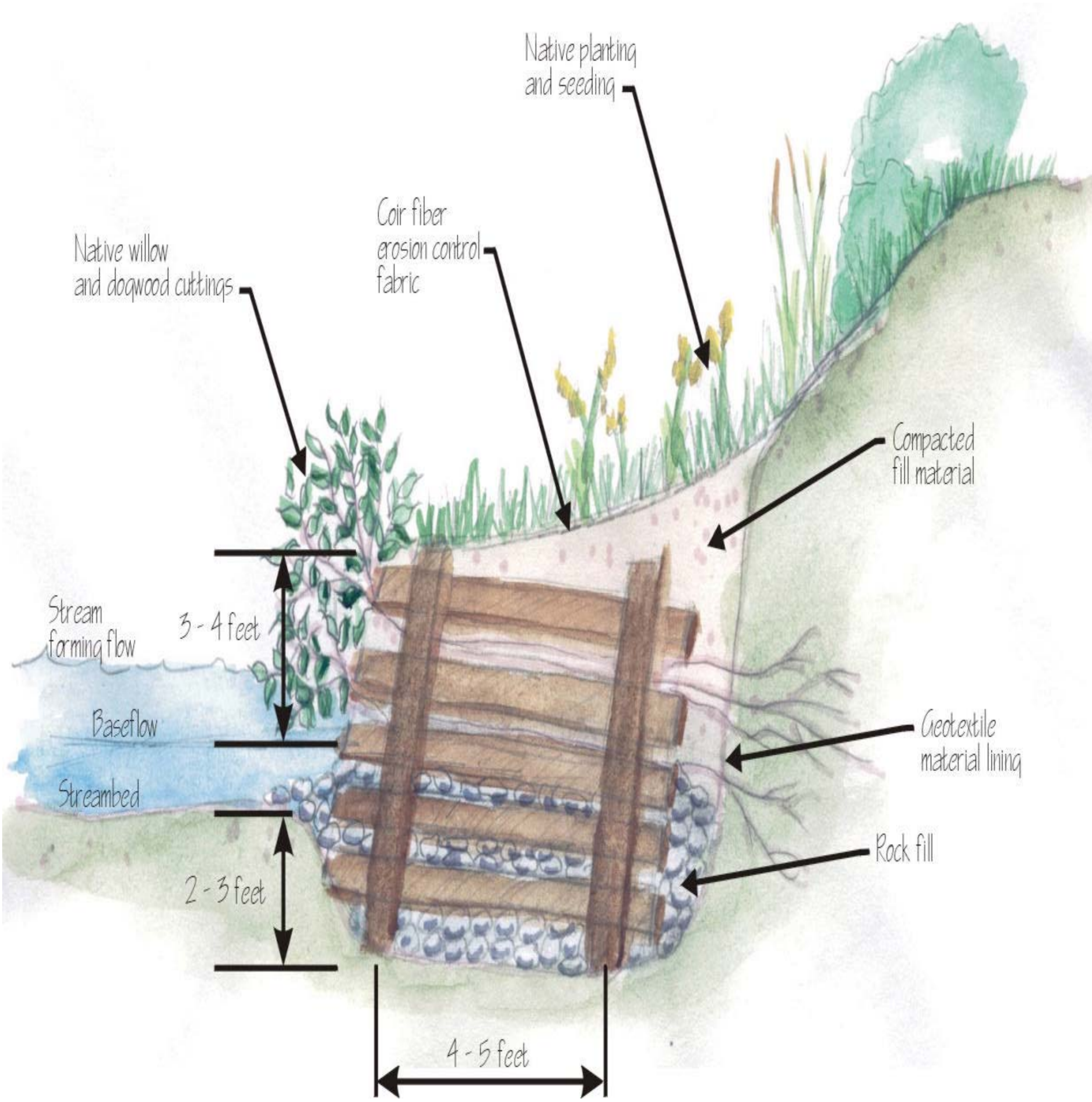

Figure 2.6-5 Live cribwall installation
Source: F. X. Browne, Inc.

Applicability

Because of their structural nature, live cribwalls can be used to stabilize sites that are exposed to high shear stress and velocities. Live cribwalls are naturalized retaining walls. They can be used to stabilize streambanks in areas where grading is not possible or structures must be protected. They provide both toe, middle, and upper bank protection. Because they incorporate live material, they are more effective in sunny environments. However, they can be used in shady environments because treatment stability is derived primarily from non-living elements. Live cribwalls should not be installed where active channel incision (downcutting) is occurring.

Installation of the first course of timbers and live material in a live crib wall
Source: Natural Resource Conservation Services

Design Considerations

Logs or timbers used to construct the frame of the cribwall typically range from 4 to 6 inches in diameter. Length will vary according to the size of the application. Large nails or rebar are used to join adjacent timbers. Typically, the crib is built in a 2-3 feet deep and 4-5 feet wide trench. The trench is typically sloped away from the stream to provide added stability. Fill for the cribwall typically consists of rock for the below grade portion of the crib and soil for the above grade portion of the crib. Live cuttings of native willow and dogwood are layered among the soil fill. The treatment is completed by covering the top course with a layer of soil fill, erosion blanket, and native seeding. Generally, cribwall structures should not exceed 7 feet in height. Backfill behind the cribwall should be granular in nature. This will help to relieve hydrostatic pressure on the wall and will also help to keep the cribwall dry.

Installation of a cribwall structure during the Palomares Creek Streambank Restoration Project Source: Alameda County Resource Conservation District

Maintenance Recommendations

Periodic visual assessments should be performed to assess the integrity of the crib structure. The base of the crib structure should be inspected for signs of scour. If scour if observed, additional stone fill should be added to protect the base of the structure. The growth and development of the live material and native seeding should also be assessed regularly. Replanting of live material within the crib is difficult after initial installation, however.

Cost Considerations

The construction of a live cribwall requires significant investments of labor and materials. Some type of excavator or back-hoe is required to prepare the base trench. According to the Maryland Department of the Environment Waterway Construction Guidelines (2000), costs for a live cribwall range from $11 to $28 per square foot of the front face.

Rootwads

Description

A rootwad consists of the root structure and lower truck portion a large tree. Rows of rootwads can be used to stabilize the toe area of streambanks. Footer logs and boulders are used to anchor and stabilize the rootwads. Vegetation is usually planted above and between the rootwads.

Applicability

Rootwad installations are designed to control toe erosion. Rootwads should not be installed where active channel incision (downcutting) is occurring. Rootwads should also be avoided in sand-dominated channels. Many rootwad failures have been associated with installation on tight meanders and highly-confined stream channels. Rootwads can be susceptible to flanking, so they should only be installed where the upstream and downstream ends can be tied into stable bank locations. The size and type of rootwad anchoring system can be varied to accommodate high velocity and sheer stress applications. Because rootwad systems typically rely on vegetation to provide stabilization between and above the rootwads, installation on sunny, moist sites is most successful. In addition to providing stream erosion protection, rootwads also provide substantial habitat benefits. Because

A stockpile of rootwads ready for installation

rootwads are not living, they have a finite life span. Therefore, rootwads are most appropriate where long-term stability can be provided by vegetation alone.

Design Considerations

Like many naturalized stream stabilization measures, there are few specific design standards for rootwads. For instance, there are no engineering standards relating footer log, boulder, or rootwad size to hydraulic design criteria such as velocity and shear stress. Typically, rootwads should be large enough to effectively cover the bank from the maximum expected scour depth to the bankfull elevation. Rootwads should have a basal diameter of 18-20 inches. The trunk section of the rootwad (not including the root fan) should be at least 12 feet in length. Boulders used to anchor the rootwads should be at least 1.5 times the diameter of the trunk portion of the rootwad. Particularly when scour depths are high, footer logs should be used and should have a diameter equal to the basal diameter of the root wad. Various bioengineering techniques are used to provide stabilization above and between rootwads.

A track hoe is used to lower a large rootwad into place

Maintenance Recommendations

Rootwad failures are frequently documented in the literature. Rootwad installations should be monitored regularly for scour, flanking, and erosion between and above the rootwads. Monitoring after large flow events is critical. Survivorship and growth of live materials used in conjunction with the rootwad installation should be monitored regularly as well.

Cost Considerations

According to the Maryland Department of the Environment Waterway Construction Guidelines (2000) costs range from $168 to $1,121 per rootwad.

Native Seeding and Planting

Description

Native seeding and planting involves the establishment of native vegetation on streambanks using plants and seed. Native seeding and planting is an important aspect of many integrated soil bioengineering systems.

Native grass and wildflower 2 in. plugs awaiting installation. Plugs are a good way to establish native plants on a graded streambank.
Source: F. X. Browne, Inc.

Applicability

Native seeding and planting can be used to stabilize the middle and upper bank portions of eroding streambanks. Seeding and planting is seldom used as the sole method of bank stabilization; it tends to be used in combination with other soil bioengineering and/or biostructural techniques. Planting and seeding is generally not effective below bankfull elevation and should not be used to stabilize the bank toe. Native seeds and plants must be selected to match the moisture, soil, and light requirements of the site. In general, native seeding is most effective as a stabilization technique in sunny moist sites with loamy soil and a grade of 3:1 or less. In less desirable sites, planting should be favored over seeding due to lower growth rates.

Design Considerations

A careful assessment of site conditions is critical to species selection for both seeding and planting. In general, most seed mixes contain about a 60:40 ratio of grasses to forbs. Seeding rates range from 5-15 pounds per acres. Usually, a native seed mix is combined with temporary seeding (usually annual rye at a rate of 40-48 pounds per acre). Seed preparation is critical to seeding success. Soil should be scarified prior to seeding. Seed should be applied evenly, covered with a thin layer (usually 0.25 in.) of soil and compacted using a roller or cultipacker. Native seed should be covered with erosion blanket (100% coir fiber is best). New seed should be watered for at least two weeks following installation. Planting is

Installation of native herbaceous plugs through an erosion blanket
Source: F. X. Browne, Inc.

often used in conjunction with seeding to increase the diversity of the treatment and to provide more immediate vegetative cover. Wholesale nurseries provide native plants in a variety of sizes and formats. However, 2-inch plugs are typically used for streambank installation.

Game deterrent measures are essential for most native seeding or planting installations. Table 2.6-3 shows some recommended species for native seeding and planting applications.

Maintenance Recommendations

Regular monitoring and maintenance is critical for native seeding and planting success. New seed installations should be monitored closely during the first few weeks to identify and reseed areas of poor germination. New growth should be trimmed to a height of approximately eight inches twice during the first growing season. Exotic and invasive plant species should be flagged and removed by appropriate mechanical or chemical methods. Game deterrent measures (e.g., string fields, fencing) should be monitored and maintained. New planting and seeding areas should be watered during drought conditions.

Native seeding can be an effective way to beautify any streamside landscape. Source: Fred Rozumalski

Cost Considerations

Native seeding and planting can typically be accomplished using trained volunteers. Costs for plant plugs range from $0.75-$1.00 each. Gallon-sized containerized plants can cost between $4-7 each. Good quality native seed mixes typically range from $50-$100 per pound.

Table 2.6-3
Recommended Species for Native Seeding and Planting Applications

Common name	Latin name	Soil	Light	Height	Flower
Big bluestem	*Andropogon gerardii*	WM-D	S-PS	3-8'	n/a
Little bluestem	*Andropogon scoparius*	M-D	S-PS	2-3'	n/a
Swamp milkweed	*Asclepias incarnate*	W-M	S-PS	3-4'	Summer
Butterfly weed	*Asclepias tuberose*	M-D	S-PS	2-3'	Summer
New England aster	*Aster novae-angliae*	W-DM	S-PS	2-5'	Fall
Blue joint grass	*Calamagrostis canadensis*	W-M	S-PS	3-5'	n/a
Lurid sedge	*Carex lurida*	W-WM	S-PS	1-3'	n/a
Tussock sedge	*Carex stricta*	W-WM	S-PS	1-4'	n/a
Fox sedge	*Carex vulpinoidea*	W-DM	S-PS	1-3'	n/a
Turtlehead	*Chelone glabra*	W-WM	S	3-4'	Summer
Purple coneflower	*Echinacea purpurea*	WM-DM	S-PS	3-4'	Summer
Canada wild rye	*Elymus canadensis*	WM-D	S-PS	3-6'	n/a
Virginia wild rye	*Elymus virginicus*	W-M	S-Sh	2-4'	n/a
Spotted joe-pye weed	*Eupatorium maculatum*	W-WM	S-PS	4-6'	Summer
Common boneset	*Eupatorium perfoliatum*	W-WM	S-PS	3-4'	Summer
Sneezeweed	*Helenium autumnale*	W-WM	S-PS	2-5'	Fall
Blue flag iris	*Iris virginica shrevei*	W-M	S-PS	2-3'	Summer
Common rush	*Juncus effusus*	W-WM	S	2-4'	n/a
Marsh blazing star	*Liatris spicata*	W-M	S-PS	3-6'	Summer
Cardinal flower	*Lobelia cardinalis*	W-WM	S-PS	2-5'	Summer
Great blue lobelia	*Lobelia siphilitica*	W-M	S-PS	1-4'	Fall
Monkey flower	*Mimulus ringens*	W-M	S-PS	1-3'	Summer
Wild bergamot	*Monarda fistulosa*	WM-D	S-PS	2-4'	Summer
Switch grass	*Panicum virgatum*	WM-D	S-PS	3-5'	n/a
Black-eyed susan	*Rudbeckia hirta*	WM-D	S-PS	1-3'	Summer/Fall
Indian grass	*Sorghastrum nutans*	M-D	S-PS	3-6'	n/a
Blue vervain	*Verbena hastata*	W-M	S-PS	2-6'	Summer
Common ironweed	*Vernonia fasciculate*	WM-M	S-PS	4-6'	Summer
Culver's root	*Veronicastrum virginicum*	WM-DM	S-PS	3-6'	Summer
Golden alexanders	*Zizia aurea*	WM-DM	S-PS	1-3'	Spring

Key: W=wet, WM= wet mesic, M= mesic, DM = dry mesic, D=dry.
S=full Sun, PS=partial sun, Sh=shade.

Boulder Toe

Description

Boulder toe consists of the placement of angular rock (rip-rap) at the base of a streambank to provide toe stabilization protection. Boulder toe applications are often used in conjunction with soil bioengineering and biostructural methods for middle and upper bank stabilization.

Boulder toe installation along a streambank stabilization project in Perkasie Borough, Bucks County, PA
Source: F. X. Browne, Inc.

Installation of a Boulder toe along Sambo Creek, Monroe County, PA
Source: F. X. Browne, Inc.

Applicability

Boulder toe treatments are widely applicable to a variety of stream types, environmental conditions, and hydraulic conditions. Boulder toe stabilization should be considered only when less structural methods (e.g., dormant posts, fiber roll revetments) are insufficient to provide toe stability.

Design Considerations

Rock used in the boulder toe should be well-graded and angular. Rock size is the most critical design consideration. Numerous methods have been developed to predict rock size based on velocity, shear stress, or a combination of the two. These include the Isbash Method and the Federal Highway Administration Method.

Other primary design considerations include the thickness, depth, and extent of the boulder toe. Usually, the boulder toe extends vertically from the expected depth of scour to the bankfull elevation and horizontally from the toe of the slope to the horizontal location of the bankfull elevation on the existing streambank. Typically, the boulder toe is lined with a geotextile fabric to provide separation. Dormant post plantings can be installed among the rocks to provide a softer appearance and to add habitat value (see section on dormant posts).

Maintenance Recommendations

Boulder toe treatment typically requires minimal maintenance. Still, treatments should be inspected regularly for signs of scour or flanking.

Cost Considerations

Boulder toe treatments are typically installed by professional contractors. Boulder toe installation costs approximately $40 - 70 per linear foot, depending on the size of the project. The larger the project, the lower the cost per square foot. Similarly, the cost per square foot for boulder toe installation will be lower when the installation is performed in conjunction with other streambank stabilization applications, combining the overall project costs.

Completed boulder toe installation along Teedyuskung Creek, Pike County, PA. Source: F. X. Browne, Inc.

Tree Revetments

Description

Tree revetments consist of whole trees that are anchored to a streambank to provide erosion control, as shown in Figure 2.6-6.

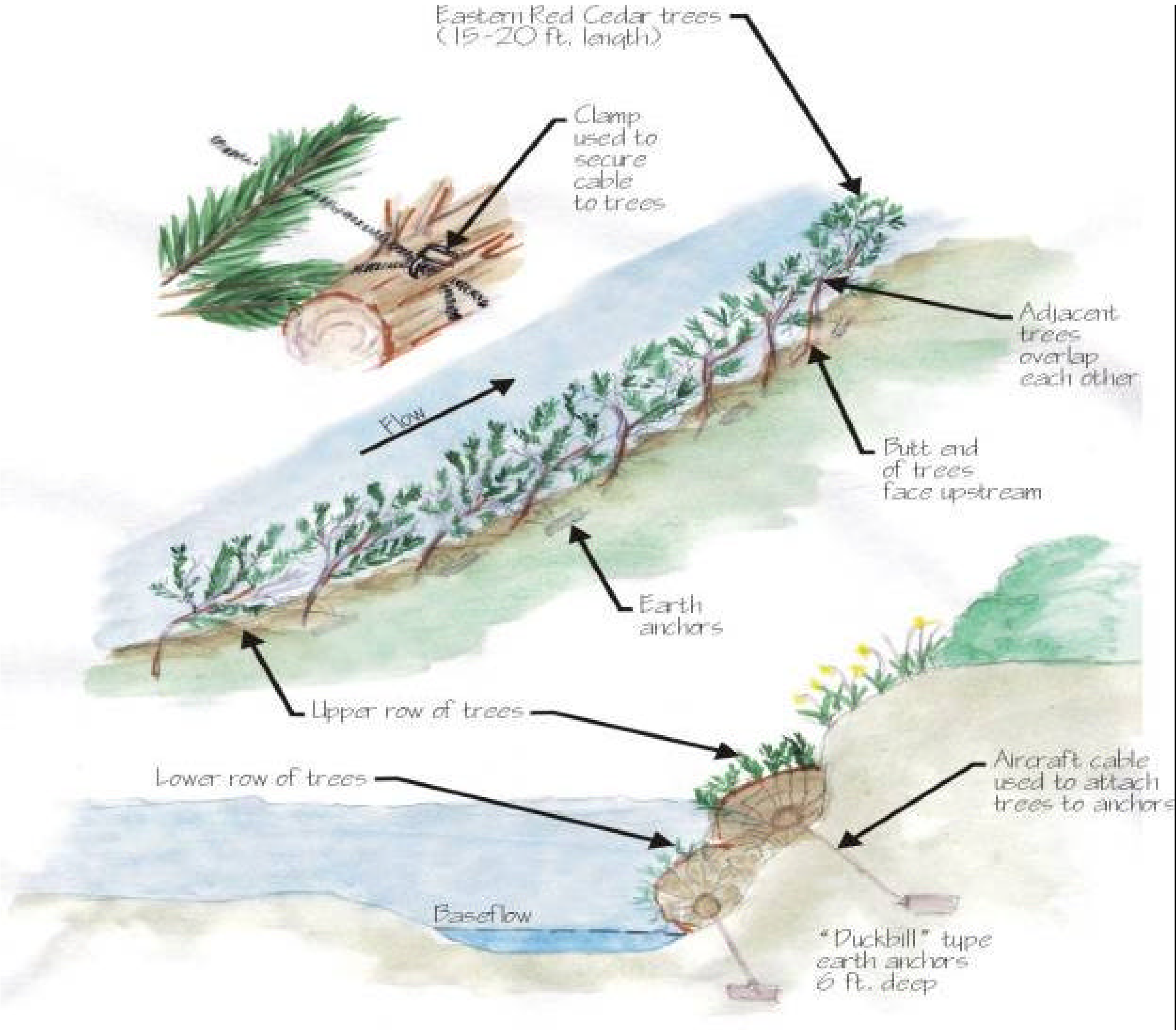

Figure 2.6-6 **Tree revetment installation**
Source: F. X. Browne, Inc.

Applicability

Tree revetments are typically used to control erosion when extensive tree cover and shading prevents grading of the streambanks and/or significant vegetation growth. Tree revetments are usually placed at the toe of the bank, but some applications use multiple layers of trees to protect middle and upper bank areas as well. Although tree revetments are temporary, they slow water velocity and, in doing so, promote the deposition of significant amounts of suspended sediment and bed load. Native trees and shrubs then colonize this newly deposited sediment creating a stable bank profile. Tree revetments are also useful in locations where significant earth disturbance is not desired.

Cabling a tree revetment to an earth anchoring system
Source: F. X. Browne, Inc.

Many designers do not like to use tree revetments upstream of bridges because of the potential for one or more of the trees to dislodge during a large flow event. Sites must have adequate soil strength to hold the earth anchors or t-posts used to anchor individual trees. Sites must also have adequate depth to bedrock to allow for the insertion of the anchoring systems. Bank height should be less than 15 feet. Tree revetments, as with most stabilization practices, are prone to failure at sites that are undergoing active channel downcutting. The trees should not decrease the bankfull channel width by more than 20 percent. Tree revetment treatments must begin and end at locations that are not actively eroding.

Design Considerations

Trees used for tree revetments are usually densely-branching evergreen trees such as eastern red cedar (*Juniperus virginiana*), although pin oak (*Quercus spp.*) has also been used with success. Tree size can vary, but 15 to 20 feet is a common length. Upstream trees should overlap downstream trees by about 1/3 of their length. Trees should be oriented so that the butt end of the tree faces upstream. Typically, 3/16-inch aircraft cable is used to attach the trees to the anchoring system. Anchoring systems can include Duckbill Model 88 anchors, 4-inch or 6-inch Laconia arrowhead anchors, 5.5-foot t-posts, or 4-inch helical anchors. Trees should be secured tightly to the bank in all locations. Anchors are driven to a depth of 5-6 feet in most instances. Live stakes can be driven through the tree revetments to aid in revegetation.

Maintenance Recommendations

Tree revetments require frequent monitoring and occasional maintenance. Large storms often produce isolated damage to individual trees, requiring replacement of those trees or repair of the anchoring systems.

Cost Considerations

Typically, tree revetment costs range from $5-$10 per linear foot. Often, trees can be obtained free of charge from local sources to reduce costs.

Fiber Roll Revetments

Description

Fiber roll revetments (often referred to as Biologs) consist of coir fiber "logs" placed at the toe of an eroding streambank to provide stability. The fiber roll is usually planted with herbaceous plugs, as shown in Figure 2.6-7.

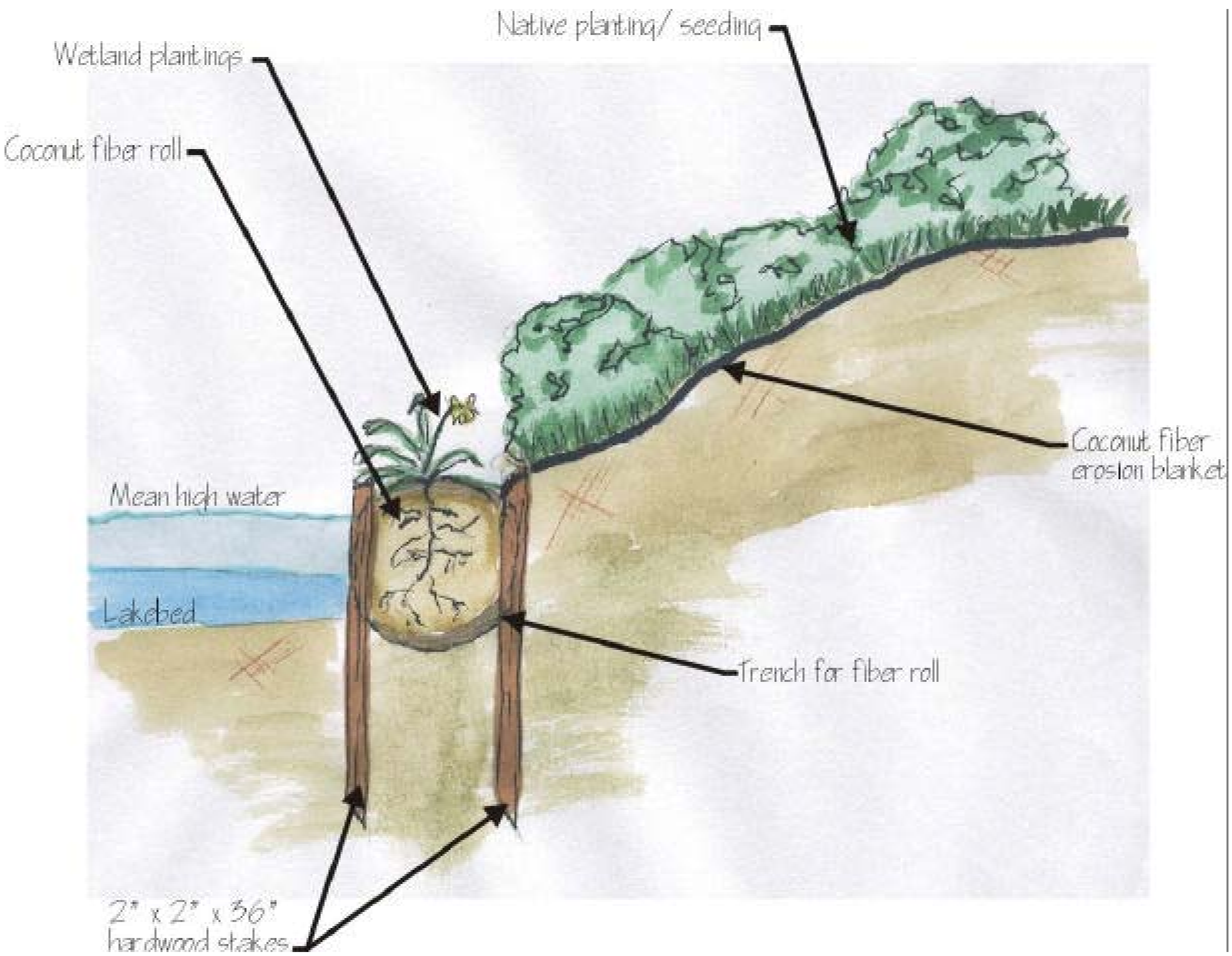

Figure 2.6-7 Fiber roll revetment installation
Source: F. X. Browne, Inc.

Applicability

Fiber roll revetments are useful for toe protection in low velocity, low shear stress environments only. Since fiber rolls rely on the establishment of herbaceous vegetation to provide long-term toe stabilization, these applications work best in sunny sites. Sites that are actively downcutting should be avoided. The flexibility of the fiber roll is well adapted to conform to the natural contours of a streambank.

Design Considerations

The standard fiber roll width is 12 inches, although sizes up to 20 inches are commercially available. The length of the fiber roll depends on the length of the treatment area. The fiber roll should be placed in a shallow trench at the toe of the slope such that at low-flow (baseflow), the fiber log is approximately half inundated by the streamflow. The fiber roll is typically staked to the bank at both the streamward and landward sides of the fiber roll using 2”x2”x36” hardwood stakes placed at 4-foot intervals. The fiber roll is then planted with native herbaceous 2-inch plugs at 6-inch spacing. Effective game deterrent measures are critical. Other soil bioengineering techniques are used to provide middle and upper bank stability above the bank toe.

Fiber roll revetment used for toe stabilization along a small stream. Note the ability of the fiber roll to mold to the bank contours.

Maintenance Recommendations

Fiber roll installations must be monitored frequently to check for scouring and to evaluate plant growth. Game deterrent measures must be monitored and repaired if needed.

Cost Considerations

Fiber roll revetments can be effectively installed by trained volunteers. A Ditch Witch® or similar mechanical trenching device is recommended for the preparation of the trenches. Rental rates for mechanical trenchers range from $90-150 per day. Manual preparation of the trenches is possible but very labor intensive. Fiber rolls (12-inch diameter) typically cost approximately $7 per linear foot. Cost for plant plugs typically range from $0.60-$1.00 each.

2.6.2 In-stream Habitat Enhancement Techniques

In-stream habitat enhancement techniques refers to a wide variety of structures that are placed within the active stream channel to improve stream habitat, usually for coldwater fish species such as trout. Most in-stream habitat enhancement techniques function by deflecting, concentrating, or otherwise modifying stream flow to create specific physical and hydraulic conditions within the stream channel.

In-stream structures are also used to deflect flow away from eroding banks, and to reduce flow stress and velocity in the near-bank region. In this capacity, in-stream structures are often used to augment bioengineering and biostructural streambank stabilization practices. Certain in-stream structures are also used to provide grade control for streams that are actively downcutting. Finally, in-stream structures can be used as energy-dissipation devices.

A double wing flow deflector on Teedyuskung Creek, Pike County, PA. Note the formation of a scour pool downstream of the structure. Source: F. X. Browne, Inc.

The majority of in-stream structures consist of flow deflection devices (also referred to as barbs, bendway weirs, jetties, and vanes). These devices are usually linear structures made of either logs or stone that extend from the bank into the channel at a particular angle. There are many different flow deflector designs, but their intent is much the same. Most deflectors try to redirect flow from the edges of the channel, where it can cause bank erosion, to the center of the channel, where it can be used to scour pool features, thereby dissipating energy and providing habitat.

The design criteria for flow deflectors and other habitat enhancement techniques range from extremely complex design procedures to simple qualitative guidelines. Many of the structures used for fisheries enhancement were originally developed by trout enthusiasts and lack well-defined design criteria. The location, size, and orientation of these structures are often determined in the field based on the response of the water to the structure. Some deflector structures were developed for engineering purposes such as preventing bridge scour and maintaining navigational channels. These structures tend to be associated with detailed design and construction criteria. Natural channel designers have developed a class of in-stream structures that are based on a combination of geomorphic theory and field testing. Design criteria for these modern structures are usually based on channel characteristics such as active channel width and channel slope.

The in-stream habitat techniques presented here represent some of the more commonly used and thoroughly tested practices for in-stream habitat enhancement. In general, this handbook does not describe the many varieties of in-stream deflector structures that have been developed without the benefit of fluvial geomorphology or hydraulic science. The long-term efficacy of these structures is questionable, and the literature is replete with instances where these types of structures have either failed completely or failed to meet their design objectives.

J-hook Rock Vanes

Description

The J-hook rock vane is a linear, upstream-facing structure usually built using large flat boulders. The upstream end of the structure hooks toward the center of the channel.

Rock vane installation along Martin's Creek, Northampton County, PA. Source: F. X. Browne, Inc.

J-hook rock vane and dormant post installation in Cooks Creek, Bucks County, PA. Source: F. X. Browne, Inc.

Applicability

The J-hook structure is mainly used to deflect flow away from eroding banks on outside meander stream bends. Near-bank shear stress and velocity are reduced, and scouring is induced in the center of the channel at the tip of the vane. This scour pool provides both energy dissipation and habitat for trout. The rocks in the hook portion of the vane are separated from one another. This design produces a variety of water currents and speeds within the scour pool. This is thought to enhance the habitat value of the scour pool for trout and other fish species.

J-hooks should not be used in unstable channel reaches that are undergoing active downcutting or rapid lateral migration. The use of j-hook rock vanes in bedrock channels is generally ineffective because limited channel bed scouring can occur. J-hooks should be used with caution in sand and silt bed channels where significant scouring potential under and around the vane can compromise the integrity of the vane structure.

Design Considerations

J-hook rock vanes are always angled in the upstream direction. The acute vane angle is typically 20 to 30 degrees. The slope of the vane should be between 2 and 7 percent. The terminus of the straight portion of the rock vane is located at 1/3 of the bankfull channel width. The hook portion of the rock vane spans the middle third of the bankfull channel. Vane length and vane spacing are predicted based on bankfull channel width. The vane structure intersects the streambank at the bankfull elevation. Footer rocks are used as a platform upon which the vane rocks rest. Footer rocks should be keyed into the streambed to a depth of 3 times the height of the endmost vane rock above the streambed. For sand bed streams this vane depth should be doubled. Bankfull shear stress is used to predict vane and footer rock size. Vane and footer rocks are large (at least 1-2 tons) usually rectangular, flat-bottomed rocks.

Maintenance Recommendations

J-hooks, if installed properly, require little active maintenance. Each structure should be inspected periodically and after large flow events. Scouring around the footer rocks is a cause for concern and may indicate that the footer rocks are not embedded deeply enough into the stream channel. Also, erosion of the bank opposite the rock vane may indicate that the vane is deflecting flow too drastically and may require a reduction of the vane angle.

A track hoe with a grapple attachment is used to place vane rocks for a J-hook rock vane installation on Cooks Creek, Bucks County, PA. Source: F. X. Browne, Inc.

Vane rocks are placed starting from the vane tip back towards the streambank. Source: F. X. Browne, Inc.

Cost Considerations

According to the Maryland Department of the Environment Waterway Construction Guidelines, (2000) costs per rock vane averaged $406.

Cross Vanes

Description

A cross vane consists of two upstream facing rock vanes located on opposite banks which are linked together by a central rock arm. The construction of the vane arms of a cross-vane is very similar to the straight portion of the j-hook rock vane.

Construction of a cross-vane structure and downstream scour pool for a natural channel design project
Source: Ecotone, Inc.

Applicability

The cross vane is used primarily to provide grade control in medium to high gradient streams. Cross-vanes also create scour pools downstream of the structures, which serve as holding areas for trout. The cross-vane can also induce trout spawning habitat formation at the downstream end of the scour pool. Near-bank velocity and shear stress are also reduced, making the cross vane an effective addition to streambank stabilization projects.

As with other vane-like structures, cross-vanes are ineffective in bedrock streams where scouring of the bed cannot occur. Likewise, cross vanes are particularly susceptible to undermining and scour in channels dominated by sand and silt.

Design Considerations

The upstream arms of the cross vane should intersect the streambank at bankfull elevation and slope downward at a 2 to 7 percent slope. The acute vane angle of each vane arm is typically 20 to 30 degrees. Vane arms are always oriented upstream. Each vane arm occupies 1/3 of the bankfull channel, while the central connecting arm between the two vane arms occupies the central third of the channel.

Footer rocks are used as a platform upon which the vane rocks rest. Footer rocks should be keyed into the streambed to a depth of 3 times the height of the endmost vane rock above the streambed. For sand bed streams, this depth should be doubled. Bankfull shear stress is used to predict vane and footer rock size. Vane and footer rocks are large (at least 1-2 tons) usually rectangular, flat-bottomed rocks.

Maintenance Recommendations

Cross vanes, if installed properly, require little active maintenance. Each structure should be inspected periodically and after large flow events. Scouring around the footer rocks is a cause for concern and may indicate that the footer rocks are not embedded deeply enough into the stream channel. Because the cross-vane directs flow from both banks toward the center of the channel, unintended bank scour is not a concern as it is with the j-hook structure.

Cost Considerations

Installation costs for a single cross-vane are estimated to be approximately $850, based on the Maryland Department of the Environment Waterway Construction Guidelines, (2000) estimated cost for single-arm rock vanes ($406).

Boulder placement

Description

Boulder placement consists of the placement of dispersed boulders within the active stream channel. The interaction of flow with the boulders creates hydraulic features such as eddies and slackwater areas as well as small scour areas.

Boulder placement for habitat enhancement along a stretch of Cooks Creek, Bucks County, PA
Source: F. X. Browne, Inc.

Applicability

Boulder placement is most applicable in cobble or gravel-bottomed streams with high flow velocity. Streams with non-cohesive sediment (e.g., small gravel or sand) should be avoided due to their high scour potential. Also, boulder placements are generally ineffective in shallow gradient streams where low water velocity prevents the development of scour pools. Also, channels that possess highly erodible bank sediments or on-going bank erosion problems may be adversely affected by boulder placement.

Design Considerations

Boulders ranging in diameter from 2 to 5 feet are recommended. Boulders should be angular rather than rounded. Boulders should be placed on buried footer rocks, similar to the footer rock system used in j-hook and cross-vane applications. Boulders should be partially embedded (20 to 30 percent of bankfull depth) in the streambed. An analysis of hydraulic conditions (e.g., shear stress, velocity) should be conducted to ensure that boulders will not move during high flow events. Boulders should be arranged in discrete clusters of 3-5 boulders arranged in a triangular fashion. Adjacent clusters should be located at least 1/3 of the bankfull channel width apart.

Maintenance Recommendations

Boulder installations should be inspected periodically to ensure that the installation is having the intended effects (e.g., formation of scour pools) and that the installation is not producing unintended effects such as localized increases in bank erosion. Individual boulders should be inspected for signs of movement or undermining following large storm events.

Cost Considerations

According to the Maryland Department of the Environment Waterway Construction Guidelines, (2000) estimated cost for 10 placed boulders is $583.

LUNKER Structures

Description

LUNKER structures ("Little Underwater Neighborhood Keepers Encompassing Rheotactic Salmonids") are open-ended boxes constructed from wood and rebar that are installed at the toe of streambanks to create fish habitat, as shown in Figure 2.6-8.

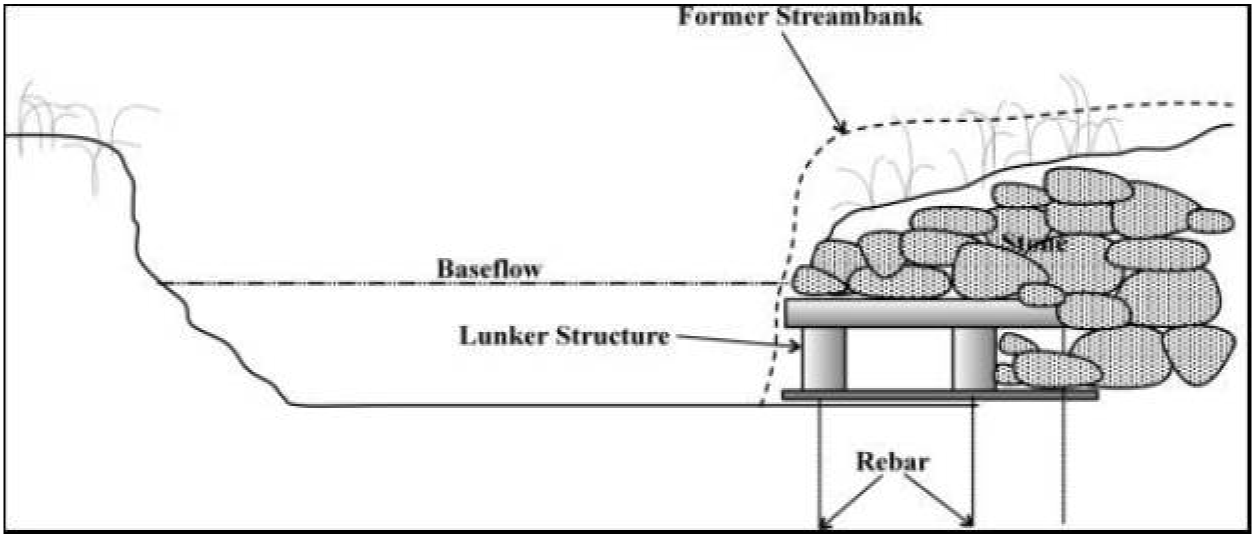

Figure 2.6-8 Cross-sectional view of a LUNKER structure
Source: F. X. Browne, Inc.

Applicability

LUNKER structures are used primarily in gravel- or cobble-bottomed creeks that lack suitable in-stream cover for fish habitat. LUNKERs are unsuitable for use in sand or silt dominated channels. LUNKERs are most often installed on the outside bend of stream meanders. LUNKERs are suitable for use in both high and low gradient streams. LUNKERs can be incorporated into bank stabilization projects. Bioengineering and biostructural stabilization practices are often used to provide stability above the bank toe.

Construction of a LUNKER structure prior to in-stream placement.
Source: Harry and Laura Nohr Chapter of Trout Unlimited

Design Considerations

The LUNKER structure is typically constructed using hardwood boards (width, thickness, and length vary). The LUNKER structure is constructed prior to placement in the stream and is anchored to the streambed using rebar. Rebar should extend at least four feet into the streambed or, if known, to the anticipated depth of scour. When installed, the entire LUNKER structure should remain at least six inches below the baseflow elevation to avoid rotting of the structure. Large boulders should be placed along the upstream and downstream edges of the structure to provide stability. Boulders should be sized according to recommendations for boulder sizing in the Boulder Toe section. The LUNKER should be backfilled with a combination of gravel and soil to provide drainage. The streambank above the LUNKER structure should be graded and stabilized using appropriate soil bioengineering and/or biostructural stabilization measures.

Maintenance Recommendations

LUNKERs should be inspected periodically to ensure that they remain in place and that they do not fill in with sediment.

Cost Considerations

LUNKER installation by a professional contractor costs approximately $180 per linear foot (F. X. Browne, Inc., personal communication). However, if volunteers were utilized for construction of the LUNKER structures and installation, the cost could be considerably less, perhaps even half that amount. Expenses include the cost of the lumber and rebar for the structures, rental of the installation machinery, and boulders for stabilization.

2.6.3 Natural Channel Design

Description

Natural channel design refers to a diverse and emerging set of design methodologies aimed at restoring and creating natural physical channel forms. The natural channel design approach to stream restoration is strongly rooted in the science of fluvial geomorphology, which is the study of water-influenced land forms. Unlike streambank stabilization and in-stream habitat enhancement projects, natural channel designs often result in a significant change in the size, pattern, shape, or profile of a stream channel. Natural Channel Design is often referred to as FGM (which stands for Fluvial Geomorphology) or Rosgen (after Dave Rosgen, who is one of the pioneers of Natural Channel Design methods).

Although fluvial geomorphology has been well understood for at least a half a century, the use of this science to develop design methods for the creation of naturally functioning channels has only emerged in earnest within the last 20 years. Dave Rosgen's 1996 publication "Applied River Morphology" popularized the natural channel design technique. Since that time, Natural Channel Design has steadily gained popularity and legitimacy among restoration practitioners and has been applied to an increasingly wide range of stream restoration design objectives, including daylighting of once-buried streams, and stream relocation and mitigation projects. Several state agencies now require or strongly encourage the use of Natural Channel Design methods in stream restoration efforts.

At its core, Natural Channel Design is based on the concept that the physical form (e.g., the size, shape, and meander pattern) of a river system is largely determined by three interrelated factors:

- The amount of water the river carries (the more area the river drains, the more water it carries and thus, the larger the channel will tend to be)

- The amount and type of sediment that the river must transport with the available water

- The type of valley in which the river is located (e.g., mountainous vs. flat)

Over time, natural rivers attain a stable form in response to these variables. Applying this concept to stream restoration, natural channel design methodologies attempt to create or restore stable natural channels based on driving variables such as flow, sediment load, and valley type. Procedures for designing stable natural channels generally fall into one of three categories:

- ***Geomorphic analog:*** Using this approach, the designer determines stable natural channel specifications for the restoration area by mimicking a reference reach that is similar to the proposed restoration area but exhibits a stable channel form. This approach was popularized by Dave Rosgen and is the most widely used approach to natural channel design. Limitations to the analog approach center around the difficulty in identifying stable reference reaches that are similar to the proposed reach. This is particularly problematic in urban watersheds, where the very concept of river stability is poorly defined.

- ***Empirical design:*** This approach uses empirical equations to relate channel dimension, profile, and plan form to one another or to watershed characteristics such as size and land use. This approach is also referred to as the hydraulic geometry approach or the regime theory approach. The empirical approach is often limited by the range of applicability associated with various empirical equations. Empirical equations that attempt to establish hydraulic geometry relationships over a wide geographical area or for a wide range of stream types are often too general to be useful for design purposes. Regional equations that define hydraulic geometry relationships for stable channels within a specific physiographic province and land use type are better suited for design applications, but have not been developed in most areas.

- ***Analytical approach:*** The analytical approach uses sophisticated computer models to simulate water flow and sediment transport processes. These simulations are then used to determine stable channel characteristics for a particular set of input variables. The primary limitation of the analytical approach is its complexity. Computer modeling requires complex data acquisition and verification procedures to achieve the accuracy needed for design work. As the limitations of the analog and empirical approaches become more apparent, analytical design procedures are gaining popularity.

Applicability

Natural channel design methods are applicable to a wide range of stream restoration-related applications, including:

- Dechannelization: Natural channel design methods can be used to restore natural stream form and function to stream channels that have been artificially straightened, ditched, or paved.

- Daylighting: Natural channel design can be applied to restoring stable channel form to streams that have been piped and buried.

- Stream Relocation: Natural channel design is increasingly being used to design stream channels when public works projects (e.g., road building, bridge construction) require the relocation of a portion of stream channel.

- Destabilized Stream Restoration: Natural channel design can be used to enhance the ecological functions and values of streams that have become unstable due to changes in sediment loading and hydrology as a result of large-scale land use changes.

- Flood control projects: Natural channel design can be used as an environmentally-friendly alternative to conventional flood control channels and levee projects.

- Dam removal: Dam removal projects often produce stream instability, which can be mitigated through the use of natural channel design techniques.

Many of these applications go well beyond the scope of streambank stabilization and in-stream habitat techniques. In this sense, the emergence of natural channel design technology has significantly extended the ability of restoration practitioners to restore whole river systems.

While natural channel design has, in many ways, revolutionized the field of stream restoration, it does have its share of skeptics and detractors. Natural channel design is an aggressive technique to stream restoration which, to be successful, requires extensive data collection and professional knowledge of applied fluvial geomorphology. Its growing popularity has resulted in increasing numbers of examples where the approach has been misapplied by inexperienced practitioners. Also, it is unclear whether natural channel design methods, which were originally developed in rangeland streams in the intermountain west, are effective in restoring urban streams. Finally, the high cost associated with designing and implementing natural channel design projects has caused some to question whether restoration funds might be better spent on less expensive technology that could address problems over a larger scale.

While the debate over natural channel design will undoubtedly continue, several conclusions can be made. First, natural channel design is a complex technology that must be carefully applied by experienced practitioners to be successful. Second, natural channel design, particularly in urban environments, is still very much an emerging technology that will require significant methodological advances before it can be a truly effective restoration tool. Third, natural channel design is an aggressive approach to restoring streams and should only be used when simpler, less expensive approaches are insufficient or when the severity of the problem demands an aggressive design approach.

Design Considerations

The Pennsylvania Department of Environmental Protection strongly favors the use of Dave Rosgen's design methodology for natural channel design projects in Pennsylvania. The Keystone Stream Team, a group of stream restoration professionals throughout Pennsylvania, has developed a guidance document for the implementation of natural channel design in Pennsylvania entitled, *Guidelines for Natural Stream Channel Design for Pennsylvania Waterways*.

Natural channel design projects typically require extensive site assessment, survey, and data collection. If a reference reach approach is used, potential reference reaches must be identified and assessed to determine their suitability to the project. This process can be extremely lengthy and time consuming. Once a reference reach has been identified, a detailed survey of the reference reach is conducted to obtain channel dimension, profile, and plan dimension. This information is then used to develop design criteria for the restored channel.

Concurrently, the restoration site must be thoroughly evaluated to determine the existing channel type and condition as well as the probable stable form of the channel. Natural channel design practitioners assess predictor variables such as valley form, channel particle size, and watershed land use to develop an idea of what the stable channel form should be. Designers also use conceptual models of channel response called channel evolution models to help diagnose the potential causes and solutions to channel instability problems. These models posit that channels undergo a predicable sequence of physical changes in response to land use changes.

Developing design criteria for the restoration reach based on reference reach characteristics is an iterative process that involves many intricate steps. Several step-by-step design procedures have been developed to help structure this process. These design procedures are beyond the scope of this handbook. For further information, the reader should consult Stream *Restoration: A Natural Channel Design Handbook* produced by the North Carolina Stream Restoration Institute and North Carolina Sea Grant (1999).

Maintenance Recommendations

Natural channel design projects must be carefully monitored after installation. Regardless of the rigor of the design process, natural channel design projects are dynamic entities that change after installation in response to flood events. Typically, monumented cross sections are resurveyed following project installation to determine whether the channel dimension is stable. Changes to the stream's longitudinal profile should also be monitored. Bank stabilization and in-stream structures need to be carefully monitored and maintained. Periodically obtaining photographs at established photo-points throughout the restoration site is a good way to qualitatively assess the stability of the restored channel.

While some changes to the channel form are expected following installation, significant changes to channel size, shape, slope, or pattern may indicate that the stream design is not stable. If this conclusion is reached, redesign of all or part of the channel may be needed to achieve stable conditions.

Cost Considerations

Data from a recent study completed by the North Carolina Wetlands Restoration Program-Division of Water Quality-Department of Environment and Natural Resources (2002) found that the average total cost (including design, permitting, and construction costs) for five large stream restoration projects was $118 per linear foot, with rural projects costing $106 per linear foot and urban projects costing $218 per linear foot. The study also found that per linear foot costs decreased significantly with increasing project size.

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2.7 Riparian Corridor Restoration

Riparian corridor restoration focuses on establishing vegetated buffers along streams and lakes. A riparian buffer is an area of vegetation that is maintained along the shore of a water body to protect stream channels and the banks of streams and lakes. Buffers can reduce the pollutants entering a stream or lake by trapping, filtering and converting sediments, nutrients and other chemicals in runoff from surrounding lands (PA DEP & Alliance for the Chesapeake Bay 1998).

Applicability

Riparian corridor restoration is a watershed best management practice used to establish adequate wooded riparian buffers along streams and lakes. This practice should be implemented after assessing and stabilizing severe stream channel erosion (headcutting) and lake and streambank erosion (USDA NRCS Practice Code 391).

Riparian Buffer
Source: USDA NRCS

The riparian forest buffer is a multi-purpose practice design to accomplish one or more of the following (USDA NRCS Practice Code 391):

- Create shade to lower water temperatures and improve habitat for aquatic animals.
- Provide a source of debris necessary for healthy, robust populations of aquatic organisms and wildlife.
- Act as a buffer to filter out sediment, organic material, fertilizer, pesticides and other pollutants that may adversely impact the water body, including shallow ground water.

Dominant vegetation consists of existing or planted trees and shrubs suited to the site and purpose(s) of the practice. Grasses and forbs that come in naturally further enhance the wildlife habitat and filtering effect of the practice (USDA NRCS Practice Code 391).

Design Considerations

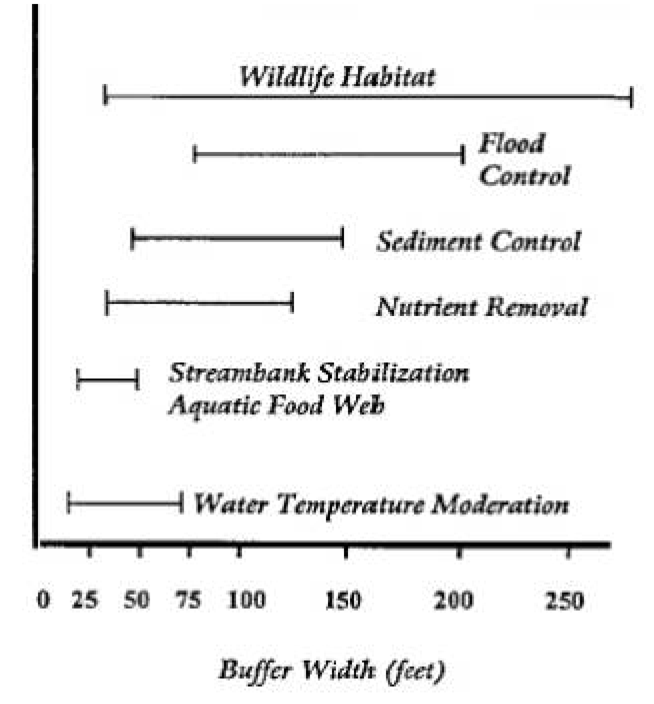

Figure 2.7-1 Range of Minimum Widths for Meeting Specific Buffer Objectives Source: PA DEP & Alliance for the Chesapeake Bay

Buffer width is site specific and dependent on both scientific criteria and landowner objectives. When a scientifically-derived buffer width is reduced because of land use constraints, it's important to recognize that compromises are being made to the long term ecological function of the buffer. For example, when a decision is made to choose warm-season grasses over forest as the target buffer vegetation, reductions in stream stability, flood mitigation, groundwater nutrient removal, and aquatic and terrestrial habitat should be recognized. The most commonly prescribed minimum buffer widths for use in water quality and habitat maintenance are approximately 35 to 100 feet. Buffers of less than 35 feet cannot sustain long-term protection of aquatic resources because they do not contain a "critical mass" or sustainable width that is essential for long-term sediment and nutrient reductions. Buffers that are larger than needed may unnecessarily restrict use of a portion of the land and may burden resources available for establishment and maintenance (PA DEP & Alliance for the Chesapeake Bay 1998).

Riparian buffers should consist of various layers of vegetation (grasses, herbaceous vegetation, shrubs and trees) to achieve optimal benefits. The USDA Forest Service recommends establishing a three-zoned riparian buffer. Zone 1 is the nearest to the streambank and should have a fixed 15-foot width. Plants selected for this zone must exhibit excellent soil stabilizing characteristics and be capable of tolerating wet soil conditions and periodic flooding. Zone 2 should be at least 60 feet wide and is considered a managed forest. Within this zone, trees may be harvested to promote nutrient removal as newly planted trees take up more nitrogen. Zone 3 should be 20 feet wide and consists of dense grasses and forbs to convert concentrated water flow to uniform sheet flow (Alliance for the Chesapeake Bay 1998).

A sample planting scheme for riparian buffers using woody shrubs and trees is shown in Figure 2.7-2. In this figure, shrubs and trees are planted according their overall preference to soil moisture. A comprehensive list of woody plants that are suitable for establishing riparian buffers in Pennsylvania is presented as Table 2.7-1.

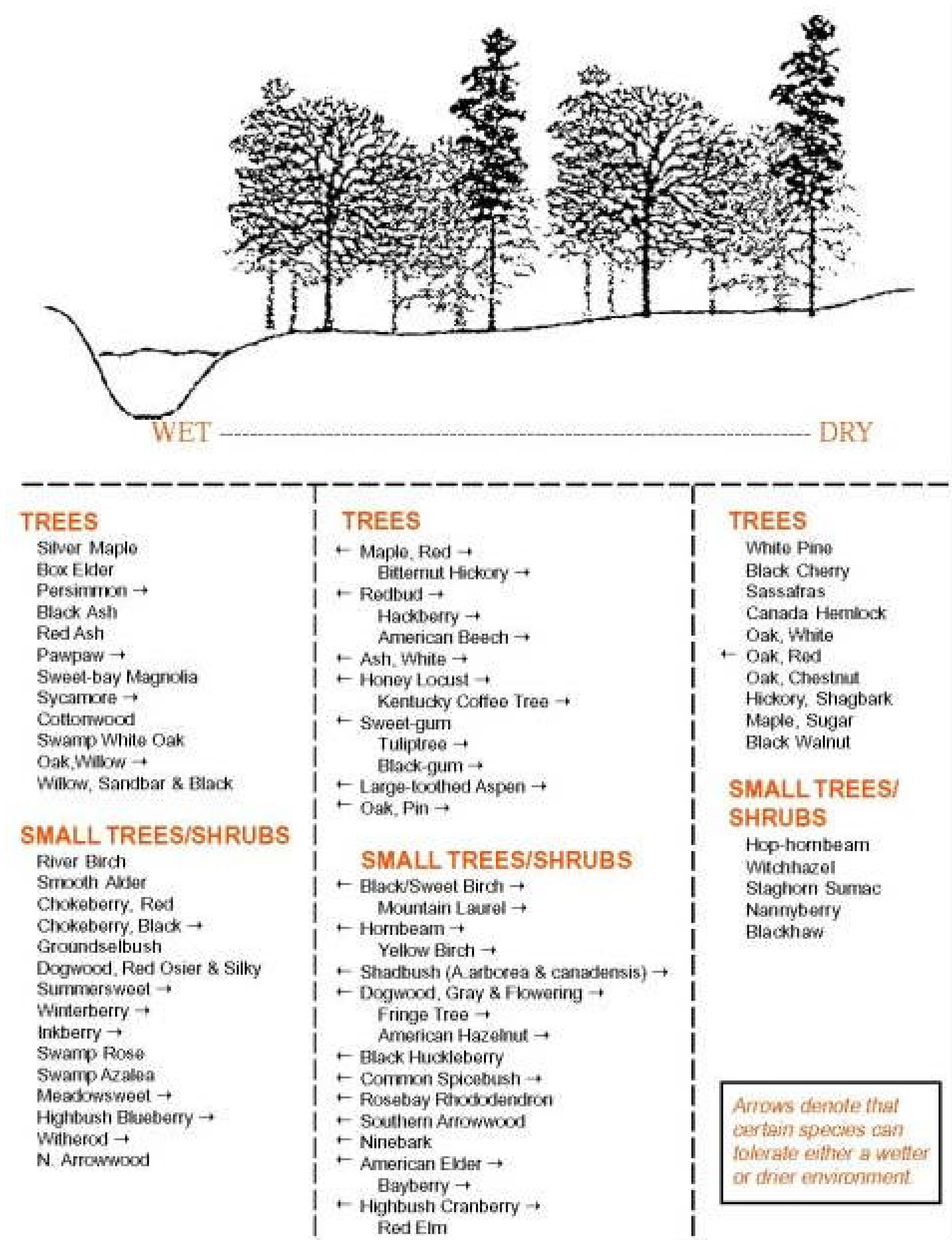

Figure 2.7-2 Sample Planting Recommendations for Riparian Buffers
Source: PA DEP & Alliance for the Chesapeake Bay

Table 2.7-1 Native Riparian Tree and Shrub Plant Selection

Common/ Scientific Name	Region	Hardiness Zone	Soil pH	Flood Tolerance	Height(ft)	Shade Tolerance	Wildlife Value	Economic Value
Red maple *Acer rubrum*	P, R, A	3a	4.5-6.5	tolerant	75-100	tolerant	food source-fruits and young shoots	used in furniture, flooring and grown as an ornamental
+Silver maple *A. saccharinum*	P, R, A	3b	5.5-6.5	tolerant	75-100	intermediate	food source - seeds and young twigs	
Sugar maple *A. saccharum*	R, A	3a	6.0-7.5	intolerant	75-100	very tolerant	food source-seeds and twigs	important lumber source and maple sugar source
Shadbush *Amelanchier arborea (laevis)*	P, R, A	4,5,6		tolerant	15-20	very tolerant	food source-fruit	
*Pawpaw *Asimina triloba*	P, R, A	5b	6.0-8.0	intolerant	20-35	tolerant	food source-fruit	
*Yellow birch *Betula alleghaniensis*	P, R, A			tolerant	60-70	tolerant	moderate value to wildlife - seeds	important source of hardwood lumber
Black (Sweet) birch *B. lenta*	R, A	3b	4.5-5.0	intolerant	50-75	intermediate	food source - catkins, buds, seeds, and twigs	lumber and fuel source
+Hornbeam *Carpinus caroliniana*	P, R, A	2	6.0-7.5	intolerant	35-50	very tolerant	minimal value, food source seeds, buds, catkins and twigs	
*Bitternut hickory *Carya cordiformis*	P, R, A	4a	5.6-8.0	intermediate	75-100	intermediate	bitter nuts not favored as much as other hickories	high value for fuel
Shagbark hickory *C. ovata*	P, R, A	4a	6.0-6.5	intolerant	75-100	intermediate	food source-twigs and nuts	one of the best commercial hickories-lumber source
Redbud *Cercis canadensis*	P, R	5a	6.0-8.0	intolerant	20-35	tolerant	minimal food source-seeds	grown as an ornamental
Hackberry *Celtis occidentalis*	P, R	3a	6.5-8.0	intermediate	75-100	intermediate	food source-fruits and twigs	little importance as timber producer
Flowering dogwood *Cornus florida*	R, A	5b	5.5-6.5	very intolerant	35-50		food source-fruit	Only dogwood important for its wood
Persimmon *Diospyros virginiana*	P	5a	6.0-6.5	intermediate	50-75	intolerant	food source-fruit	yields an inferior grade of lumber

+ Short Lived
Trees < 100 years Shrubs < 20 years

* May be hard to find in a nursery.

Common/ Scientific Name	Region	Hardiness Zone	Soil pH	Flood Tolerance	Height(ft)	Shade Tolerance	Wildlife Value	Economic Value
American beech *Fagus grandifolia*	P, R, A	3b	5.5-6.5	very intolerant	75-100	very tolerant	food source-fruit	wood not durable, but used in some furniture
White ash *Fraxinus americana*	P, R, A	3b	6.0-7.5	intermediate	75-100	tolerant	food source-fruit	wood used for many purposes
*Black ash *F. nigra*	R, A	2	4.5-6.5	very tolerant	50-75	intolerant	food source-fruit	wood used for baskets, furniture
Red ash *F. pennsylvanica*	P, R	2	6.0-7.5	tolerant	50-75	intolerant	minimal food source-twigs and fruits	important lumber tree
Honey-locust *Gleditsia triacanthos*	R, A	4b	6.0-7.5	intermediate	50-75	intolerant	food source - seeds and pods	not widely used as lumber source a thornless variety used for street and shade tree
*Kentucky coffee-tree *Gymnocladus dioica*	A	5a	6.5-7.5	intermediate	75-100	intolerant	low appeal to wildlife	wood used for various purposes, though not abundant
Black walnut *Juglans nigra*	P, R	4b	6.5-8.0	intermediate	75-100	intolerant	food source-twigs and nuts	very important lumber tree
Sweet-gum *Liquidambar styraciflua*	P	6	6.0-6.5	tolerant	75-100	intolerant	low value to wildlife	wood used as veneer in furniture
Tuliptree *Liriodendron tulipifera*	P, R, A	5a	6.0-6.5	intermediate	75-100	intermediate	food source-fruits	very valuable hardwood species
Sweet-bay magnolia *Magnolia virginiana*	P	6a	5.0-6.5	very tolerant	12-20	tolerant	food source-seeds	grown as an ornamental
Black-gum *Nyssa sylvatica*	P, R, A	5a	6.0-6.5	intermediate	50-75	intolerant	food source-fruits and twigs	lumber source
*+Hop-hornbeam *Ostrya virginiana*	P, R	5a	6.0-8.0	very intolerant	35-50	very tolerant	food source-seeds	
Eastern white pine *Pinus strobus*	P, R, A	3b	4.5-6.5	intolerant	75-100	intermediate	high value food source - needles and seeds	formerly a very valuable timber species - grown as an ornamental
Sycamore *Platanus occidentalis*	P, R, A	4a	6.5-8.0	intermediate	75-100	intermediate	moderate value for cover and food source - fruits	very limited commercial value

+ Short Lived
Trees < 100 years Shrubs < 20 years

* May be hard to find in a nursery.

Common/ Scientific Name	Region	Hardiness Zone	Soil pH	Flood Tolerance	Height(ft)	Shade Tolerance	Wildlife Value	Economic Value
*Eastern cottonwood *Populus deltoides*	P, A	3b	6.5-7.5	tolerant	75-100	intolerant	food source-seeds, twigs, buds	softwood used mostly for paper pulp
*Large-toothed aspen *P. grandidentata*	P, R, A	3a	5.0-6.5	intolerant	50-75	very intolerant	food source-seeds	wood is very valuable
Wild black cherry *Prunus serotina*	P, R, A	3b	6.07.5	very intolerant	50-75	intolerant	food source-fruits and twigs	excellent lumber tree
White oak *Quercus alba*	P, R, A	4a	6.0-7.5	intolerant	75-100	intermediate	food source-acorns and twigs	important lumber tree
Swamp white oak *Q. bicolor*	P, R	4a	6.0-6.5	tolerant	75-100	intermediate	food source-acorns and twigs	lumber occasionally used in general construction
*Chestnut oak *Q. montana*	P, R	5a	6.0-6.5	intolerant	50-75	intermediate	food source-acorns and twigs	lumber used for various uses
Pin oak *Q. palustris*	P, R, A	5a	5.5-6.5	tolerant	50-75	intolerant	food source-acorns and twigs	lumber often sold as white oak
*Willow oak *Q. phellos*	P	5,6	<6.0	tolerant	75-100	intermediate	food source-acorns and twigs	important lumber source
Northern red oak *Q. rubra*	P, R, A	5,6		intermediate	75-100	intermediate	medium value for nesting, food source	only willow of any commercial value
*Sandbar willow *Salix exigua*	P, R, A			very tolerant	15-20	very intolerant	food source-fruits and twigs	
+Black willow *S. nigra*	P, R, A	3a	7.5-8.0	very tolerant	35-50	very intolerant	food source-buds, fruit, and twigs	excellent for wicker baskets and furniture
Sassafras *Sassafras albidum*	P, R, A	5b	6.0-6.5	very intolerant	35-50	intolerant	food source-twigs and fruits	poor quality wood used occasionally
*American basswood *Tilia americana*	P, R, A	3a	6.5-7.5	intolerant	75-100	tolerant	food source-twigs and seeds	important timber tree and for paper pulp
Canada hemlock *Tsuga canadensis*	P, R, A	3b	4.5-6.5	intolerant	75-100	very tolerant	food source - seeds, twigs, needles and bark	poor quality wood used occassionaly for pulp
*Red (Slippery) elm *Ulmus rubra*	P, R, A			tolerant	50-80	intermediate	food source - seeds and twigs	wood inferior to American Elm but used for furniture and paneling

+ Short Lived
Trees < 100 years Shrubs < 20 years

* May be hard to find in a nursery.

SMALL TREES/ SHRUBS	Region	Hardiness Zone	Soil pH	Flood Tolerance	Height(ft)	Shade Tolerance	Wildlife Value	Economic Value
*Smooth alder *Alnus serrulata*	P, R, A	5a	5.5-7.5	very tolerant	12-20	very intolerant	food source-fruit	
Serviceberry *Amelanchier canadensis*	P, R, A	3a	6.0-6.5	intolerant	5-25	very tolerant	food source-fruit, twigs, and leaves	grown as an ornamental
Red chokeberry *Aronia arbutifolia*	P, R, A	4b	5.0-6.5	very tolerant	6-12	intermediate	very low wildlife value	
Black chokeberry *A. melanocarpa*	P, R, A	3a	5.0-6.5	very tolerant	3-6	intermediate	food source-seeds and twigs	
*Groundsel-bush *Baccharis halimifolia*	P	4a	7.0-8.5	very tolerant	6-12	very intolerant	little value to wildlife	
Buttonbush *Cephalanthus occidentalis*	P, R, A	4a	6.0-8.5	very tolerant	6-12	very intolerant	food source-fruit	
Fringe tree *Chionanthus virginicus*	P	5b	4.5-6.5	intolerant	20-35	very tolerant	food source-fruit	grown as an ornamental
Summersweet *Clethra alnifolia*	P	4a	4.5-6.5	very tolerant	6-12	tolerant	food source-fruits and twigs	grown as an ornamental
Silky dogwood *Cornus amomum*	P, R, A	4a	6.0-7.5	very tolerant	6-12	intolerant	food source-fruits	
Grey dogwood *C. racemosa*	P, R, A	3a	6.0-8.5	intermediate	6-12	tolerant		
Red-osier dogwood *C. sericea*	P, R, A	2	6.0-8.5	very tolerant	6-12	very intolerant	food source-fruits, buds, and twigs	
*Amer. hazelnut *Corylus americana*	P, R, A	3a	6.0-7.5	intolerant	6-12	tolerant	food source-nuts	
*Black huckleberry *Gaylussacia baccata*	P, R, A		< 6.0	intolerant	1-3		food source - fruits	
Witchhazel *Hamamelis virginiana*	P, R, A	5a	6.0-6.5	intolerant	20-35	very tolerant	low value to wildlife; leaves toxic to some animals	

+ Short Lived
Trees < 100 years Shrubs < 20 years

* May be hard to find in a nursery.

SMALL TREES/ SHRUBS	Region	Hardi ness Zone	Soil pH	Flood Tolerance	Height(ft)	Shade Tolerance	Wildlife Value	Economic Value
Inkberry *Ilex glabra*	P	4a	4.5-6.0	very tolerant	6-12	tolerant	high value for food source - fruits	
Winterberry *I. verticillata*	P, R, A	3b	4.5-6.0	very tolerant	6-12	intermediate	intermediate wildlife value	
Mountain laurel *Kalmia latifolia*	P, R, A	5a	4.5-6.0	intolerant	12-20	very tolerant	high value as food esp. for winter browse for deer	
Common spicebush *Lindera benzoin*	P, R, A	5a	4.5-6.5	intermediate	6-12	very tolerant	low value as food source - fruits	
Bayberry *Myrica pennsylvanica*	P, R	4b	5.0-6.5	very tolerant	6-12	intolerant	food source - fruits	
*Ninebark *Physocarpus opulifolius*	P, R, A	2	6.0-8.5	very tolerant	6-12	intolerant	food source-fruit	
Rosebay rhododendron *Rhododendron maximum*	P, R, A	3b	4.5-6.0	tolerant	20-35	intolerant	food source-buds and twigs (winter browse)	
*Swamp azalea *R. viscosum*	P	4a	4.0-6.0	very tolerant	6-12	intermediate		
Staghorn sumac *Rhus typhina*	P, R, A	3a	6.0-7.0	intolerant	35-50	very tolerant	food source-fruit	
*Swamp rose *Rosa palustris*	P, R, A		5.5 - 8.0	very tolerant	4-10		food source-fruit	
American elder *Sambucus canadensis*	P, R, A	3a	6.1-7.5	very tolerant	6-12	very tolerant	food source-fruit	
Meadowsweet *Spiraea latifolia*	P, A	3a	6.5-7.5	very tolerant	3-6	intermediate	food source-fruit and twigs	
Highbush blueberry *Vaccinium corymbosum*	P	4b	3.5-6.0	very tolerant	6-12	tolerant	food source-fruit	commercial food crop

+ Short Lived
Trees < 100 years Shrubs < 20 years

* May be hard to find in a nursery.

SMALL TREES/ SHRUBS	Region	Hardi ness Zone	Soil pH	Flood Tolerance	Height(ft)	Shade Tolerance	Wildlife Value	Economic Value
*Wither-rod *Viburnum cassinoides*	P, R, A	2	5.0-6.5	very tolerant	6-12	tolerant	foof source - fruit	
Southern arrowwood *V. dentatum*	P	3a	5.0-6.5	tolerant	6-12	tolerant	food source-fruit	
Nannyberry *V. lentago*	P, A	2	6.0-7.5	intolerant	20-35	intermediate	food source - fruit & twigs	
Blackhaw *V. prunifolium*	P, R, A	3b	6.5-8.0	very intolerant	20-35	intolerant	food source - fruit	
*Northern arrowwood *V. regonitum*	P, R, A			tolerant	6-12	tolerant	food source - fruit	
Highbush cranberry *V. trilobum*	R	2	6.5-7.5	tolerant	6-12	very tolerant	food source - fruit	

+ Short Lived
Trees < 100 years Shrubs < 20 years

* May be hard to find in a nursery.

Source: PA DEP & Alliance for the Chesapeake Bay

The best way to reduce the maintenance activities and therefore the costs of a riparian buffer is to tailor the buffer plantings to the specific needs of the site. Planting native vegetation rated for the proper climatological zone and site conditions will improve the chances of seedling survival. Incorporating wildlife-resistant, salt-resistant, flood-tolerant, shade-tolerant, and/or disease-resistant plantings can be helpful, depending on the location and function of a given buffer. A good list of native plants recommended for riparian buffers, as well as planting information and a guide to native plant nurseries can be found in the appendices of the

Chesapeake Bay Local Assistance Department's Riparian Buffer Guidance Manual, at http://www.cblad.state.va.us/news_events_publications.cfm.

Maintenance Recommendations

A newly-planted riparian buffer is more fragile than one might realize, requiring a certain amount of maintenance during the initial growing season. Frequent inspection of a newly-planted riparian buffer is imperative, especially after large storms. The inspection should include watching for damage to fences, the formation of gullies, weed problems (especially invasive weed colonization), wildlife damage, insect and disease problems, and bank erosion. In addition, depending on the weather, the new plantings may need to be watered periodically during the first growing season.

Weed control is essential for the survival and rapid growth of trees and shrubs in a buffer during the first year. In particular, any invasive weeds seen colonizing the buffer area should be immediately removed before a large stand becomes established. Weed control options include applying 4 to 6 inches of organic mulch, using weed control fabrics, and mowing. Chemical weed control techniques are not recommended in most cases because chemicals can quickly enter the water system in riparian areas. Weed control should continue until woody plants are well established, normally 2 to 3 years. In some cases, prescribed burns will help control weeds and rejuvenate native grasses. During the life of the riparian buffer, tree seedlings will begin to compete with each other. In order to maintain an optimal growth rate, trees should be pruned and trimmed regularly.

Wildlife, even native wildlife such as beavers, muskrats, and deer, can be particularly problematic to newly-established riparian buffers. Repellants and fencing may be the best option for short-term nuisance wildlife control while the buffer is being established. If long-term control is necessary, more aggressive management techniques such as hunting, trapping, and physical exclusion methods may be necessary. The long-term management method should be tailored to the particular problem at a given site, but in general, a reduction in the local population of the nuisance animal will be required.

Over time, if the buffer is located in an area of high sediment loadings, sediments may accumulate in the buffer, creating a small berm between the buffer and the field edge. The berm will eventually prevent field runoff from flowing through the buffer and cause runoff to flow parallel to the buffer instead. Where this occurs, accumulated sediments should be removed and the area regraded and reseeded.

Cost Considerations

The unit cost for establishing riparian buffers is quite variable and depends highly on the type of plant materials used. The least expensive approach is to use seedlings and bare root stock, while the more expensive approach is to install plants as balled and burlapped (B&B) or large container stock. Seedlings are typically planted at 6 to 10 feet spacing or roughly 700 seedlings per acre. Bare root stock are generally planted 14 to 16 feet apart or about 200 plants per acre when the bare root plants are several feet in height and around ¾ inches in diameter. Balled and burlapped or large containerized plants are planted 16 to 18 feet apart or approximately 150 plants per acre (PA DEP & Alliance for the Chesapeake Bay 1998).

Tree Seedlings and Tree Tubes Installed along the Shawnee Branch in Bedford County. Source: Edward Molesky, Aqua-Link, Inc.

For comparison, unit cost estimates to install the various materials are as follow: $120 to $ 495 per acre for seedlings, $575 to $1,500 per acre for bare root stock and $2,700 to $7,500 per acre for balled & burlapped (B&B) and container stock (PA DEP & Alliance for the Chesapeake Bay 1998). The above costs do not include any costs associated with developing a riparian design plan, fencing, tree shelters (tubes) or maintenance (mowing or herbicide treatments). It should be noted that cost sharing is often available for implementing this watershed best management practices. For more information, contact the local USDA NRCS or county conservation district offices.

References

Chesapeake Bay Local Assistance Department. 2003. Riparian Buffer Modification & Mitigation Guidance Manual. Richmond, VA. Website: http://www.cblad.state.va.us/ripbuffstat.cfm.

Pennsylvania Department of Environmental Protection and the Alliance for the Chesapeake Bay. 1998. Stream Releaf Forest Buffer Toolkit.

United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS). Practice Code 391. Website: www.ftw.nrcs.usda.gov.

2.8 Terrestrial Invasive Plant Management

Terrestrial invasive plant management is a best management practice that is implemented in order to control the unwanted spread of aggressive plants in riparian areas. Invasive plants are generally undesirable because they are difficult to control, can escape from cultivation, and can dominate entire areas, threatening natural ecosystems. This section specifically addresses the practice of terrestrial invasive plant management; Section 1.12 addresses aquatic invasive plant management. Several invasive aquatic animal species are discussed in Section 1.10.

Applicability

Invasive plant management (also known as exotic plant management) is a best management practice that should be implemented whenever such species are detected. Terrestrial invasive plant management is especially critical to address shortly after bioretention systems, wet ponds and constructed wetlands have been constructed or streambanks and riparian corridors have been either stabilized or restored. If the invasion of exotics is ignored, installed native plants may be overtaken by more aggressive, less desirable, nuisance vegetation.

Purple Loosestrife invading the shoreline of Silver Lake in Bucks County. Source: Edward Molesky, Aqua-Link, Inc.

The term “invasive” plant refers to a plant species that has become a weed pest, growing aggressively and displacing other plants. Invasive plants tend to appear first on disturbed ground, but many will invade existing ecosystems over time. Invasive plant infestations can be extremely expensive to control, as well as environmentally destructive. A small number of invasives are "native," meaning they occurred in Pennsylvania before settlement by Europeans but became aggressive after the landscape was altered. However, most invasive plants arrived from other continents and are often referred to as "exotic," "alien," “introduced," or "non-native" invasives. An aggressive plant freed from its environmental, pest, and disease limits, can invade other ecosystems (PA DCNR website).

Table 2.8-1 provides a list of exotic invasive plant species common to the Mid-Atlantic Region of the U.S, which includes Pennsylvania.

Table 2.8-1 List of Common Terrestrial Invasive Plants	
Herbaceous Plants	
Garlic mustard (*Alliaria petiolata*) Japanese knotweed (*Polygonum cuspidatum*) Japanese stiltgrass (*Microstegium vimineum*) Lesser celandine (*Ranunculus ficaria*) Purple loosestrife (*Lythrum salicaria*) Bamboos, exotic (*Bambusa, Phyllostachys & Pseudosassa* species) Canada thistle (*Cirsium arvense*)	Chinese lespedeza (*Lespedeza cuneata*) Chinese silver grass (*Miscanthus sinensis*) Common daylily (*Hemerocallis fulva*) Common reed (*Phragmites australis*) Giant hogweed (*Heracleum mantegazzianum*) Giant reed, wild cane (*Arundo donax*) Marsh dewflower (*Murdannia keisak*) Spotted knapweed (*Centaurea biebersteinii*)
Shrubs	
Autumn olive (*Elaeagnus umbellata*) Bush honeysuckles, exotic (*Lonicera species*) Japanese barberry (*Berberis thunbergii*) Multiflora rose (*Rosa multiflora*) Privets (*Ligustrum species*) Wineberry (*Rubus phoenicolasius*)	Winged burning bush (*Euonymus alata*) Butterfly bush (*Buddleja species*) Japanese spiraea, Japanese meadowsweet (*Spiraea japonica*) Jetbead (*Rhodotypos scandens*)
Trees	
Bradford pear (*Pyrus calleryana*) Norway maple (*Acer platanoides*) Princess tree (*Paulownia tomentosa*) Tree of Heaven (*Ailanthus altissima*)	Silk tree, mimosa tree (*Albizia julibrissin*) Paper mulberry (*Broussonetia papyrifera*) White mulberry (*Morus alba*)
Vines	
English ivy (*Hedera helix*) Kudzu (*Pueraria montana v. lobata*) Mile-a-minute (*Polygonum perfoliatum*) Oriental bittersweet (*Celastrus orbiculatus*) Porcelainberry (*Ampelopsis brevipedunculata*) Wisterias, exotic (Wisteria sinensis, *W. floribunda*)	Creeping euonymus (*Euonymus fortunei*) Five-leaved akebia (*Akebia quinata*) Japanese honeysuckle (*Lonicera japonica*) Louis' swallowwort (*Cynanchum louiseae*) Periwinkle (*Vinca minor*)

Source: Swearingen et al. 2002

Humans introduce exotic plants to new areas through a variety of means. Some species were introduced purposefully for use in gardening and landscaping, erosion control, forage or other purposes. For instance, in the 1930s, the Civilian Conservation Corps planted kudzu vine (introduced from Japan), throughout the Southeast to help stabilize soil in erodible areas. Kudzu grew so prolifically that it was nicknamed the "vine that ate the South." Other invasive plants were introduced accidentally on various imported products or in soil, water and other materials used for ship ballast. Once established in a new environment, these exotic species may proliferate and expand over large areas, becoming invasive pests (Swearingen et al, 2002).

Invasive terrestrial plants spread by seed, vegetative growth (producing new plants from rhizomes, shoots, tubers, etc.) or both. Seeds, roots and other plant fragments are often dispersed by wind, water and wildlife. Animals spread invasive plants by consuming fruits and depositing seeds as well as transporting seeds on their feet and fur. People also help spread invasive plants by carrying seeds and other plant parts on shoes, clothing and equipment and by using contaminated fill dirt and mulch (Swearingen et al. 2002).

Invasive plants can be very problematic in natural areas. Like an invading army, invasive plants take over and degrade natural ecosystems. They disrupt the intricate web of life for plants, animals, and microorganisms, and compete for limited natural resources. Invasive plants impact nature in many ways, including growing and spreading rapidly over large areas, displacing native plants including some very rare species, reducing food and shelter for native wildlife; eliminating host plants of native insects, and competing for native plant pollinators. Some invasives spread so rapidly that they exclude most other plants, changing a forest, meadow, or wetland into a landscape dominated by one species. Such "monocultures" (stands of a single plant species) have little ecological value and greatly reduce the natural biological diversity of an area (Swearingen et al. 2002).

Invasive Species Prevention and Control

Methods designed to prevent or control invasive species are separated into four categories: cultural, biological, mechanical, and chemical. Determination of the most suitable control method depends on several variables, including the species involved, the nature of the invasion, the condition of the surrounding environment, and the management objectives for the area in question. In some instances, several control methods may be combined such as cutting followed by a chemical application to inhibit re-sprouting (WI DNR Website).

- Cultural control involves the modification of human behavior both within and around natural areas. Recreational and other land uses that contribute to the introduction and proliferation of invasive species should be discouraged in these areas. A monitoring program should be implemented to identify species invasions before they become a significant problem.

- Biological control uses a plant's natural phytophagous (plant-eating) enemies to control the species population. Highly host-specific predators must be used in order to reduce negative impacts on non-target species. Biological control insects for leafy spurge (*Euphorbia esula*), purple loosestrife (*Lythrum salicaria*), and spotted knapweed (*Centauria maculosa*) have been released on an experimental basis.

- Mechanical control methods include prescribed burning, mowing, cutting, girdling, and other methods that physically remove the target species. Control methods that imitate natural processes (such as prescribed burning in a fire-adapted community) are preferable to other tactics. Whatever the control method, it should be tailored to fit the environment, the targeted plant species, and the management goals for the community. Because disturbance provides fertile ground for invasive species, it should be minimized.

- Chemical controls may be justified when invasive species are severely degrading the natural community, or when effective non-chemical control methods are not known or do not adequately curb invasive species populations.

The Pennsylvania Department of Conservation and Natural Resources has created a list of actions that individuals can take to prevent the spread of invasive plant species (PA DCNR website). Items on this list are:

- Minimize landscape disturbance. Invasive plants thrive on bare soil and disturbed ground where the native plant community has been displaced. The key to controlling invasives is to protect healthy native plant communities.

- Use fertilizers wisely. Proper site preparation begins with a soil test before applying fertilizer. High nitrogen levels sometimes give an advantage to invasive species that are better adapted to using plentiful nutrients for explosive growth. For soil fertility, try using organic, slow-decomposing compost and mulches.

- Remove invasives before they are a problem. Effective scouting allows problems to be found while they are still small and easily controllable. For instance, do not let invasive plants go to seed. Mechanical removal through digging or cutting is preferred. Large populations of invasives may need to be stopped chemically with spot applications of herbicide by trained individuals or by homeowners carefully following label instructions.

- Replace invasive plants with native or noninvasive species. Invasives are good at exploiting bare soil and empty niches. When an invasive plant is removed, unless there is another plant substituted, the invasive will tend to come right back. What grows in the future depends largely on what is there now; so it is important to fill that niche with a desirable plant that will provide seed for the future.

- Remove invasives when their densities are low. Invasive plant control works best where a functioning native plant community still exists that can colonize the empty niche.

Maintenance Recommendations

Have a land management plan for maintenance over time. When designing a property, plan for future maintenance. Lawns are maintained by weekly mowing, while gardens are often hand-weeded. Meadows in Pennsylvania may need to be mowed every year. Woodlands are probably the lowest-maintenance landscape, but they too will need to be monitored and invasive plants removed. Scout the property annually for invasives or other problems. The best way to control invasives is prevention, and prevention can only happen through vigilance.

Cost Considerations

Terrestrial invasive plant management is often a very labor-intensive practice. The overall cost of the practice is highly variable and largely depends upon what control method is selected and whether volunteer assistance will be provided. It should be noted that the use of any chemical or biological controls may require approved permits from the appropriate local, state and/or federal agencies. These agencies should be contacted well in advance of implementing the practice, especially if the use of these control methods on public lands is being considered.

References

Pennsylvania Department of Conservation and Natural Resources. Invasive Plants in Pennsylvania. Website: http://www.dcnr.state.pa.us/forestry/wildplant/invasive.

Swearingen, J., K. Reshetiloff, B. Slattery, and S. Zwicker. 2002. Plant Invaders of Mid-Atlantic Natural Areas. National Park Service and U.S. Fish & Wildlife Service, 82 pp.

Wisconsin Department of Natural Resources. Wisconsin's Invasive Plants. Website: http://www.dnr.state.wi.us/org/land/er/invasive.

2.9 Construction Erosion and Sediment Pollution Control

Construction erosion and sediment pollution control methods are designed to protect nearby waters by controlling accelerated soil erosion from construction sites using applicable construction best management practices. An Erosion and Sediment Control Plan (E&S Plan) and National Pollutant Discharge Elimination System (NPDES) permit may be required for construction projects depending upon the overall size of the project. Any construction project that disturbs more than one acre of land requires a NPDES permit under the 2003 Federal Stormwater Phase II NPDES regulations.

Sediment-laden surface runoff generated at an active construction site (left). Surface runoff flowing into storm drain, which discharges directly into nearby stream (right). Source: Edward Molesky of Aqua-Link, Inc.

Excessive sediments transported to streams and lakes are harmful because of the following (PA DEP 2003a):

- Fish gills, which extract dissolved oxygen from the water, can become clogged when the water transports excessive amounts of sediment.
- Sediment can cover fish eggs within their nests.
- Sediment can destroy the food supply for many species of fish by covering aquatic insect habitat on the stream bottom.
- Sediment clouds the water and deprives plants of light needed for photosynthesis.
- Sediment may carry other pollutants such as heavy metals, pesticides and excess nutrients that are spread by water action and cause problems not only at the source, but also downstream.

- Sediment contains nutrients such as phosphorus that can provide fuel for algae blooms and excessive aquatic plant growth in downstream water bodies.

- Sediment increases public drinking water treatment costs or may render unfiltered drinking water supplies harmful for consumption.

- Excess sediment deposits in streams and rivers may necessitate the dredging of a reservoir or other body of water.

Applicability

Under Chapter 102 of Title 25 of the Pennsylvania Code and the Pennsylvania Clean Streams Law, anyone conducting earth disturbance activities must use Best Management Practices (BMPs) to minimize the amount of sediment leaving the earth disturbance activity and polluting the waters of the Commonwealth. The Pennsylvania Department of Environmental Protection (DEP) is responsible for the administration and enforcement of Chapter 102 regulations. As per the amended Chapter 102 Erosion and Sediment Control regulations (January 2000), development of an Erosion and Sediment Control Plan is required for all earth disturbances of 5,000 square feet or greater, for earth disturbances in High Quality or Exceptional Value watersheds, or if required by other PA DEP permits pertaining to the project. Projects which involve earth disturbance but do not meet the above requirements are still required to develop, implement, and maintain erosion and sediment control BMPs. They are only exempt from preparing a written Erosion and Sediment Control Plan.

The PA DEP has delegated the administration and enforcement of Chapter 102 Erosion and Sediment Control regulations to County Conservation Districts with trained staff. Every county in Pennsylvania has a County Conservation District office except Philadelphia County. A list of County Conservation District offices can be found on the Pennsylvania Association of Conservation Districts website at http://www.pacd.org/districts/directory.htm. The County Conservation Districts are responsible for reviewing and approving Erosion and Sediment Control Plans, performing site inspections, and in some cases, conducting compliance and enforcement actions. Failure to have an Erosion and Sediment Control plan on site where required is a violation of Chapter 102 Erosion and Sediment Control regulations and both landowners and their contractors may be held responsible for this violation.

Along with County Conservation Districts, PA DEP staff conduct periodic inspections of earth disturbance project sites to ensure that Erosion and Sediment Control Plans are properly implemented and maintained. Individuals implementing an Erosion and Sediment Control Plan are also responsible for conducting routine site inspections and maintenance to ensure that BMPs are operational and effective and to minimize the potential for sediment pollution or other off-site impacts. If sediment pollution is occurring, or if there is evidence that sediment pollution has occurred due to an on-going earth disturbance activity, individuals should contact the County Conservation District.

Any project with earth disturbance activities greater than one acre that have a point source discharge to a surface water of the Commonwealth requires a National Pollutant Discharge Elimination System (NPDES) permit for stormwater discharges under the Clean Water Act. There are two kinds of NPDES Permits: General and Individual. Any activity that disturbs greater than one but less than five acres of land requires a General NPDES Permit. Projects that disturb greater than five acres of land, projects that are located in special protection watersheds, activities that will alter existing water quality standards, and activities that may result in pollutant or toxic discharges do not qualify for coverage under a General NPDES Permit and must obtain coverage under an Individual NPDES Permit. The Notice of Intent (NOI) for a NPDES general permit should be submitted to the PA DEP at least 30 days prior to the anticipated start date of the project to ensure adequate time for reviewing and processing. Processing time for a General Permit is largely dependant upon the complexity and thoroughness of the application and Erosion and Sediment Control Plan. Individual Permits are generally more complex and processing time is typically 90 to 120 days. A pre-application meeting between the project applicant, consultant, County Conservation District, and PA DEP is recommended for Individual Permits.

For more information about Erosion and Sediment Control Plans and NPDES Permits, contact the local County Conservation District or the PA DEP regional office. PA DEP regional office contact information is provided in the Regulatory Status section in the Introduction of this handbook.

Design Considerations

An Erosion and Sediment Control Plan that meets the Chapter 102 requirements must be properly designed, implemented, and available on site for all earth disturbance activities. The Plan must show how land and water resources are to be protected against accelerated erosion through the use of BMPs. Examples of BMPs include: silt fence, mulch, diversion ditches, sediment traps, sediment basins, and the establishment of grasses or other BMPs for permanent stabilization. The plan must show the site, location of BMPs, and the timing and sequence of their installation for maximum effectiveness. County Conservation Districts are able to provide guidance for plan development (PA DEP 2003a).

Well maintained silt fence
Source: Edward Molesky, Aqua-Link, Inc.

Cost Considerations

The cost for developing and implementing an Erosion and Sediment Control Plan will highly depend upon the size of the project and specific site conditions. An additional cost may include preparing and submitting a NPDES permit if applicable. Check with the local conservation district for a list of fees for reviewing Erosion and Sediment Control Plans and the application fees for General and Individual NPDES Permits.

References

Clearfield County Conservation District Website: http://www.clfdccd.com/erosion.

Pennsylvania Department of Environmental Protection, Office of Water Management. 2000. Erosion and Sediment Pollution Control Manual. Document No. 363-2134-008.

Pennsylvania Department of Environmental Protection. 2003a. Minimizing Accelerated Soil Erosion and Preventing Sediment Pollution. Fact Sheet 3930-FS-DEP-1841.

Pennsylvania Department of Environmental Protection. 2003b.NPDES Permits for Stormwater Discharges Associated with Construction Activities. Fact Sheet 3930-FS-DEP-3042.

2.10 Dirt and Gravel Road Management

Unpaved roadways are known sources of nutrient and sediment pollution to rivers, lakes, and ponds. Improper road surface drainage, improper placement and maintenance of stream crossings and generally poor construction of dirt and gravel roads can cause significant environmental degradation. Municipalities owning and maintaining local unpaved roads may benefit from Pennsylvania's "Dirt and Gravel Road Pollution Prevention Program" which was signed into law in April 1997 as Section 9106 of the Pennsylvania Vehicle Code (§9106) creating funding to local communities for local road maintenance.

The Center for Dirt and Gravel Road Studies is contracted by the Pennsylvania State Conservation Commission (SCC) to coordinate the program, which is administered through the individual County Conservation Districts. Although funding opportunities from this program are limited to municipal roads, private road owners may find solutions through the program for improving unpaved roads and reducing sediment pollution. Contact the local County Conservation District for information on the Dirt and Gravel Road Program. A list of contact information for Pennsylvania County Conservation Districts can be found at http://www.pacd.org/districts/directory.htm.

Applicability

Properly constructed and maintained dirt road with well-vegetated road edges
Source: Center for Dirt and Gravel Road Studies

Dirt and gravel roads should be properly constructed and maintained so that sediment does not enter waterways. Roads should be graded and the road edges well vegetated. Properly sized culverts at stream crossings and under driveways and cross streets are imperative, as well as adequate roadside drainage structures. Dirt and gravel roads should be carefully planned and sited before construction begins, avoiding steep slopes, rocky terrain and any bodies of water. Permits are required by the Pennsylvania Department of Environmental Protection to build roads across streams or wetlands. A sufficient vegetated buffer should be maintained between roadways and waterways. When possible, roads should be designed to parallel the contours of the land. This will avoid expensive grading and potential drainage and road wash-out problems.

Design Considerations

Before the final road surface can be placed, the following rough grading and installations must be completed.

1. Clear and grub only the land that is necessary to accommodate the width of the desired road surface and appropriate side drainage swales.

2. Fine grade or place fill to provide a rough yet relatively flat sub-grade. Avoid creating entrenched or sunken road beds (Figure 2.10-1). The base of the road should sit a few inches below the adjacent landscape. After the final driving surface aggregate is spread and compacted, the road should sit slightly higher than the surrounding land allowing proper drainage off the road to infiltrate into the ground.

3. Prepare under-drainages (e.g., culverts at stream crossings) and surface drainage structures (e.g., broad-based dips, grade breaks, crown). The proper crown is pre-established by creating a ½ to ¾ inch fall per foot with the high point typically in the center of the road.

4. Prepare drain areas including diversion and collection swales, parallel ditches, turnouts and discharge ditches.

5. Upon completion of the dirt and gravel road project, all disturbed areas should be quickly stabilized with native vegetation.

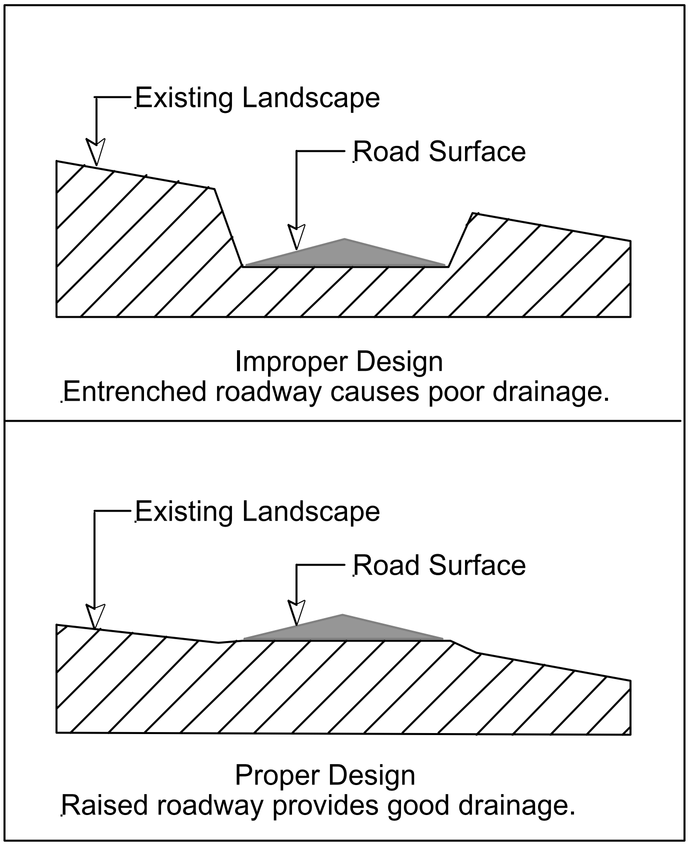

Figure 2.10-1 Road Design

The driving surface should consist of specially formulated quarry aggregates that are compacted to provide a smooth driving surface. Known as a Driving Surface Aggregate (DSA), Penn State University's Center for Dirt and Gravel Road Studies has developed specifications and formulations of aggregate road surfaces that have proven to be stable road surfaces recommended for the Dirt and Gravel Road Pollution Prevention Program. Components of the aggregate mix are derived from crushed parent rock material free of clay or silt soil. Aggregate should be in the range of pH 6 to pH 12.45. The driving surface aggregate should have a nominal diameter of 1½ inches. The driving surface aggregate is best placed with a "paver" typically used for applying asphalt on highways. However, the traditional method of "tailgating" is more economical and most times the only means of application. Tailgating consists of dumping the aggregate from the tailgate of a truck directly to the road surface in a uniform and consistent spread. A small bulldozer follows behind to spread the aggregate to a depth of eight inches. An environmentally sound stabilizing agent may be incorporated into the DSA to bond the aggregate together to form a more compact and durable road surface. The aggregate is then compacted to a depth of six inches by a 10-ton roller or equivalent, or frequent passes by a truck with sufficient weight and smooth tires. A highly compacted aggregate will withstand the forces of traffic and be more erosion resistant.

The following BMPs should be incorporated into dirt and gravel road designs where applicable.

Grade Breaks

Grade breaks are small, intentional increases in road elevation on downhill slopes, which cause water to flow from the road surface into side ditches or drainage areas. The purpose of a grade break is to prevent erosion of road materials caused by the build up of water volume and velocity in travel lanes. This reduces road maintenance expenses and sedimentation to nearby waterbodies. Grade breaks also aid in calming traffic speeds.

Grade breaks should be used on any sloping section of roadway that has evidence of water velocity damage to the surface (Figure 2.10-2). Grade breaks should be located before stream crossings to force road surface drainage into turnouts or vegetated buffers. Conversely, grade breaks should be placed just before cross drain pipes to direct flow into side ditches leading to the head of a cross pipe. Grade breaks should be spaced at intervals frequent enough to prevent a concentration of water on the road surface that will cause erosion of road surface materials. The steeper the grade, the closer together grade breaks should be located. A bulldozer is the preferred equipment used to construct grade breaks, but a grader or small tractor equipped with a front loader or small backhoe will work for smaller applications. Grade breaks should be built with gradual grade changes so as to avoid bottoming-out of car's undercarriages. Gradually taper the edges of a grade break back into the road grade and always maintain the road's crown (high point in center of road).

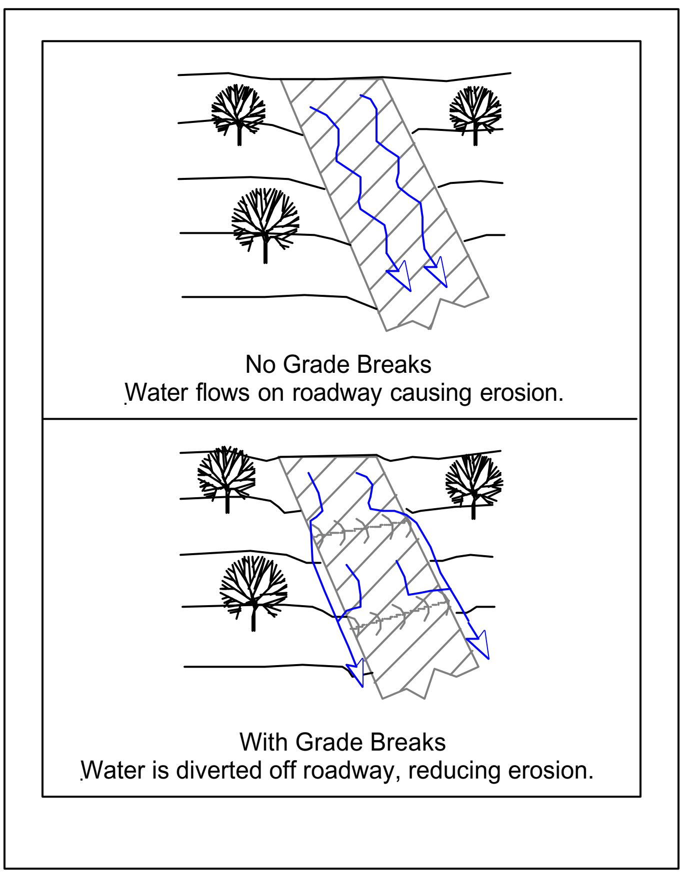

Figure 2.10-2 Grade Breaks

Broad Based Dips

A broad based dip conveys water from an uphill road ditch, across the road surface and into a discharge area on the lower side of the road (Figure 2.10-3). Broad based dips are better suited on gradual side-hill slopes where the roadway is relatively level and not on a steep incline or decline. Broad based dips are effective where a significant amount of runoff is not expected and gradual sheet flow across a road will not cause erosion of the road surface.

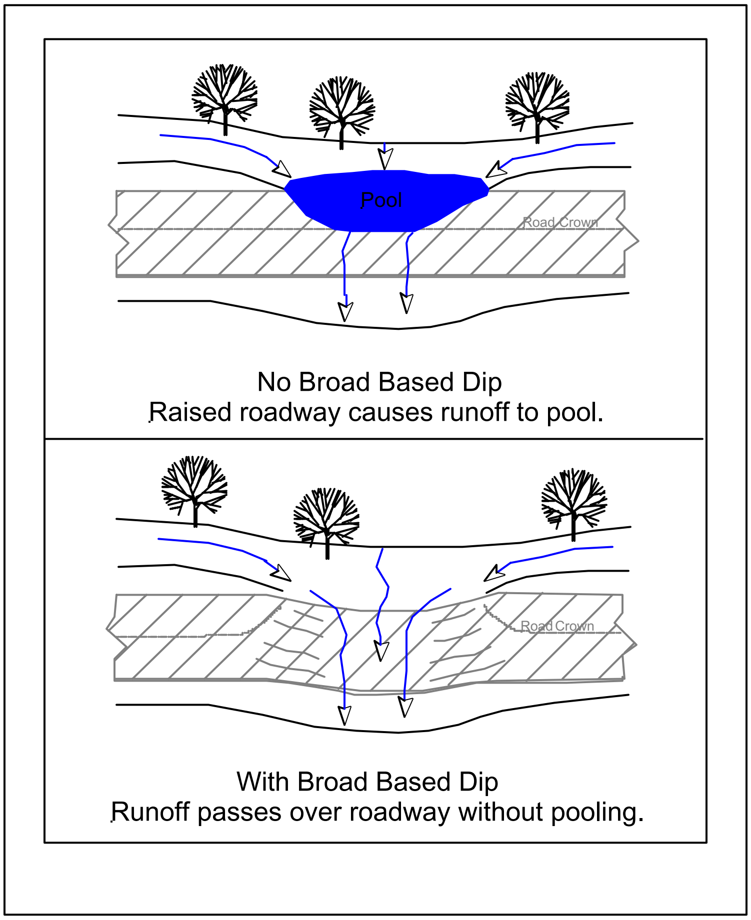

Figure 2.10-3 Broad Based Dips

French Mattress

The French Mattress structure is a relatively new design developed by the Penn State University Center for Dirt and Gravel Roads Studies. If use this type of structure is planned, it is highly recommended to consult with the Center for Dirt & Gravel Road Studies early in the planning process.

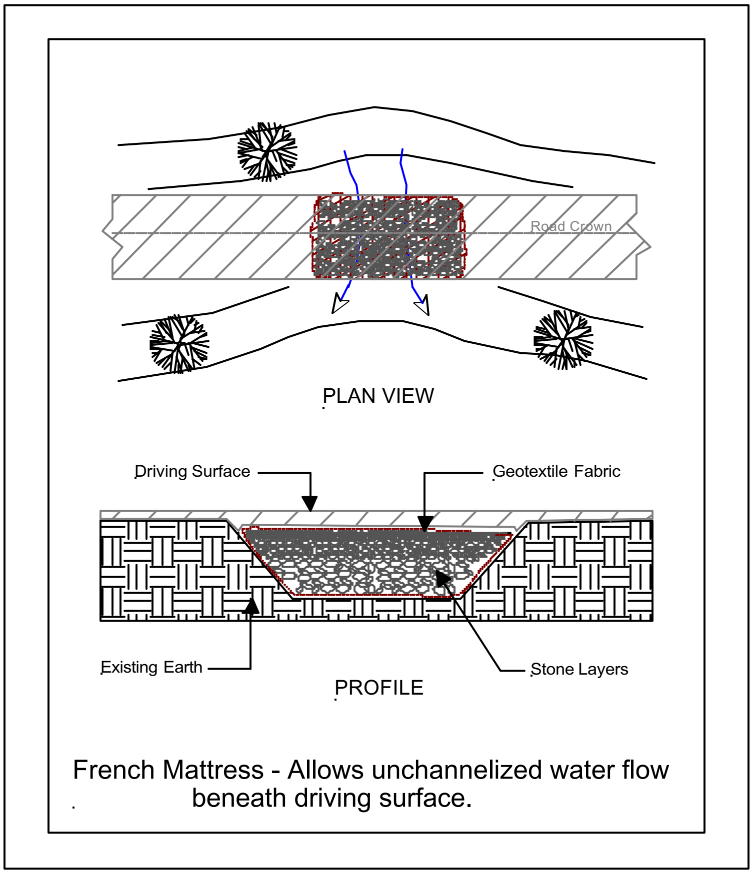

Figure 2.10-4 French Mattress

A French mattress is a structure placed under the road surface consisting of coarse rock wrapped in fabric that allows water to freely pass through the road bed (Figure 2.10-4). The French mattress provides road support while maintaining subsurface water flow on both sides of the road. The support strength is provided by large rocks placed on the bottom with progressively smaller diameter rocks placed on top. The entire rock structure is wrapped with geotextile fabric. Road surface material is placed on top of the fabric encased structure. The geotextile fabric allows water to enter the structure while retaining fine particles. Perforated drain pipes can be embedded in the rock layers to convey water to drainage areas, or the structure may be left open on both sides of the road to allow cross draining.

French mattresses can be used in place of culvert pipes where minimal cross drainage is needed or concentrated flow is undesired. French mattresses are effective in correcting road support problems in areas where the roadway has been damaged by water saturation and the road acts as a dam to natural water flow.

French Mattress Construction Materials

- Large, clean stone (R4) at a depth at least three times the diameter of the largest stone used.
- Smaller stone (#3) placed on top of the large stone tapering to smaller stone.
- Heavy-duty geotextile fabric encasing the stone.
- Sufficient road aggregate for driving surface providing at least six inches after compaction.

The length of the mattress must at least extend to the width of the road or a couple feet beyond. The mattress width depends on the amount of water that will need to pass through.

Maintenance Recommendations

Road grading, ditch cleaning, and shoulder cutting may be necessary to maintain the proper road crown. Ditch cleaning and shoulder maintenance operations can be combined with surface grading as one operation. If shoulder cutting is necessary to establish the proper crown and facilitate sheet flow off the road, the shoulder should be cut and the material blended back into the road. If ditch cleaning is also necessary and it is desired to do the operations at the same time, the shoulder should be cut and that material blended back into the road before cleaning the ditch.

Roadside swales should be properly maintained and should always be immediately stabilized by hydroseeding or other methods if they are disturbed. Eroded areas should be repaired using methods such as grassed swales, riprap swales, bank stabilization, bioengineering techniques, level spreaders, and other methods. Emergency procedures should be established to handle accidental spills such as cargo fuel or other materials. The use of ice melting materials, such as salt, calcium chloride, or magnesium chloride, is necessary on occasion to ensure safe driving conditions. These chemicals should be used only when necessary and only in amounts required to provide effective results.

Cost Considerations

The recommended Penn State Dirt and Gravel Road Program driving surface aggregate (DSA) costs about the same as other stone products and is available throughout the majority of the Commonwealth. Many of the maintenance tasks can be performed by local municipal road crews at no additional cost over traditional dirt road maintenance. In fact, with proper dirt and gravel road design, maintenance costs should be reduced since the amount of erosion, potholes, and rutting will be reduced.

The State Conservation Commission apportions Dirt and Gravel Road Maintenance funds to County Conservation Districts. A four-member Quality Assurance Board (QAB) made up of local appointees representing the Conservation District, the Pennsylvania Fish and Boat Commission, and the federal Natural Resources Conservation Service, has been established in every county of Pennsylvania to assist the Conservation District with grant application review and grant award making. Grants awarded to successful applicants will provide advance payments to aid with project cash flow and complete project work tasks on a timely basis.

References

Penn State University, Center for Dirt and Gravel Road Studies
Website: http://www.mri.psu.edu/centers/cdgrs/Index.html

2.11 Septic Systems and Wastewater Management

A septic system is an on-lot wastewater system designed to separate household wastewater into a solid and liquid phase, and then treat the waste prior to disposal. A typical septic system consists of two main parts: a septic tank and an absorption field, also known as a leach field. Water leaving the house first enters the septic tank, where the solids settle out on the bottom of the tank in the form of sludge. The liquid (effluent) then leaves the septic tank and enters the absorption field. A conventional absorption field consists of lengths of perforated pipe buried in gravel-filled trenches. The effluent passes through the holes in the pipe, trickles through the gravel, and is absorbed by the soil. Under ideal conditions, the soil particles filter out pathogens and nutrients before the treated effluent reaches the underlying groundwater. However, if a septic system is not properly installed or maintained, the effluent may not be treated properly. Malfunctioning septic systems can result in nutrient and bacteria loadings to downstream watercourses, as well as public health concerns.

2.11.1 Septic System Management Issues

According to a 1995 American Housing Survey by the U. S. Census Bureau, approximately one quarter of housing units in the United States are served by septic tanks or cesspools. More and more commonly in Pennsylvania and around the nation, lakeshore homes that were once weekend getaways are being converted to year-round use, either when the owners retire or through change of ownership. Frequently, the existing septic system is not designed to handle the increased usage, especially if the home is expanded. When this happens, septic systems become overloaded and effluent leaks into surrounding water bodies. This is more apt to occur in waterfront homes since the water table tends to be higher. If the system is not maintained properly, or if it was installed in an area of unsuitable soils to begin with, problems can occur.

Failing Septic System
Source: Anish Jantrania, Ph.D., P.E.

Septic system failures can cause both public health and environmental concerns. If wastewater from a leaky septic system enters the groundwater, the unfiltered pathogens can enter area water sources and cause illness. In addition to these diseases, mosquitoes and flies that spread infectious diseases may breed in areas where liquid waste reaches the surface. When septic systems fail, the effluent can flow overland or via groundwater and enter area streams and lakes. Nutrients (especially phosphorus) from leaky septic systems can play a major role in causing excessive weed and algae growth in lakes and ponds. Excessive weed and algae growth decreases the recreational value of the lake, alters the ecological balance, and can be deleterious to fish survival. Wastewater from failing septic systems that reaches adjacent surface waters can also increase the chance that swimmers could contract a variety of infectious diseases associated with contaminated water. Chemical or nutrient poisoning can also be a problem. Many of the products people use around the house, such as strong cleaning products, can be poisonous to humans, pets, and wildlife if they travel through soil to wells or to lakes, streams or ponds.

Some signs of septic system failure include:

- Sewage backup in drains or toilets. This is often a gray or black liquid with a disagreeable odor.

- Slowly draining sinks, bathtubs and toilets. The drains in the house will drain much more slowly than usual, despite the use of plungers or drain cleaners.

- Surface flow of wastewater. Sometimes soggy areas or standing water will become noticeable on the ground above or near the septic system. There may be a foul odor.

- Lush green grass over the absorption field, even during dry weather. Often, this indicates that an excessive amount of liquid from the septic system is moving upward through the soil instead of downward, as it should.

- The presence of nitrates or bacteria in drinking water wells. This indicates that wastewater from septic systems may be flowing into the well through the ground or over the surface. A water test will identify this problem. The health department can provide information about where to have tests done.

- Excessive growth of aquatic weeds or algae in lakes or ponds adjacent to the house. This may indicate that nutrient-rich septic system water is leaching into the surface water.

- Often, improperly vented or failing septic systems cause a buildup up of disagreeable odors around the house.

Frequent inspection of the septic tank and drainage area will detect problems before they become severe. A dye test is one method used to detect septic system failure. The dye test is conducted by flushing a small amount of fluorescent dye down a toilet in the house, and then watching for the appearance of dye over the drainage field or in nearby surface waters over a period of one to two hours. Dye tests can locate catastrophic septic system failures such as broken pipes, but will usually not detect more subtle problems. In lakes, septic problems can be detected via septic leachate surveys. This involves traveling along the lake shoreline in a boat with specialized equipment (usually a fluorometer and a conductivity meter) to locate septic leachate plumes in the water. Such surveys are best conducted on busy summer weekends when most of the shoreline properties are likely to be occupied, and preferably during periods of wet weather. These conditions represent the worst-case scenario for septic leachfield function. Testing water samples from homes and the lake for fecal coliform bacteria is another method of detecting septic system failure.

2.11.2 Septic System Maintenance Recommendations

The simplest yet most effective way to prevent septic system failure is regular inspection and maintenance. Regular maintenance also protects the value of the home by helping to ensure a safe water supply and disposal system. The following are some recommendations for septic system care:

DO have the septic tank pumped at least every two to five years, depending upon tank capacity and usage. A rule of thumb is to pump whenever the total depth of sludge and scum in the septic tank exceeds one-third of the liquid depth of the tank. The use of a garbage disposal will increase the amount of solids in the tank by as much as 50 percent, and will affect the pump-out frequency accordingly.

DO learn the location of the septic tank and absorption field. Keep a sketch handy for service visits, and maintain pumping and maintenance records.

DO reduce water usage in the house, and spread out usage over time. Repair dripping faucets and leaky toilets, run washing machines and dishwashers only when full, avoid using too many water-using appliances at the same time, and install water-saving devices on faucets, sinks, and toilets. Too much wastewater flowing into the drain field can result in surface overflow or sewage backup into the home.

DO reduce solids going into the septic tank. Avoid putting disposable diapers, tampons, sanitary napkins, and cigarettes down the drain. These items build up rapidly in septic tanks and can clog the drain field pipes.

DON'T install a garbage grinder or disposal in the sink. Food wastes place a greater burden on the septic system. If garden space is available, compost the material instead.

DON'T dump oil and grease down the drain. These do not decompose in the system and can rapidly clog the drain fields.

DON'T dump harsh chemicals and acids (pesticides, disinfectants, paint thinner, medicines, some cleaners) into the system. These will destroy the bacterial action in the tank.

DON'T use chemical or enzyme septic system cleaners. These have not proved to be of any significant value and should never be used as a substitute for pumping.

DON'T drive over the system with heavy vehicles or dig up the system for utility lines. Physical damage to the system can result.

DON'T construct buildings or install pavement over the septic system. Grass is the best filter.

DON'T connect cellar drains, sump pumps or rain downspouts to the system. Excess water will saturate the soil, causing it to be ineffective for wastewater treatment.

DON'T plant trees over or near the absorption area. Roots will enter and damage the pipes.

DON"T attempt to enter your septic tank. Toxic gases may be present that can be lethal. Hire a professional for inspection and pumping.

2.11.3 Wastewater Planning

Wherever concentrated areas of outdated septic systems exist, individual townships should address the issue on a municipal scale. Townships should require homeowners to connect to area central wastewater treatment facilities whenever feasible. Townships can adopt inspection and repair programs for on-lot systems when they update their township Sewage Facilities (Act 537) Plans. Alternatively, townships can adopt ordinances that require failing on-lot septic systems to be identified and replaced in remote areas where central collection and treatment systems are not feasible. Enforcement of these regulations is typically the responsibility of the Township Sewage Enforcement Officer.

2.11.4 Septic System Design Considerations

If replacement or repair of failing septic systems is deemed necessary, several issues must be considered. In areas where high concentrations of failing systems are identified, connection to an existing centralized wastewater collection and treatment facility may be preferred and may be justified by a cost-benefit analysis. Or, construction of smaller community wastewater treatment facilities or package treatment plants may be an option. However, in rural areas where the closest centralized wastewater treatment facility is located at a considerable distance, replacement of the existing on-lot septic system is usually necessary. When replacing or repairing an on-lot wastewater system, it is important to take into account setback and isolation distances. As shown in Figure 2.11-1, the distribution box and absorption field must be located at least 100 feet from any water well – either the homeowner's or a neighbor's. The system must be located at least 50 feet from any seasonal or perennial water body or wetland. Ideally, a 100 percent reserve area should be designated for a replacement system in the event of a future system failure.

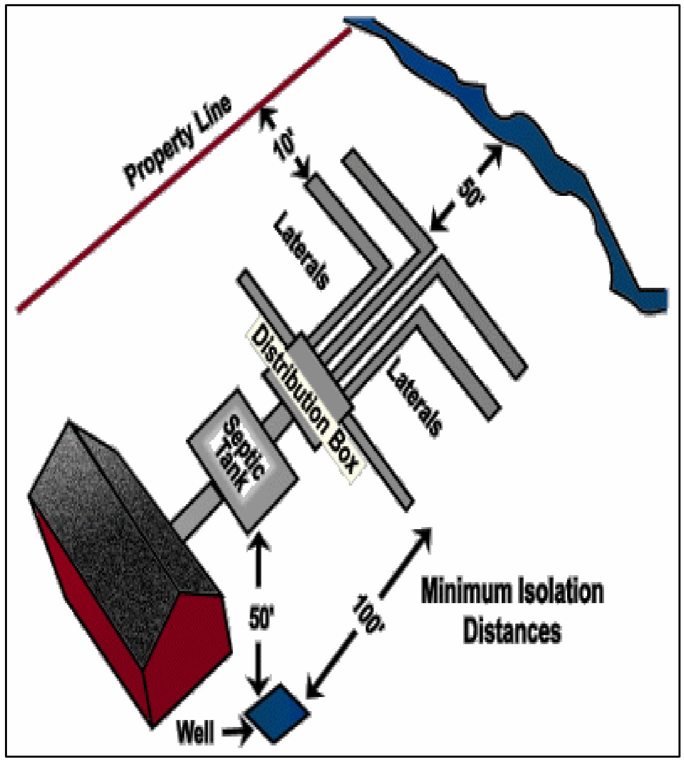

Figure 2.11-1 Required Setback and Isolation Distances for On-Lot Septic Systems
Source: Tobyhanna/Tunkhannock Creek WA

When designing a new or replacement septic system, the most important factor to consider is the soil characteristics in the absorption area. The absorption area is sized based on the number of bedrooms in the house that the system is serving and the percolation (or "perc") rate of the soil. The perc rate is determined by digging two or more perc holes in the area of the proposed absorption field. The holes must be 6-inches to 10-inches in diameter, with a depth of eight inches above the limiting zone or 20 inches, whichever is less. The holes are pre-soaked, and then water is poured into the holes to a depth of six inches. The perc rate is the time it takes for the water level in the hole to go down one inch. If the soil in the absorption area is sandy, the perc rate will be shorter, meaning the soil will absorb effluent faster. Conversely, if the soil has a high clay content, the perc rate will be longer, sometimes prohibitively so.

Just as important as the perc test when designing a septic system is the deep hole, or deep probe test. A deep hole test is performed by using a backhoe to dig a six- to seven-foot deep hole in or near the proposed absorption area. The hole is examined by a Sewage Enforcement Officer, licensed engineer, or soil scientist to determine the existence of any limiting zone. A limiting zone is defined as the upper limit of any zone, or soil layer, that is expected to limit the soil's ability to percolate and treat wastewater. There are three types of limiting zones:

1. A soil layer that contains a permanent or seasonally high water table (a seasonally high water table is usually evident as a mottled soil layer),

2. A soil or rock layer that has such slow permeability that the effluent will not be able to penetrate this layer at a rate that will permit the proper treatment of the wastewater, or

3. A soil layer such as a gravel or shattered stone layer that does not contain sufficient fines to provide sufficient contact between the effluent and the soil particles to properly treat the effluent.

The septic tank and distribution box should be placed on a 12-inch level layer of sand or pea gravel to provide adequate bedding. All outlets from the distribution box should be at the same elevation. The slope of the outlet lines should be the same for at least 10 feet beyond the distribution boxes. The pipe from the house to the septic tank and from the septic tank to the distribution box should be 4-inch solid PVC. The absorption field should consist of specified lengths (depending on the design rate) of 4-inch perforated high-density polyethylene pipe. All trenches in the absorption field should be level and arranged parallel to site contours. Stormwater runoff should be directed away from the absorption field. After construction is completed, disturbed areas should be seeded and mulched.

2.11.5 Other On-Lot Wastewater Treatment Options

The minimum soil depth required for a conventional on-lot septic system is 60 inches. Raised (elevated) sand mounds or other, alternative on-lot septic systems such as spray irrigation or "greenhouse" systems may be installed where soil depths are insufficient, or where conventional septic leach fields have failed and are in need of replacement. Elevated sand mound systems consist of distribution pipes in gravel trenches situated within a mound of sand and topsoil that is placed on top of the original soil, as shown in Figure 2.11-2. Elevated sand mounds are generally suitable for soils with limiting zones of 20 inches or greater. A properly designed and maintained sand mound has a design life of over 20 years; therefore, raised sand mounds are considered an adequate long-term wastewater disposal method.

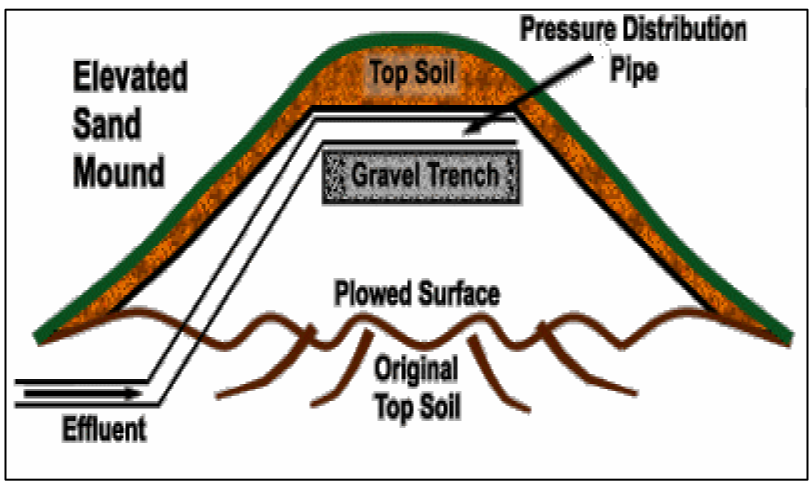

Figure 2.11-2 Typical Cross Section of an Elevated Sand Mound System
Source: Tobyhanna/Tunkhannock Creek Watershed Assoc.

Drip irrigation systems apply treated wastewater to soil absorption fields slowly and uniformly from a network of narrow plastic, polyethylene or polyvinylchloride (pvc) tubing. The tubing is placed at shallow depths of usually six to 12 inches, in the plant root zone. The wastewater is pumped through the drip lines under pressure but drips slowly from a series of evenly spaced openings called "emitters." Wastewater must be pretreated and filtered prior to subsurface drip irrigation dispersal. One advantage to these systems is the minimal site disturbance required due to the flexible tubing that can be placed around trees and shrubs. The principal difference between drip irrigation systems and conventional on-lot wastewater systems is that is that irrigation systems are specifically designed to allow the water and nutrients to be used by plants.

Low pressure pipe (LPP) wastewater systems use one to two inch diameter plastic pipes with orifices (small spray holes) spaced 2.5 to 7.5 feet apart to deliver wastewater to the soil. A pump delivers effluent throughout the system on a regular basis as determined by a timer or the pump tank capacity. With this technology, absorption fields can be located upslope of the septic tank, or on uneven terrain that would otherwise be unsuitable for gravity flow systems.

Spray irrigation involves pumping pretreated effluent at 80 to 100 psi through nozzles and spraying it directly onto the land. Spray irrigation for wastewater disposal requires the availability of a relatively large parcel of suitable land for wastewater storage (lagoons) and disposal (spray field). However, spray irrigation systems require only 10 inches of usable soil beneath the spray field where percolation rates are adequate. Properly designed, maintained, and operated spray irrigation systems provide highly effective treatment of residential wastewater and allow for maximum recharge of groundwater, a benefit that is completely lost by small package and large community wastewater treatment facilities that use stream discharge for treated effluent.

Other alternative on-lot wastewater alternatives exist, but many require special approvals and are allowed only when more conventional systems are not feasible. Alternative wastewater systems require maintenance just like conventional septic systems, and they tend to have a higher failure rate due to improper maintenance and installation. Composting toilets and low-flow fixtures can be used to reduce the amount of wastewater entering a septic system, but should not be used in lieu of a functioning wastewater treatment system.

Most townships require permits for construction or repair of existing or replacement on-lot septic system. The township Sewage Enforcement Officer (SEO) should be contacted for permits and regulations.

2.11.6 CENTRALIZED WASTEWATER TREATMENT

When large clusters of failing septic systems exist, a centralized wastewater treatment facility may be applicable. Small communities often worry that if a large wastewater collection and treatment system is developed in their town at a reasonable cost, the town will become a more desirable place to live and community growth may result. This is a valid concern, but the phenomenon most frequently applies to areas connecting to large central wastewater treatment plants. Smaller, community-scale treatment options exist that cost less and require less planning. A combination of several alternative systems that serve more than one property can sometimes be more cost-effective than individual wastewater systems.

Wastewater systems that serve more than one residence are called community systems. Community systems that serve fewer than 50 properties are referred to as cluster systems, while those that serve from 50 to as many as several thousand properties are known as small centralized community systems. Discharge type and location, soil conditions, and space considerations must be evaluated before constructing a community wastewater system. For some community systems, the wastewater is collected from a group of homes and discharged into a mass drainfield. Other systems involve advanced treatment and disinfection before being directly discharged to a waterway or a spray irrigation field. The means of collection can include gravity sewers (both conventional and small diameter), pressure sewers with grinder pumps, pressure sewers with septic tank effluent pumping (STEP system), and vacuum sewers. Treatment options can include treatment lagoons, sequencing batch reactors, oxidation ditches, filters such as sand filters, and constructed treatment wetlands.

"Package" Wastewater Treatment Plants are small, pre-fabricated plants that treat wastewater via activated sludge processes. According to manufacturers, package plants can be designed to treat flows as low as 0.002 million gallons per day (MGD) or as high as 0.5 MGD, although they more commonly treat flows between 0.01 and 0.25 MGD (US EPA, 2000). They are usually operated by a contractor and are permitted under federal National Pollutant Discharge Elimination System (NPDES) regulations. Typically these small treatment plants operate in a similar manner to large centralized treatment plants, just on a smaller scale. Collection options are the same as with community systems.

In Pennsylvania, the Department of Environmental Protection requires the completion of a Sewage Facilities Planning Module for all community and package wastewater treatment facilities. Depending on the size and extent of the new wastewater system, a new sanitary district or authority may be required. Additional permits may also be required by the individual township. The Township Sewage Enforcement Officer should be contacted during the earliest planning stages of any centralized wastewater treatment facility.

Cost Considerations

As the old adage goes, an ounce of prevention is worth a pound of cure. Properly maintaining one's septic system is significantly less costly than replacing a failed system. Septic pumping costs run approximately $150 to $300 per event, and need to be performed every three to five years, depending on usage.

Most septic systems will eventually fail. On-lot systems typically have a design life of 15 to 25 years even when properly maintained. Eventually, the soil in the absorption field becomes clogged with organic material, and percolation will no longer occur. An extension or replacement septic system can cost anywhere from $3,000 to $5,000, or sometimes more if a suitable replacement location is not available at the site. One must also consider the indirect costs of being without the use of the house while the system isn't working, and the long-term inconvenience of a poorly-functioning system. If a home with a failed septic system is up for sale, it cannot be sold until the problem is fixed. This can lead to additional legal fees and unexpected costs during the transaction process.

Typical sand mound on-lot wastewater systems cost between $6,000 and $10,000 (McComas, 1993). Spray Irrigation system installation costs are typically about $5,000 (CES, 2001b) for an individual system, and close to a million dollars for a centralized spray irrigation system. Drip Irrigation systems can cost up to $15,000 to install (CES, 2001a). Low Pressure Pipe (LPP) System installation costs range from $1,500 to $5,000 (Solomon, et. al, 1998). The annual operating costs for these alternative systems includes additional power consumption for the pumps.

The cost to an individual for a community cluster system with a collective drainfield is approximately $1,500 more per user than for a conventional on-lot system (McComas, 1993). This includes the cost for a pump, extra pipes and engineering fees. Package treatment plants can cost $15-$30 per gallon treated, not including conveyance structure or engineering fees. Connection to an existing wastewater treatment facility is not always the most expensive option, costing about $3,000 to $10,000 per homeowner depending on location and the number of homes being connected. Usually the costs can be financed over a number of years. Monthly surcharges for sewage treatment typically run about $20 to $50 per month (Sarasota CES, 2003).

State or federal financial assistance may be available for the installation of community or package wastewater systems, usually in the form of grants or low-interest loans. In Pennsylvania, the Pennsylvania Infrastructure Investment Authority (PENNVEST), funds sewer, stormwater and drinking water projects throughout the Commonwealth. Funds may also be available through the Clean Water State Revolving Fund, and the Department of Environmental Protection Sewage Management (Act 537) Program.

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APPENDIX A
GLOSSARY OF TERMS

Glossary of Lake Management and Restoration Terms

Adapted from *Managing Lakes and Reservoirs*, Third Edition (US EPA, 2001)

Acid neutralizing capacity (ANC) or Alkalinity: the equivalent capacity of a solution to neutralize strong acids.

Acidic deposition (acid rain): transfer of acids and acidifying compounds from the atmosphere to terrestrial and aquatic environments via rain, snow, sleet, hail, cloud droplets, particles, and gas exchange.

Adsorption: The adhesion of one substance to the surface of another: clays, for example, can adsorb phosphorus and organic molecules

Aerobic: Describes life or processes that require the presence of molecular oxygen.

Algae: Small aquatic plants that occur as single cells, colonies, or filaments. Planktonic algae float freely in the open water. Filamentous algae form long threads and are often seen as mats on the surface in shallow areas of the lake.

Algicide: A chemical used to kill algae.

Alum (aluminum sulfate): a chemical compound used in sediment phosphorus inactivation treatments.

Anaerobic: Describes processes that occur in the absence of molecular oxygen.

Anoxia: A condition of no oxygen in the water. Often occurs near the bottom of fertile stratified lakes in the summer and under ice in late winter.

Aquifer: an underground, water-bearing bed of permeable rock, sand, or gravel. Aquifers contain large amounts of groundwater that feed into wells and springs.

Bankfull Flow: The condition where streamflow just fills a stream channel up to the top of the bank and at a point where the water begins to overflow onto a floodplain.

Baseflow: The portion of stream flow that is not due to stormwater runoff, and is supported by groundwater seepage into a channel.

Basin: The largest single watershed management unit for water planning that combines the drainage of a series of subbasins. Often basins have a total area of more than a thousand square miles.

Bathymetric map: A map showing the bottom contours and depth of a lake; can be used to calculate lake volume.

Benthic: Macroscopic (seen without aid of a microscope) organisms living in and on the bottom sediments of lakes and streams.

Berm: a narrow shelf, ledge, or barricade, typically at the top or bottom of a slope; a mound or wall of earth; for example, small dams or ridges.

Best Management Practices (BMPs): Systems, activities, and structures that human beings can construct or practice to prevent nonpoint source pollution.

Biochemical Oxygen Demand (BOD): The rate of oxygen consumption by organisms during the decomposition (respiration) of organic matter, expressed as grams oxygen per cubic meter of water per hour.

Biodiversity: A multiplicity of different, mutually dependent living things characteristic of a particular region or habitat.

Biomass: The weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time.

Bioretention: A water quality practice that utilizes landscaping and soils to treat urban stormwater runoff.

Biota: All plant and animal species occurring in a specified area.

Boulder toe: the placement of angular rock (rip-rap) at the base of a streambank to provide toe protection.

Branch packing: the stabilization of small streambank scour areas using layers of compacted soil and live cuttings.

Buffer: An area adjacent to a shoreline, wetland or stream where development is restricted or prohibited.

Channel: A natural stream that conveys water; a ditch or channel excavated for the flow of water.

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

Chemical oxygen demand (COD): Non-biological uptake of molecular oxygen by organic and inorganic compounds in water.

Chlorophyll a: A green pigment in algae and other green plants that is essential for the conversion of sunlight, carbon dioxide and water to sugar (photosynthesis).

Citizens Advisory Committee (Cac): A group of citizens that oversee the implementation of a watershed plan and ensure that all stakeholders are involved in the process of a watershed plan.

Clean Water Act: The federal Clean Water Act of 1972 requires the development of comprehensive programs for preventing, reducing, or eliminating the pollution and improving the condition of the nation's navigable, surface, and groundwaters.

Cluster development: Placement of housing and other buildings of a development in groups to provide larger areas of open space.

Coir Bundles: Rolls of natural coconut fiber designed to be used for streambank stabilization.

Compliance: the act of fulfilling an official requirement: submission to operative laws, regulations, practices, terms, or conditions.

Conservation Easement: Legal agreements between a landowner and a qualified government agency or nongovernmental organization (i.e. land trust) that permanently limit a property's uses, even if it is sold.

Conservation Reserve Program (CRP): A U.S. Department of Agriculture program that takes highly erodible or environmentally sensitive cropland out of production for 10 to 15 years. Farmers receive annual rental payments and most of the erodible land is planted in perennial grasses and grass/legume mixtures.

Conservation Tillage: A practice or method of plowing in which crop residue is left on the field as protective mulch or cover instead of being plowed under.

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

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

Decomposition: The transformation of organic molecules (e.g., sugar) to inorganic molecules (e.g., carbon dioxide and water) through biological and non-biological processes.

Design Storm: A rainfall event of specified size and return frequency (e.g., a storm that occurs only once every 2 years) that is used to calculate the runoff volume and peak discharge rate to a BMP.

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

Detritus: Non-living dissolved and particulate organic material from the metabolic activities and deaths of terrestrial and aquatic organisms.

De-Watering: Refers to a process used during dredging whereby water is completely removed from sediments that have been removed from the lake bottom.

Discharge: 1. Outflow; the flow of a stream, canal, or aquifer. 2. Rate of flow, specifically fluid flow; a volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day.

Dissolved Oxygen (DO): Oxygen which is present (dissolved) in water and available for use by fish and other aquatic animals.

Diversion: A channel, embankment, or other human-made structure constructed to divert water from one area to another.

Dormant posts: large live stakes (4-6 inches thick and 6-10 feet long) that are installed at the base of an eroding streambank to prevent toe erosion.

Drainage basin: Land area from which water flows into a stream or lake (see watershed).

Drainage lakes: Lakes having a defined surface inlet and outlet.

Dredging: The process of removing sediments from the bottom of a lake or reservoir with a large power shovel. Also known as lake deepening.

Dry Pond: A stormwater pond design with no permanent pool. Stormwater is detained in the practice temporarily to settle pollutants, protect downstream channels, and prevent flooding.

Ecology: Scientific study of relationships between organisms and their environment: also defined as the study of the structure and function of nature.

Ecosystem: A system of interrelated organisms and their physical-chemical environment. In limnology, the ecosystem is usually considered to include the lake and its watershed.

Effluent: Liquid wastes from sewage treatment, septic systems or industrial sources that are released to a surface water.

Environment: Collectively, the surrounding conditions, influences and living and inert matter that affect a particular organism or biological community.

Environmental Advisory Council (EAC): a committee of local citizens appointed to advise a municipality's decision makers about the protection, management, and use of natural resources within the municipality.

Environmental Impact Statement (EIS): A report required by the National Environmental Policy Act (NEPA), for all major projects which significantly impact on the quality of the human environment or are environmentally controversial. The EIS is a detailed and formal evaluation of the favorable and adverse environmental and social impacts of a proposed project and its alternatives.

Environmental planning: The development of implementation strategies for guiding the protection of natural resources in a given area. The practice of requiring the use of these strategies for new development and changes in land-use.

Environmental Protection Agency (EPA): The office of government, either federal or state, responsible for safeguarding and managing a region's natural resources and quality of life.

Epilimnion: Uppermost, warmest, well-mixed layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.

Erosion: Breakdown and movement of land surface which is often intensified by human disturbances.

Eutrophic: From Greek for well-nourished; describes a lake of high photosynthetic activity and low transparency.

Eutrophication: The process of physical, chemical, and biological changes associated with nutrients, organic matter, silt enrichment, and sedimentation of a lake or reservoir. If the process is accelerated by man-made influences it is termed cultural eutrophication.

Extended Detention (ED): A stormwater design feature that provides for the gradual release of a volume of water (0.25 - 1.0 inches per impervious acre) over a 12 to 48 hour interval time to increase settling of urban pollutants, and protect channels from frequent flooding.

Fecal coliform test: Most common test for the presence of fecal material from warm-blooded animals. Fecal coliforms indicate the potential presence of other disease-causing organisms.

Fiber roll revetments: Coir fiber "logs" (often referred to as Biologs) that are placed at the toe of an eroding streambank to provide stability. The fiber roll is usually planted with herbaceous plugs.

Flanking: the condition where erosion continues around and behind a streambank stabilization practice.

Floc: The nutrient/sediment precipitate that forms when alum is added to a lake for phosphorus inactivation.

Floodplain: Land adjacent to lakes or rivers that is covered as water levels rise and overflow the normal water channels.

Flushing rate: The rate at which water enters and leaves a lake relative to lake volume, usually expressed as time needed to replace the lake volume with inflowing water.

Flux: The rate at which a measurable amount of a material flows past a designated point in a given amount of time.

Food chain: The general progression of feeding levels from primary producers, to herbivores, to planktivores, to the larger predators.

Food web: The complex of feeding interactions existing among the lake's organisms.

Forage fish: Fish, including a variety of panfish and minnows, that are prey for game fish.

Forebay: An extra storage area provided near the inlet of a BMP to trap incoming sediments before they accumulate in the BMP structure.

Gabion: A large rectangular box of heavy gauge wire mesh that holds large cobbles or boulders. Used in streams and ponds to change flow patterns, stabilize banks, or prevent erosion.

Geotextile Fabric: Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through. (Also known as filter fabric).

Grading: The cutting and/or filling of the land surface to a desired slope or elevation.

Groundwater: Water found beneath the soil surface; saturates the stratum at which it is located; often connected to lakes.

Habitat: The physical environment or typical place within which a plant or animal naturally or normally lives and grows.

Heavy Metals: Metals of relatively high atomic weight, including but not limited to chromium, copper, lead, mercury, nickel, and zinc. These metals are generally found in minimal quantities in stormwater, but can be highly toxic even at trace levels.

Hotspot runoff: Stormwater runoff from areas of concentrated contaminants or hazardous materials.

Hydrographic map: A map showing the location of areas or objects within a lake.

Hydrologic cycle: The circular flow or cycling of water from the atmosphere to the earth (precipitation) and back to the atmosphere (evaporation and plant transpiration). Runoff, surface water, groundwater, and water infiltrated in soils are all part of the hydrologic cycle.

Hypolimnion: Lower, cooler layer of a lake during summertime thermal stratification.

Impermeable: Properties that prevent the movement of water through a material.

Impervious Surface: Material which resists or blocks the passage of water.

Infiltration: The penetration of water through the ground surface into subsurface soil. The infiltration rate is expressed in terms of inches per hour. Infiltration rates will be slower when the soil is dense (e.g., clays) and faster when the soil is loosely compacted (e.g., sands). Can also refer to seepage of groundwater into sewer pipes through cracks and joints.

Inlet: 1. A drainage passway. 2. A short, narrow waterway connecting a bay, lagoon, or similar body of water with a large parent body of water. 3. An arm of the sea (or other body of water) that is long compared to its width and may extend a considerable distance inland.

In-stream habitat enhancement*:* the placement of various structures in the stream channel that are designed to deflect or alter streamflow to enhance in-stream habitats.

Isothermal: The same temperature throughout the water column of a lake.

Karst Topography: The structure of land surface resulting from limestone, dolomite, gypsum beds, and other rocks formed by dissolution and characterized by closed depressions, sinkholes, caves, and underground drainage.

Lake: A considerable inland body of standing water, either naturally formed or manmade.

Lake district: A special purpose unit of government with authority to manage a lake(s) and with financial powers to raise funds through mill levy, user charge, special assessment, bonding, and borrowing. May or may not have police power to inspect septic systems, regulate surface water use, or zone land.

Lake management: The practice of keeping lake quality in a state such that attainable uses can be achieved and maintained.

Lake protection: The act of preventing degradation or deterioration of attainable lake uses.

Lake restoration: The act of bringing a lake back to its attainable uses.

Lentic: Relating to standing water (versus lotic, running water).

Limnologist: One who studies limnology.

Limnology: Scientific study of fresh water, especially the history, geology, biology, physics, and chemistry of lakes. Also termed freshwater ecology.

Littoral zone: That portion of a waterbody extending from the shoreline lakeward to the greatest depth occupied by rooted plants.

Live cribwalls: log-cabin like streambank stabilization structures composed of railroad ties or timbers filled with stone and soil and planted with live material.

Live fascines: bundles of live material, usually native shrub willows and dogwoods, that are placed in a series of shallow trenches parallel to the streambank for the purpose of stabilization. Also called wattles.

Live staking: the practice of inserting dormant shrub and tree cuttings into a streambank for the purpose of stabilization.

Loading: The total amount of material (sediment, nutrients, oxygen-demanding material) brought into the lake by inflowing streams, runoff, direct discharge through pipes, groundwater, the air, and other sources over a specific period of time (often annually).

Low-Impact Development (LID): A comprehensive land planning and engineering design approach with the goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds. LID designs maximize the amount of natural features and vegetation at a site, in order to allow stormwater to be infiltrated on site and recharge the groundwater rather than being conveyed to detention facilities or storm sewers.

Lot: A parcel of undivided land.

LUNKER structures: open-ended boxes constructed from wood and rebar that are installed at the toe of streambanks to create fish habitat.

Macroinvertebrates: Aquatic insects, worms, clams, snails, and other animals visible without the aid of a microscope, that may be associated with or live on substrates such as sediments and macrophytes.

Macrophytes: Rooted and floating aquatic plants, commonly referred to as waterweeds. These plants may be rooted or free-floating.

Mesotrophic: Describes a lake of moderate plant productivity and transparency; a trophic state between oligotrophic and eutrophic.

Metalimnion: Layer of rapid temperature and density change in a thermally stratified lake. Resistance to mixing is high in this region.

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

Morphometry: Relating to a lake's physical structure (e.g., depth, shoreline length).

Mulch: A protective covering (such as sawdust, leaves, bark, compost) spread or left on the ground. Mulch prevents evaporation, maintains even soil temperature, prevents erosion, controls weeds, and enriches the soil.

National Pollutant Discharge Elimination System (NPDES): Federal operating permits issued by EPA to industrial and municipal facilities to help them comply with the Clean Water Act.

Natural channel design: the restoration of the natural form and pattern of stream channels that have been severely destabilized by land use changes, channelization, piping, or dredging.

Natural Resources Conservation Service (NRCS): A federal agency responsible for safeguarding and managing soil and water resources. NRCS operates within the Department of Agriculture and maintains local offices throughout the country.

Nonpoint Source (NPS) Pollution: Pollution that cannot be traced to a specific origin, but seems to flow from many different sources. NPS pollutants are generally carried off the land by stormwater or snowmelt runoff.

Nutria: A non-native species of rodent that causes damage to riparian areas in many parts of the US.

Nutrient: An element or chemical essential to life, such as carbon, oxygen, nitrogen, and phosphorus.

Nutrient budget: Quantitative assessment of nutrients (e.g., nitrogen or phosphorus) moving into, being retained in, and moving out of an ecosystem; commonly constructed for phosphorus because of its tendency to control lake trophic state.

Nutrient cycling: The flow of nutrients from one component of an ecosystem to another, as when macrophytes die and release nutrients that become available to algae (organic to inorganic phase and return).

Oligotrophic: "Poorly nourished," from the Greek. Describes a lake of low plant productivity and high transparency.

Ordinance: a statute or regulation that is enacted by a municipality, such as a township, borough, or city.

Ordinary high water mark: Physical demarcation line, indicating the highest point that water level reaches and maintains for some time. Line is visible on rocks, or shoreline, and by the location of certain types of vegetation.

Organic matter: Molecules manufactured by plants and animals and containing linked carbon atoms and elements such as hydrogen, oxygen, nitrogen, sulfur, and phosphorus.

Outfall: The point of discharge for a river, drain, or pipe.

Overturn: The mixing, top to bottom, of lake water caused by cooling and wind-derived energy. Overturn usually happens in the spring and the fall in stratified lakes.

PA DEP: Pennsylvania Department of Environmental Protection. State agency in charge of protecting environmental resources in Pennsylvania.

Pathogen: A microorganism capable of producing disease. They are of great concern to human health relative to drinking water and swimming beaches.

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

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

Pelagic zone: This is the open area of a lake, from the edge of the littoral zone to the center of the lake.

Perched: A condition where the lake water is isolated from the groundwater table by impermeable material such as clay.

Perc Test: Soil test that determines the rate of percolation of water through the soil in a proposed drainage area.

Percolation: The downward movement of water through the soil.

Permeable: A surface or material that has pores or openings that allow liquids to penetrate or pass through.

pH: A measure of the concentration of hydrogen ions of a substance, which ranges from very acid (pH = 1) to very alkaline (pH = 14). pH 7 is neutral and most lake waters range between 6 and 9. pH values less than 6 are considered acidic, and most life forms can not survive at pH of 4.0 or lower.

Photic zone: The lighted region of a lake where photosynthesis takes place. Extends down to a depth where plant growth and respiration are balanced by the amount of light available.

Photosynthesis: A chemical reaction that occurs only in plants. The plants use a green pigment called chlorophyll to convert water and carbon dioxide into food in the presence of sunlight.

Phytoplankton: Microscopic algae and microbes that float freely in open water of lakes and oceans.

Point Source (PS) Pollution: Pollution discharged into water bodies from specific, identifiable pipes or points, such as an industrial facility or municipal sewage treatment plant.

Pollutant: A solid, liquid, or gaseous substance that contaminates the environment.

Pollution: The condition of being polluted. A generic word for any type of contamination of water, land, or air.

Pond: A body of water smaller than a lake, often artificially formed.

Pondscaping: A method of designing the plant structure of a stormwater wetland or pond using inundation zones. The proposed marsh or pond system is divided into zones which differ in the level and frequency of inflow. For each zone, plant species are chosen based on their potential to thrive, given the inflow pattern of the zone.

Porous Pavement: An alternative to conventional pavement whereby runoff is diverted through a porous asphalt layer and into an underground reservoir. The stored runoff then gradually infiltrates into the subsoil.

Precipitation: A water deposit on earth in the form of hail, rain, sleet, or snow.

Pretreatment: Techniques employed in stormwater practices to provide initial storage or filtering to help trap coarse materials before they enter the system.

Primary productivity: The rate at which algae and macrophytes fix or convert light, water and carbon dioxide to sugar in plant cells (through photosynthesis).

Primary producers: Green plants that manufacture their own food through photosynthesis.

Property owners association: Organization of property owners in a subdivision or development with membership and annual fee required by covenants on the property deed. The association will often enforce deed restrictions on members' property and may have common facilities such as bathhouse, clubhouse, golf course, etc.

Raw Water: Untreated water, usually that entering the first unit of a water treatment plant.

Receiving Waters: Rivers, lakes, oceans, or other water courses or bodies of water that receive waters from another source.

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

Reservoir: A manmade lake where water is collected and kept in quantity for a variety of uses, including flood control, water supply, recreation and hydroelectric power.

Residence time: Commonly called the hydraulic residence time -- the amount of time required to completely replace the lake's current volume of water with an equal volume of new water.

Respiration: Process by which organic matter is oxidized by organisms, including plants, animals, and bacteria. The process releases energy, carbon dioxide, and water.

Retention: The amount of precipitation on a drainage area that does not escape as runoff. The difference between total precipitation and total runoff.

Retrofit: The installation of a new stormwater practice or the improvement of an existing one in a previously developed area.

Rip-Rap: Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves or streamflow); also applies to brush or pole mattresses, or brush and stone, or similar materials used for soil erosion control.

Riparian: Pertaining to the land area immediately adjacent to a lake, river, reservoir, or other water body.

Riparian Forest Buffer: The area from the streambank in the floodplain to, and including, an area of trees, shrubs, and herbaceous vegetation located upslope from the body of water.

Riverine System: A system of freshwater river and stream channels, mainly a deepwater habitat system.

Rock vane: an in-stream enhancement structure built using large, flat boulders. Several design variations exist, but all are used to deflect stream flow and create in-stream habitat.

Rootwad: the root structure and lower truck portion a large tree. Rows of rootwads are used to stabilize the toe area of streambanks.

Runoff: That portion of precipitation that flows over the land carrying with it nutrient and pollutants until it ultimately reaches streams, rivers, lakes, or other water bodies.

Sand Filter: A stormwater BMP in which the first flush of runoff is diverted into a self-contained bed of sand. The runoff is then strained through the sand, collected in underground pipes and returned back to the stream or channel. Can also be used to treat wastewater.

Scour: Concentrated erosive action of flowing water in streams that removes material from the bed and banks.

Secchi depth: A measure of transparency of water obtained by lowering a black and white, or all white, disk (Secchi disk, 20 cm in diameter) into water until it is no longer visible. Measured in units of meters or feet.

Sediment: Bottom material in a lake that has been deposited after the formation of a lake basin. It originates from remains of aquatic organisms, chemical precipitation of dissolved minerals, and erosion of surrounding lands (see detritus).

Sedimentation: The process of soil and silt settling and building up on the bottom of a creek, river, lake, or wetland.

Seepage: Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring, where the water emerges from a localized spot.

Seepage lakes: Lakes having either an inlet or outlet (but not both) and generally obtaining their water from groundwater and rain or snow.

Septic Tank: A holding tank for collecting residential wastwaters. Used as an alternative to municipal sewer systems in some areas.

Septic System: A conventional on-lot wastewater system where household wastewater is transported via a septic tank to a drain field (leach field) where it is treated by the soil.

Setbacks: The minimum distance requirements for location of a stormwater or wastewater treatment practice in relation to roads, wells, septic fields, and other structures.

Sewage Treatment Plant: A facility (usually municipal) that treats wastewater collected from many sources to remove harmful substances before discharge.

Smart Growth: A development trend that focuses on restoring community and vitality to center cities and older suburbs and reducing sprawl. Smart growth is more town-centered, is transit and pedestrian oriented, and has a greater mix of housing, commercial and retail uses than traditional development.

Soil bioengineering: The use of various combinations of living and non-living natural materials to restore eroding streambanks. Also known as *biostructural stabilization*.

Sprawl Development: Expansion of low-density development into previously undeveloped land.

Stakeholder: Any agency, organization, or individual that is involved in or affected by the decisions made in the development of a watershed plan.

Storm Drain (or Storm Sewer System): Above- and below-ground structures for transporting stormwater to streams or outfalls for flood control purposes.

Stormflow: The portion of stream flow that is due to stormwater runoff.

Stormwater Management: Programs designed to maintain or return the quality and quantity of stormwater runoff to pre-development levels.

Stormwater Runoff: Excess precipitation that is not retained by vegetation, surface depressions, or infiltration, and thereby collects on the surface and drains into a surface water body.

Stormwater Wetland: A shallow, constructed pool that captures stormwater and allows for the growth of characteristic wetland vegetation.

Stratification: Layering of water caused by differences in water density. Thermal stratification is typical of most deep lakes during summer. Chemical stratification can also occur.

Streambank stabilization: structural measures such as boulders and nonstructural measures such as plantings designed to secure the structural integrity of earthen stream channel banks to prevent bank slumping and undercutting of riparian trees, and overall erosion prevention.

Subdivision and Land Development Ordinance (SALDO): a set of municipal regulations that outlines specific, detailed requirements or development standards within each municipal zoning district.

Subwatershed: A smaller geographic section of a larger watershed unit with a drainage area of between 2 and 15 square miles, and whose boundaries include all the land area draining to a point where two second order streams combine to form a third order stream.

Swale: A natural depression or wide shallow ditch used to temporarily store, route, or filter runoff.

Swimmers itch: A rash caused by penetration into the skin of the immature stage (cercaria) of a flatworm (not easily controlled due to complex life cycle). A shower or alcohol rubdown should minimize penetration.

Thermal stratification: Lake stratification caused by temperature-created differences in water density.

Thermocline: A horizontal plane across a lake at the depth of the most rapid vertical change in temperature and density in a stratified lake (see metalimnion.).

Topographic map: A map showing the elevation of the landscape at specified contour intervals (typically 10 or 20 foot intervals, may be expressed in feet or meters). Can be used to delineate the watershed.

Total Maximum Daily Load (TMDL): A tool for establishing the allowable loadings of a given pollutant in a surface water resource to meet predetermined water quality standards.

Total Suspended Solids: The total amount of particulate matter that is suspended in the water column.

Toxic: Poisonous or harmful to living things.

Tree revetments: whole trees that are anchored to a streambank to provide erosion control.

Trophic state: The degree of eutrophication of a lake. Transparency, chlorophyll a levels, phosphorus concentrations, amount of macrophytes, and quantity of dissolved oxygen in the hypolimnion can be used to assess state.

Trophic State Index: A number used to categorize lakes as oligo-, meso-, or eutrophic, on a scale generally from 1 to 100; the higher the number, the more eutrophic.

Turbidity: Cloudiness, characterized by obscurity.

USDA: United State Department of Agriculture.

US EPA: United States Environmental Protection Agency (see Environmental Protection Agency).

Undermining: the condition where erosion continues below a streambank stabilization practice.

Vegetated Filter Strip: A vegetated section of land designed to accept runoff as overload sheet flow from upstream development. It may consist of any natural vegetated form, from grass meadow to small forest. A vegetated filter strip differs from a natural buffer in that the strip is designed and constructed specifically for the purpose of pollutant removal.

Vegetated geogrids: a series of rock and soil lifts that are wrapped with erosion blanket or geotextile and interspersed with live cuttings for streambank stabilization.

Vernal pool: A type of wetland in which water is present for only part of the year, usually during the spring wet or rainy seasons.

Warm-season grass: Grass species that green later in the spring, often reaching their peak growth in the warm summer months and flower in July.

Wastewater Treatment Facility: Sometimes synonymous with sewage treatment plant. An industrial facility that processes wastewater to remove toxic and hazardous wastes.

Water Body: A land basin filled with water. Refers to any river, lake, stream, or ocean that receives runoff waters from a watershed.

Water column: Water in the lake between the interface with the atmosphere at the surface and the interface with the sediment layer at the bottom. Idea derives from vertical series of measurements (oxygen, temperature, phosphorus) used to characterize lake water.

Water Quality Design Storm: Benchmark rainfall event, used to develop criteria for the design of water quality BMPs. Water quality design storms are used to size BMPs that are intended to achieve specific quality treatment objectives. See Pennsylvania Handbook of Best Management Practices for Developing Areas (PACD 1998 or later edition) for more precise calculations.

Water table: The upper surface of groundwater; below this point, the soil is saturated with water.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Wet Pond: A stormwater pond design that captures the entire water quality volume in a permanent pool.

Wetland: Land on which water covers the soil or is present either at or near the surface of the soil or within the root zone, all year or for varying periods of time during the year, including during the growing season. Wetlands are identified by determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Human-made wetlands include constructed stormwater wetlands designed to treat stormwater runoff, and artificial wetlands created to comply with mitigation requirements.

Wetland Mitigation: The construction of artificial wetlands in order to comply with a regulatory requirement to replace wetland areas destroyed or impacted by proposed land disturbances.

Zooplankton: Microscopic animals that float or swim freely in lake water, graze on detritus particles, bacteria, and algae, and may be consumed by fish.

Zoning: A set of regulations and requirements that govern the use, placement, spacing and size of buildings and lots within a specific area or in a common class (zone).

APPENDIX B
LIST OF CONVERSIONS

Table B-1 Common Conversions Used in Lake and Watershed Management				
To Convert From:		**Multiply by:**	**To Get:**	
Unit	**Symbol**		**Unit**	**Symbol**
LENGTH				
inches	in	2.54	centimeters	cm
centimeters	cm	0.3937	inches	in
feet	ft	0.3048	meters	m
meters	m	3.281	feet	ft
miles	mi	1.609	kilometers	km
kilometers	km	0.6214	miles	mi
nautical miles	n mi	1.852	kilometers	km
kilometers	km	0.5400	nautical miles	n mi
AREA				
square feet	ft^2	0.09290	square meters	m^2
square meters	m^2	10.76	square feet	ft^2
square miles	mi^2	2.590	square kilometers	km^2
square kilometers	km^2	0.3861	square miles	mi^2
square miles	mi^2	640	acres	ac
acres	ac	0.001563	square miles	mi^2
acres	ac	43,560	square feet	ft^2
square feet	ft^2	2.296×10^{-5}	acres	ac
acres	ac	0.4047	hectares	ha
hectares	ha	2.471	acres	ac
TEMPERATURE				
degrees Fahrenheit	ºF	$5/9\ (T_f - 32)$	degrees Celsius	ºC
degrees Celsius	ºC	$9/5\ (T_c + 32)$	degrees Fahrenheit	ºF
degrees Celsius	ºC	$T_c + 273.15$	Kelvins	K
Kelvins	K	K – 273.15	degrees Celsius	ºC
degrees Fahrenheit	ºF	$5/9\ (T_f + 459.7)$	Kelvins	K
Kelvins	K	9/5 (K – 459.7)	degrees Fahrenheit	ºF
PRESSURE				
millibars	mb	0.02953	inches of mercury	in Hg
inches of mercury	in Hg	33.87	millibars	mb
millibars	mb	0.1000	kilopascals	kPa
kilopascals	kPa	10.00	millibars	mb

Table B-1, Continued Common Conversions Used in Lake and Watershed Management				
To Convert From:		**Multiply by:**	**To Get:**	
Unit	**Symbol**		**Unit**	**Symbol**
VOLUME				
cubic feet	ft^3	0.02832	cubic meters	m^3
cubic meters	m^3	35.31	cubic feet	ft^3
acre-feet	ac-ft	43,560	cubic feet	ft^3
cubic feet	ft^3	2.296×10^{-5}	acre-feet	ac-ft
acre-feet	ac-ft	3.259×10^{5}	gallons	gal
gallons	gal	3.069×10^{-6}	acre-feet	ac-ft
acre-feet	ac-ft	1233	cubic meters	m^3
cubic meters	m^3	8.107×10^{-4}	acre-feet	ac-ft
cubic feet per second-day	cfs-d	86,400	cubic feet	ft^3
cubic feet	ft^3	1.157×10^{-5}	cubic feet per second-day	cfs-d
gallons	gal	0.1337	cubic feet	ft^3
cubic feet	ft^3	7.479	gallons	gal
gallons	gal	3.785	liters	L
liters	L	0.2641	gallons	gal
SPEED				
feet per second	ft/s	0.3048	meters per second	m/sec
meters per second	m/sec	3.281	feet per second	ft/s
miles per hour	mi/hr (mph)	1.609	kilometers per hour	km/hr
kilometers per hour	km/hr	0.6214	miles per hour	mi/hr (mph)
miles per hour	mi/hr (mph)	0.8684	knots	kt
knots	kt	1.152	miles per hour	mi/hr (mph)
miles per hour	mi/hr (mph)	0.4470	meters per second	m/sec
meters per second	m/sec	2.237	miles per hour	mi/hr (mph)

Table B-1, Continued Common Conversions in Lake and Watershed Management				
To Convert From:		**Multiply by:**	**To Get:**	
Unit	**Symbol**		**Unit**	**Symbol**
FLOW				
cubic feet per second	ft^3/s (cfs)	0.02832	cubic meters per second	m^3/s
cubic meters per second	m^3/s	35.31	cubic feet per second	ft^3/s (cfs)
cubic feet per second	ft^3/s (cfs)	448.8	gallons per minute	gal/min (gpm)
gallons per minute	gal/min (gpm)	0.002228	cubic feet per second	ft^3/s (cfs)
cubic feet per second	ft^3/s (cfs)	1.983	acre-feet per day	ac-ft/day
acre-feet per day	ac-ft/day	0.5042	cubic feet per second	ft^3/s (cfs)

Other Equivalents

1 cfs-day/mi^2 = 0.03719 inches of runoff
1 inch of runoff/mi^2 = 26.89 cfs-day = 2.323×10^6 ft^3
1 milligram per liter (mg/L) = 1 part per million (ppm)
1 microgram per liter (µg/L) = 1 part per billion (ppb)
1 ppm = 1,000 ppb
1 mg/L = 1,000 µg/L
1 milliliter (mL) = 1 cubic centimeter (cm^3)

APPENDIX C
INTERNET LINKS

Federal Links

US Environmental Protection Agency (US EPA) Home Page http://www.epa.gov/

US EPA National Pollutant Discharge Elimination System (NPDES)
http://cfpub.epa.gov/npdes/index.cfm

US EPA Office of Water http://www.epa.gov/water/

US EPA Wastewater Management http://www.epa.gov/OWM/

US EPA Watershed Management http://www.epa.gov/owow/watershed/

US EPA Wetlands, Oceans, and Watersheds http://www.epa.gov/owow/

US Department of Agriculture http://www.usda.gov/

US Fish and Wildlife Service http://www.fws.gov/

US Natural Resources Conservation Service http://www.nrcs.usda.gov/

State Links

Consortium for Scientific Assistance to Watersheds (C-SAW) http://pa.water.usgs.gov/csaw/

EPA Region 3 (Mid-Atlantic Region) http://www.epa.gov/region03/

Pennsylvania Department of Conservation and Natural Resources http://www.dcnr.state.pa.us/

Pennsylvania Department of Environmental Protection http://www.dep.state.pa.us/

Pennsylvania Farm Services Agency http://www.fsa.usda.gov/pa/

State of Pennsylvania http://www.state.pa.us/

US Geological Survey, Water Resources of Pennsylvania http://wwwpah2o.er.usgs.gov/

Pennsylvania Organizations

Center for Rural Pennsylvania http://www.ruralpa.org/

Penn State Cooperative Extension http://www.extension.psu.edu/

Pennsylvania Growing Greener Grants http://www.dep.state.pa.us/growgreen/defaultdep.htm

Pennsylvania Lake Management Society http://www.palakes.org/

Pennsylvania Organization for Watersheds and Rivers http://www.pawatersheds.org

Pennsylvania Rural Watershed Association http://www.prwa.com/v1/index.htm

National/Regional Organizations

American Rivers http://www.amrivers.org/

Center for Watershed Protection http://www.cwp.org/

Chesapeake Bay Program http://www.chesapeakebay.net/

Delaware River Basin Commission http://www.state.nj.us/drbc/drbc.htm

Ducks Unlimited http://www.ducks.org/

Great Lakes Commission http://www.glc.org/

North American Lake Management Society http://www.nalms.org/

Ohio River Foundation http://www.ohioriverfdn.org/

Potomac River Conservancy http://www.potomac.org/

Susquehanna River Basin Commission http://www.srbc.net/

The Nature Conservancy http://nature.org/

Trout Unlimited http://www.tu.org/index.asp

Reference

Government Invasive Species Programs http://www.invasivespecies.gov/

Pennsylvania Citizen's Volunteer Monitoring Program
http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/cvmp/backupfiles/cvmpbackup.htm

Stormwater Manager's Resource Center http://www.stormwatercenter.net/

Understanding Lake Data http://www.dnr.state.wi.us/org/water/fhp/lakes/under/