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The Lake and Reservoir Restoration Guidance Manual

Second Edition

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Lake and Reservoir Restoration Guidance Manual

Prepared by the

NORTH AMERICAN LAKE MANAGEMENT SOCIETY

for the

U.S. Environmental Protection Agency
Office of Water
Assessment and Watershed Protection Division
Nonpoint Sources Branch
Washington, D.C.

Second Edition

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PREFACE

Just as lakes are continually evolving bodies of water, so are the methods developed to protect, restore, and manage them. For that reason, in the Water Quality Act of 1987 Congress mandated that the *Lake and Reservoir Restoration Guidance Manual* be updated every two years.

Readers will note many differences in this, the second edition: additions, changes, new information. This is the product of careful review and rewrite by the authors of each chapter. Both the side notes and the index have also been expanded, as have the appendices.

A companion volume, *Monitoring Lake and Reservoir Restoration*, is being published simultaneously as the first in a series of technical supplements to this Manual.

Your suggestions are welcomed by the Clean Lakes Program staff as they continue the updating process and the development of further technical supplements. Please address your comments and requests for the manuals to:

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Acknowledgements

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Chapter 1

OVERVIEW OF MANUAL

Introduction

This Guidance Manual pursues a very broad subject—protecting and restoring lakes and reservoirs. An enormous amount of information trails behind that topic. The burden on those who wrote this Manual was not in finding good material to put in but in deciding where to stop. To make a book so full of information that it deserves premier shelf space for its reference value but remains compact enough to lift easily required some guiding assumptions.

First, this Manual supplies its own context. Therefore, any point the reader finds in midbook is prefaced with adequate background information to understand it and then followed with guidance on how to apply it. The material presented here was chosen because it fits a fourfold purpose:

1. To help users identify, describe, and define their lake problems;

2. To help them evaluate available lake and watershed management practices for addressing problems or protecting current quality;

3. To describe the process of developing a site-specific lake or reservoir management plan; and

4. To illustrate how to put a lake management plan into practice and evaluate its effectiveness.

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.

Audience

This Manual is written for the informed citizen who is interested in lakes and reservoirs—in protecting, restoring, and managing them. It is not written for the scientist or engineer. Consequently, English units of measure are used here, except for a few terms that are always reported in metric units. Appendix A provides the reader with information on the metric system. Many other, more technical documents discuss specific points of lake and reservoir management in detail. Additional references and sources of information are given wherever appropriate.

Lake management:
The practice of keeping lake quality in a state such that attainable uses can be achieved.

Focus

The focal point of this book is water quality, particularly the effects of excessive inputs of silt, nutrients, and organic matter known as *eutrophication*. The reader will find some information here on the effects of water quality on fish, for example, but will need another source for detailed advice on fisheries management. State game and fish agencies, the Fish and Wildlife Service of the U.S. Department of Interior, the Soil Conservation Service of the U.S. Department of Agriculture, and other agencies publish numerous booklets, fact sheets, and technical bulletins on fish management that more than suffice for this omission.

Technical jargon is kept to a minimum to help the reader grasp important points without stumbling over the words. Even so, a handful of terms are so important to lake management that working around them would be a disservice. These terms are defined in a side note the first time they appear, clearly explained in the text, and included in the glossary. The only term that needs some advance explanation is the relatively simple word, *lake*, which is used generically in this Manual to include both natural lakes and manmade lakes, which are called reservoirs. Distinctions between the two types of systems are discussed when they have important management implications.

Lakes as Resources

Lakes are important resources. As sources of recreation, they support fishing, boating, and swimming. Fishing and swimming are among the fastest growing and most popular forms of outdoor recreation in the United States and Canada. Lakes' commercial value in food supply, tourism, and transportation is worth many billions of dollars each year. Lakes also provide life-sustaining functions such as flood protection, generation of electricity, and sources of drinking water. Finally, as places of beauty, they offer solitude and relaxation. This quality is not a minor asset—over 60 percent of Wisconsin lake property owners who were asked what they valued in lakes rated aesthetics as especially important.

Natural Lake Conditions

The natural condition of a lake—before home construction, before deforestation, before agriculture and other human activities—may not have been nearly as pristine as is commonly believed. The natural geologic process is for lakes of moderate depth to gradually fill and become wetlands. The position of a lake along this geologic continuum from deep to shallow influences its natural water quality.

Many lakes would be eutrophic despite development in the watershed and other human activities. In the Southeast, for example, soil fertility, runoff patterns, and geology encourage a somewhat more eutrophic natural condition compared to northern lakes. Northerners expecting to see deep blue waters may find the color of healthy southern lakes dismaying. Even comparing nearby lakes may be misleading because the lakes may differ in critical ways—depth, water source, erodibility of watershed soils, comparative watershed size, and local land use. Major differences can occur from one side of town to the other or across a State. For example, changes in lake quality from northern to southern Wisconsin or from eastern to western Minnesota reflect regional differences in these factors.

Regional differences in climate, rainfall, topography (hills, valleys, plains), soils, geology, and land use all influence lake water quality and land use. These factors have been studied and used to define areas with similar characteristics called ecoregions (Omernik, 1987). Each of these ecoregions has its natural landscape features that can influence lake quality and should be factored into lake management. Because the natural lake water quality obviously affects uses, an important goal of both this Manual and lake management is to identify and define supportable uses and to develop a compatible lake and watershed management plan to restore the lake to this natural condition or protect its current condition.

This Manual provides general guidance on lake restoration and management techniques that have been proven on lakes throughout the United States and Europe. Different techniques might have to be modified for your particular lake in a specific region.

This variability brings up a key point in lake management: whatever the starting conditions and the limitations on what can ultimately be achieved, the goal is always the same—to minimize lake quality problems.

Desired Lake Uses

Lake usage is a match between people's desires and the lake's capacity to satisfy these desires. Lake problems are defined in terms of the limits on desired uses—as limitations that can reasonably be prevented or corrected with proper management. This is a critical definition for developing lake management programs: *A lake problem is a limitation on the desired uses by a particular set of users.* Before undertaking a management program, these desired uses need to be clearly defined, limitations on the uses identified, and the causes understood.

What a Lake is NOT

A lake cannot be all things to all people. Desirable uses, even obtainable ones, can conflict. Lake organizations invariably would like to see their lake do everything. They want aesthetic pleasure, great fishing, clean water, sandy shorelines and bottoms, and a healthy wildlife population—all without pests, insects, or weeds. Unfortunately, almost no lake can meet all of these demands.

Depending on physical characteristics of the lake basin and watershed and the quality of incoming water, lakes are suited to particular uses. Even when a lake can be used several ways, however, management for a specific use may still be required. Like cattlemen and sheepherders, motorboaters and trout fishermen don't necessarily get along.

Although it might be technically possible to drastically alter a lake to meet the needs of a particular user group, the cost will be high, and the decision is usually unwise. It is important to understand a lake's capacity and attainable quality when developing a management plan to obtain certain desired uses. Some lakes will never be crystal clear. No matter what restoration or management measures are taken, if the drainage area is large relative to lake surface area and the soils are highly erodible and nutrient-rich, the lake will promptly return to its former state.

Even the most reliable restoration techniques are not universally appropriate. The procedure that improves water quality in one lake can diminish it in another. For example, a technique called *artificial circulation* can decrease algal problems in some lakes but may increase algal production in others.

This Manual concentrates on how to determine what uses the lake can support with reasonable management efforts. It is critical, therefore, to determine the desired lake uses and have these goals clearly in mind as the problems are delineated.

Defining Desired Uses

While user groups obviously are the prime candidates for identifying desirable goals, they often lack sufficient knowledge to assess the practicality of their wishes. The material in this Manual will be helpful in examining the feasibility of proposed goals. In addition, the advice of experts is highly recommended. Many State and Federal sources are listed in later chapters of this Manual.

User Involvement

Lake and reservoir management is an active process. Informed citizens must become involved if desired and attainable lake uses are to be achieved. Getting people together and simply finding out what they want may require as much effort as figuring out how to do it. Since a given lake may serve many different groups of users, several methods might be required to involve them all.

Lake homeowners and other local users can get involved with lake use decisions through membership in one of several types of lake organizations. The local powers and financial ability of these groups vary considerably from community to community and State to State. (See Chapter 8 for additional discussion of legal authority and issues.) Also, the annual meeting of the local lake group is an obvious place to discuss and vote on priority uses for the lake. If the lake serves primarily local property owners and residents, such votes are likely to be respected by government agencies.

Reaching a consensus on specific lake uses may be difficult, however, if more than one lake organization exists on the lake, especially if conflicting uses are already well established.

There are several procedures or approaches that can be used to reach a consensus on desired lake uses and to identify various lake problems. These approaches, described in Appendix 3-A, include the nominal group process and the Delphi process. While these techniques can be very effective when properly used, most lake managers or informed citizens will need professional assistance. Lake associations typically include people of diverse occupations, however, so a member of the association may have the experience needed to use these methods.

Based on the beginning statement—a lake problem is a limitation on the desired uses by a particular set of users — a definition of desired lake uses and the limitations on these uses represents the cornerstone of any lake management program.

Causes Versus Symptoms—A Major Reason for This Manual

Lake users tend to confuse the symptoms of problems with their causes. Most communities need professional help to identify causes of lake problems. To decide when professional advice is warranted and how much help is needed, community leaders need to understand lakes in general. The purpose of this Manual is to help lake users define problems, understand underlying causes, evaluate techniques for addressing problems, develop an effective lake management plan, implement this plan, and evaluate its effectiveness.

In most cases, managing or restoring a lake eventually requires help from a professional lake manager, limnologist, or environmental engineer. This Manual provides guidance for finding and selecting qualified consultants.

Manual Organization

The Manual is divided into three parts.

Part 1—Understanding and Defining the Problem

- **Chapter 2** provides information on how inseparably lakes and watersheds are coupled and how lakes function as ecosystems. It is important to have some understanding of how the various components of a lake and watershed work and fit together. You don't have to be a mechanic to drive a car, but you do need to understand what makes the car go and what makes it stop. The eutrophication process can be accelerated or slowed down by various management techniques. Chapter 2 describes eutrophication and other ecological concepts.

- **Chapter 3** describes the process used to identify lake problems and differentiate symptoms from causes. This is a critical part of lake management.

Part 2—Management Techniques

- **Chapter 4** discusses analytical tools for evaluating the potential effectiveness of lake and watershed management techniques in achieving a desired lake use or certain level of lake quality.

- **Chapter 5** discusses the effects of watershed land use on lake quality and various watershed management techniques available to control point and nonpoint source pollutants entering the lake.

- **Chapter 6** discusses in-lake management techniques for achieving a desired lake use. It focuses not only on methods but also on their mode of action and possible interactions with other techniques.

Part 3—Development and Implementation of a Lake Management Plan

- **Chapter 7** describes how the watershed and lake management techniques are integrated to formulate and develop an effective lake management plan. The procedure is illustrated by a comprehensive example—a hypothetical case study.

- **Chapter 8** discusses putting the lake management plan into practice, which requires attention to numerous practical details such as permits, bonding, insurance, and scheduling.

- **Chapter 9** discusses how to protect the current lake quality or the lake quality after restoration. Lake organizations and associations can be effective forces in protecting lakes. Monitoring the lake status and changes occurring in the lake is the keystone of lake management and protection.

- **Appendices and a glossary** supplement the material covered in Chapters 1 through 9. As mentioned earlier, this Manual uses English units of measure. Appendix A shows how to convert English units to metric units, which are more common units of measure in lake management.

Restoration is not the return of a lake to its original state or some desired state but rather to the condition in which attainable uses can be achieved. This Manual explains how to determine the attainable condition of your lake, identify and prioritize the desired uses that are possible with this attainable lake condition, and then restore the lake to that condition. Once the lake is restored, it must be managed if these uses are to be maintained over time. This Manual is intended to help you determine how to restore, manage, and protect your lake so that you can enjoy its many benefits.

Definitions

Terms important to the understanding of lake management are defined in the margins beside their first appearance in the text. (See the definitions of lake protection, restoration, and management in the margin of the first page of this chapter.)

Chapter 2

ECOLOGICAL CONCEPTS

Lake and Reservoir Ecosystems

Lake management must be based on an understanding that lakes are complex and dynamic ecosystems.

Ecosystem: *A system of interrelated organisms and their physical-chemical environment. In this manual, the ecosystem is usually defined to include the lake and its watershed.*

Viewed simply as water systems, lakes are influenced by a set of hydrologic conditions, the watershed, the shape of the lake basin, the lake water, and the bottom sediments. These physical and chemical components, in turn, support a community of organisms that is unique to lake environments (Fig. 2-1). The biota enrich the complexity of lake ecosystems; they not only have a myriad of links to one another but also affect a lake's physical and chemical features. All of these components of lakes—physical, chemical, and biological—are in constant change, and the chemical and biological components are particularly dynamic.

Biota: *All plant and animal species occurring in a specified area.*

Because lakes are highly interactive systems, it is impossible to alter one characteristic, such as the amount of weeds or the clarity of the water, without affecting some other aspect of the system, such as fish production.

For example, a lake association might decide to remove weeds by mechanical means, and, in the process, accidentally destroy important habitat needed for fish survival and increase proliferation of algae, which would feed on nutrients inadvertently released during the weed harvesting. If the lake association then decided on chemical treatment to solve the algae problem and help clear up the water, the next step in this sequence of events could be increased penetration of sunlight through the water, which would encourage new weed growth.

Ecology is the scientific study of the interrelationships among organisms and their environment. Managing a lake for maximum benefit requires an understanding of how its ecosystems are structured and how they function. This lake management example is hypothetical, but variations on such unexpected results occur repeatedly when programs are implemented without adequate knowledge of lake ecology. It also illustrates a common confusion between causes and symptoms. Not only did the lake association members fail to consider how lake organisms interacted with one another, they also did not determine why weeds and algae were growing profusely and whether this aquatic plant production should be viewed as a problem or an asset.

Ecology: *Scientific study of relationships between organisms, and their environment. Also, defined as the study of the structure and function of nature.*

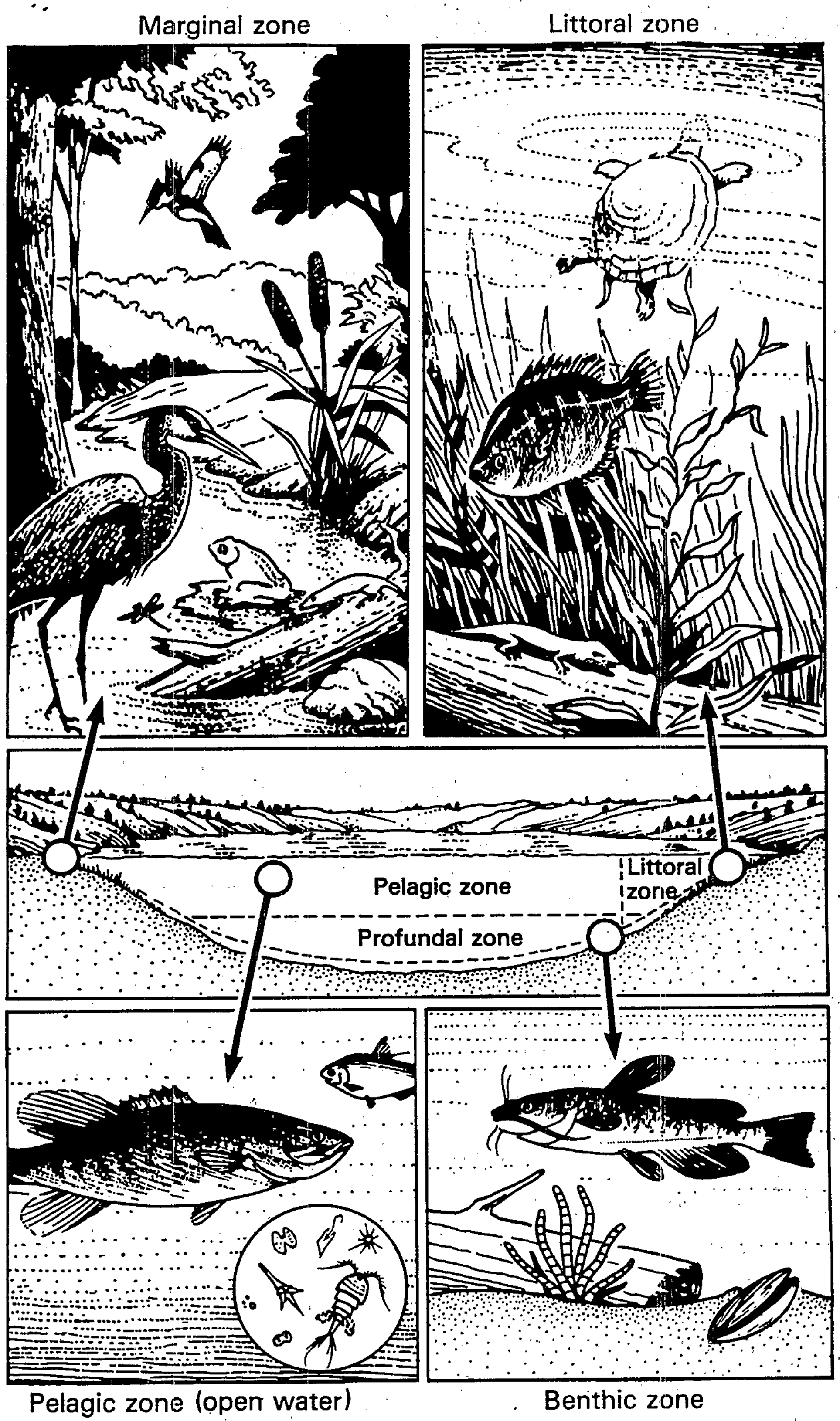


Figure 2-1.—The location and nature of typical lake communities, habitats, and organisms. In addition to the lake's watershed, all of these components are part of the lake ecosystem.

Limnology is the scientific study of the physical, chemical, geological, and biological factors that affect aquatic productivity and water quality in freshwater ecosystems—lakes, reservoirs, rivers, and streams. An understanding of limnology is the backbone of sound lake management.

This chapter is not intended to be a text on either aquatic ecology or limnology. Rather, its goal is to provide the background information necessary to understand the causes of lake degradation problems and to identify the most applicable lake management and restoration approaches.

Limnology *is the scientific study of the physical, chemical, geological, and biological factors that affect aquatic productivity and water quality in freshwater ecosystems—lakes, reservoirs, rivers, and streams.*

The Lake and Its Watershed

Water, dissolved materials carried in water, and particulates, such as soil, enter the lake from its watershed.

Lakes are constantly receiving these materials from watersheds, acid precipitation and dust from the atmosphere, and energy from the sun and wind. Therefore, water quality and productivity are as much influenced by what can (and will) go into the lake as by what is already there. Important factors include watershed topography, local geology, soil fertility and erodibility, vegetation in the watershed, and other surface water sources such as runoff and tributary streams. See the boxed section and Figure 2-A on the hydrologic cycle, which describes major natural phenomena controlling water supply availability.

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.*

Water

The amount of water entering the lake from its watershed controls volume and several other factors that influence the lake's overall health. A lake, like any water tank, takes a predictable amount of time to fill and to empty, given a certain rate of flow. Unlike rivers, lakes essentially slow the flow of water; thus, any water entering the lake will remain in it for a period called the *hydraulic residence time* (see boxed section and Fig. 2-B). Water quality reflects the history of the lake water, as well as the condition of new incoming water.

Because of hydraulic residence time, management programs directed at improving incoming water and, therefore, lake water quality, will face a lag period between the time that incoming water quality gets better and the time that change becomes evident in the lake. The longer the hydraulic residence time, the greater the lag.

Since water affects and is affected by the biota, sediments, and existing water chemistry, additional delays between changes in the quality of incoming water and that of in-lake water may also occur.

Dissolved Materials

One of the most important materials dissolved in water is oxygen. Sources of dissolved oxygen include inflowing water, transfer from the atmosphere (gas exchange), and photosynthetic production by aquatic plants.

Oxygen production by plants is discussed later in this chapter. Oxygen is consumed or removed from the lake by outflow, loss to the atmosphere, nonbiological combination with chemicals in the water and mud (chemical oxygen demand or COD), or plant, bacterial, and animal respiration. Biochemical oxygen demand (BOD), which is a common measure used to describe the rate of oxygen consumption by organisms and materials under dark conditions, varies with the amount of organic matter and bacteria in the water. Municipal wastewater discharges have very high BOD, for example.

Chemical oxygen demand (COD): *Nonbiological uptake of molecular oxygen by organic and inorganic compounds in water.*

The Hydrologic Cycle

Because precipitation and surface water runoff directly influence the nature of lake ecosystems, a good way to begin to learn about lakes is to understand the hydrologic (water) cycle. The circulation of water from atmosphere to Earth and back to the atmosphere is a process that is powered by the sun. About three-fourths of the precipitation that falls on land is returned to the atmosphere as vapor through evaporation and transpiration from terrestrial plants and emergent and floating aquatic plants. The remaining precipitation either is stored in ice caps, or drains directly off the land into surface water systems (such as streams, rivers, lakes, or oceans) from which it eventually evaporates, or infiltrates the soil and underlying rock layers and enters the groundwater system. Groundwater enters lakes and streams through underwater seeps, springs, or surface channels and then evaporates into the atmosphere.

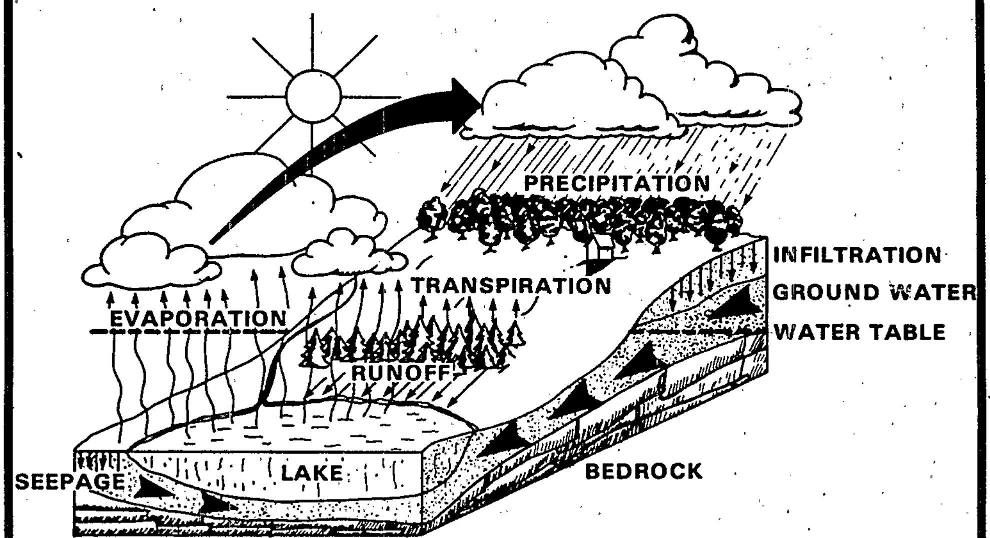


Figure 2-A.—Hydrologic cycle.

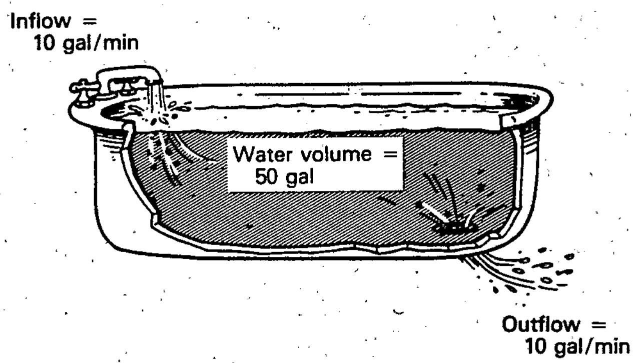
Lakes and reservoirs have a water "balance," as described in this simple equation: water input = water output +/- the amount of water stored in the lake. Inputs are direct precipitation, groundwater, and surface stream inflow, while outputs are surface discharge (outflow), evaporation, losses to groundwater, and water withdrawn for domestic, agricultural and industrial purposes. If inputs are greater than outputs, lake levels rise as water is stored. Conversely, when outputs are greater—for example, during a summer drought—lake levels fall as losses exceed gains.

Some lakes, called *seepage lakes*, form where the groundwater flow system intersects with the land surface. Seepage lakes are maintained primarily by groundwater inflow, and their water levels fluctuate with seasonal variations in the local water table. *Drainage lakes*, on the other hand, are fed primarily by inflowing rivers and streams; therefore, their water levels vary with the surface water runoff from their watersheds. In both cases, the balance between hydrologic inputs and outputs influences the nutrient supply to the lake, the lake's water residence time, and, consequently, the lake's productivity and water quality.

Hydraulic Residence Time

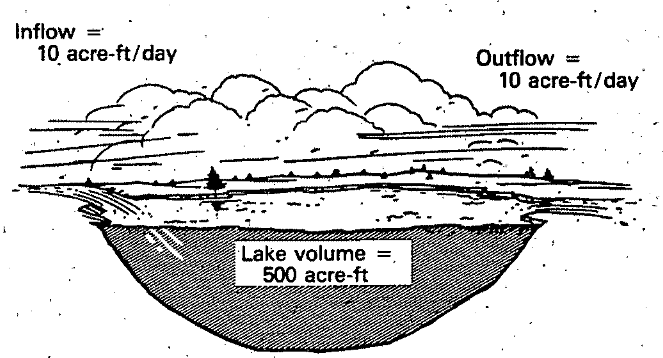
The average time required to completely renew a lake's water volume is called the hydraulic residence time. For instance, it might take 5 minutes to completely fill a bathtub with the tap fully open and the bottom drain closed. The hydraulic residence time of the tub, then, is 5 minutes. With the tap and drain only half open, the hydraulic residence time would be 10 minutes.

(a)



Hydraulic residence time = Volume ÷ Flow Rate
= 50 gal ÷ 10 gal/min = 5 min

(b)



Water residence time = 500 acre-ft ÷ 10 acre-ft/day = 50 days

Figure 2-B.—Hydraulic residence time is an important factor to consider in restoration programs. The simple formula given in the figure assumes that inflow is equal to outflow.

If the lake basin volume is relatively small and the flow of water is relatively high, the hydraulic residence time can be so short (10 days or less) that algal cells produced in the water column are washed out faster than they can grow and accumulate.

An intermediate water residence time allows both an abundant supply of plant nutrients and adequate time for algae to assimilate them, to grow, and then accumulate.

Longer water residence times from 100 days to several years provide plenty of time for algal biomass to accumulate if there are sufficient nutrients present. The production of algae may ultimately be limited by the supply of nutrients. If the nutrient supply is high, algal biomass will be very large. The combined effects of nutrient income (or "nutrient loading") and hydraulic residence time on the production of algae is the basis of methods for predicting changes in the lake's condition following variations in one or both of these processes (such as the diversion of wastewater flows.) These methods are discussed in Chapter 4.

When the loss of oxygen from the water exceeds the input of oxygen from various sources, the oxygen content of the lake water is decreased. If the dissolved oxygen becomes severely depleted, anoxic conditions can occur that lead to odors, fishkills, increased phosphorus and ammonia concentrations, and other undesirable effects.

Inflowing stream water also carries the two principal plant nutrients—nitrogen and phosphorus—in both dissolved organic and inorganic forms. Nitrogen and phosphorus are required for the biological production of phytoplankton (free-floating microscopic algae) and macrophytes (larger floating and rooted plants). (See **Organic Matter Production and Consumption** in this chapter.)

Surface and subsurface drainage from fertile (nutrient-rich) watersheds results in biologically productive lakes, and drainage from infertile (nutrient-poor) watersheds results in biologically unproductive lakes. The relative fertility of watersheds and, thus, of lakes varies locally and regionally, as is discussed in the boxed section on regional differences in lake water quality and biological productivity.

Soils, weathered minerals, and decomposing organic matter in the watershed are the main natural sources of phosphorus and nitrogen. However, manmade sources such as agriculture, crop and forest fertilizers, and wastewater discharges commonly increase the rate of nutrient income or loading from watersheds and are the major causes of biological overproduction in many lakes (Table 2-1). Watershed disturbances such as logging and mining, which remove natural vegetation, can greatly increase the amount of silt and nutrients exported from the land to the lake (see Chapter 5). Finally, pesticides, herbicides, toxic pollutants, chemicals in wastewater discharges, and industrial waste materials may also enter the lake with incoming water.

Table 2–1.—Representative values for nutrient export rates and input rates for various land uses. All values are medians and are only approximations owing to the highly variable nature of data on these rates.

LAND USE	TOTAL PHOSPHORUS	TOTAL NITROGEN
A. Export rates (kg/ha/yr)[1,2]		
Forest	0.2	2.5
Nonrow crops	0.7	6.0
Pasture	0.8	14.5
Mixed agriculture	1.1	5.0
Row crops	2.2	9.0
Feedlot, manure storage	255.0	2920.0
B. Total atmospheric input rates (kg/ha/yr)[1,3]		
Forest	0.26	6.5
Agricultural/rural	0.28	13.1
Urban industrial	1.01	21.4
C. Wastewater input rates (kg/capita/yr)[4]		
Septic tank input[5]	1.45	4.65

[1] Values in this table are all in kg ha yr, which is the standard for such measurements. To convert to pounds per acre per year, multiply by 0.892.
[2] Source: Reckhow et al. 1980, Figure 3.
[3] Source: Reckhow et al. 1980, Table 13.
[4] Source: Reckhow et al. 1980, Table 14.
[5] This is prior to absorption to soil during infiltration; generally, soils will absorb 80 percent or more of this phosphorus

Regional Differences in Lake Water Quality, Productivity, and Suitability

Lake water quality and productivity are influenced directly by the nature of the lake watershed; that is, by the watershed topography, soil fertility and erodibility, vegetation, and hydrology. Similarly, but on a larger scale, the character of lakes located in regional drainage systems are broadly influenced by the regional geology, topography, hydrology, soils, and vegetative cover. Both the lake watershed and regional conditions exert natural controls on lake trophic status, water quality, and biological productivity. For example, a deep alpine lake located in a granitic watershed in the Colorado Rockies is almost certain to have pristine, crystal clear, high quality water but very low biological productivity and poor fishing. On the other hand, a turbid reservoir in southern Mississippi or Alabama may be considered to have poor water quality because of its high turbidity, high concentrations of nutrients and organic matter, and frequent occurrences of algal blooms; however, this impoundment will likely support a productive sport fishery and be highly valued for its trophy bass.

North American lakes have extremely variable water quality, biological productivity, and fish community structure. This variability is due in large part to regional differences in the nature of lake watersheds and to a tremendous local diversity in lake morphometry (i.e., shape, depth, volume, surface area). Studies of the relationship between lake morphometry, water chemistry, and fish yield have generally shown that nutrient-rich, shallower lakes are typically more biologically productive and have higher fish yields per unit area than deeper, less fertile lakes. Along a water quality or trophic-status continuum ranging from oligotrophic (nutrient-poor, biologically unproductive, good water quality) through eutrophic (nutrient-rich, productive, poor water quality) lake conditions, there is also a continuum of fishery yield and fish community structure.

Generally, the better the lake water quality, the poorer the fishery yield (and vice versa) and, depending on the desired uses of a particular lake, there is often potential conflict between fishery optimization and water quality-related lake management objectives. Necessarily, maximum fishery yield results from high biological productivity and high plankton biomass (Jones and Hoyer, 1982; Wagner and Oglesby, 1984), while high water quality, high water transparency, low treatment costs, and the greatest aesthetic appeal are usually associated with low plankton biomass (Fig. 2-C). Consequently, without clearly established lake management priorities, maximized (or even improved) fish production may be incompatible with water quality-related lake management objectives.

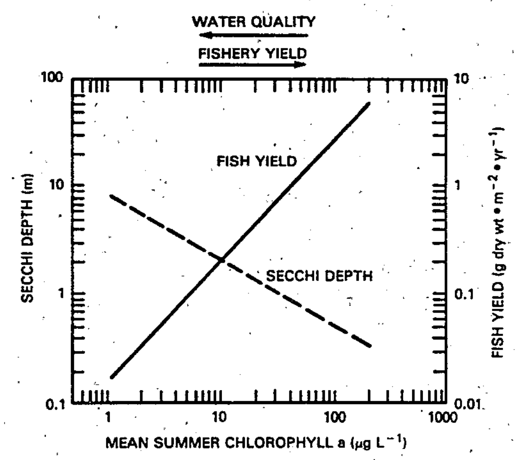


Figure 2-C.—Relationship between lake characteristics (e.g., water clarity, algal biomass) and management objectives (e.g., water quality, fishery yield). Modified from Wagner and Oglesby (1984).

Given the strong natural controls that the regional setting and the nature of the watershed exert on lake conditions, it is clear that particular lakes are best suited for particular uses. To be most effective, lake managers must first identify those uses that a lake can best support and then develop a compatible lake and watershed management plan to take advantage of the lake's natural condition.

Particulates

Organic matter, clays, and silt particles wash from the watershed into the lake. Where the land is disturbed, the soil loss is apt to be high. Even removing brush and replacing it with a poor stand of lawn can increase the rate of erosion. Although erodibility among soil types varies, it is one factor that must be considered in watershed management programs.

In addition to soil loss from the land through rainfall and snowmelt, streams may scour soil from their banks. Wind also carries some particulates, such as dust and pollen, directly to lakes. Inputs of suspended particles result in increased turbidity, which decreases water transparency and light availability and reduces plant growth.

Lakes are extremely efficient sediment traps. Filling in with silt is part of a lake's natural aging pattern, but poor land management practices can speed up the process significantly. Suspended sediment particles that can be easily carried by rivers and streams settle out once they reach the relatively quiescent lake environment. As a consequence, particle-associated nutrients, organic matter, and toxic contaminants are often retained in lake sediments, and the influx of herbicides, pesticides, and toxics adhered to soil particles is becoming an increasingly common problem for lakes.

Incoming silt is another problem. Silt-laden water can reduce penetration of sunlight and, consequently, the light available to algae. Many species of fish are sight feeders; they cannot locate prey efficiently in muddy waters. Silt deposits can also prevent successful hatching of fish eggs that require clean surfaces. Finally, excessive levels of silt can irritate the gills of fish, causing respiratory difficulties and poor health.

The **Sedimentation and Decomposition** section in this chapter discusses how organic matter in the water affects dissolved oxygen. Particles of organic matter can enter the lake suspended in tributary streams or can originate from aquatic plants and animals within the lake itself. Controlling soil loss from the watershed is treated in Chapter 5 in the discussion of best management practices. The use of dredging to deepen a lake and remove sediments is discussed in Chapter 6.

Organic matter: *Molecules manufactured by plants and animals and containing linked carbon atoms and elements such as hydrogen, oxygen, nitrogen, sulfur, and phosphorus.*

Sediment: *Bottom material in a lake that has 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 ooze).*

Effects of Lake Depth

Shallow lakes tend to be more biologically productive than deep lakes because of the large area of bottom sediments relative to the volume of water, more complete wind mixing of the lake water, and the large, very shallow (littoral) areas along the lake perimeter that can be colonized by rooted and floating macrophytes. Indeed, shallow lakes may be dominated by plant production in littoral areas and have little open water habitat. Large inputs of silt and incomplete decomposition of macrophytes can make lakes become shallow rapidly and, usually, shallow lakes have a shorter hydraulic residence time.

Deep, steep-sided lakes usually stratify thermally during the summer, which prevents complete mixing of the lake water. These lakes may have fewer areas that are shallow enough for rooted aquatic plants to receive light and grow. Thus, deep lakes generally have a high proportion of open water (pelagic) habitat, and their food webs tend to be based on the organic matter produced by planktonic algae or phytoplankton. Many reservoirs have large areas of shallow water, but flood control operations often cause water level fluctuations that discourage well-developed stands of aquatic weeds along the shoreline.

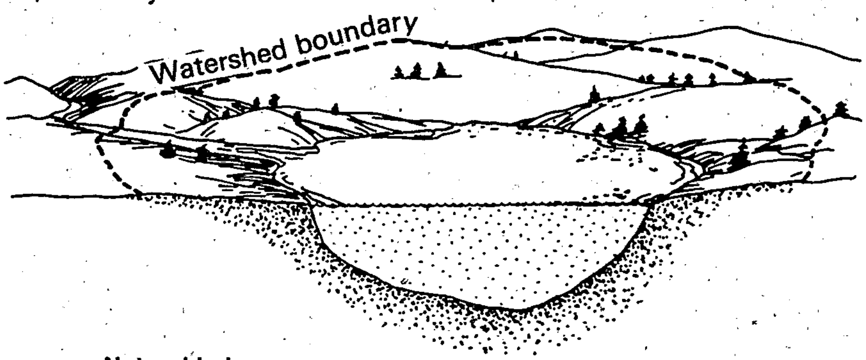
Littoral zone: *That portion of a waterbody extending from the shoreline lakeward to the greatest depth occupied by rooted plants.*

Pelagic zone: *This is the open area of a lake, from the edge of the littoral zone to the center of the lake.*

Manmade Lakes

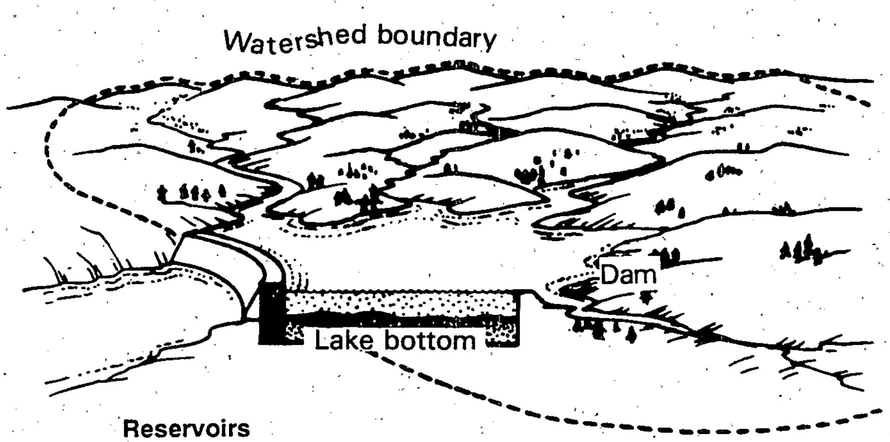
In contrast to the glacial lakes that may be thousands of years old, most manmade impoundments have been constructed within the past 100 years. Ponds, stock tanks, and small reservoirs have been formed for agricultural use, municipal water supply, soil and water conservation, sport fishing, and recreation. Large reservoirs are usually constructed by Federal agencies by impounding major rivers and are operated for multiple purposes that include water supply, flood control, and hydroelectric power generation.

The purpose and location of an impoundment usually determine its basin size, and the topography of the inundated valley dictates the basin shape. The geology, soil type, and vegetation in the valley and the watershed directly affect reservoir productivity and water quality. Because reservoirs are often flooded river valleys, many of these manmade lakes are long and narrow rather than circular or ovoid like many natural lakes, and they tend to have irregular shorelines (Fig. 2-2). Additionally, while natural lakes tend to have diffuse sources of inflowing water, relatively low watershed areas compared to lake surface area, and long



Natural Lakes

- Smaller watershed area
- Longer hydraulic residence time
- Simpler shape, shoreline
- Surface outlet



Reservoirs

- Larger drainage area
- Shorter hydraulic residence time
- More complex shape, shoreline
- May have surface and/or subsurface outlet(s).

Figure 2-2.—General comparison of reservoirs to natural lakes.

hydraulic residence times, reservoirs usually differ in all of these traits, and these differences account for the great variety in water quality and productivity that can occur between and among lakes and reservoirs.

Typically, a reservoir has one or two major tributaries, a very large watershed compared to lake surface, and relatively short hydraulic residence times. The inputs of dissolved and particulate organic and inorganic materials from the watershed are also likely to be very high. Of course, the most distinctive difference between natural lakes and reservoirs is the subsurface outlet commonly possessed by large reservoirs with dams designed for hydroelectric power generation.

Actually, there are probably more similarities than differences between natural lakes and reservoirs. The physical, chemical, and biological conditions in both overlap greatly, as illustrated in Figure 2-3. With regard to the environmental factors that control water quality and biological productivity, reservoirs occupy an intermediate position between natural lakes and rivers on a conceptualized continuum of aquatic environments (Kimmel and Groeger, 1984). Hydraulic residence time is the characteristic that most influences the relative productivity and water quality of natural lakes and reservoirs (Soballe and Kimmel, 1987).

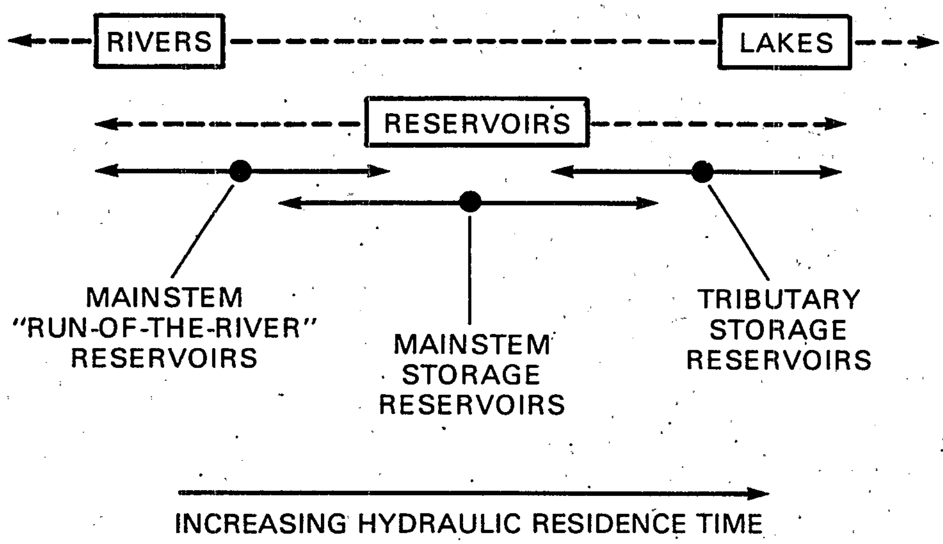


Figure 2-3.—Reservoirs occupy an intermediate position between rivers and natural lakes along a continuum of aquatic ecosystems ranging from rivers to natural lakes. Water residence time and the degree of riverine influence are primary factors determining the relative positions of different types of reservoirs (mainstem-run-of-the-river, mainstem storage, and tributary storage impoundments) along the river-lake continuum. Modified from Kimmel and Groeger (1984).

Lake Processes

Lake Stratification and Mixing

In spring and early summer, the combination of solar heating and wind mixing of near-surface water layers brings about the warming of the upper portion of the lake water column and the stratification of many lakes and reservoirs into layers of water with different temperatures and densities (Fig. 2-4). Rapidly flushed, shallow lakes that are exposed to strong winds, however, do not normally develop persistent thermal stratification. Refer to the boxed section on the unique properties of water for a discussion of the water temperature–density relationship that results in the thermal stratification of lakes.

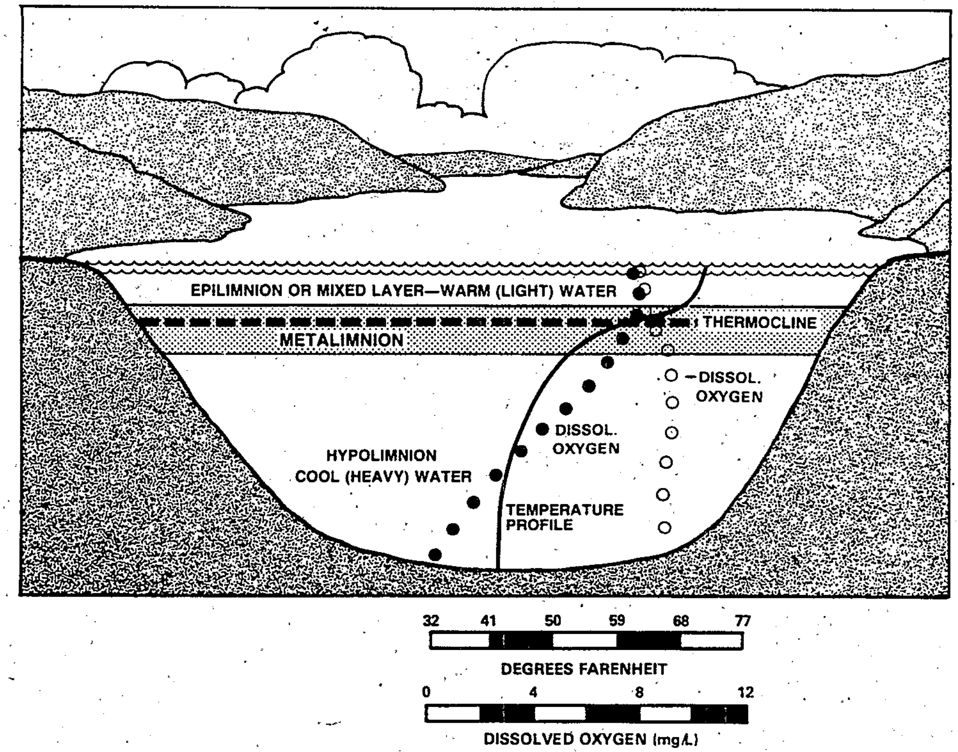


Figure 2-4.—A cross-sectional view of a thermally stratified lake in mid-summer. The water temperature profile (curved solid line) illustrates how rapidly the water temperature decreases in the metalimnion compared to the nearly uniform temperatures in the epilimnion and hypolimnion. The metalimnetic density gradient associated with this region of rapid temperature change provides a strong, effective barrier to water column mixing during the summer months. Open circles represent the dissolved oxygen (DO) profile in an unproductive (oligotrophic) lake: the DO concentration increases slightly in the hypolimnion because oxygen solubility is greater in colder water. Solid circles represent the DO profile in a productive (eutrophic) lake in which the rate of organic matter decomposition is sufficient to deplete the DO content of the hypolimnion.

During summertime thermal stratification, a warmer, less dense layer of water (the *epilimnion*) floats on a cooler, denser water layer (the *hypolimnion*). These two layers are separated by a zone of rapidly changing temperature and density called the *metalimnion*. The term "metalimnion" is often used loosely, but the classical definition is the stratum of water of rapid thermal change with depth, above and below which are zones of uniformly warm (epilimnion) and cold (hypolimnion) water layers. The *thermocline*, defined as a horizontal plane of water across the lake through the point of the greatest temperature change, is within the metalimnion.

Epilimnion: *Uppermost, warmest, well-mixed layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.*

Hypolimnion: *Lower, cooler layer of a lake during summertime thermal stratification.*

Mixing Processes

The most important lake mixing mechanisms are wind, inflowing water, and outflowing water. Wind affects the surface waters of all lakes, but the effectiveness of wind in mixing the entire water column is sharply curtailed in some lakes during the summer. During summertime thermal stratification, a lake usually cannot be completely mixed by wind. When the lake water cools in the fall, the temperature-controlled zonation breaks down and the water column mixes completely.

The Unique Properties of Water

Water is a unique substance, and to understand how lakes behave, it is useful to understand water's physical and chemical properties. The molecular structure of water and the way in which water molecules associate with each other dictate these properties:

1. Water is an excellent solvent; many gases, minerals, and organic compounds dissolve readily in it.

2. Water is a liquid at natural environmental temperatures and pressures. Although this property seems rather common and obvious, in fact, it is quite important. If water behaved at ordinary temperatures and pressures as do chemically similar inorganic compounds, it would be present only as a vapor, and lakes would not exist.

3. The temperature-density relationship of water is also unique. Most liquids become increasingly dense (more mass, or weight, per unit volume) as they cool. Water also rapidly becomes more dense as its temperature drops, but only to a certain point (Fig. 2-D). Water reaches its maximum density at 39.2°F (3.94°C), then it decreases slightly in density until it reaches 32°F (0°C), the freezing point. At this point, ice forms and its density decreases sharply. Ice, therefore, is much lighter than liquid water and forms at the surface of lakes rather than at the lake bottom.

   A second important consequence of the temperature-density relationship of water is the thermal stratification of lakes. Energy is required to mix fluids of differing densities, and the amount of energy necessary is related to the difference in density. In the case of the water column mixing in lakes, this energy is provided primarily by wind. Therefore, the changes in water density that accompany rapidly decreasing water temperatures in the metalimnion during summer stratification are of great importance. The metalimnetic density gradient provides a strong and effective barrier to water column mixing.

**The layer of greatest temperature change, the metalimnion, presents a barrier to mixing. The thermocline is not a layer, but a plane through the point of maximum temperature change. The epilimnion and hypolimnion are relatively uniform in temperature. As the graph illustrates, ice is much less dense (lighter) than water. Warm water is less dense than cold water, but not as light as ice. Density changes most rapidly at warm temperatures.*

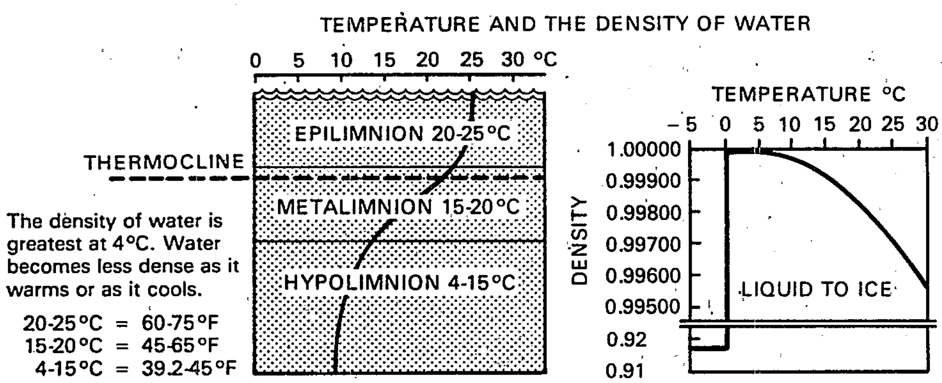


Figure 2-D.—The temperature-density relationship of water enables deep lakes to stratify during summer. (*See explanation in side column.)

4. Water also has an unusually high specific heat. Specific heat is the amount of energy required to change the temperature of 1 g of water by 1°C. Water also has a high latent heat of fusion, which is the energy required to melt 1 g of ice at 0°C. These properties make lakes slow to thaw and warm in the spring and slow to cool and freeze in the fall, thus providing exceptionally stable thermal environments for aquatic organisms.

   Additionally, because water gains and loses heat slowly, the presence of large lakes can exert a significant influence on local and regional climate. A good example is the Great Lakes, which have a dramatic effect on both the air temperature and on the precipitation in the States and Provinces surrounding them.

In stratified lakes, the thickness of the epilimnion is considered to be the depth to which water is consistently mixed by wind. How deep (or thick) this layer becomes during the summer depends upon how resistant the water column is to mixing. The greater the temperature difference between the epilimnion and the hypolimnion, the more wind energy is required to mix the water column completely to the bottom of the lake. The density gradient (change in density) of the metalimnion acts as a physical barrier to the complete mixing of the epilimnion and hypolimnion.

In the spring, just after thermal stratification is established, the hypolimnion is rich in dissolved oxygen from early spring mixing of the water column and plant oxygen production. However, because of the barrier properties of the thermocline, the hypolimnion is isolated from gas exchanges with the atmosphere during the summer and is often too dark for photosynthetic production of oxygen by green plants. In a productive lake, the hypolimnion can become oxygen-depleted during the period of summer thermal stratification as its reserve of dissolved oxygen is consumed by the decomposition (respiration) of organic matter.

This event has very important consequences for lake productivity and fishery management and is one of the major targets of lake restoration activities. Most fish require relatively high dissolved oxygen levels and cannot survive in an oxygen-deficient hypolimnion; however, the epilimnion may be too warm for their survival. Additionally, under anoxic conditions, nutrients such as nitrogen and phosphorus are released from the bottom sediments to the water column, where they ultimately promote additional algal production organic matter decomposition, and more severe hypolimnetic oxygen depletion.

Decomposition: *The transformation of organic molecules (e.g., sugar) to inorganic molecules (e.g., carbon dioxide and water) through biological and nonbiological processes.*

As the epilimnion cools in the late summer and fall, the temperature difference between layers decreases, and mixing becomes easier. With the cooling of the surface, the mixing layer gradually extends downward until the entire water column is again mixed and homogeneous (Fig. 2-5). This destratification process is often referred to as the fall overturn.

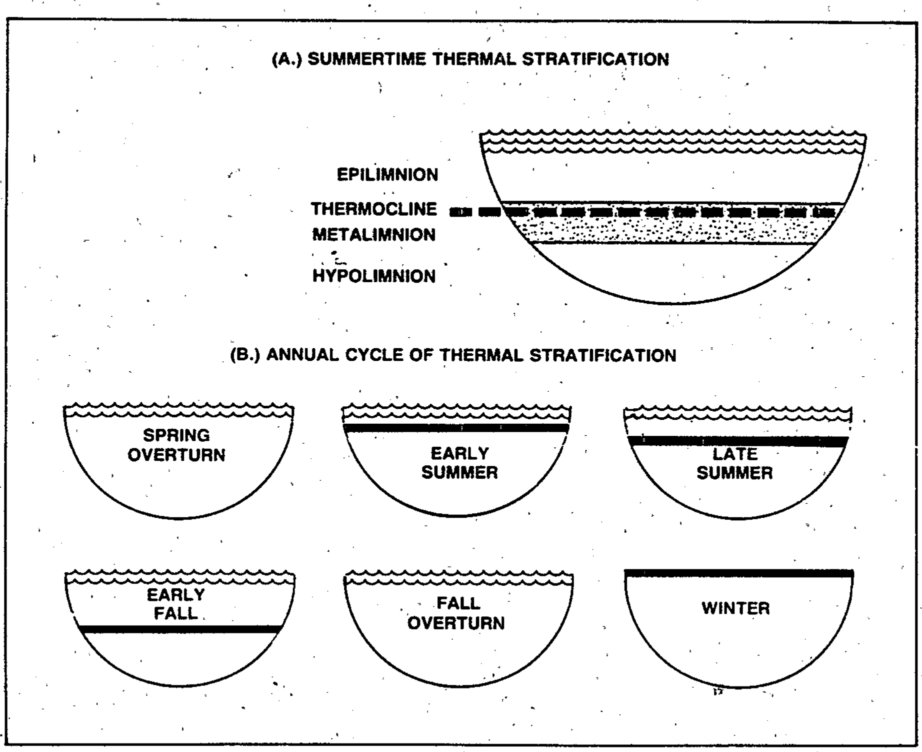


Figure 2-5.—Seasonal patterns in the thermal stratification of North Temperate Zone lakes and reservoirs: (A) summertime stratification; (B) the annual cycle of lake thermal stratification.

Water Movements

The wind-driven vertical mixing of the water column, just discussed, is only one of several types of water movements in lakes.

The downstream flow of water usually controls the transport of dissolved and suspended particles, particularly in river-like lakes and in many large, manmade impoundments dominated by major tributaries. Many natural lakes, however, have numerous, diffuse inflows (including subsurface inflows) and a surface outlet. In such lakes, the downstream flow of water from the watershed is not a major influence on lake water movements. Commonly, however, large reservoirs have deep subsurface (often hypolimnetic) outlets from the dam that tend to promote subsurface density flows (Fig. 2-6). A density flow occurs when inflowing water is cooler and thus denser than the epilimnetic water and, therefore, sinks or plunges to a depth of equivalent water temperature or density before continuing its downlake flow.

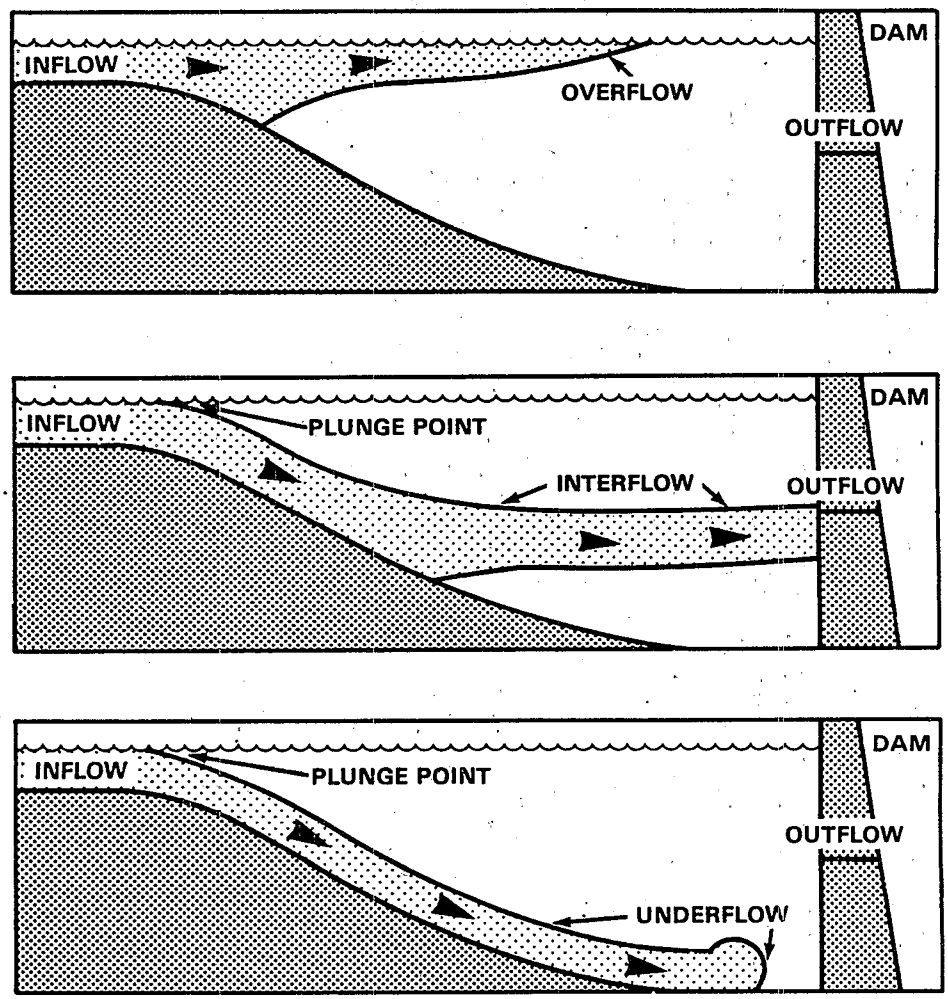


Figure 2-6.—Types of density flows in reservoirs. Often the inflowing river water and the reservoir water differ in temperature, and therefore, in the density. If the river inflow is warmer than the reservoir, the less dense river water will spread over the reservoir surface as an overflow (upper panel). If the river inflow is of an intermediate temperature and density, it will plunge from the surface and proceed downstream as an interflow at the depth at which the river water and reservoir water densities are equal (middle panel). If the river inflow is cooler and denser than the entire reservoir water mass, the inflowing river water will plunge from the surface and flow along the reservoir bottom as an underflow (lower panel). Modified from Wunderlich (1971).

Under stratified conditions, these density flows may pass through an entire reservoir along the bottom or at an intermediate depth without contributing significant amounts of nutrients or oxygen to the upper mixed layer. This is a common phenomenon in series of deep-discharge impoundments. Cold water released from an upstream reservoir may traverse the next reservoir in the series as a discrete subsurface flow. This short-circuiting underflow may even be perceived as desirable for water quality because it allows nutrient-laden water to flow through the reservoir without contributing to nuisance levels of algal production. Fishermen, however, may view this short circuit with less enthusiasm because a reduction in algal production may be detrimental to overall lake production of fish.

Density flows: *A flow of water of one density (determined by temperature or salinity) over or under water of another density (e.g., flow of cold river water under warm reservoir surface water).*

Organic Matter Production and Consumption

Photosynthesis and Respiration

Planktonic algae (phytoplankton) and macrophytes use the energy from sunlight, carbon dioxide, and water to produce sugar, water, and molecular oxygen (Fig. 2-7). The sun's energy is stored in the sugar as chemical bond energy. The green pigment, chlorophyll, is generally required for plants to do this. Sugar, along with certain inorganic elements such as phosphorus, nitrogen, and sulfur, is then converted by plant cells into organic compounds such as proteins and fats. The rate of photosynthetic uptake of carbon to form sugar is called *primary productivity*. The amount of plant material produced and remaining in the system is called *primary production* and analogous to the standing crop or biomass of plants in a farmer's field. While in-lake photosynthesis normally is the dominant source of or-

Macrophytes: *Rooted and floating aquatic plants, commonly referred to as waterweeds. These plants may flower and bear seed. Some forms, such as duckweed and coontail (Ceratophyllum), are free-floating forms without roots in the sediment.*

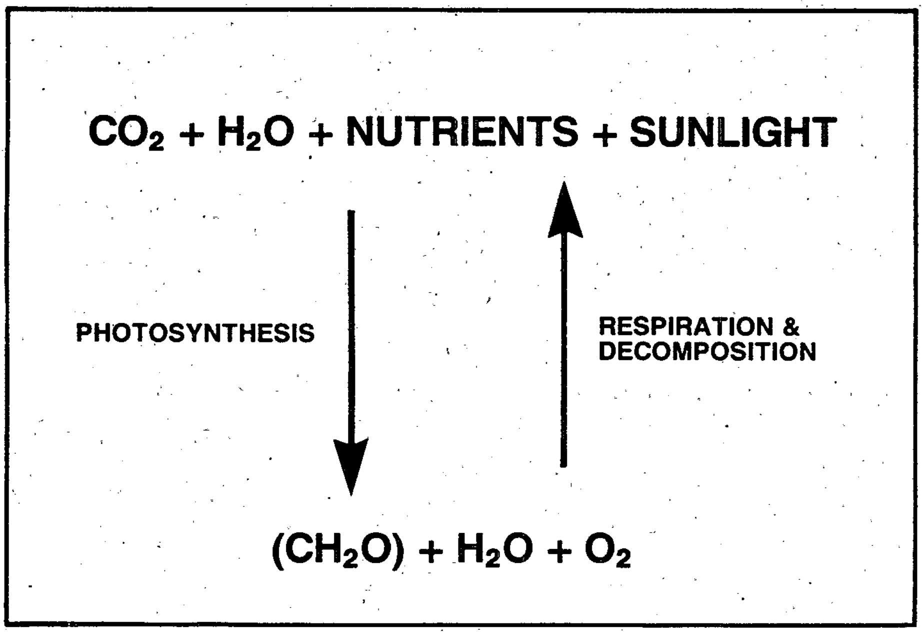


Figure 2-7.—The equilibrium relationship between photosynthesis and respiration-decomposition processes. The photosynthetic conversion of light energy, carbon dioxide (CO_2), water (H_2O), and nutrients into organic matter produces oxygen (O_2) and results in nonequilibrium concentrations of carbon, nitrogen, sulfur, and phosphorus in organic compounds of high potential energy. Respiration-decompostion processes tend to restore the equilibrium by consuming oxygen and decomposing organic materials to inorganic compounds.

Primary productivity: *The rate at which algae and macrophytes fix or convert light, water, and carbon dioxide to sugar in plant cells. Commonly measures as milligrams of carbon per square meter per hour.*

Phytoplankton: *Microscopic algae and microbes that float freely in open water of lakes and oceans.*

ganic matter for the lake's food web, most lakes also receive significant inputs of energy in the forms of dissolved and particulate organic matter from their watersheds.

In the process of photosynthesis, molecular oxygen is produced as well, and this is the primary source of dissolved oxygen in the water and of oxygen in the atmosphere. Oxygen is usually required to completely break down organic molecules and release their chemical energy. Plants and animals release this energy through a process called *respiration.* Its end products—energy, carbon dioxide, and water—are produced by the breakdown of organic molecules in the presence of oxygen (Fig. 2-7).

Because of the requirement for light, the primary (photosynthetic) production of organic matter by aquatic plants is restricted to the portion of the lake water column that is lighted (also called the *photic zone*). The thickness of the photic zone depends upon the transparency of the lake water and corresponds to the depth to which at least 1 percent of the surface light intensity penetrates. Below this, in the *aphotic zone*, the available light is too weak to support a significant amount of photosynthetic production.

Phytoplankton production is controlled primarily by water temperature, light availability, nutrient availability, hydraulic residence time, and plant consumption by animals. Macrophyte production is controlled more by temperature, light, and bottom soil types. Most rooted macrophytes obtain their nutrients from the bottom sediments rather than the water and are restricted by light penetration to the shallow littoral water.

When light is adequate for photosynthesis, the availability of nutrients often controls phytoplankton productivity. In the lake, differences between plant requirements for an element and its availability exert the most significant limit on lake productivity. Table 2-2 compares the relative supply of essential nutrients to their demand for plant growth. Phosphorus and nitrogen are the least available elements, and therefore they are the most likely to limit lake productivity.

Table 2–2.—**The listed elements are required for plant growth. Plant demand is represented by the percentage of these essential elements in the living tissue of freshwater plants. Supply is represented by the proportions of these elements in world mean river water. The imbalance between demand and supply is an important factor in limiting plant growth (after Vallentyne, 1974).**

ELEMENT	SYMBOL	DEMAND BY PLANTS (%)	SUPPLY IN WATER (%)	DEMAND: SUPPLY RATIO[1]
Oxygen	O	80.5	89	1
Hydrogen	H	9.7	11	1
Carbon	C	6.5	.0012	5,000
Silicon	Si	1.3	.00065	2,000
NITROGEN	**N**	**.7**	**.000023**	**30,000**
Calcium	Ca	.4	.0015	<1,000
Potassium	K	.3	.00023	1,300
PHOSPHORUS	**P**	**.08**	**.000001**	**80,000**
Magnesium	Mg	.07	.0004	<1,000
Sulfur	S	.06	.0004	<1,000
Chlorine	Cl	.06	.0008	<1,000
Sodium	Na	.04	.0006	<1,000
Iron	Fe	.02	.00007	<1,000

[1] Percent of element in plant tissue ÷ percent in available water. The higher the ratio, the more scarce the nutrient. Phosphorus, in particular, is likely to limit plant growth in a lake. If more phosphorus is supplied, however, plant growth is likely to accelerate unless and until limited by some other factor.

Phosphorus in particular can often severely limit the biological productivity of a lake. The by-products of modern society, however, are rich sources of this element. Wastewaters, fertilizers, agricultural drainage, detergents, and municipal sewage contain high concentrations of phosphorus, and if allowed to enter the lake, they can stimulate algal productivity. Such high productivity, however, may result in nuisance algal blooms, noxious tastes and odors, oxygen depletion in the water column, and undesirable fishkills during winter and summer.

Since phosphorus is most often the nutrient that limits algal productivity, it is usually the element that is the focus of many lake management or restoration efforts aimed at reducing algal production and improving lake water quality. Phosphorus loading can be reduced, for example, by chemical flocculation in advanced wastewater treatment plants or controlled in the watershed by using proper agricultural and land management practices, improving septic systems, and applying fertilizer carefully (see Chapter 5).

In the past 20 years, there have been increasing efforts to minimize phosphorus inputs to lakes as a way to curb eutrophication. Methods for precipitating or inactivating phosphorus within the lake are discussed in Chapter 6 under Algae/Techniques With Long-Term Effectiveness. A method for determining the amount of phosphorus coming from the watershed is discussed in Chapter 3, and a formula for calculating the amount is given in Chapter 4. In contrast, however, poor fishing may be considered the problem of highest priority for infertile lakes in some regions and improving the fishery yield may be the primary lake management objective. In such cases, additions of phosphorus- and nitrogen-containing fertilizers may be used as a lake management tool to increase phytoplankton production, plankton standing crop, and ultimately, to enhance fish production.

Phytoplankton Community Succession

As the growing season proceeds, a succession of algal communities typically occurs in a lake (Fig. 2-8). Phytoplankton biomass usually tends to be high in the spring and early summer by virtue of increasing water temperature and light availability, relatively high nutrient availability, and low losses to zooplankton grazing (consumption by microscopic animals). As grazing pressure increases and nutrient availability declines from early to midsummer, algal biomass declines. It rises again in the late summer and fall when water column mixing increases the supply of nutrients and other conditions provide a favorable environment for the growth of algae. Sometimes, particularly in very productive lakes, blue-green algae form floating scums on the surface of the lake. Algal production and biomass are usually low in the winter because of low water temperatures and low light availability.

Sedimentation and Decomposition

Sedimentation occurs when particles (silt, algae, animal feces, and dead organisms) sink through the lake water column onto the lake bottom. Sedimentation is a very important process that affects phytoplankton biomass levels, phytoplankton community succession, and transfers of organic matter, nutrients, and particle-associated contaminants from the lake's upper layers to the bottom sediments. One reason for the dominance of blue-green algae in some lakes is their ability to regulate their buoyancy and, therefore, to counter sedimentation. Sedimentation of particulate organic matter from the water column to the lake bottom provides a critical linkage between planktonic

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. Often measured in terms of grams per square meter of surface.*

Zooplankton: *Microscopic animals that float freely in lake water, graze on detritus particles, bacteria, and algae, and may be consumed by fish.*

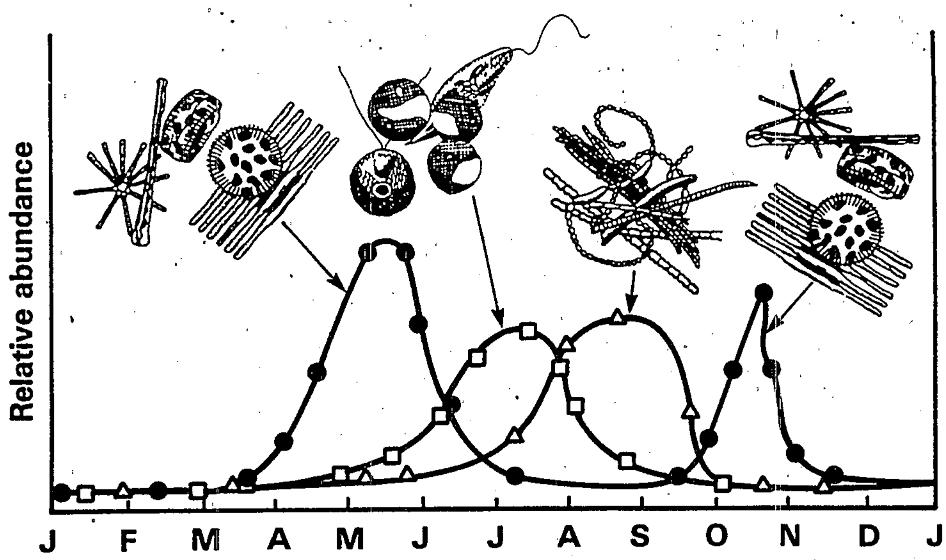


Figure 2-8.—A typical seasonal succession of lake phytoplankton communities. Diatoms dominate the phytoplankton in the spring and the autumn, green algae in midsummer, and blue-green algae (cyanobacteria) in late summer.

primary production and the growth of bottom-dwelling organisms (such as aquatic insect larvae, clams, and crayfish) that eat this detrital organic matter and, in turn, are eaten by larger predatory organisms, such as fish and turtles.

Settling plankton, zooplankton feces, and other organic detritus particles are degraded in the water column and in the bottom sediments through oxygen-consuming decomposition processes. *Organic matter decomposition*, a collective term for the net conversion of organic material back to inorganic compounds (see Fig. 2-7), occurs through the respiratory activities of all organisms, including bacteria, fungi, and other microbes.

In the hypolimnion of productive lakes, the sedimentation of organic matter from the surface waters is extensive. And because algae and other suspended particles are abundant, light penetration through the water column to the hypolimnion is limited or absent and photosynthesis cannot occur. Under these conditions, the oxygen consumed in the hypolimnion and bottom sediments during the decomposition (respiration) of this organic matter greatly exceeds the oxygen produced. Also, as described earlier, the hypolimnion is isolated from the atmosphere by a temperature or water density barrier to mixing known as the metalimnion. The result, in productive thermally stratified lakes, is a depletion and sometimes a complete absence of dissolved oxygen in the hypolimnion (see Fig. 2-4). A similar result can occur, though more slowly, in shallow, productive lakes with a prolonged snow and ice cover.

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 trophic state.*

The chemical and physical changes associated with oxygen depletion are marked. They include increased nutrient release from the bottom sediments, destruction of oxygenated habitats for aquatic animals, and incomplete decomposition of sedimented organic matter (Fig. 2-9). These symptoms are often characteristic of lake trophic status (see description of trophic status in **Lake Aging and Cultural Eutrophication** in this chapter).

■ **Oligotrophic lakes:** Insufficient organic matter is produced in the epilimnion to reduce hypolimnetic oxygen concentrations significantly; the hypolimnion remains relatively oxygenated throughout the year.

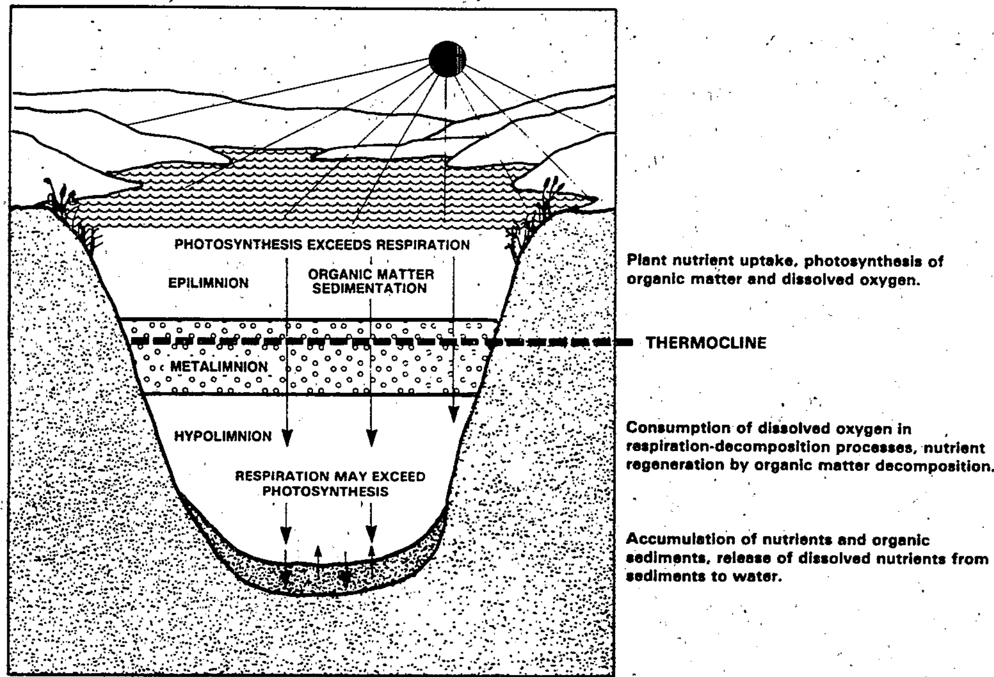


Figure 2-9.—Influence of photosynthesis and respiration-decomposition processes and organic matter sedimentation on the distribution of nutrients, organic matter, and dissolved oxygen in a stratified lake.

■ **Eutrophic lakes:** Organic matter decomposition can rapidly exhaust the dissolved oxygen in unlighted zones, leading to anoxia in the hypolimnion. During midsummer, when a temperature–oxygen squeeze can develop in stratified lakes, cool water fish such as trout cannot occupy the oxygen-depleted lower waters and must stay in less than ideal warmer upper waters.

In anoxic conditions, metals such as iron, manganese, and sulfur and the nutrients phosphorus and ammonium (a nitrogen compound) become increasingly soluble and are released from the sediments into the hypolimnion. Summer partial mixing events, which can occur during the passage of summer cold fronts with wind and cold rains, can transport some of these released nutrients to the lake surface where they may stimulate more algal production. At fall turnover, these metals and nutrients reenter the photic zone and may also stimulate algal blooms. Nutrients that reenter the water column from sediments constitute an "internal nutrient load" to the lake. Lake managers must be aware of this internal source of nutrients in addition to the nutrients entering from the watershed.

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.*

Food Web Structure, Energy Flow, and Nutrient Cycling

In-lake plant production usually forms the organic matter base of the lake's food web. Although some waterbodies (especially rapidly flushed reservoirs) receive important supplements of organic matter from river and stream inflow, most lakes require a reliable level of algal and macrophyte production to maintain productive food webs (Adams et al. 1983).

Nutrient Cycling: *The flow of nutrients from one component of an ecosystem to another, as when macrophytes die and release nutrients that became available to algae (organic to inorganic phase and return).*

Producers: *Green plants that manufacture their own food through photosynthesis.*

Some of the organic matter produced photosynthetically by the lake's primary producers (algae and macrophytes) is consumed by herbivores (grazers) that range from tiny zooplankton to snails to grazing minnows. Herbivores, such as the zooplankton, are fed on by planktivores (including predatory zooplankton and planktivorous fish) that, in turn, provide a food source for the higher-level consumers such as piscivorous fish (bass, walleye, trout) and fish-eating birds (kingfishers, herons, ospreys, eagles). This general progression of feeding levels (also called trophic levels) from primary producers, to herbivores, to planktivores, to the larger predators, constitutes the *food chain* (Fig. 2-10). The actual complex of feeding the interactions that exists among all of the lake's organisms is called the *food web*.

As shown in Fig. 2-10, the food chain concept also involves the flow of energy among the lake organisms and the recycling of nutrients. The energy flow originates with the light energy from the sun, which is converted by green plant photosynthesis into the chemical bond energy represented by the organic matter produced by the plants. Each subsequent consumer level (herbivore, planktivore, piscivore) transfers only a fraction (usually only about 10 to 20 percent) of the energy received on up the chain to the next trophic level (Kozlovsky, 1968; Gulland, 1970).

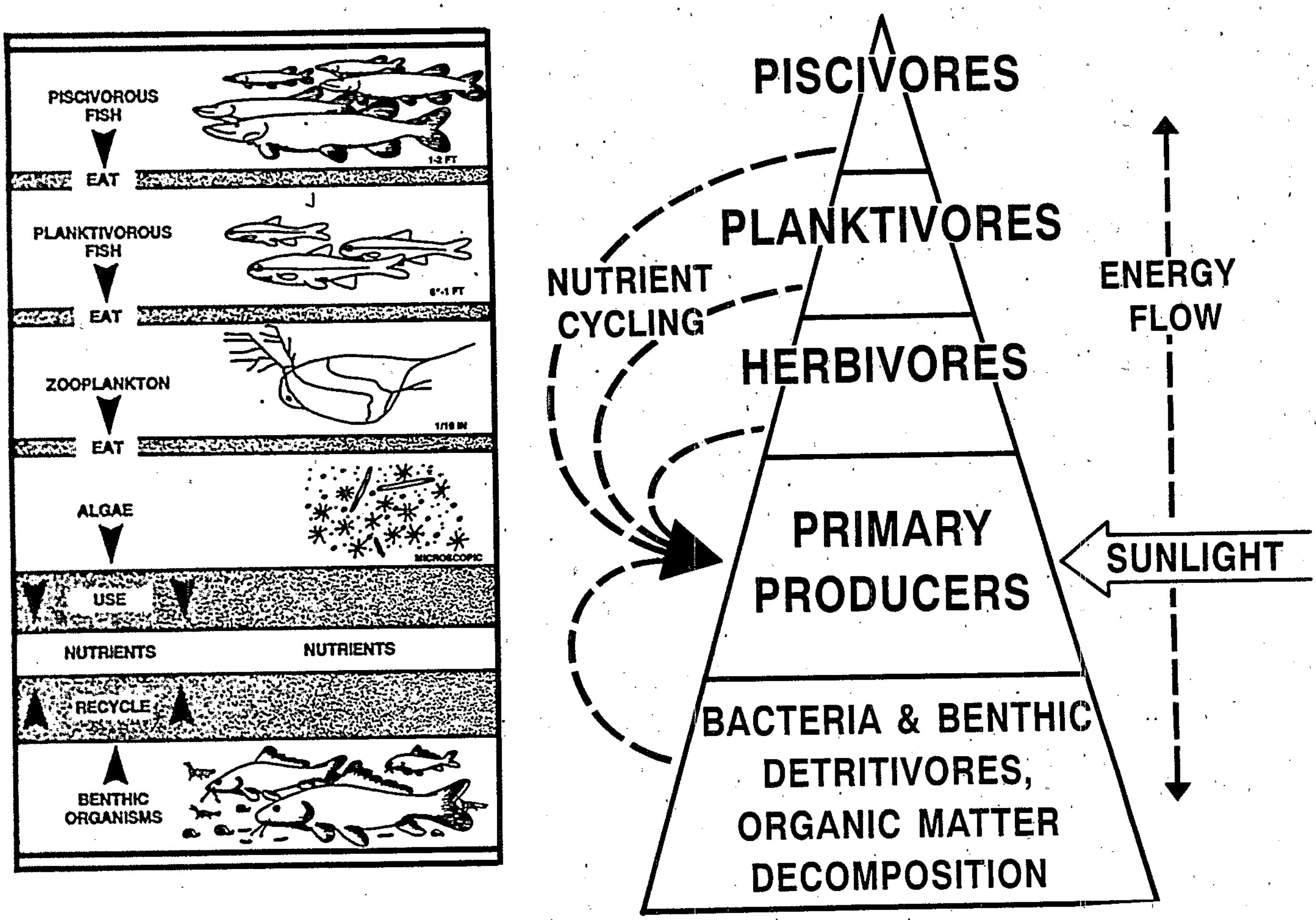


Figure 2-10.—The food-chain concept refers to the progression of feeding (or trophic) levels from primary producers, to herbivores, to higher predators. As shown, this process involves both the transfer of energy among lake organisms and the recycling of nutrients. Because the available energy decreases at each trophic level, a large food base of primary producers, herbivores, and planktivores is required to support a few large game fish.

In practice, this means that a few large game fish depend on a large supply of smaller fish, which depend on a very large supply of smaller herbivores, which depend on a successively much larger base of photosynthetic production by phytoplankton and other aquatic plants. Finally, by constantly producing wastes and eventually dying, all of these organisms provide nourishment to detritivores (detritus-eating organisms) and to bacteria and fungi, which derive their energy by decomposing organic matter. Organic matter decomposition results in the recycling of nutrients that are required for further plant production.

A more complex view of energy flow and nutrient cycling in a lake or reservoir ecosystem is shown in Fig. 2-11. Much of the organic matter input from the watershed directly supports the growth of detritivores, bacteria, and fungi. A significant fraction of the in-lake primary production provides food for herbivores and, ultimately, for higher consumers (as described before); however, much of the in-lake plant production may also become detritus and provide nourishment to both planktonic and benthic detritus feeders. Sorption of dissolved organic compounds to suspended detritus particles, microbial colonization of these particles, and particle aggregation or clumping produces microbial-detrital aggregates large enough to be consumed by filter-feeding zooplankton. Additionally, the sedimentation of detritus particles to the lake bottom provides energy to the benthic detritivores, which are preyed upon by the higher consumers. Nutrient regeneration occurs at virtually every level of the food web, and only a small fraction of the organic matter produced ultimately accumulates as permanent bottom sediment.

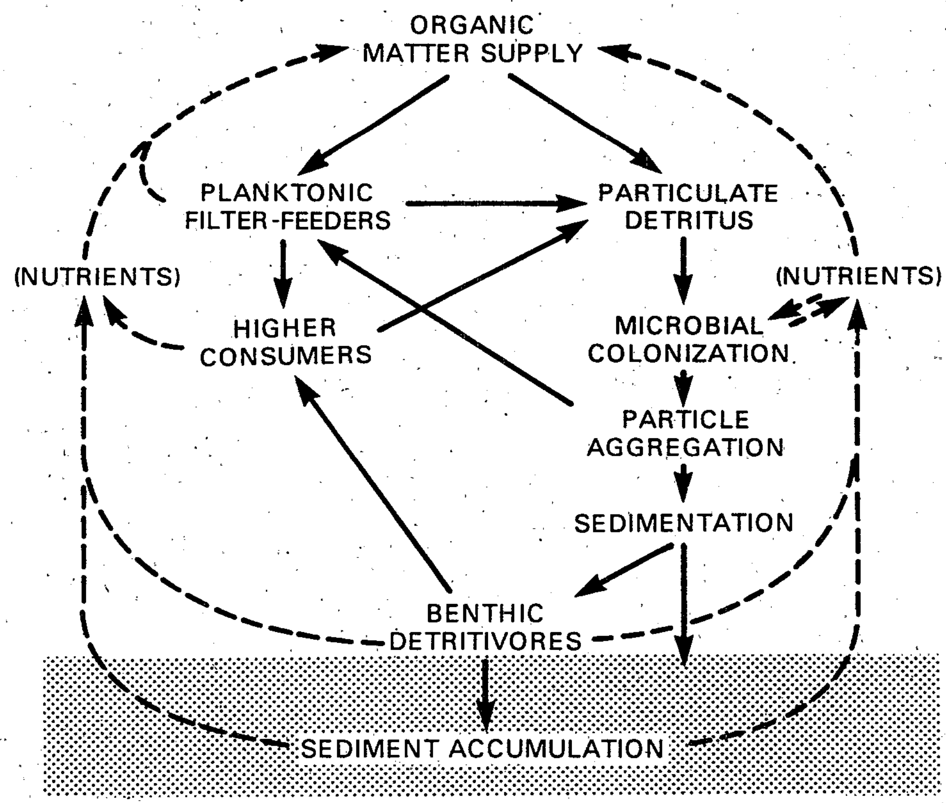


Figure 2-11.—A more complex view of energy flow and nutrient recycling in a lake or reservoir. Solid lines represent pathways of energy flow, and dashed lines indicate nutrient recycling. Refer to the text for a detailed explanation. Modified from Goldman and Kimmel (1978).

Lake Aging and Cultural Eutrophication

Lakes are temporary features of the landscape. The Great Lakes, for example, have had their current shapes for only about 12,000 years. Over tens to many thousands of years, lake basins change in size and depth as a result of climate, movements in the earth's crust, shoreline erosion, and the accumulation of sediment. Lake eutrophication is a natural process resulting from the gradual accumulation of nutrients, increased productivity, and a slow filling in of the basin with accumulated sediments, silt, and organic matter from the watershed.

The original shape of the basin and the relative stability of watershed soils strongly influence the lifespan of a lake (see the boxed section and Fig. 2-D on lake basin origin and shape).

The classical lake succession sequence (Fig. 2-12) is usually depicted as a unidirectional progression through the following series of phases or trophic states:

- ***Oligotrophy:*** Nutrient-poor, biologically unproductive
- ***Mesotrophy:*** Intermediate nutrient availability and biological productivity
- ***Eutrophy:*** Nutrient-rich, highly productive
- ***Hypereutrophy:*** Pea-soup conditions, the extreme end of the eutrophic stage

These lake trophic states correspond to gradual increases in lake productivity from oligotrophy to eutrophy (Fig. 2-12).

Evidence obtained from sediment cores (see Chapter 3), however, indicates that changes in lake trophic status are not necessarily gradual or unidirectional. If their watersheds remain relatively undisturbed, lakes can retain the same trophic status for many thousands of years. Oligotrophic Lake Superior is a good example of this. In contrast, rapid changes in lake nutrient status and productivity are often a result of human-induced disturbances to the watershed rather than gradual enrichment and filling of the lake basin through natural means.

Human-induced cultural eutrophication occurs when nutrient, soil, or organic matter loads to the lake are dramatically increased. A lake's lifespan can be shortened drastically by activities such as forest clearing, road building, cultivation, residential development, and wastewater treatment discharges because these activities increase soil and nutrient loads that eventually move into the lake. Chapter 5 explains watershed influences from these activities in the sections on nonpoint and cultural sources.

Some lakes, however, are naturally eutrophic. It is important to recognize that many lakes and reservoirs located in naturally fertile watersheds have little chance of being anything other than eutrophic. Unless some other factor such as turbidity or hydraulic residence time intervenes, these lakes will naturally have very high rates of primary production.

Natural and man-made lakes undergo eutrophication by the same processes—nutrient enrichment and basin filling—but at very different rates. Reservoirs become eutrophic more rapidly than natural lakes, as a rule, because

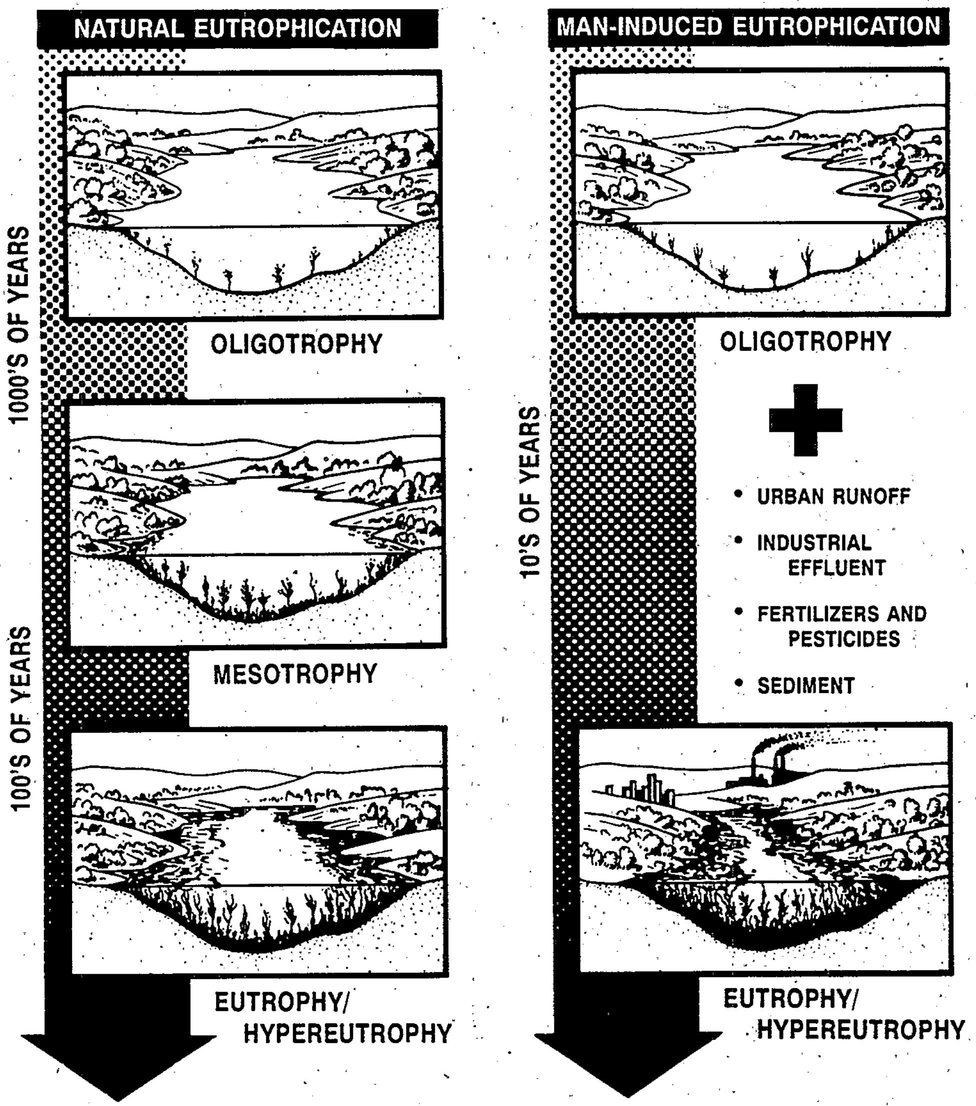


Figure 2-12.— *(left column)* The progression of natural lake aging or eutrophication through nutrient-poor (oligotrophy) to nutrient-rich (eutrophy) sites. Hypereutrophy represents extreme productivity characterized by algal blooms or dense macrophyte populations (or both) plus a high level of sedimentation. The diagram depicts the natural process of gradual nutrient enrichment and basin filling over a long period of time (e.g., thousands of years).

(right column) Man-induced or cultural eutrophication in which lake aging is greatly accelerated (e.g., tens of years) by increased inputs of nutrients and sediments into a lake, as a result of watershed disturbance by humans.

most reservoirs receive higher sediment and nutrient loads than do most natural lakes. They may even be eutrophic when initially filled. Reservoirs, especially those with hypolimnetic outlets, are considerably more efficient at trapping sediments than at retaining nutrients, and therefore the filling of their basins with river-borne silts and clays is the dominant aging process for these waterbodies.

However, reservoirs often do not go through the classical trophic progression from oligotrophy to eutrophy, as described for natural lakes. In fact, newly filled impoundments usually go through a relatively short period of trophic in-

Lake Basin Origin and Shape

The origin of the lake basin often determines the size and shape of the lake, which, in turn, influences the lake's productivity, water quality, the habitats it offers, and its lifespan.

Glacial activity has been the most common origin of lake basins in North America (Fig. 2-E). Glacial lakes of Canada and the upper midwestern United States were formed about 8,000 to 12,000 years ago. Some lake basins resulted from large-scale glacial scouring—the wearing away of bedrock and deepening of valleys by expansion and recession of glaciers. Deep depressions left by receding glaciers filled with meltwater to form lakes. The Finger Lakes of upper New York State were formed this way.

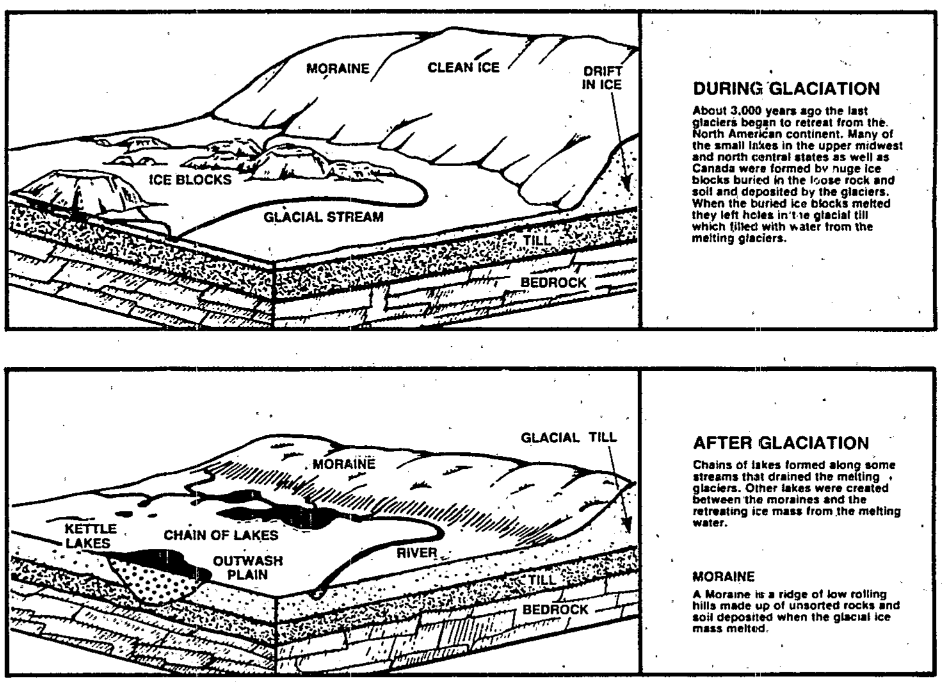


Figure 2-E.—The effects of glaciation in shaping lake basins.

Kettle or "pothole" lakes, which formed in the depressions left by melting ice blocks, are very common throughout the upper midwestern United States and large portions of Canada. These lakes and their watersheds are popular home and cottage sites and recreational areas. The size and shape of the kettle lake basins reflect the size of the original ice block and how deeply it was buried in the glacial debris.

Natural lakes have also been formed by volcanism; Crater Lake in Oregon is an example. Large-scale movements of large segments of the earth's crust, called *tectonic activity*, created Reelfoot Lake in Tennessee and Lake Tahoe in California, among others.

Solution lakes are formed where groundwater has dissolved limestone; Florida has a number of these lakes. Lakes may also originate from shifting of river channels; oxbow lakes are stranded segments of meandering rivers. Finally, natural lakes can also be created by the persistence of the dam-building beaver.

stability in which a highly productive period (termed the "trophic upsurge") is followed by a decline in lake productivity (called the "trophic depression"), and the eventual establishment of a less productive but more stable trophic state (Fig. 2-13). The trophic upsurge results largely from nutrient inputs from both external sources (the watershed) and internal sources (leaching of nutrients from the flooded soils of the reservoir basin and from the decomposition of terrestrial vegetation and litter), which results in high productivity of both plankton and fish.

The trophic depression is, in fact, the initial approach of the reservoir system toward its natural productivity level dictated by the level of external nutrient inputs. However, reservoir fish production depends on a complex of factors that affect both trophic and habitat resources. Flooding of soils, vegetation, and litter as the new reservoir fills contributes to both abundant food and expanding habitat. As the reservoir matures, both food and habitat resources decline, fish production decreases, and the fish community stabilizes.

The trophic upsurge and depression or "boom and bust" period of trophic instability in reservoirs has received much attention from limnologists and fishery biologists because it inevitably produces both initial concerns about poor water quality and simultaneously raises false hopes for a higher level of fishery yield than can be sustained over the long term. Ultimately, in reservoirs and in natural lakes, the nature of the watershed (or human-induced changes of the watershed) will determine the water quality, biological productivity, and trophic status of the system.

Ecology's Place in Lake Protection, Restoration, and Management

The goal of this chapter on ecological and limnological concepts is to provide the reader with a basic background for understanding the environmental factors controlling lake productivity, water quality, and trophic status. This background is intended to help the reader evaluate the potential benefits and limitations on lake protection and restoration approaches and techniques described in the rest of this Manual.

This Manual emphasizes two basic, complementary approaches to lake restoration and management for water quality:

1. Treat the causes of eutrophication. This approach involves limiting lake fertility by controlling nutrient availability.

2. Treat the products of overfertilization and thus control plant production in the lake.

Methods employed to control nutrient availability include proper watershed management practices, advanced treatment of wastewater, and diversion of wastewater and stormwater (see Chapter 5). Hypolimnetic withdrawal, dilution and flushing, phosphorus precipitation and inactivation, sediment oxidation, sediment removal, and hypolimnetic aeration are techniques to deal with nutrients already in the lake system; they are discussed in Chapter 6.

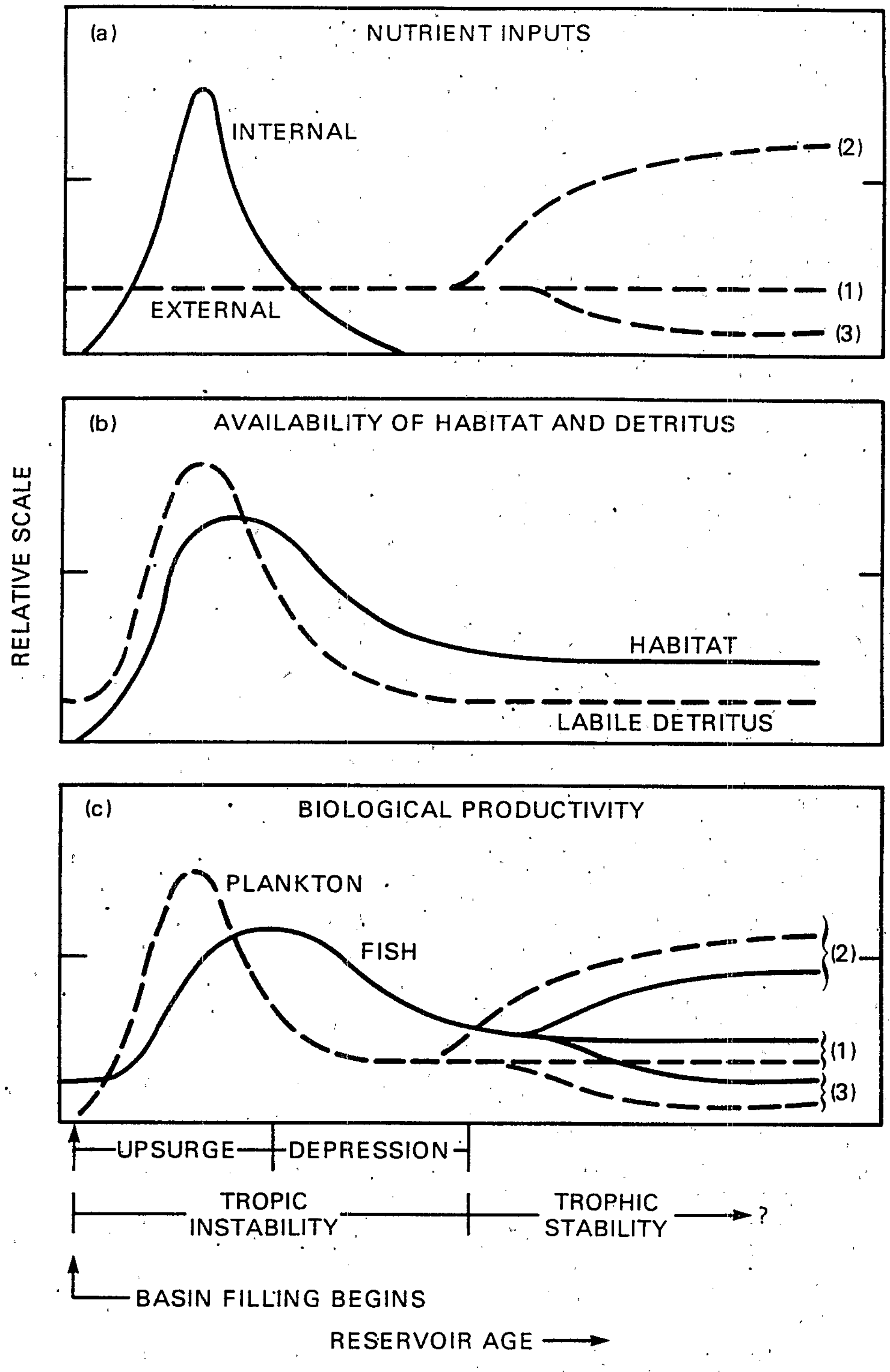


Figure 2-13.—Factors influencing biological productivity or "trophic progression" in a reservoir in the initial years after impoundment: (a) internal nutrient loading from the flooded reservoir basin and external nutrient loading from the watershed, (b) availability of habitat (flooded vegetation) and labile terrestrial detritus supporting macroinvertebrates and fish, and (c) plankton and fish production. The initial period of trophic instability (i.e., upsurge and depression) is followed by a less productive, but more stable, period in the maturing reservoir (1). However, disturbances or land-use changes in the watershed can result in increases (2) or decreases (3) in external nutrient loading and, consequently, in reservoir productivity. Modified from Kimmel and Groeger (1986).

Methods used to control plant biomass include artificial circulation, water-level drawdown, harvesting, chemical treatments (herbicides and algicides), biological controls, and shading and sediment covers for macrophyte control. Chapter 6 also provides details on these techniques.

How to determine what needs to be treated and where problems may originate is discussed in Chapter 3. Chapter 5 gives further information on watershed influences and how to manage them.

Most of what we know about lake and reservoir restoration has been learned in the last 15 years through experience gained from many studies conducted in the United States, Canada, Europe, and Scandinavia. Experience gained from previous restoration efforts clearly leads to the following conclusions:

1. There is no panacea for lake management or restoration problems; different situations require different approaches and solutions.

2. A complex set of physical, chemical, and biological factors influences lake ecosystems and affects their responsiveness to restoration and management efforts.

3. Because of the tight coupling between lakes and their watersheds, good conservation practices in the watershed are essential for improving and protecting lake water quality. Efforts to control both external loading of nutrients from the watershed and internal nutrient loading and recycling are often required to produce a noticeable improvement in water quality.

4. The physical, chemical, and biological components of lake ecosystems are intricately linked. Lake restoration or management efforts to enhance water quality by limiting nutrient availability and thereby reducing algal production will also decrease fish production. Decisions must be made and priorities must be set.

5. To be successful, lake restoration and management objectives must be compatible with the uses that the natural condition of the lake (and its watershed) can support most readily.

In summary, the character of a lake or reservoir is determined by a complex set of physical, chemical, and biological factors that vary with lake origin, the regional setting, and the nature of the watershed. Important factors include hydrology, climate, watershed geology, watershed to lake ratio, soil fertility, hydraulic residence time, lake basin shape, external and internal nutrient loading rates, presence or absence of thermal stratification, lake habitats, and lake biota.

In some situations, a natural combination of these factors may dictate that a lake will be highly productive (eutrophic) and management or restoration efforts to transform such a system to an unproductive, clear-water (oligotrophic) state would be ill-advised. However, if a lake has become eutrophic or has developed other water quality problems as a result of, for example, increased nutrient loading from the watershed, then these effects can be reversed and the lake's condition can be improved or restored by an appropriate combination of management efforts in the watershed and in the lake itself. The best situation is one where steps are taken to protect the lake's watershed before problems develop.

In the chapters to follow, a variety of lake and watershed management techniques are discussed and compared. While reading through this information, it is important to remember that the potential effectiveness of any lake restoration method or combination of methods will depend entirely on the ecological soundness of its application. Recent experience in lake restoration has clearly shown that there is no panacea for lake restoration or for lake management problems. That is (despite the salesperson's claims), introducing grass carp, harvesting weeds, or installing an artificial aeration/destratification system is not necessarily the solution for a particular lake. In fact, all three of these commonly used methods address symptoms rather than causes.

Finally, lakes and their watersheds are tightly coupled. Therefore, to be effective, lake and reservoir restoration and management efforts must consider both watershed processes and lake dynamics.

Chapter 3

PROBLEM IDENTIFICATION

Chapter Objectives

In the first chapter of this Manual, a lake problem was defined as a limitation on a desired use of the lake. Based on this definition, problems can often be identified by simply listing lake users' complaints. When boat owners find they cannot use the lake for recreation because of weed infestation, for example, they have clearly identified a problem. While this assessment is usually the first action in the process of reaching a solution, a number of other steps (Fig. 3-1) must be taken before lake managers can implement a plan.

❑ The purpose of this chapter is to help lake users, managers, and associations

- Identify problems;
- Put problems in perspective for a particular lake;
- Understand how the causes, not the symptoms of problems are determined through diagnostic analysis; and
- Define the causes of the lake's problems.

Finally, Chapter 3 directs the reader to appropriate parts of this Manual to evaluate alternatives for solving these problems.

Common Lake Problems

Most types of problems commonly occur in a number of lakes within a region; rarely is a problem unique to a particular waterbody. Some of the impaired uses, possible causes, and widely occurring lake problems are listed in Table 3-1. Among the latter, poor fishing, overabundant algae, excessive macrophytes, lack of depth and user conflicts are frequent public complaints that provide good examples of the relationship between lake users and lake conditions.

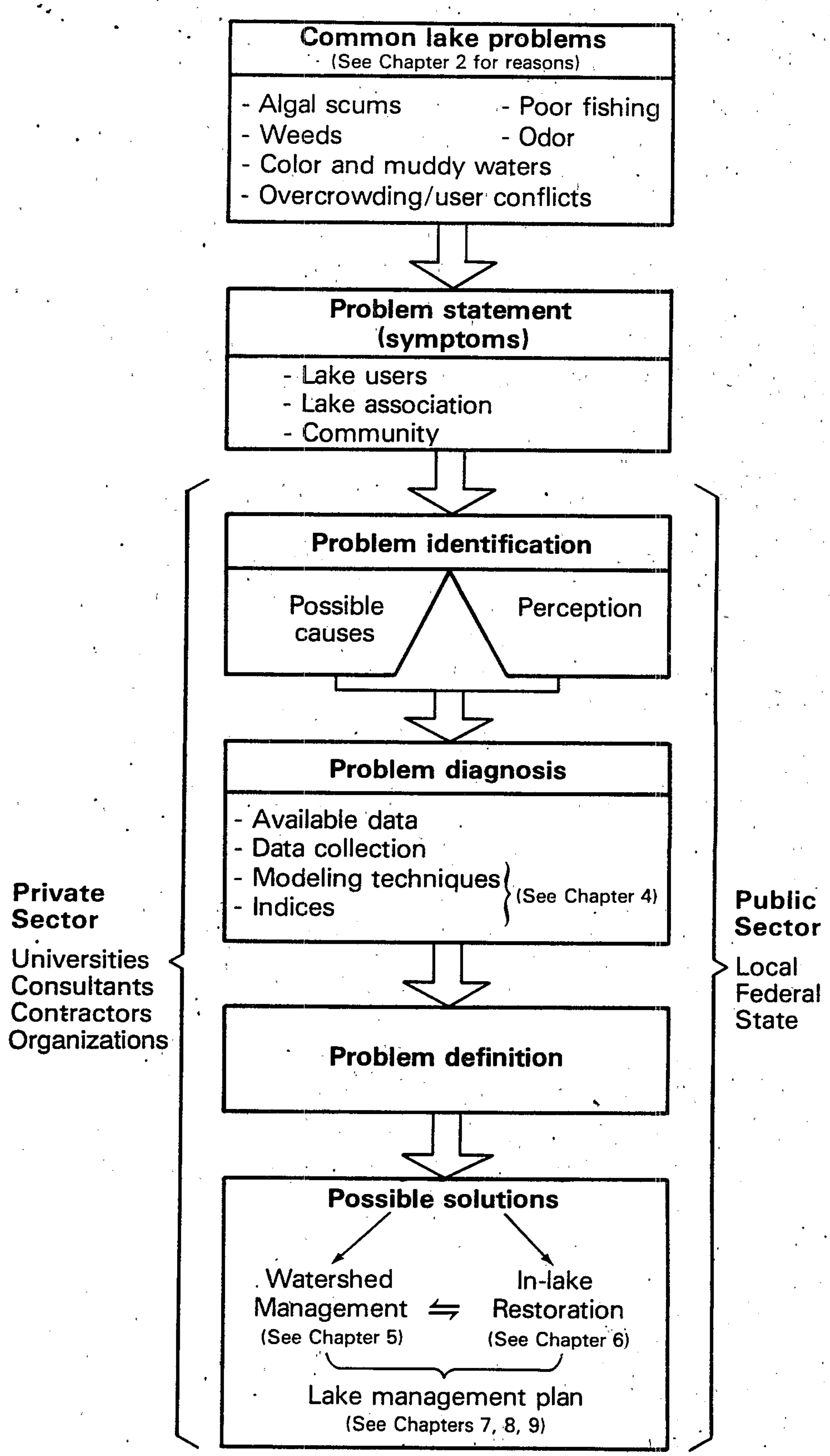


Figure 3-1.—General approaches can be described for defining lake problems in terms of users' needs and investigating causes to reach a solution that fits both the lake's capabilities and the needs of users.

Table 3–1.—Examples of common lake problems, impaired uses, and possible causes of the problem.

	COMMON PROBLEMS/SYMPTOMS					
Impared Uses	ALGAE SCUM	WEEDS	FISH KILLS	DEPTH	USER CONFLICTS	TASTE & ODOR
Aesthetics	*High Nutrients	*Shallowness *High Nutrients *Sediment		✓	*Motor Boat Noise *Debris	*High Nutrients *High Organics *Algae
Fishing		✓	*Toxins *No Oxygen *High Organics *Sediment	✓	*Motor Boating *Swimming	✓✓
Swimming	✓✓	✓		✓✓	*Motor Boating	✓✓
Motorboating		✓		✓✓	*Swimming *Scuba Diving	
Sailing		✓		✓✓	*Motor Boating *Swimming *Scuba Diving	
Water Supply	✓			✓✓	*Swimming (contamination) *Motor Oils, Gas *Debris	✓✓

✓✓ = problem shown above definitely impairs use shown at left
✓ = problem shown above may impair use shown at left
* = common causes of problem shown above; definite impairment of use

Algae: *Small aquatic plants that occur as single cells, colonies, or filaments.*

Algae

One of the sources of food and energy for fish and other lake organisms, algae are a vital part of all lakes (see Chapter 2). Too many algae and the wrong kinds, however, can interfere with some lake uses by, among other things, clogging the filters in drinking water treatment plants, inhibiting the growth of other plants by shading them, contributing to oxygen depletion and fishkills, and causing taste and odor problems in water and fish. Organic matter produced by algae can react with chlorine; trihalomethanes—possible products of this chemical reaction—are believed to cause cancer. Lastly, some species of algae release toxins.

The most common use of lakes is aesthetic enjoyment, and excess algae can interfere with this simple pleasure. Unsightly scums are usually caused either by tangled masses of filamentous algae or by "blooms" of certain planktonic algae that float on the lake's surface. The regular occurrence of visible algal blooms often indicates that nutrient levels in the lake are too high.

Weeds

Weeds also limit many lake uses. Like algae, weeds (or aquatic macrophytes) are a vital part of the lake (see Chapter 2) because they provide cover for fish and food for wildlife. However, too many weeds can limit swimming, fishing, skiing, sailing, boating, and aesthetic appreciation. Indeed, getting rid of noxious weeds is one of the most common projects among lake associations. Fifty percent of Wisconsin's lake districts report weed harvesting programs, and 25 percent use herbicides (Klessig et al. 1984).

Depth

The loss of lake volume, or infilling, is a problem in a majority of lakes and reservoirs. Depth problems result from the loss of volume because of increased sediment loads that can originate externally as soil erosion in the watershed or internally from decaying algae and weeds in the lake itself. Increased sediment generally leads to turbid or murky water, and reduction in depth usually disrupts swimming, boating, and sailing and encourages extensive weed growth. Dredging has been one of the major lake restoration approaches used in lake management. Dredging, however, does not stop soil erosion in the watershed, which is the main cause of lake infilling.

Acidity

Acidic lakes are found in areas where the watershed soils have no natural buffering capacity. Acid rain and other manmade or natural processes can further contribute to lake acidity. Acid rain (scientifically referred to as "acidic deposition") occurs in areas where the combustion of fossil fuels increases the concentration of atmospheric sulfur and nitrogen oxides. These acids can be transported thousands of miles and deposited back to earth in precipitation or as dry particles.

Drainage from naturally acidic organic soils also contributes to lake acidity, and these soils often become more acidic through land use practices such as logging, reforestation, and mining. Acidic outflows from abandoned mines affect thousands of miles of streams and numerous lakes throughout Appalachia; acid mine drainage also occurs in the coal fields of Illinois, Indiana, and Ohio, and in coal and metal mining areas in the western States.

Most aquatic plants and animals are sensitive to acidity. Fish, especially, are negatively impacted; in fact, many acidic lakes have no fish. Fish populations may be restored by reducing the sources of acidity reaching a lake. Addition of base materials (liming) has been the major restoration technique for acidic lakes.

User Conflicts

Not all problems occur because of physical, chemical, and biological conditions. User conflicts arise from limitations on the time and space available for recreational activities, and some lake uses clearly conflict with others. Motorboating can disrupt fishing, swimming, and scuba diving, and just the sound of boat motors can disturb aesthetic pleasures.

As discussed in Chapter 2, management practices for water quality and sport fishing are occasionally in direct conflict. Mudflats created by lake drawdown for power generation or water supply vie with the desire to have a constant water level for aesthetics, docking boats, and wading. In fact, conflicts about desired lake uses can cause greater problems than algal scums or an overabundance of weeds.

Problem Statement

A local homeowner or lake user will probably be aware of lake problems before a professional lake manager suggests that something is wrong. If a boater cannot move across the shallow areas because of dense macrophytes or a swimmer cannot enjoy a dip without tangling with weeds, there is a problem. If a homeowner is offended by the smell of decaying macrophytes and algae from the lake, a problem exists.

For these lake users, the most productive response is to form an organized group to deal with the problems and to determine the interest in seeking a solution. Local initiative is an important part of lake restoration; it helps users understand how the lake works (and their role in the problems) and enables them to cooperate in the solution. Determining why problems exist and how serious they are relative to the natural carrying capacity of the lake, however, typically requires professional assistance.

Lake organizations invariably would like to see their lake do everything. They want aesthetic pleasure, great fishing, healthy water, sandy shorelines and bottoms, and a healthy wildlife population — all without insects or weeds. Unfortunately, almost no lake can meet all of these demands. Systematically clarifying the attainable uses in a lake management effort must be the first step of any plan.

Local users, homeowners, or lake associations have two responsibilities in lake restoration that require considerable attention. The first is to come to some agreement on what the problems are, clearly state these problems, and determine how to organize to resolve them. Appendix 3-A describes two democratic procedures—the nominal group process and the Delphi process—that may prove useful for this responsibility. The second responsibility is to assure that analysis of the causes of problems and a viable response to these factors is carried out by competent professionals.

Based on both what the users want and what the lake itself is capable of supporting, problem identification focuses first on establishing a set of realistic uses desired in the lake.

Problem Identification

Problem Perception

Depending on physical characteristics of the lake basin, the watershed, and the quality of incoming water, lakes are suited to particular purposes. Table 3-2 summarizes general lake types that are suited to specific uses.

Table 3–2.—Priorities for lake use based on lake characteristics

	SIZE OF LAKE		DEPTH		CLARITY	
USES	SMALL *(LESS THAN 10 ACRES)*	LARGE *(OVER 500 ACRES)*	SHALLOW *(LESS THAN 5' AVG. DEPTH)*	DEEP *(OVER 20')*	TURBID *(SECCHI UNDER 2')*	CLEAR *(OVER 6')*
Water Supply	–	+	–	+	–	+
Fishing/ Wildlife	+	+	–/+	+	–/+	+
Swimming/ Skiing	+/–	+	–	+	–	+
Boating/ Sailing	–	+	–	+	+	+
Aesthetics	+	+	+	+	–	+

– = not suitable
+ = suitable
+/– = suitability depends on modifying factors

Although it may be technically possible to drastically alter a lake to meet the needs of a certain user group, the cost will be high, and the decision is usually unwise. It is important to determine lake uses that can realistically be attained when choosing a desired use. Some lakes can never be crystal clear, no matter what measures are taken. If the watershed area is large relative to lake surface area and watershed soils are highly erodible and nutrient-rich, the lake will always have excessive algae and weed growth regardless of any lake treatments.

Regional differences in lakes across the country represent an important factor in understanding the limitations of lake management. These differences are distinct enough to group lakes in areas called ecoregions (Omernik, 1987). Regional differences in geology, soils, land use, and vegetation in these ecoregions result in very different lake quality. Lakes in northern Minnesota, for example, have lower nutrient and algal concentrations and greater transparency than lakes in southern Minnesota where there are more naturally fertile soils. Reservoirs often are more turbid than natural lakes. Because lake users from different regions of the country may perceive a problem in local lakes that is a natural phenomenon, it is important to delineate both natural and manmade causes.

Sometimes, users perceive a lake problem for which a source or cause might not exist. Perceived problems should be addressed; they are no less important than real problems with underlying causes. For example, if people won't swim in a lake because 15 years ago sewage was discharged into a tributary, they are reacting to historic conditions. People perceive a continuing situation, even though the problem was resolved more than a decade ago. It is important to distinguish between real and perceived problems, but it is equally important to identify and deal with the causes.

Causes of Lake Problems

Since most problems occur in a number of lakes in the region, the general causes and approaches for solving them are usually known. While the solution for each problem must be lake-specific because every lake has unique characteristics, general approaches can be described for defining lake problems and causes (see Fig. 3-1).

Identifying the potential causes of lake problems requires an understanding and appreciation of the interactions not only among components within the lake such as algae, macrophytes, fish, and other organisms but also the interactions between the lake and its watershed (see Chapters 2 and 5). In some situations, a natural combination of these factors may dictate that a lake will be highly biologically productive and that management and restoration efforts to transform such a system to an oligotrophic state would be ill-advised.

Oligotrophic: *"Poorly nourished," from the Greek. Describes a lake with low plant productivity and high transparency.*

If, however, a lake has become eutrophic or has developed other water quality problems as a result of manageable problems (such as an increased nutrient load from manmade causes), then these effects can be reversed, and the condition of the lake can be improved or restored by an appropriate combination of management efforts in both the watershed and the lake itself.

Delineation of natural versus manmade causes of problems can be enhanced by looking at other lakes in the same region. If there are some that have similar water quality but relatively undisturbed watersheds, then the specific lake's problems might occur from natural causes. However, if other lakes in the region with relatively undisturbed watersheds have the desired water quality, then manmade causes are probably contributing to the former lake's problems and should be identified. Using other lakes in the region with relatively undisturbed watersheds as reference is a good way to initially assess the potential impacts of manmade sources to the lake's problems.

There are numerous tools for identifying causes of lake problems. Qualitative approaches, such as comparing the target lake to surrounding lakes, document subjective observations, which can reveal important patterns. Quantitative approaches, such as the models discussed in Chapter 4 and trophic state indices, rely on objective data.

In practice, both qualitative and quantitative approaches are usually considered. Using these methods to identify underlying causes of problems usually requires professional assistance. An important step in problem definition, therefore, is selecting a competent consultant or firm to interpret the results of various diagnostic approaches.

Selecting a Consultant

Limnology: *Scientific study of fresh water, especially the history, geology, biology, physics, and chemistry of lakes. Also termed freshwater ecology.*

Among the criteria to consider when selecting a consultant are the candidate's (or firm's) experience in conducting lake studies, identifying the underlying causes, and formulating effective lake management plans; expertise in engineering, limnology, biology, or other disciplines associated with lake management; past performance in conducting similar studies or dealing with similar problems; and the firm's or candidate's capabilities (support staff or office facilities) to address the problems in the lake. A series of questions related to these criteria are listed in Table 3-3 and can be used to help select a consultant or contractor. These questions need to be tailored to the particular set of lake problems and should not be considered all-inclusive. The questions, however, should assist the lake manager and lake associations in thinking about appropriate questions to ask when seeking professional assistance.

Table 3–3.—Criteria for selecting consultants and contractors

A. Experience

1. How many lake restoration projects have they performed and for whom (reference and dates)?
2. Have they successfully submitted Phase I and Phase II applications and obtained EPA and/or State funding?
3. Have they performed Phase I Diagnostic/Feasibility Studies?
4. Have they managed Phase II Implementation Projects?
5. Have they worked on integrated watershed lake management projects?
6. Have they ever developed ordinances, zoning recommendations, or other institutional approaches for protecting lakes?
7. Do they have experience with both structural and nonstructural management techniques and procedures?
8. Have they prepared environmental assessments or impact statements?

B. Expertise

1. Do they have interdisciplinary capabilities (i.e., engineers, limnologists, chemists, biologists)?
2. Are they familiar with the EPA and State regulations for Clean Lakes studies?
3. What is the educational background of the project team?

C. Past Performance

1. Have they worked as a prime contractor before or primarily as a subcontractor?
2. Have they ever had cost overruns? If so, how much and why?
3. Have previous projects been completed on time?

D. Company Capabilities

1. Do they do everything in-house or do they use subcontractors?
2. Do they perform the chemical analyses themselves or in a contract laboratory?
3. Do they have the capability to collect and evaluate water quality and biological data?
4. Do they have a quality assurance/quality control (QA/QC) program?
5. Do they have experience in the following areas?
   a. Analyzing physical, chemical, and biological factors
   b. Performing nonpoint source studies, including setting up automated monitoring stations and stream gaging stations
   c. Analyzing the trophic condition of the lake
   d. Analyzing the status of the fish community and estimating the potential quality of the fishery and production yield
   e. Analyzing wet and dry weather data to calculate a reliable annual nutrient and sediment loading budget
   f. Evaluating best management practices and in-lake restoration techniques
   g. Analyzing institutional approaches for implementation of proposed management and in-lake restoration activities
   h. Assisting in public participation activities
   i. Understanding and working with the EPA Clean Lakes Program

Problem Diagnosis

Investigate the Problem

After selecting professional assistance and identifying lake problems, the next step is to diagnose and quantify the problems and determine their causes. Although this process should be guided by a professional consultant, the lake manager and/or lake association must understand the steps in problem diagnosis to effectively manage and protect the lake.

Problem diagnosis is a process that provides greater quantitative resolution on the sources or causes of the lake problems with each step. Once the causes of the lake problems are clearly defined, then several alternative watershed management practices (Chapter 5) and lake restoration techniques (Chapter 6) can be evaluated to reduce or resolve these problems.

At this stage, problems have been identified by the lake users, and potential causes generally are known. Problem diagnosis identifies which of the potential causes are contributing to the problems and determines their relative importance.

Diagnosis is generally a two-step process: (1) collating and evaluating existing data and (2) collecting and analyzing additional data. The first step, using existing data, might be sufficient in some instances to provide enough problem resolution for evaluation of alternative control strategies. Generally, additional data are required, but this first step, at a minimum, identifies major data gaps and aids in the design and implementation of a more cost-effective and efficient data collection program.

Preliminary Analyses

Preliminary analyses include obtaining any existing information available on both the watershed and the lake and making a few basic back-of-the-envelope or desk-top calculations. Typically, a considerable amount of information will be available on the watershed and lake. Watershed districts, sanitary districts, county extension offices, county soil and water conservation districts, and city, county, and regional planning agencies usually have maps, land use data, or aerial photographs on the watershed and lake. Water quality data might be available on the inflowing streams or the lake itself. Fishing maps might be available that show the surface area, depth contours, location of inflowing streams, coves and embayments, and other features of the lake that can be important in diagnosis. Recent aerial photographs taken during mid- to late summer can show the extent of weed beds in the lake. Creel census records from State fish or game agencies can provide valuable information on historical changes in the fish community and in relative lake productivity.

Watershed land use and topographic maps can be used to determine the location and acreage of various types of crops in the watershed; the soil types in the watershed, including their potential for erosion; and the location of feedlots and barnyards, residential developments, forested and open land, and any conservancy districts. The locations of wastewater treatment, industrial discharges, and storm sewers can be obtained from the sanitary district, city health department, or State natural resource or pollution control agency. In addition, discharge data as well as data on organic matter (for example, BOD)

Groundwater: *Water found beneath the soil's surface and saturating the stratum at which it is located; often connected to lakes.*

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.*

and nutrient concentrations in the wastewater discharge usually can be obtained from the wastewater treatment plant's discharge monitoring records (DMR's), which are required by the U.S. Environmental Protection Agency.

Estimates of annual runoff of water from the watershed or the amount of stream inflow to the lake might be available from the city or county planning agencies, U.S. Geological Survey, or the Soil Conservation Service. Locations of groundwater wells in the watershed also might be available from these agencies, the local health department, or pollution control agencies. Groundwater wells can indicate the direction of flow and loading to seepage lakes (Fig. 3-2).

Existing monitoring data for temperature, dissolved oxygen, nutrients, and algae (chlorophyll) in the inflowing stream or lake are invaluable in this phase of problem diagnosis. Unfortunately, in many instances monitoring data are not available for even Secchi depth determinations, which are quick and easy to do. If monitoring data are available, the progressive deterioration of lake water quality or onset of a lake problem might be traced back to some change in use of the watershed land or the lake.

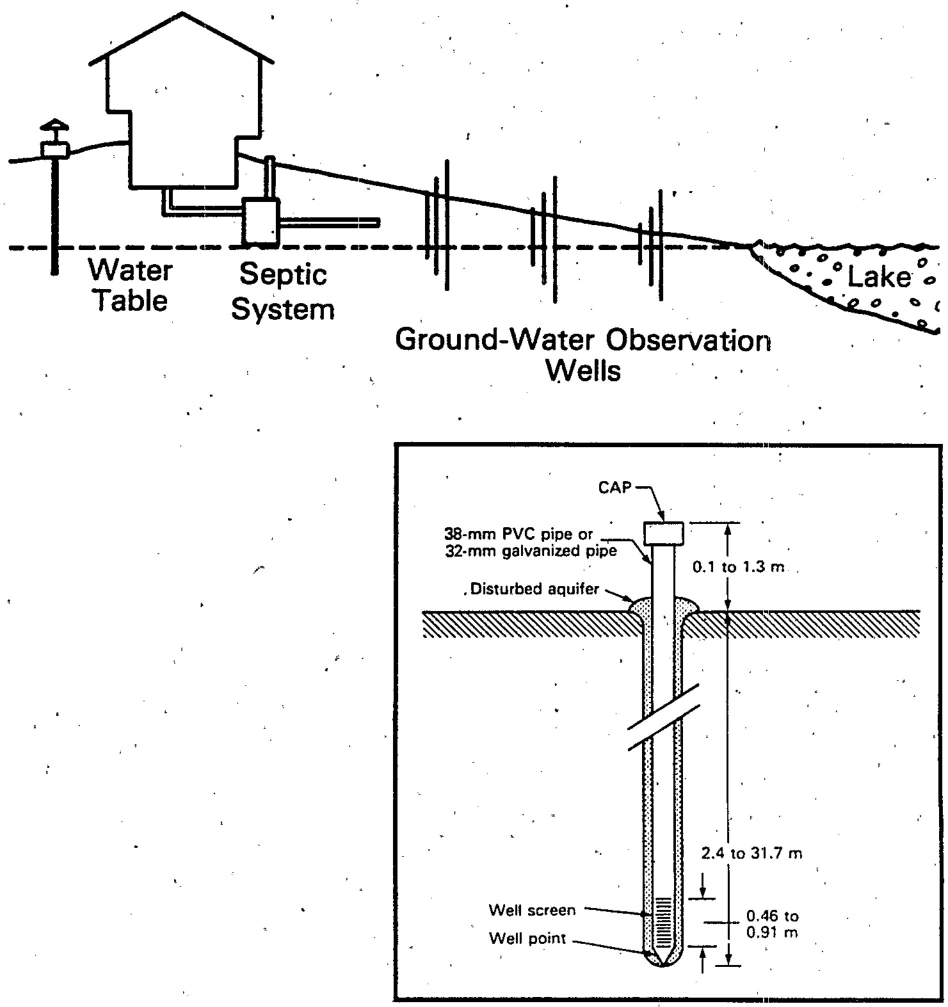


Figure 3-2.—Groundwater observation wells.

Existing data should be evaluated for clues on why problems are occurring in the lake. This diagnosis is enhanced by performing some basic back-of-the-envelope analyses involving the construction of a simple lake budget that accounts for the input and output of organic matter, sediment, and nutrients to and from the lake. Similar to a household budget that balances income versus savings and expenses, the lake budget (for example) attempts to account for the sources and total load of phosphorus entering the lake (income), the amount retained in the lake that might stimulate algae or macrophyte growth (savings), and the amount leaving the lake (expenses). The total phosphorus load, as described in greater detail in Chapter 4, is an important diagnostic tool in determining the potential cause of several lake problems.

The potential sources of nutrients, sediments, and organic matter from agricultural land uses, wastewater treatment plants, urban areas, and forests can be identified. These types of land uses and levels of wastewater treatment have been investigated, and some general nutrient and sediment export coefficients associated with various land uses have been published. These land use coefficients can be used with the annual runoff coefficients and wastewater discharge estimates to estimate the total load of material to the lake.

The relative contribution of the various land use activities or wastewater treatment plants to the total lake load also can be determined. A rough estimate of the amount of material retained in the lake versus that flowing out of the lake can be estimated based on the hydraulic residence time (see Chapters 2 and 4). Quantities of materials such as phosphorus or BOD associated with various levels of severity of problems in other similar lakes can be compared with the quantity estimated for the lake under study.

The preliminary lake budget can indicate those land use activities—including wastewater treatment—that appear to be contributing the greatest proportions of organic matter, sediment, and nutrients to the lake and, therefore, warrant consideration for watershed management practices (see Chapter 5). The budget also might indicate that loading from the watershed doesn't appear sufficient to produce the magnitude or severity of the lake's problems. Other factors such as internal processing of material in the lake or an unmeasured and unestimated component of the budget such as septic tank drainage or groundwater may also be contributing material that is causing problems.

The budget approach provides limited information on internal lake processes, although it does provide insight into which processes might be important based on external loads. High sediment loads indicate potential problems with lake filling while high nutrient loads indicate algae or weed production is a potential problem.

To refine the diagnosis and better define the cause of the problem, additional data must be collected and analyzed. This data collection effort, however, should be guided by the results of the preliminary analysis. If agricultural runoff appears to be a major contributor to the nutrient and sediment load, for example, then data collection efforts should focus on better estimates of loading from the various agricultural locations in the watershed to determine which locations are contributing the greatest portion of the load to the lake. Wastewater discharges to a lake are usually an important source of nutrients and organic matter. The relative contribution from wastewater treatment plant effluent, storm water sewers, or septic tank seepage to the lake can be determined by collecting samples to characterize these inputs.

Data Collection and Analysis

With the preliminary analysis as a guide, a data collection program can be designed for problem definition. A typical data set for problem diagnosis will include measurements on

- ***Water budget:*** surface and groundwater inputs and changes in lake level;
- ***Physical parameters:*** sedimentation rate, temperature, and transparency;
- ***Chemical parameters:*** dissolved oxygen and plant nutrients;
- ***Biological parameters:*** algae, macrophytes, a fish survey;
- ***Other parameters as required,*** such as alkalinity, pH, and conductivity; and
- Use of ***trophic state indices.***

Water Budget

Surface Water and Lake Level

Determining water flow into and out of the lake, as well as recording changes in lake level, are essential for determining the annual nutrient, organic matter, and sediment loads to the lake and for establishing the carrying capacity of the lake—the amount a lake or reservoir can assimilate each year without exhibiting problems.

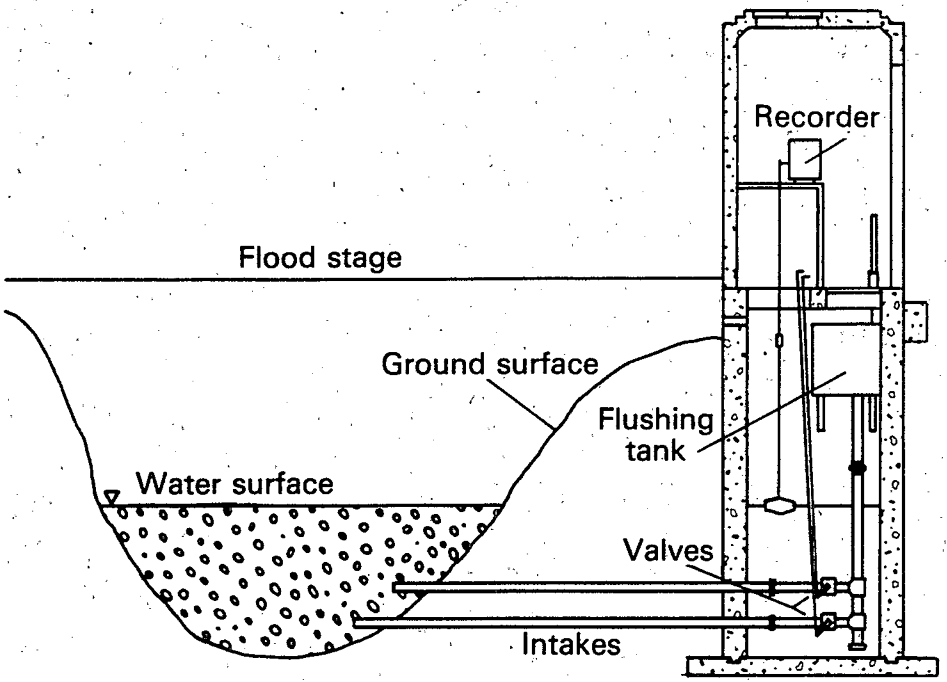
The first step is to establish a lake-level gaging station. This usually consists of placing a staff gage in the lake and making regular readings, which are most accurate when the water is calm. An alternative method is placing a stilling well that dampers out the effect of waves and continually records water level (Fig. 3-3).

Stream gaging stations are required on major tributaries as close to where they enter the lake as possible and at the outlet of the lake. Gaging every tributary to a lake, however, is not usually required. The water yields from monitored subbasins within the watershed can be substituted for similar unmonitored basins. If obvious sources of pollution are recognized near a tributary stream, then it is prudent to place another gaging station in the vicinity of the pollution site.

Groundwater Measurements

The importance of groundwater nutrient contributions to a lake depends on the size of the surface watershed contributing to the lake. For example, if the surface watershed of a 1,000-acre lake is 50,000 acres, the water and nutrient incomes for that lake are probably dominated by surface inputs, and the groundwater contribution might be of little consequence. However, if the watershed area around a 100-acre lake is only 300 acres, then the groundwater contribution might become more important.

Typical 1960 cost $5000 per installation.



From U.S. Geological Survey

Figure 3-3.—Conventional stilling well installation for water stage recorder.

When managing groundwater-dominated seepage lakes such as those found in Florida, Minnesota, Michigan, the New England States, New York, and Wisconsin, the groundwater component of a nutrient budget becomes essential.

Defining the groundwater contribution to a lake is not as precise as for surface waters. The same general principle, however, holds true: water flows downhill. The actual definition of the groundwater component is determined by measuring the elevation of the groundwater table relative to the elevation of the lake surface. Where the groundwater table is higher than the lake, the water is moving toward the lake; if the groundwater table is lower than the lake, then the lake water is moving out of the lake into the groundwater.

To define the groundwater basin around a lake, wells must be placed on the surrounding land, and the water level in each well must be measured in relation to the lake level (Fig. 3-4). Along with locating and placing of individual wells, the variation of possible groundwater table slopes, soil types, bedrock types and locations, and location of permeable nearshore sediments should be evaluated.

In lieu of the well system approach, several other, more focused techniques are often employed. These methods are used to locate specific areas within a lake where groundwater is entering or leaving. Techniques include use of seepage meters, small tube wells that are placed directly in the lake, temperature surveys, and fluorometric/conductivity measuring devices.

- A **seepage meter** is a device constructed by cutting off the top few inches of a closed metal or plastic drum. A plastic bag with a known quantity of water is then placed over an open hole on the top. Flow into or out of the lake is determined by measuring the change in water volume in the plastic bag over time.

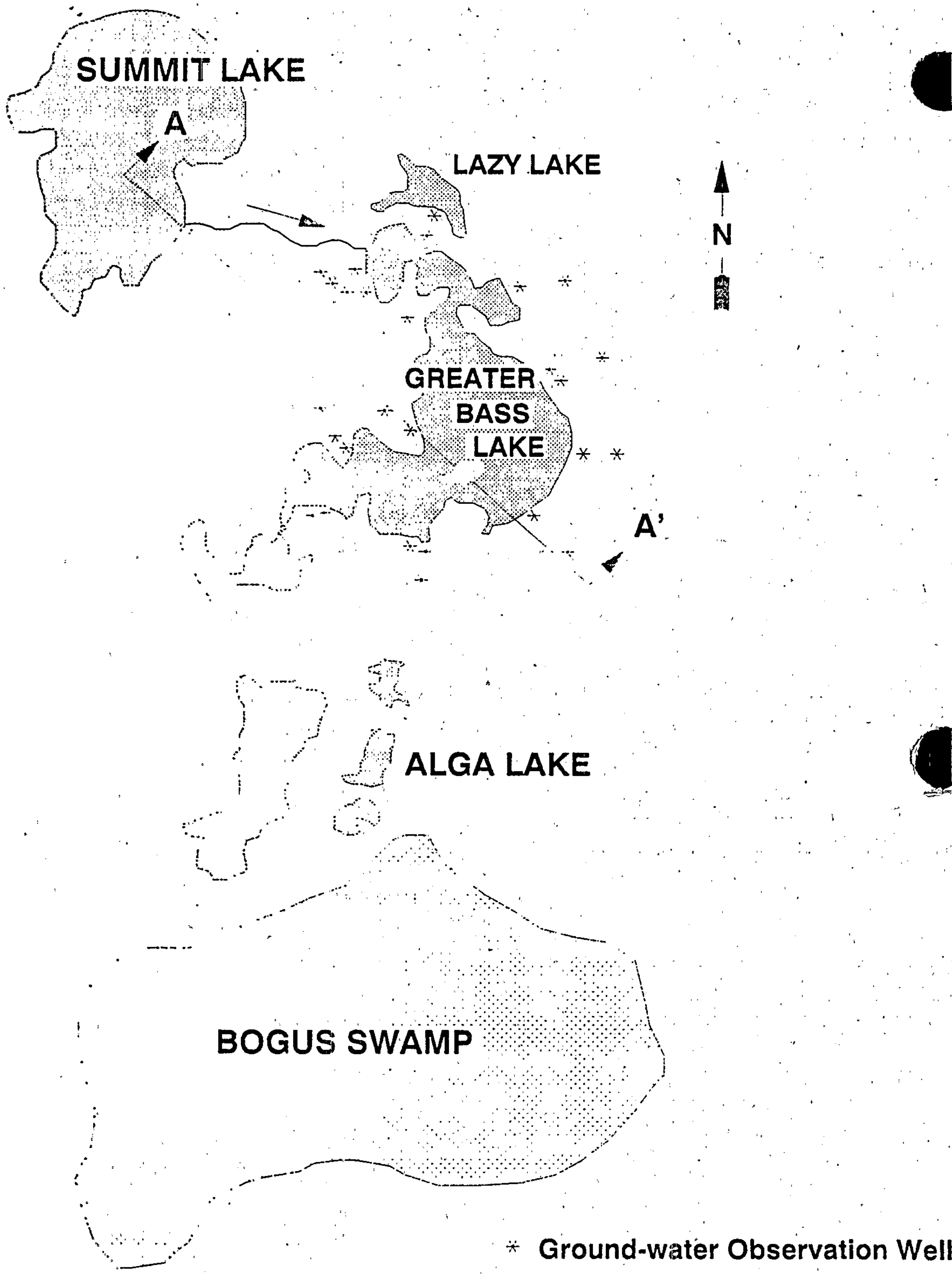


Figure 3-4a.—Groundwater observation well locations on Greater Bass Lake.

- Small tube wells, also called **mini-piezometers,** are essentially very small tubes that are pushed into a lake's bottom sediments. The water level within these tubes is measured to determine if groundwater flow is into or out of a lake.

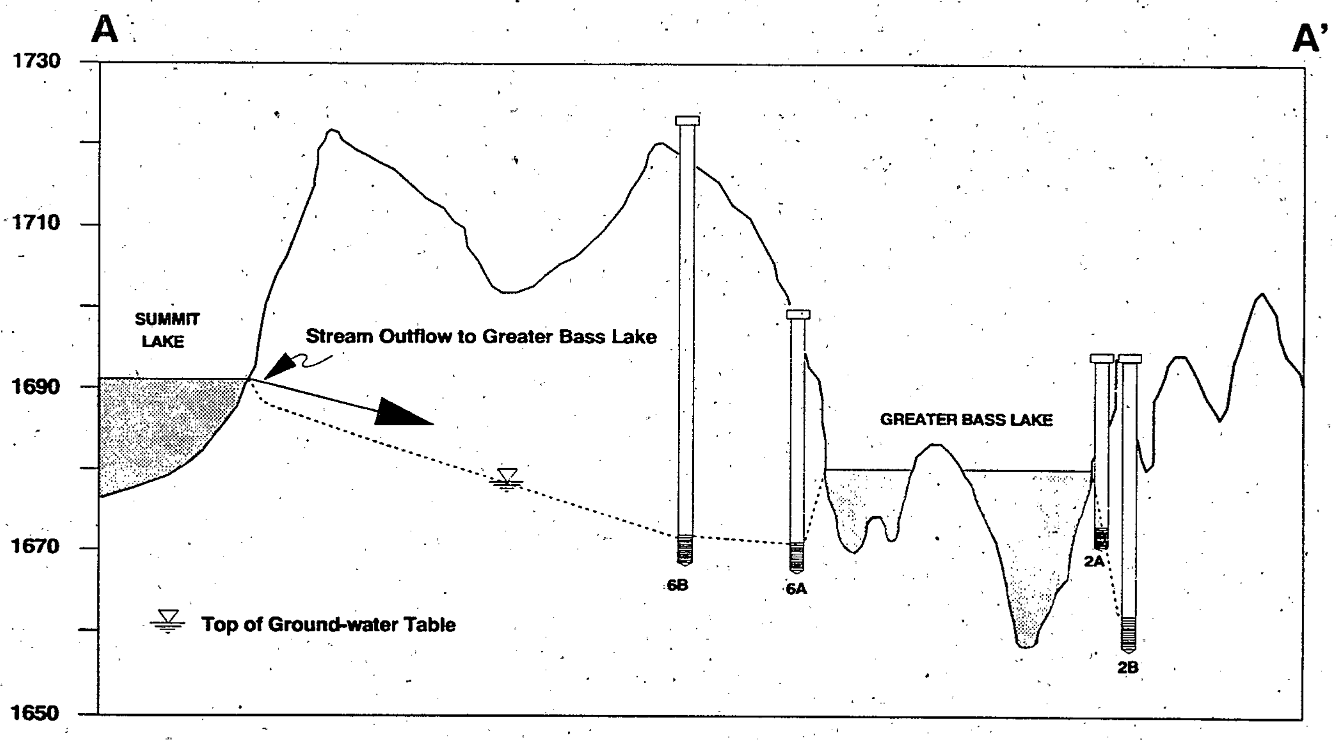


Figure 3-4b.—Cross section showing estimated groundwater table near Greater Bass Lake. In this case, the groundwater table was always lower than the lake level and any influence of the groundwater system, including on-site waste disposal contributions to it, would be considered negligible.

- Another method, most commonly used to explore the bottom of the lake for contaminated groundwater inflow areas, uses an instrument called a **fluorometer**. The Septic Snooper is the commercial tradename for a device that employs this technology. The instrument works by pumping a continuous stream of lake water, normally from nearshore bottom areas, through itself and continually measuring changes of specific electrical conductivity and fluorescence, which in some cases can be related to septic seepage.

- Occasionally, location of groundwater inflow areas can be determined by use of a simple **thermometer** that is pushed into the lake's sediments. If done when a lake water/groundwater temperature differential exists (such as during late summer), groundwater inflow areas can be located.

However, regardless of the method employed, it is important to remember that groundwater flow into or out of a lake often varies considerably from season to season or year to year. For example, during times when the lake is low, such as during the summer when evaporation is high, groundwater is often found to be flowing into the lake. When lake water levels are high, as in the spring, flow is often reversed, with the lake contributing to the groundwater. Additionally, groundwater flow into or out of a lake is not usually uniformly distributed, being more concentrated in those areas of the lake (springs) where bottom sediments are most permeable.

Knowledge of general groundwater flow direction and quantity can assist in making judgments about the feasibility of sewering a lake. For example, in a situation where soils are sandy and have little phosphorus retention capability, and when septic tank seepage easily flows into the groundwater, there may be concern that nutrients will be delivered to a lake via the groundwater. In these cases, for example, if it is found that the groundwater flow is always away from the lake on the east shore and toward the lake on the west shore, then consideration should be given to sewering only the west shore so that any nutrients leached into the groundwater on the east shore will not be carried into the lake.

Unfortunately, most lake environments are not this simple, and additional evaluations are often necessary to define the effects of on-site wastewater disposal systems. Most groundwater evaluations require experienced professionals, so these studies are usually conducted by consultants, university faculty, and State and Federal agencies.

On-site Septic Systems

Evaluations of nutrient loadings to a lake from on-site disposal systems require a detailed, site-by-site inspection and evaluation of each individual system. When combined with information on how frequently systems are used, how much water they handle, how well they are maintained, and so forth, good first-cut estimates of the potential nutrient loads contributed from these systems can be made.

It is very common for residents living around a eutrophic lake to suspect on-site waste disposal systems as the major culprit causing their lake problems. Unfortunately, little quantitative information exists that compares measured nutrient loadings from on-site waste disposal systems to the total nutrient load received by a lake. As a result of over-estimating the importance of on-site systems, many lakes have been sewered at large expense with no resulting improvement in water quality.

In detailed studies of 13 developed lakes in Wisconsin where on-site systems were examined, phosphorus contributions from these systems were measured and found to have provided between 1 percent and 33 percent of a lake's total nutrient load. When compared to the total phosphorus budget for these lakes, the contributions from the disposal systems did not have a significant impact on the overall trophic condition of these lakes.

If the results of the physical site-by-site evaluation of existing waste disposal systems suggest they may be contributing a significant nutrient loading to a lake, then selected sites around the lake should be included as part of a more comprehensive study to define lake problems.

As described in Chapter 5, on-site systems for the disposal of domestic wastes frequently employ a septic tank to remove settleable and floatable solids and to store the sludges and scums. As a result of bacterial decomposition in the tank, approximately 40 percent of the solids passing from the waste source to the septic tank are broken down and pass on to the soil absorption area, which may be a bed, pit, or trench or some combination of artificially placed materials and the natural soil. The soils in the absorption field then react with the septic tank effluent, providing further treatment.

Calcium, aluminum, and iron compounds associated with soil particle surfaces are particularly important when considering the ability of soils to remove phosphate ions from septic tank effluent. The phosphate ion binds relatively tightly to soils containing iron and aluminum in neutral to acidic soils or calcium in neutral to alkaline soils.

There have been several approaches used to determine how on-site disposal systems affect the nutrient budget of a lake, all of which have significant limitations. The most direct method involves making actual phosphorus measurements in the groundwater from observation wells located around individual adsorption fields. Other methods include sampling water collected from seepage meters or mini-piezometers placed over lake sediments identified as contributing zones. If high concentrations of phosphorus are isolated in the seepage meter waters, they are often assumed to have originated from a waste disposal system.

The capacity of the soil beneath the absorption field to sorb phosphorus can also be determined by taking plugs of soil from the area between the drain field and the lake, followed by laboratory tests to determine how much phosphorus the soils can still adsorb. If the soil's capacity to sorb phosphorus is still large, and wastewater is seeping adequately through the soils, phosphorus is probably being retained by the soils and is not reaching the lake. If it is determined that the soil's capacity to adsorb phosphorus is minimal, than it might be assumed that inadequately treated wastewater will probably leach into the lake.

Water Quality Monitoring

Sampling Sites

Sampling locations and depths influence the conclusions drawn from the data collected in the lake, so it is important that these stations accurately represent lake conditions.

The sampling locations and depths for physical, chemical, and biological analyses are associated directly with the properties of the lake. In lakes that are almost round, a single station located over the deepest point may be adequate. In lakes with branched, finger-like shorelines or multiple embayments, or long, narrow, natural lakes and reservoirs where significant gradients in water quality might exist, more stations will be needed (Fig. 3-5).

In shallow lakes that mix continuously throughout the summer, fewer stations will be needed, and samples taken at the surface, mid-depth, and bottom would be adequate. An integrated sample from the surface to just above the sediment would be better.

In deep, stratified lakes, samples should be collected at least near the surface, in the metalimnion near the middle of the hypolimnion, and near the bottom (see Chapter 2). One station should be at the deepest part of the lake with other stations located in the shallower areas and prominent bays. For reservoirs, stations should be located at the river inflow, below the plunge point, perhaps near the middle, and at the deepest point near the dam.

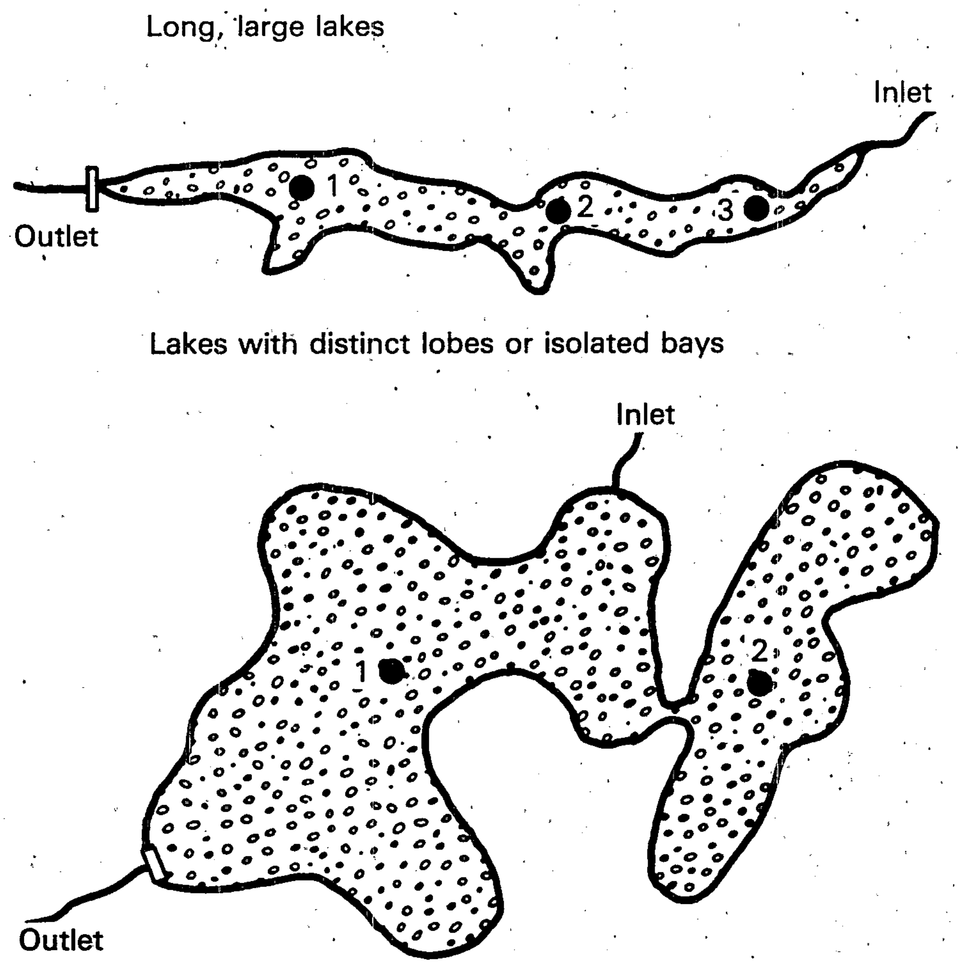


Figure 3-5.—Typical sampling locations for lakes with simple and complex shapes.

Physical Parameters

Sedimentation Rate Estimates

There are two generally accepted methods to determine recent sedimentation rates in lakes and reservoirs. One method involves the determination of the radioisotopes Cesium-137 or Lead-210 in the sediments. Although this method provides accurate estimates of sedimentation rates, it is relatively expensive.

The second method, which is far less sensitive but also much less expensive, is to compare the current bottom contours (the depth to the bottom) with a similar map made several years before. The water level for these two surveys must be the same or the depth to the bottom must be corrected if not at the same water level. For natural lakes and reservoirs receiving large sediment loads, this method is satisfactory.

The usefulness of these methods depends on the objective of the study. One use of sediment dating is in proposed dredging projects. Before any major dredging is undertaken, the rate of sedimentation should be determined. It is of little value to dredge a reservoir that is filling in at a rate of 2 inches or more a year if watershed controls for erosion are *not* implemented. In general, natural lakes fill in at a slower rate than reservoirs, with rates for lakes ranging from 0.10-0.50 an inch per year.

Temperature

Temperature patterns or thermal stratification (see Chapter 2) influence the fundamental processes occurring in a lake such as dissolved oxygen depletion, nutrient release, and algal growth. Temperature measurements are useful, for example, in deciding whether a shallow lake mixes periodically throughout the summer. If a shallow lake is suspected of thermally stratifying for brief periods and then mixing, weekly measurements should be taken during the summer. Deeper lakes that remain stratified throughout the summer may not require a high frequency of sampling for temperature to understand general temperature patterns occurring there.

An example of thermal stratification and mixing periods is shown in Figure 3-6 for Pickerel Lake over a two-year period. This figure represents the type of information a professional consultant will collect and analyze as part of a lake restoration program. The algal problems associated with this shallow lake (40 acres, 17-foot maximum depth) are directly related to the timing of the summer mixing period. When the lake mixed in mid-September, clumps of blue-green algae that were on the lake bottom were suspended into the entire lake. Cold weather prevented any prolonged algal bloom. However, the following year

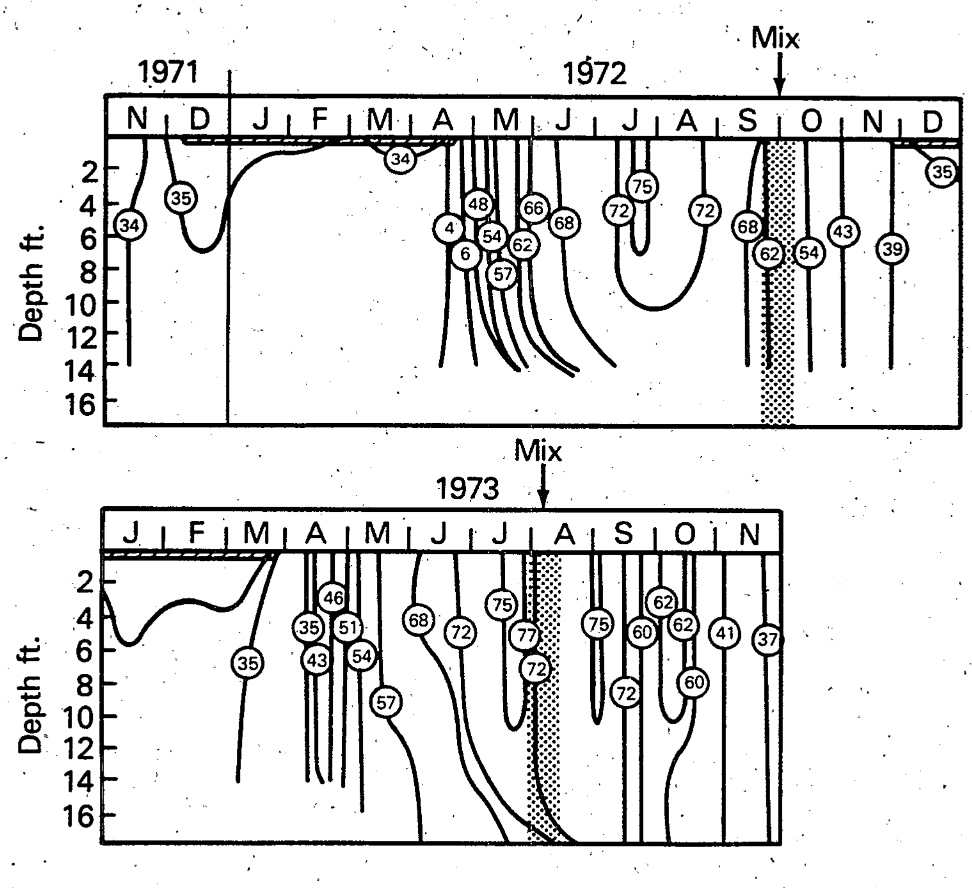


Figure 3-6.—Thermal stratification and mixing in Pickerel Lake. Lines represent the depth to which the tempearture (indicated in the circle) prevails. Temperatures are °F.

Pickerel Lake mixed in early August, again distributing blue-green algae off the bottom throughout the entire lake. During August and September, a massive blue-green algal bloom occurred as the warm weather created favorable environmental conditions for algal growth.

Transparency

Secchi depth is probably the most frequently used parameter in limnology. The Secchi disk is a 20 cm plastic or metal disk that is either painted entirely white or divided into alternating black and white quadrants. The disk is lowered into the water, and the observer measures the depth at which it can no longer be seen. This depth is recorded and is referred to as the "Secchi transparency," or Secchi depth, of the lake (see Fig. 3-7).

The assumption is that the greater the Secchi depth, the better the water quality of the lake. The transparency is based on the transmission of light through water and is related, in part, to the natural light attenuation of the water being measured, the amount of inorganic suspended solids, and the amount of organic suspended solids (algae cells). The relationship between the Secchi transparency and the amount of algal biomass as expressed in chlorophyll *a* has been developed for a large number of lakes. Each ecoregion of the country should develop this relationship independent of the others because turbid waters might be normal in some regions but unusual in others.

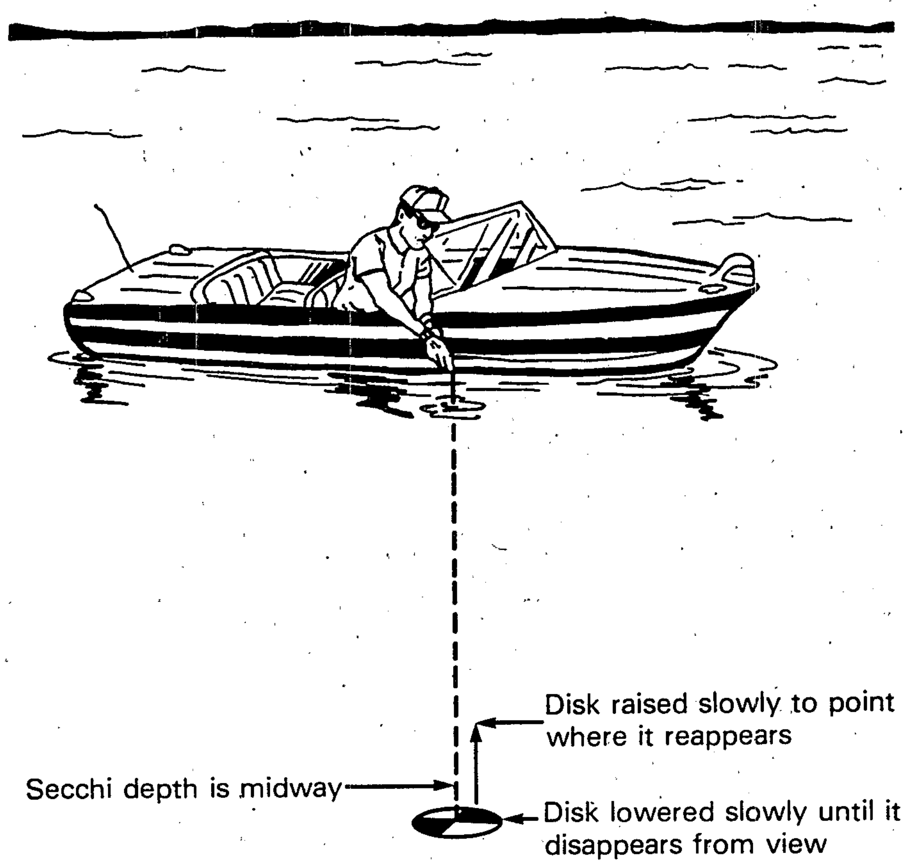


Figure 3-7.—The Secchi disk is a simple and extremely useful tool for tracking long-term trends in lake water quality.

Chemical Parameters

Dissolved Oxygen

These determinations are extremely useful because dissolved oxygen can act as an integrator of the health of the lake.

In shallow lakes that mix periodically during the summer, dissolved oxygen measurements should be made at the same time as temperature determinations. Periods of no mixing when dissolved oxygen in the bottom goes to zero followed by periods of mixing, can result in the release of phosphorus from the bottom during anoxia and its eventual redistribution throughout the lake. This can promote the development of algal blooms.

The deeper lakes that remain stratified during the summer may not require a high frequency of sampling for dissolved oxygen and temperature to understand their water quality patterns. There is, however, a critical period during the spring just as a eutrophic lake is beginning to stratify. At this point, weekly measurement of dissolved oxygen at 1- or 2-foot intervals is suggested until the dissolved oxygen concentration approaches zero in the hypolimnion. The rate of dissolved oxygen depletion can then be calculated. This rate can be useful in designing aeration systems if this is a chosen management option. The rate of dissolved oxygen depletion is also another indicator of the severity of the lake trophic condition. Generally, the more rapid the depletion rate, the more eutrophic the lake.

Low dissolved oxygen may be the cause of both summer and winter fishkills. During summer months, the dissolved oxygen in shallow eutrophic lakes may be depleted following a rapid algal die-off. Severe dissolved oxygen depletions can occur from natural causes, but they can also result from unwise management; for instance, treating an algal bloom in the entire lake with herbicides can drastically reduce the dissolved oxygen and cause a fishkill. Also, for lakes that freeze at the surface during the winter months, dissolved oxygen can be reduced by the end of winter to conditions that cause a fishkill.

pH

An indication of acidity in lake water, the pH is measured on a scale of 0 to 14. The lower the pH, the higher the concentration of hydrogen ions (H^+) and the more acidic the water. A reading of less than 7 means the water is acidic; if the pH is greater than 7, it is basic (alkaline). Because the pH scale is logarithmic, each whole number increase or decrease on the scale represents a 10-fold change.

Acid rain typically has a pH of 4.0 to 4.5. In contrast, most lakes have a natural pH of about 6 to 9.

Alkalinity/Acid Neutralizing Capacity

Alkalinity is a measure of the acid neutralizing capacity of water; that is, the ability of a solution to resist changes in pH by neutralizing acid input. In most lakes, alkalinity exists through a complex interaction of bicarbonates, carbonates, and hydroxides in the water. The higher the alkalinity, the greater the ability of water to neutralize acids.

Low alkalinity lakes are not well buffered and typically are also relatively low in pH. When alkalinities are less than 20 mg/L, the Gran analysis method should be used. The Gran method for alkalinity provides information that is referred to as "acid neutralizing capacity" because it includes alkalinity plus the additional buffering capability of dissociated organic acids and other compounds.

Nutrients

The nutrients to be sampled in a lake study are generally those (principally phosphorus and nitrogen) that are critical to plant growth. Phosphorus is often the key nutrient in determining the quantity of algae in the lake. Chapter 2 explained the role of plant nutrients and their relative availability in lake systems. Certain species of algae can fix atmospheric nitrogen and add to a lake's nitrogen pool if nitrogen is in short supply. For eutrophication studies, total phosphorus is the single most important nutrient to determine in the incoming and outgoing streams. Many lake management decisions will be made based on the total phosphorus income to a lake. The modeling efforts (see Chapter 4) to predict water quality changes as a result of an implementation project are based on the total phosphorus loadings. Other chemical analyses that are important are total soluble phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, nitrate nitrogen, ammonium nitrogen, and total and dissolved solids. Occasionally, measurements of chloride or potassium are useful indicators of agricultural or urban source problems.

The total nitrogen (N) to total phosphorus (P) ratio (N:P) in the lake water can help determine what algae might prevail (e.g., N:P 10 · 1). For example, nitrogen-fixing blue-green algae might be favored during periods of low nitrogen content in the lake. Since phosphorus is not a volatile chemical, its sources are rather limited. Because of this, controlling phosphorus is usually the only practical solution to the problems of algal growth in a lake.

Of specific interest is the nutrient load during normal streamflow and the nutrient income during storm events. A single, large storm may produce a nutrient income equal to several months' worth during normal flow. To obtain nutrient samples during storms, automatic sampling devices that are activated by rising water levels in the streams should be installed. The automatic samplers are made for convenience, since volunteers will probably not go out to collect samples during a storm, especially when it starts at 3 a.m. on Sunday morning.

The final component of stream work is the coupling of nutrient concentrations in the stream water to the streamflow to develop an annual nutrient income to the lake. Once the annual nutrient and water income for the monitored subbasins within the watershed have been calculated, they can be extrapolated to the unmonitored subbasins. In the final analysis, the incomes from all of the subbasins are added together to produce the total surface watershed income to the lake.

Biological Parameters

Biological indicators of eutrophication can be a variety of different organisms, but the most frequently monitored indicators are algae and macrophytes. An overabundance of either usually brings numerous complaints from lake users.

Algal Biomass

Biomass determinations are probably the most useful measurement of the amount of algae, followed by actual identification of species. The biomass measurement most frequently used is chlorophyll *a*. In most studies, an integrated water sample is collected from the upper portion of the lake (the photic, or lighted, zone) either by taking water samples from several depths and mixing them together, or by using a tube that extends through the photic zone. Peak chlorophyll *a* concentrations in an oligotrophic lake may range from 1.5 to 10.5 µg/L, while peak concentrations in a eutrophic lake may range from 10 to 275 µg/L. The average summer chlorophyll concentrations are good indicators of the severity of the algal problems in a lake.

Algal identification also can be useful in conjunction with the biomass measurements. A determination of the major types of algae that compose the biomass may help to understand lake problems. Blue-green algae are the most frequent cause of aesthetic problems; they can float at the surface, leave a paint-like film on the shores, and cause taste and odor problems.

The chlorophyll *a* concentrations and the relation to the major algal types during the growing season are illustrated for eutrophic North Twin Lake (Fig. 3-8), located in Polk County, Wisconsin. The period of greatest algal problems can be noted by the higher chlorophyll *a* concentrations from the end of July through September. The exact kinds of algae that contribute to the higher biomass are displayed in the kite diagrams of algal succession. *Anabaena*, a blue-green alga that often forms noxious scum at the surface of the lake, is present during the August bloom. *Lyngbya*, another troublesome blue-green alga, was dominant during September. The chlorophyll *a* concentrations detailed the severity of the algal problem, and the algal identification allowed for the recognition of the algal species that dominated during the problem period.

Chlorophyll a: *A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae.*

Macrophyte Biomass and Locations

Aquatic macrophyte communities range from completely submerged stands of large algae (for example, *Chara* or *Cladophora*) to stands of rooted plants with floating leaves (water lilies). Macrophyte densities vary seasonally between lakes in an area and among regions. In a northern Wisconsin lake, the average weight of macrophytes might be several hundred pounds per acre, while in Florida several tons per acre are common. Densities also vary within a lake. Eutrophic lakes can have very high quantities of plants as can lakes located in regions with long growing seasons, warm waters, or other favorable conditions.

Macrophytes are usually surveyed once or twice during the growing season. Several tasks are normally accomplished during a macrophyte survey. The first is mapping the location and extent of the major community types: emergents, floating leaves, and submergent plants (see Biology of Macrophytes in Chapter 6). The abundance could be described as follows: A = abundant, B = common, S = sparse. This information should be sketched on a hydrographic map to show distribution of the major communities. Figure 3-9 is an example from Pike Lake (Polk County, Wisconsin) that shows the distribution patterns of the major macrophyte communities during August when plant density, species identification frequency, and depth of growth should be determined.

Hydrographic map: *A map showing the location of areas or objects within a lake.*

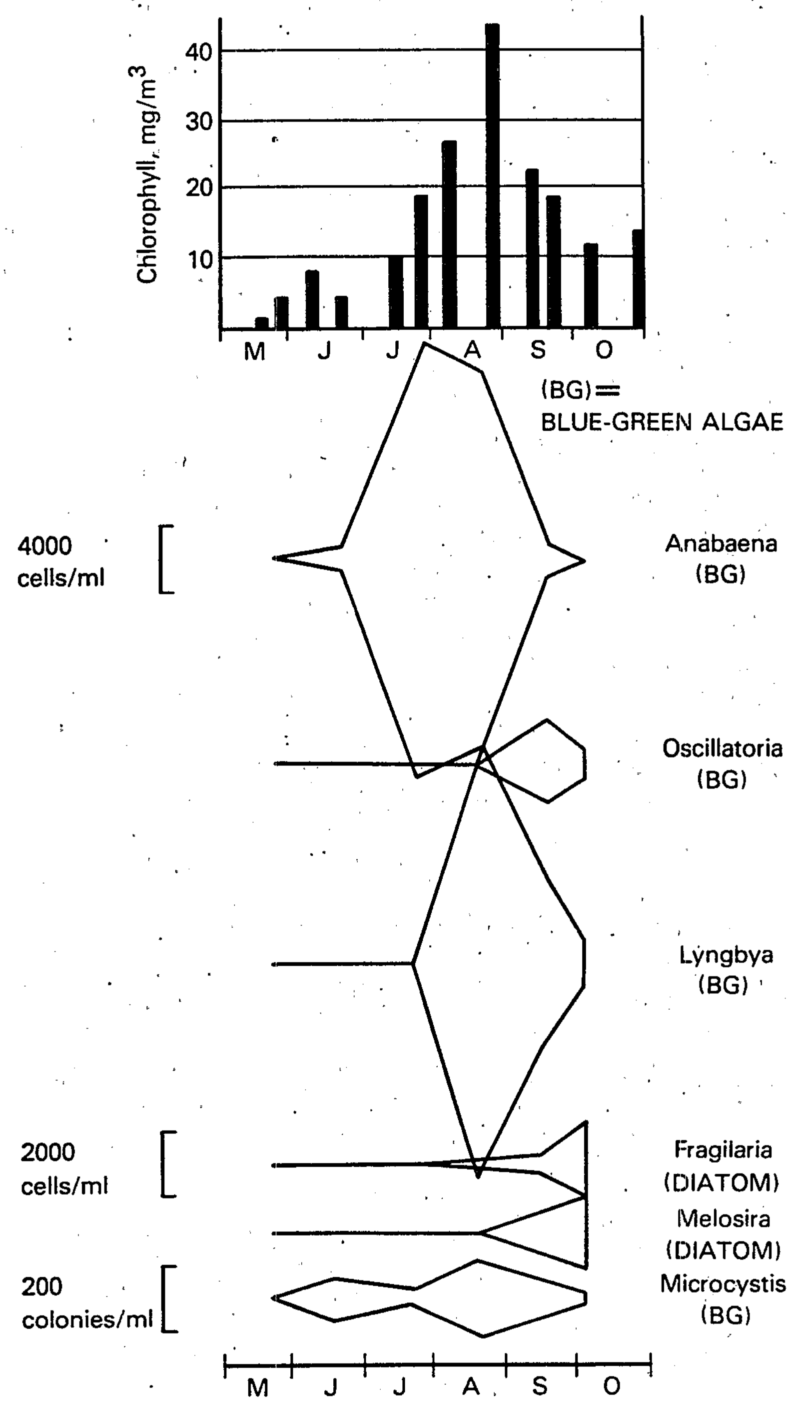


Figure 3-8.—The chlorophyll *a* concentrations and the major algal types during the growing season fo the eutrophic North Twin Lake. The period of greatest algal problems can be noted by the higher chlorophyll *a* concentrations at the end of July through September. The exact kinds of algae that contribute to the higher biomass is displayed in the kite diagrams of algal succession.

The assembled information on macrophytes is useful in deciding where to concentrate macrophyte control efforts such as harvesting or dredging and for predicting the depth to which plants might grow if the water clarity were improved (see Chapter 6).

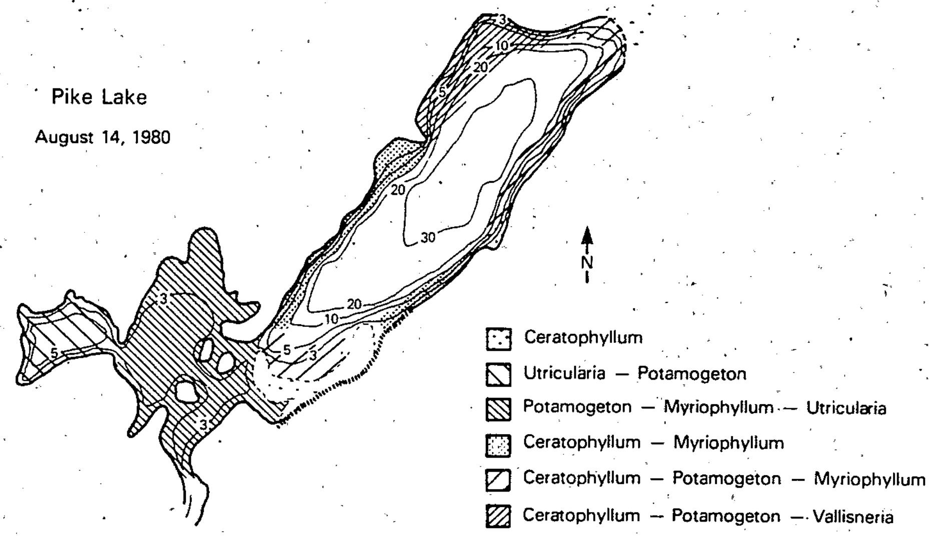


Figure 3-9.—Pike Lake distribution patterns of the major macrophyte communities during August. Depth contours are given in meters.

Fish Survey

A survey of the fish community can provide useful information on the species present, the size distribution of those fish species, and the relative availability of fish prey to the larger fish predators (e.g., the game fish species, see Chapter 2). If poor fishing has been identified as a lake problem, then a survey of the fish community is needed to document existing conditions. A fish survey can be conducted by seining if the lake is sufficiently small and shallow. However, larger lakes are usually sampled with gill nets, by electroshocking, or by rotenone poisoning.

A fish survey may reveal that a desired game fish species does not even live in the lake. Lake conditions may not be suitable for its habitat or survival; conditions could have changed to result in its elimination; or the population could have been wiped out by a combination of overfishing and poor reproduction. Alternatively, the desired species may be present but in very low numbers because of poor reproduction resulting from a lack of suitable habitat or from intense competition for food with another predator. A game fish population may be large, but in poor condition or stunted in size because of a lack of suitable prey. Appropriate fishery management practices can be applied to alleviate most of these problems, but only if the problem is first identified. The state fish and game agency can often be enlisted to conduct the fish community survey, to help interpret its results, and to suggest a fishery management strategy.

Use of Trophic State Indices

A variety of indices are available to rate measured in-lake variables on a scale so that the severity of lake problems can be compared to other lakes in the area. This provides a quantitative means of assessing lake changes after protection and restoration practices have been implemented (Carlson, 1977;

Kratzer and Brezonik, 1981; Walker, 1984). These lake indices, often referred to as "trophic state indices," attempt to simplify complicated environmental measurements. As Reckhow (1979) has pointed out, an index is a summary statistic that is used because its convenience outweighs the disadvantage of information lost in summarization.

The basis for the trophic state index concept is that, in many lakes, the degree of eutrophication is believed to be related largely to increased nutrient concentrations in the lake. Often phosphorus is the nutrient of concern. An increase in lake phosphorus concentration is expected to cause an increase in the amount of lake algae (see Chapter 2 to review this concept) as measured by chlorophyll *a*. Simultaneously, there would likely be an associated decrease in water transparency as measured by a Secchi disk and an increase in fish standing crop.

The Carlson (1977) Trophic State Index (TSI) is the most widely used (see Chapter 4). It was developed to compare determinations of chlorophyll *a*, Secchi transparency, and total phosphorus concentration. Higher index numbers indicate a degree of eutrophy while low numbers indicate a degree of oligotrophy (low nutrient and algal concentrations and high transparency). The index was scaled so that a TSI = 0 represents a Secchi transparency of 64 meters. Each halving of transparency represents an increase of 10 TSI units. A TSI of 50, thus, represents a transparency of 2 meters, the approximate demarcation between oligotrophic and eutrophic lakes.

Suppose that a lake had a transparency index of 60 prior to implementation of lake restoration. If two years later, the index is 40, this would be a quantitative estimate of the degree of improvement. A TSI of 40 might be common to undeveloped lakes in the area; this might indicate that the lake has improved about as far as it can. Significant upward movement of the index in later years would indicate a return of the lake to its previous condition. The index, therefore, is a useful tool for assessing the lake's current condition and for monitoring change over time.

The Carlson TSI works well in north temperate lakes that are phosphorus-limited but poorly in lakes that are turbid from erosion or in lakes with extensive weed problems. Figure 3-10 is an example of TSI plots for a north temperate lake of relatively poor water quality; Figure 3-11 illustrates a more complex situation when it is necessary to determine why parameters do not agree as expected. By scanning the TSI plots, the lake manager can begin to understand the patterns in a particular lake and appreciate the seasonal variations without having to analyze phytoplankton and phosphorus concentrations and place trophic interpretations on them.

The TSI values calculated for chlorophyll *a*, for example, may not be similar to simultaneous calculations of TSI from Secchi disk or total phosphorus measurements. Understanding this particular situation requires the consultant to examine the database in greater detail. In this case, an explanation might be the presence of suspended materials that reduce light attenuation and, therefore, algal productivity. An abundant population of large zooplankton might be actively feeding upon the algae and reducing their biomass. In such cases, the TSI plots would be valuable because they allow a professional to assess the situation and the possible need for additional information to make decisions.

Other indices have been developed that are more appropriate for the various major lake ecoregions in the country. Walker (1984) has developed such an index for reservoirs, and Brezonik (1984) has developed an index that more specifically fits the needs of Florida lakes and includes situations where nitrogen rather than phosphorus may be limiting algal growth. Porcella et al. (1979) have included a term in their Lake Evaluation Index that represents the amount of lake surface covered by macrophytes.

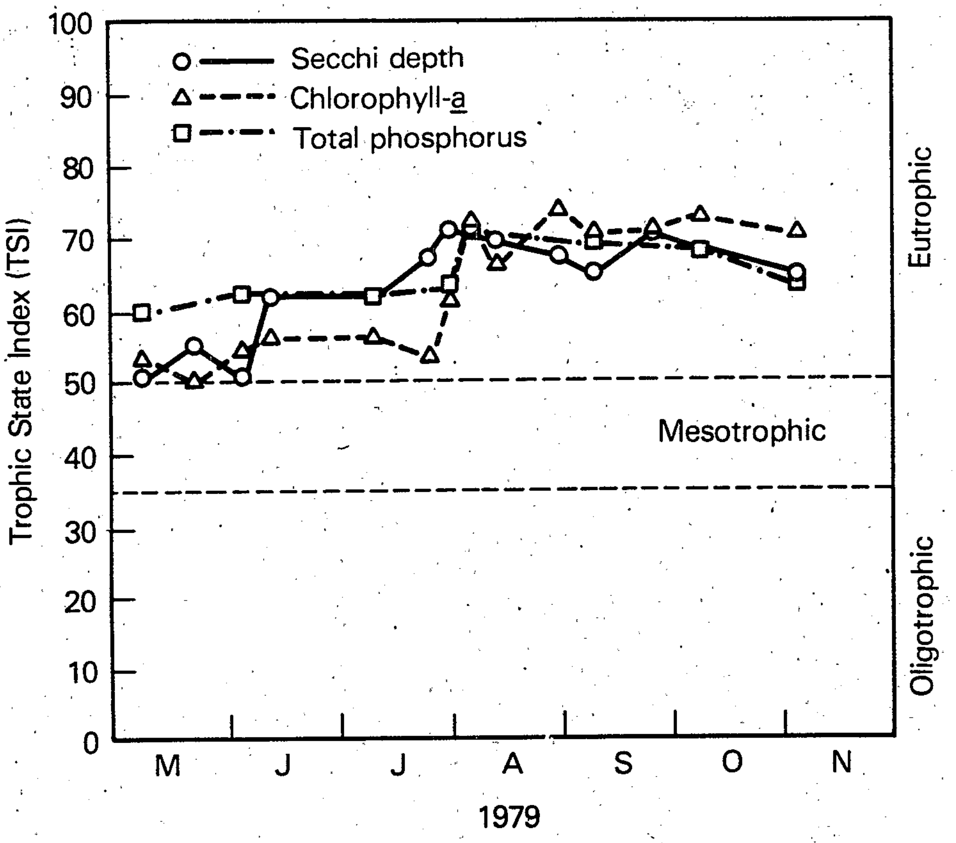


Figure 3-10.—A TSI plot for a north temperate lake that is considered to have poor water quality.

Problem Definition

Putting the Pieces of the Puzzle Together

Identifying lake problems is not that difficult; identifying the source of a particular problem takes a little more effort. The in-lake and watershed measurements necessary to identify the severity of a problem and track down the sources that cause various problems have been discussed. The final step is to use the information to make lake management decisions. The best way to illustrate the importance of measuring the severity of the lake problem and identifying the sources is to present an example.

Mirror Lake

Mirror Lake is a small urban lake located within the city limits of Waupaca, Wisconsin. The lake has a surface area of 12.5 acres and a maximum depth of 43 feet and had experienced repeated blue-green algal blooms and winter fishkills. Since the city had an interest in restoring Mirror Lake, a diagnostic study was designed to determine the annual incomes of water and total phosphorus and to examine the condition of the lake's water quality.

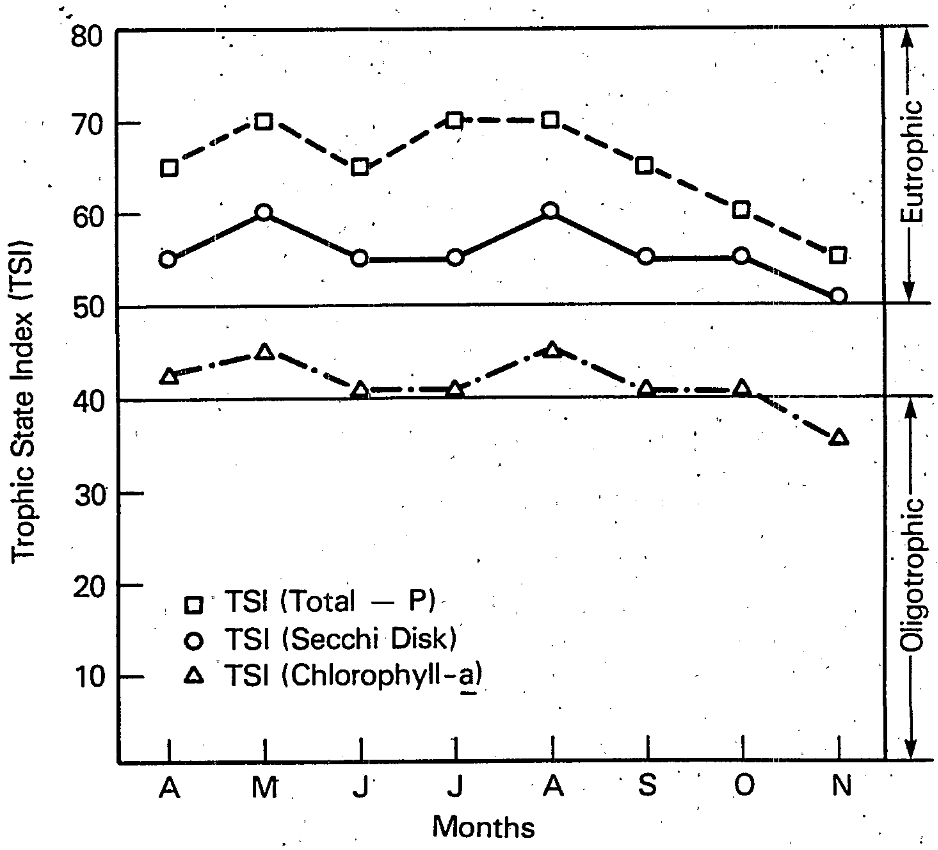


Figure 3-11.—A TSI plot that adds more complexity to the interpretation. The TSI (chl. *a*) plot does not agree with either the TSI(SD) or the TSI(TP) plots. Understanding this particular situation requires the lake manager to examine the data base in much greater detail.

Mirror Lake is a seepage lake with no permanent inflowing streams from the watershed. If it had been a drainage lake, then considerable attention would have been paid to land uses and streamflows to identify those areas of the watershed most responsible for the silt and nutrient loads causing the problem.

Water and nutrient incomes were studied during 1972 and 1973; Table 3-4 lists the results. Storm sewers from the city contributed more than 50 percent of the phosphorus income to Mirror Lake and were the obvious targets for lake protection efforts. The study demonstrated that the greatest periods of phosphorus income were during spring showers and intense late summer rainfalls.

Total phosphorus concentration in the lake averaged 90 μg phosphorus/liter, a very high value. The Carlson Trophic State index number for total phosphorus concentrations was 69, a value expected for an extremely eutrophic lake. Measurements of phosphorus throughout the water column revealed extremely high concentrations in the hypolimnion, particularly near the sediments. Experiments were then conducted to determine whether this phosphorus came from the sediments. The results revealed a high release rate or internal phosphorus loading from the sediments.

The algae in the lake during the summer were unlike those found in many other eutrophic lakes. The spring and fall months were characterized by massive blooms of a blue-green algae called *Oscillatoria agardhii*, but the summer season saw this species confined to the metalimnion (see Chapter 2), while the upper waters were dominated by green algae.

It became obvious that the year-to-year increase in the quantity of algae of Mirror Lake was a response to stormwater inputs. A sediment core was taken, dated with the Lead-210 techniques, and analyzed for the presence of particular types of chlorophyll pigments common in *Oscillatoria*. The first bloom of algae, as recorded by pigments in the sediments, occurred in the early 1940s, just a few years after storm drainage was diverted to the lake.

The diagnostic study demonstrated that very low dissolved oxygen in Mirror Lake during the winter caused winter fishkills. An analysis of the data revealed that this problem was due to poor lake mixing during fall months before ice developed (see Chapter 2 for a discussion of expected thermal histories of lakes). This meant that the lake had very low dissolved oxygen in it when the ice formed on the water's surface and eliminated oxygen exchange with the atmosphere. The data from the diagnostic study were used to determine appropriate lake protection and restoration strategies.

In 1976, storm sewer diversion reduced the phosphorus income to the lake by 50 to 60 percent. This step was taken after a historical analysis of lake sediments showed a relationship between the onset of algal blooms and the beginning of stormwater discharge to the lake. Lake users expected the lake to improve immediately. As shown in Figure 3-12, total phosphorus concentration in the Mirror Lake in 1977 and part of 1978 was very similar to the prediversion average of 90 μg phosphorus per liter. This result demonstrated that storm sewer diversion was a necessary step to lake protection, but insufficient for lake restoration. The high internal phosphorus release was recycling phosphorus stored in the sediments from the 35 years of storm drainage. These phosphorus-rich waters were probably transported from the bottom to the upper waters during summer storm mixing, which helped maintain high phosphorus levels in the water column.

This problem was identified because monitoring had continued after storm sewer diversions. This post-diversion monitoring was an integral part of diagnosis and implementation (see Chapter 8).

Aluminum sulfate was applied to Mirror Lake sediments in May 1978 to "inactivate" this phosphorus release (see Chapter 6 for a more detailed discussion of this procedure). As shown in Figure 3-12, total phosphorus fell to about 20 μg phosphorus per liter and has remained at that low level for several years. This action produced a total phosphorus TSI of about 47, a value found in lakes that are considered to be borderline eutrophic. A lake with this total phosphorus concentration would be expected to have fewer problems with algae and sharply improved transparency. This is what happened. *Oscillatoria agardhii* was not present in Mirror Lake by 1980.

The problem with low dissolved oxygen under the ice was solved by using an artificial circulation device (see Chapter 6) in the fall to thoroughly mix the lake. Figure 3-13 shows the success of the treatment. The threat of a winter fishkill was ended.

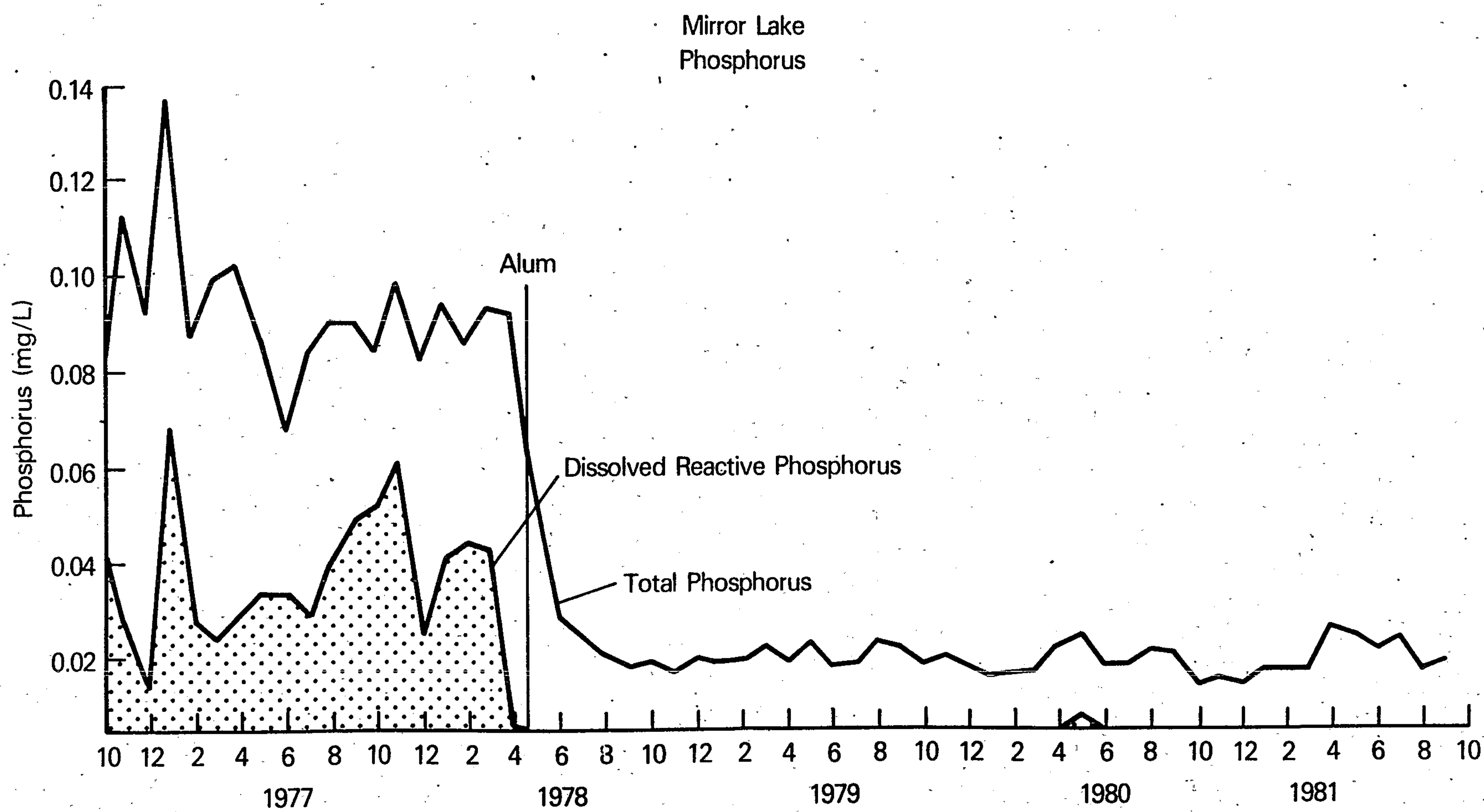


Figure 3-12.—Phosphorus concentrations in Mirror Lake water decreased dramatically following alum treatment.

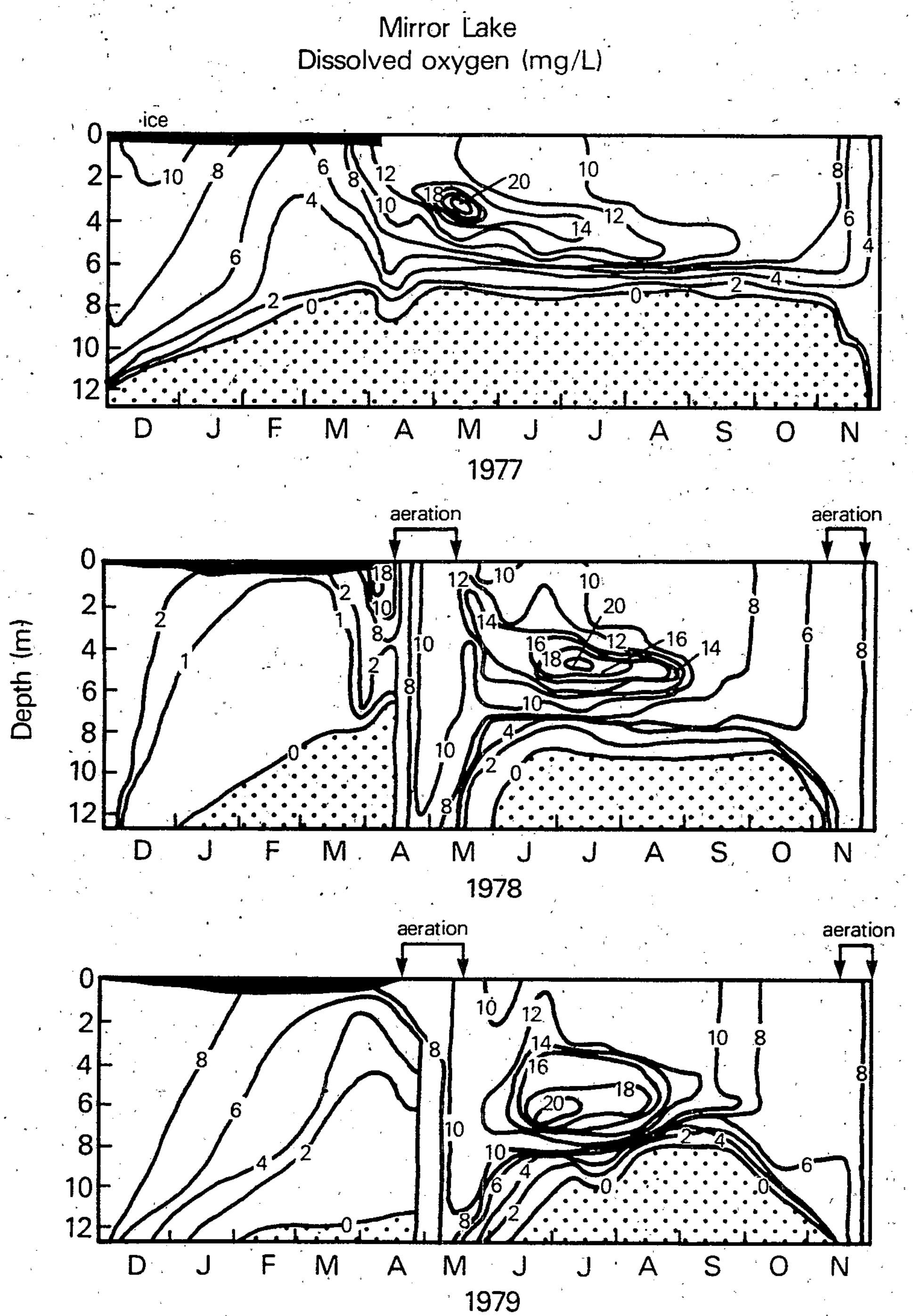


Figure 3-13.—Oxygen concentrations in Mirror Lake before and after aeration show that both the duration and severity of anoxia decreased. Oxygen concentrations are indicated by the numbers on the lines (isopleths). 0 indicates no oxygen.

This case history represents a real and highly successful use of the diagnosis-feasibility-implementation approach to lake protection and restoration. The city and its consultants looked for the causes of the problem. The continued wasting of money on temporarily effective treatments was replaced with expenditures directed toward a long-term solution. Had the obvious just been done (stormwater diversion only), it would have taken years to flush out nutrients from Mirror Lake before it came to a new average total phosphorus concentration. Instead, the consultants identified a second source of phosphorus and treated that as well. The lesson here is that lake management proceeds from step-by-step approaches that are based upon a knowledge of both the watershed and the lake and are directed at the causes of the problems. Effective lake management plans (see Chapters 7, 8, and 9) result from the integration of watershed management practices (see Chapter 5) and in-lake restoration procedures (see Chapter 6).

APPENDIX 3-A

Democratic Procedures to Obtain Consensus on Priority Uses for a Lake

Nominal Group Process

The nominal group process is an alternative to the standard group meeting procedure. In a typical group meeting, a decision is made through the following sequence: a motion, discussion, and a vote. This standard procedure is frustrating to most people because they feel intimidated about speaking up in a group setting or because discussion is monopolized by a few dominant personalities.

The nominal group process is especially effective at soliciting concerns or setting priorities. It can also be used to solicit ideas for activities or projects. Thus, the nominal group process could be used to prioritize uses, enumerate and prioritize perceived problems, or prioritize projects for a lake organization.

The process has many variations. In its simplest form, each participant is first asked to write down a list of issues. The moderator than asks each person to volunteer one issue from that person's list. The moderator proceeds around the group until all issues are transferred from individual written lists to sheets of paper hung in view of the group. During this time, there is no discussion or debate on the appropriateness of anyone's suggestion. Each participant decides whether his or her issues are already listed on the sheet. The moderator proceeds around the group until no one has any more issues to contribute.

After all issues are listed, the group debates whether certain issues should be combined. The discussion on combining issues usually leads into a general discussion, led by the person who suggested the issue, that is designed to help others understand it more fully. The moderator must be forceful in keeping the discussion focused on understanding each issue and eliminating duplication if the "authors" of those issues agree. The discussion is not allowed to become a debate on the merits of the issue.

Following the discussion, the moderator allows each person to select a limited number of issues to "save" by placing a mark or sticker next to those issues. (The physical act of getting up and placing marks provides a nice, refreshing break in the process.) The 3 to 10 issues with the largest number of votes are placed by the moderator into a priority pool. Participants then rank those issues.

The nominal group method is designed to allow equal participation by all members of the group. Dominant personalities are neutralized by the procedure. If a group exceeds 15 people, it is advisable to split the group into smaller subgroups and proceed until each subgroup has identified its priority pool. The priority pools are then combined, and the entire group ranks the issues in the combined pool.

In larger lakeshore communities, direct participation by all property owners and local lake users may not be feasible. Under such circumstances a task force or advisory committee might serve to represent the community and report to a city council or county board. The nominal group process may still be a useful procedure for the task force or advisory committee, itself, to use.

In addition to identifying issues, the participants leave the process with a much higher sense of ownership than they do after participating in a standard meeting. After the nominal group experience, they identify with the priorities because they actively help to select them.

Delphi Process

The Delphi technique is premised on incomplete knowledge and an inherent bias by any one expert (or citizen). Therefore, a panel of experts is expected to produce a more complete range of issues or solutions and a more balanced prioritization than a single expert.

This procedure is useful in setting research priorities, summarizing current knowledge, and making policy recommendations for public bodies. For instance, it could be used to design a management plan for a new reservoir.

The first stage of the process is a solicitation of the full range of issues, ideas, and concerns associated with the topic. The experts at a meeting or through correspondence simply provide a laundry list of all items that might be appropriate.

In the second stage, the list developed in Phase I is provided to the same experts for a ranking on some specified criterion of importance. The results of Phase II are communicated to the organization that initiated the effort. Additional phases can be used to obtain greater specificity regarding the highest-ranked items.

While this procedure is too complicated and expensive for most lakeshore communities, it is often a good idea for lake organizations to get a second opinion on major recommendations they receive from a consultant or agency employee.

Chapter 4

PREDICTING LAKE WATER QUALITY

Uses of Models

Mathematical models can be useful both in diagnosing lake problems and in evaluating alternative solutions. They represent the cause–effect relationships that control lake water quality in quantitative terms. Model formulas are derived from scientific theories and from observations of the processes and responses in real lakes. There are two basic ways in which models can be employed in lake studies:

1. **DIAGNOSTIC MODE: What is going on in the lake?** Models provide a frame of reference for interpreting lake and watershed monitoring data. They tell the user what to *expect* to find in a lake with a given set of morphometric, hydrologic, and watershed characteristics. These expectations are not always met, however. Differences between measured and predicted conditions contain information on the unique features of the lake under study. They help clarify important cause and effect relationships.

Morphometry: *Relating to a lake's physical structure (e.g., depth, shoreline length).*

2. **PREDICTIVE MODE: What will happen to the lake if we take certain actions?** Models can be used to predict how lake water quality conditions will change in response to changes in nutrient inputs or other controlling factors. For practical reasons, it is usually infeasible to predict lake responses based on full-scale experimentation with the lake and its watershed. Instead, mathematical models permit experiments to be performed on paper or on computer.

Examples of questions that might be addressed through lake modeling include

- What did the lake look like before anyone arrived?
- What level of nutrient loading can the lake tolerate before it develops algae problems?
- How will future watershed development plans affect the lake's water quality?

- What are the most important sources of the lake's problems?
- What reduction in nutrient loading is needed to eliminate nuisance algal blooms in the lake?
- How long will it take for lake water quality to improve once watershed or point source controls are in place?
- What is the expected range of water quality conditions over several years (given a year's worth of monitoring data collected in the lake and its watershed)?
- What is the probability that restoration efforts will be successful (given a water quality management goal such as a target level of lake phosphorus, chlorophyll *a*, or transparency and an array of feasible control techniques)?
- Are proposed lake management goals realistic?

Models are not the only means of addressing these questions, and they do have limitations. For example, modeling is feasible only for evaluating those types of problems that are understood well enough to be expressed in concise, quantitative terms. In some situations, modeling may be infeasible or unnecessary. Why make a lake study more complicated than it has to be?

Models are not monoliths. They are rather frail tools used by lake management consultants in developing their professional opinions and recommendations. The consultant should decide which models (if any) are appropriate, what supporting data should be collected, how the models should be implemented, and how the model's results should be interpreted. Consider the following analogy:

HOME ADDITION	LAKE STUDY
Carpenter	Consultant
Tools	Modeling Techniques
Raw Materials	Monitoring Data

Different carpenters may prefer certain brands of tools to others. The selection of appropriate tools to accomplish a given job is an important, but not the only factor determining the success or failure of a project. In home building, the quality of the addition depends less upon which tools are used than upon *how* they are used. The owner hires the carpenter, not the tools. This premise also applies to hiring a lake management consultant. Obviously, the quantity and quality of raw materials are every bit as important as the tools used on the job. The raw materials required for applying a model to a lake are monitoring data and other baseline information developed under diagnostic studies (see Chapter 3).

For ease in explaining modeling concepts, English units are used in the examples in this chapter. Lake modeling is far less awkward, however, when metric units are used.

Phosphorus loading models, which relate the phosphorus supply to algal growth in lakes, are the primary focus of this chapter. However, it should be noted that other models can be used to relate the relative availability of nutrients and lake morphometry to fish production (e.g., Ryder et al. 1974; Ryder, 1982; Jenkins, 1982) and to relate chlorophyll concentrations to sportfish harvest (Oglesby, 1977; Jones and Hoyer, 1982) in lakes and reservoirs. As explained in Chapter 2, the basic concept underlying these models is that nutrient availability, algal production, and fish production are strongly interrelated (see Fig. 2-10). Therefore, increasing or decreasing the nutrient loading to a lake will generally result in a corresponding increase or decrease in nutrient availability, algal growth, and fish production.

Eutrophication Model Framework

Phosphorus loading models are frequently used to evaluate eutrophication problems related to algae. These models link phosphorus loading to the average total phosphorus concentration in the lake water and to other indicators of water quality that are related to algal growth, such as chlorophyll and transparency (Fig. 4-1). Lake responses to phosphorus loading depend upon physical and hydrologic characteristics. Therefore, these models consider lake volume, average depth, flushing rate, and other characteristics when predicting lake responses to a given phosphorus load.

While the terms and equations involved may seem foreign, the three underlying concepts are simple.

1. Lake algal growth is limited by the supply of phosphorus.

2. Increasing or decreasing the mass of phosphorus discharged into the lake over an annual or seasonal time scale will increase or decrease the average concentrations of phosphorus and algae in the lake.

3. A lake's capacity to handle phosphorus loadings without experiencing nuisance algal blooms increases with volume, depth, and flushing rate.

In other words, the lake's condition depends upon how much phosphorus it receives from both internal and external sources. A large, deep lake with a high flow will be able to handle a much greater phosphorus load without noticeable deterioration than a small, shallow, or stagnant lake. Models summarize these relationships in mathematical terms, based upon observed water quality responses of large numbers of lakes and reservoirs.

Algal growth in these models is usually expressed in terms of mean, growing-season chlorophyll in the epilimnion concentrations. As discussed in Chapter 3, phosphorus, chlorophyll *a*, and transparency help to define *trophic state*, a vague concept used to characterize lake condition. Other variables related to algal productivity, such as hypolimnetic oxygen-depletion rate, seasonal maximum chlorophyll *a*, bloom frequency, or organic carbon, may also be considered in phosphorus loading models.

These methods cannot yet be used to predict aquatic weed densities, which generally depend more upon lake depth, the quantity and quality of lake bottom sediment, and light penetration than upon the loading of nutrients entering the lake from its watershed.

Eutrophication models rely heavily on the lake phosphorus budget, which is simply an itemized accounting of the inputs and outputs of phosphorus to and from the lake water column over a year or a growing season. Although budgets can be constructed for other pollutants that cause lake problems (nitrogen, silt, organic matter, bacteria, or toxics, for example) phosphorus budgets are used more frequently.

A phosphorus budget provides a means to evaluate and rank phosphorus sources that may contribute to an algal problem. The basic concept and mathematics are relatively simple, although the estimation of individual budget items often requires considerable time, monitoring data, and expertise.

Basic concepts involved in constructing phosphorus budgets and applying eutrophication models are described and illustrated in later sections of this chapter. In some situations, particularly in reservoirs, algal growth may be controlled by factors other than phosphorus, such as nitrogen, light, or flushing rate (Walker, 1985). Appropriate models for these situations are more complex than those discussed in the next section, although the general concepts and approaches are similar.

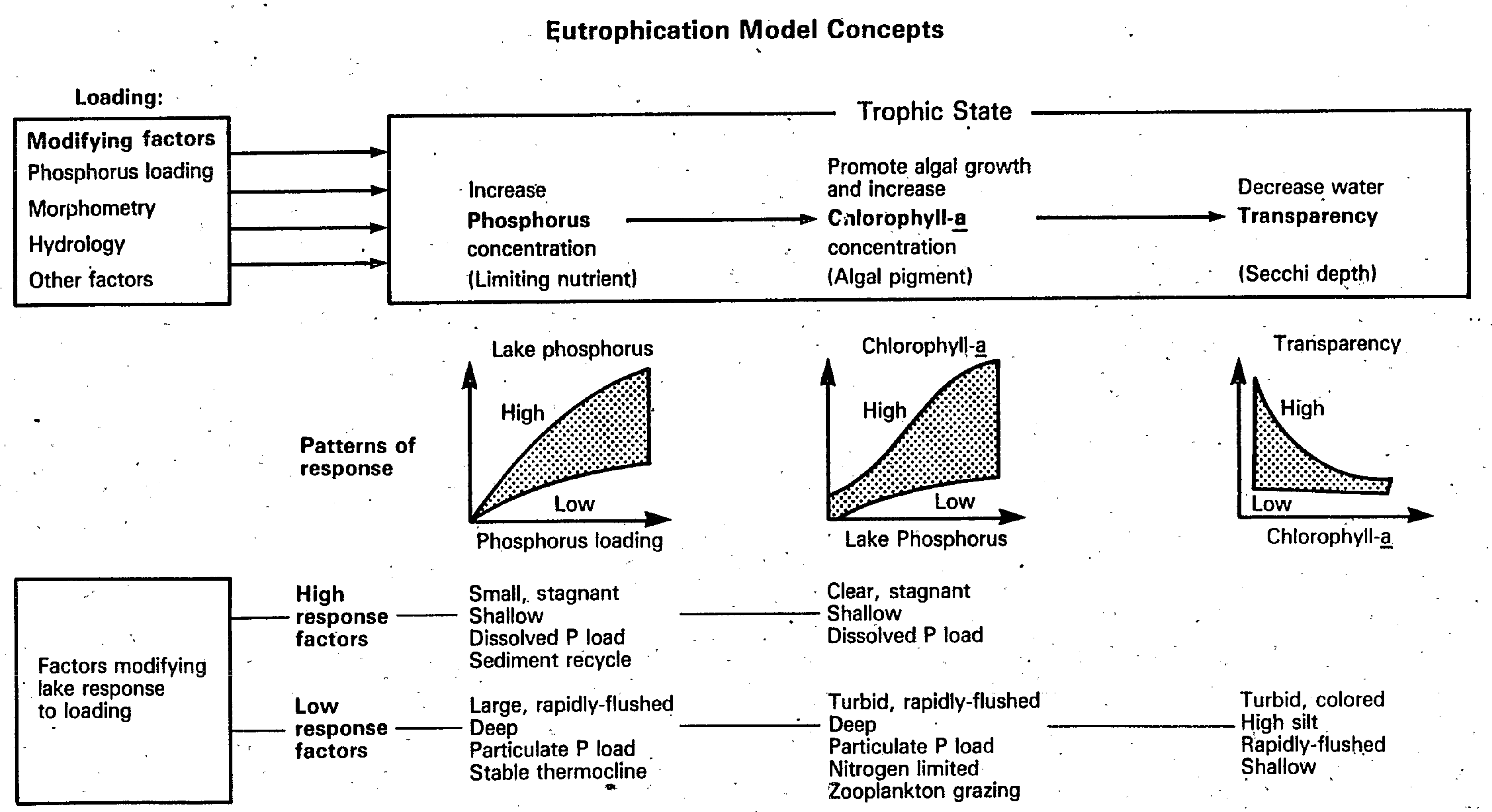


Figure 4-1.—Eutrophication modeling concepts.

Variability

Eutrophication models are geared to predicting *average* water quality conditions over a growing season or year. Unfortunately, this often gives the mistaken impression that water quality is fixed and does not vary in different areas or through time within a given lake. This is not the case. Averaging is typically done over three dimensions:

1. **DEPTH:** The top, mixed layer is the part of the water column that is generally averaged. Vertical variations within the mixed layer are usually small.

2. **SAMPLING STATION:** Stations might be located in different places of the lake. In a small, round lake, the variations among these stations will tend to be insignificant; therefore, one location is usually adequate. In a large lake with several embayments, in a long, narrow reservoir, or in a complex reservoir with several tributary arms, however, water quality may vary significantly (from oligotrophic to hypereutrophic) from station to station. In such situations, a measurement for the "average water quality" may be meaningless; it may be more appropriate to divide the lake or reservoir into segments for modeling purposes since outflow from one segment serves as inflow to the next.

3. **A SEASON:** Phosphorus, transparency, and especially chlorophyll *a* concentrations usually vary significantly at a given station from one sampling date to the next during the growing season. It is not unusual, for example, for the maximum chlorophyll *a* concentration to exceed two to three times the seasonal average. Because the input data themselves represent values within a range of actual conditions, model outputs also should be considered to represent answers within a range. Thus, model calculations are generally reported as having a certain "percent confidence" to indicate the likelihood that the answer is correct within a given range.

In addition, since chlorophyll *a*, phosphorus, and transparency vary during the season to begin with, a slight improvement or deterioration in these water quality characteristics is difficult to perceive. A model prediction that conditions would improve slightly, therefore, is not likely to represent a noticeable change in the lake. When the change becomes comparable to normal variations, it is easier to observe an improvement or deterioration.

Because of these variabilities, it is more realistic to consider measured or modeled water quality as a range of values rather than as a "point." If a consultant says that a lake has a mean chlorophyll *a* concentration of 10 ppb (parts per billion), for example, the actual mean may be 5 or 20 ppb, depending on monitoring frequency and lake variability. Perhaps more important, even if the seasonal mean is 10 ppb, 90 percent of the samples will be in the 2 to 24 ppb range for a lake with typical seasonal variability.

In a given watershed and lake, year-to-year variations in average water quality may be significant because of fluctuations in climatologic factors, particularly streamflows and factors controlling thermal stratification. Monitoring programs extending for a period of at least three years are often recommended to characterize this year-to-year variability and to provide an adequate basis for lake diagnosis and modeling.

Another source of variability is model error. Statistical analyses of data from large numbers of lakes and reservoirs indicate that phosphorus loading models generally predict average lake responses to within a range of one to two times the average. Differences between observed and predicted water quality, in part, reflect variability in the data (loading estimates and observed lake responses) and inherent model limitations. Differences between observed (directly measured) and predicted (modeled) values may contain useful information for diagnostic purposes, however. Model projections of future conditions resulting from a change in phosphorus loading are more reliable when they are expressed in relative terms (percent change from existing conditions). A good lake and watershed monitoring program can reduce the risk of significant model errors, which may lead to false conclusions and poor management decisions.

Loading Concept

Loadings most accurately express the relative impacts of various watershed sources on lake water quality. For example, a stream with a high phosphorus concentration will not necessarily be an important source to the lake, because the stream may have a very low flow and, therefore, contribute a relatively low annual loading.

Because lakes store nutrients in their water columns and bottom sediments, water quality responses are related to the total nutrient loading that occurs over a year or growing season. For this reason, water and phosphorus budgets are generally calculated on an annual or seasonal basis. Water and phosphorus residence times in the water column determine whether seasonal or annual budgets are appropriate for evaluation of a given lake.

Phosphorus loading concepts can be illustrated with the following analogy:

GROCERY BILL	**PHOSPHORUS LOADING**
Item	Source
Quantity	Flow
Unit Cost	Concentration
Cost of Item	Loading From Source
Total Cost of All Items	**Total Loading From All Sources**

The cost of a given item is determined by the quantity purchased and the unit cost. The total cost of all items purchased determines the impact on finances (lake water quality). Funds (lake capacity to handle phosphorus loading without water quality impairment) are limited. Therefore, intelligent shopping (managing the watershed and other phosphorus sources) is required to protect finances (lake water quality).

Loadings change in response to season, storm events, upstream point sources, and land use changes. For example, converting an acre of forest into urban land usually increases the loading of phosphorus by a factor of 5 to 20, a result of increases in both water flow (runoff from impervious surfaces) and nutrient concentration (phosphorus deposition and washoff from impervious surfaces). An evaluation of loadings provides a basis for projecting lake responses to changes in land use or other factors.

The grocery bill analogy breaks down in at least one important respect: shoppers can read the unit costs before they purchase the food. To estimate phosphorus loading from a given source, both flow and concentration must be quantified over annual and seasonal periods. This is difficult because both flow and concentration data vary widely in response to season, storm events, and other random factors. Flow should be monitored continuously in major streams. Concentration is usually sampled periodically (weekly, monthly) and preferably supplemented with samples taken during storms. This is why good lake and watershed studies cost so much. Particularly in small streams prone to flash flooding, a very high percentage of the annual loading may occur during short, intense storms. If these events are not sampled, it will be relatively difficult to develop reliable loading estimates.

Because of these factors, loading estimates for each source should be considered with a degree of skepticism. These are not fixed quantities but ranges. Depending upon monitoring intensity and calculation methods, an annual loading estimate for a given stream could be off by a factor of 2 or more. Where appropriate, monitoring intensity can be increased to provide better data for quantifying loadings, particularly in streams that are thought to be major contributors.

Water Budget

The first step in lake modeling is to establish a water budget. Flows carry pollutants into and out of lakes, and analyses of lake eutrophication and most other water quality problems cannot be conducted without a quantitative understanding of lake hydrology. The basic water balance equation considers the following terms, typically in units of acre-feet per year:

INFLOW + PRECIPITATION = OUTFLOW + EVAPORATION + CHANGE IN STORAGE

Water budget concepts are illustrated in Figure 4-2.

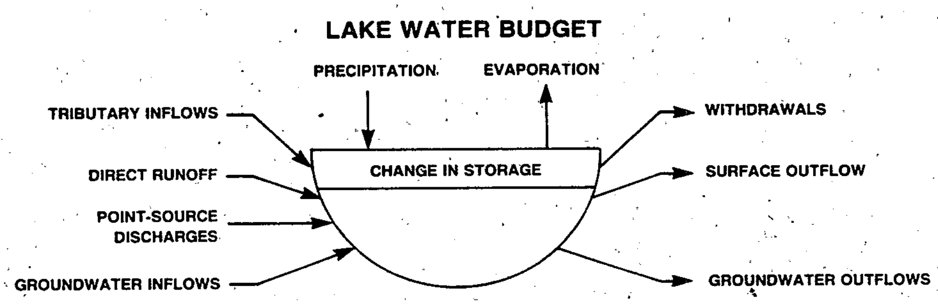


Figure 4-2.—Water budget schematic.

The data for the **INFLOW** and **OUTFLOW** should be evaluated over annual or seasonal periods. Inflows may include tributary streams, point source discharges, runoff from shoreline areas, and groundwater springs. Outflows may include the lake outlet, groundwater discharges, and withdrawals for water supply, irrigation, or other purposes. Major inflow and outflow streams should be gaged directly. Indirect estimation procedures (for example, runoff coefficients) can be used to quantify smaller streams. **PRECIPITATION** and **EVAPORATION** can be derived from regional climatologic data. The **CHANGE**

IN STORAGE accounts for changes in surface elevation over the study period, which is sometimes significant in reservoirs. This change is positive if lake volume increases over the study period, negative otherwise.

Once the flow terms have been estimated and tabulated, the water balance should be checked by comparing the total inflows with total outflows. Major discrepancies may indicate an omission or estimation error in an important source of inflow or outflow (such as unknown or poorly defined streamflow or groundwater flow). In seepage lakes, it is relatively difficult to establish water balances because of the problems and expense of monitoring groundwater flows. In any event, significant errors in the water balance may indicate a need for further study of lake hydrology.

To provide a complete accounting of the watershed, drainage areas should also balance (that is, the sum of the tributary drainage areas plus the lake surface area should equal the drainage area at the lake outlet).

Phosphorus Budget

The lake phosphorus budget (Fig.4-3) provides the cornerstone for evaluating many eutrophication problems. The following terms are evaluated and typically expressed in units of pounds per year:

INFLOW LOADING = OUTFLOW LOADING + NET SEDIMENTATION + CHANGE IN STORAGE

This equation summarizes fundamental cause and effect relationships linking watersheds, lake processes, and water quality responses.

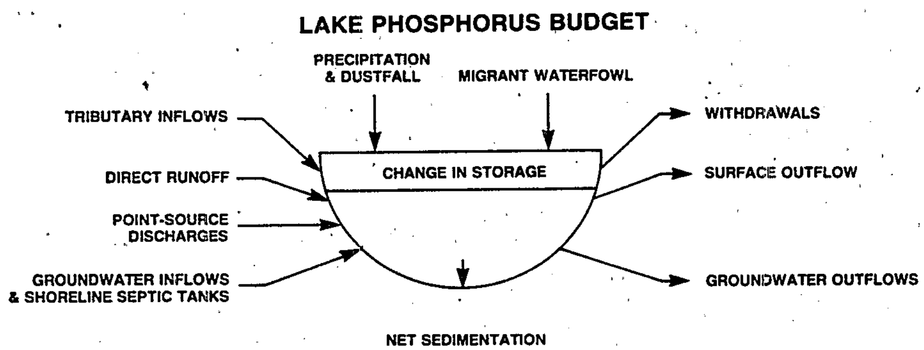


Figure 4-3.—Phosphorus budget schematic.

The **INFLOW LOADING** term indicates the sum of all external sources of phosphorus to the lake, which may include tributary inflows, point sources discharging directly to the lake, precipitation and dustfall, leachate from shoreline septic tanks, other groundwater inputs, runoff from shoreline areas, and contributions from migrant waterfowl. Estimation of individual loading terms is the most important and generally most expensive step in the modeling process. Investments in intensive monitoring programs to define and quantify major loading sources usually pay off in terms of the quality and reliability of project results. Monitoring of the lake itself is usually conducted during the same period so that loadings can be related to lake responses.

Stream loadings, usually the largest sources, are estimated from streamflow and phosphorus concentrations monitored over at least an annual period.

To provide adequate data for loading calculations, major tributaries should be sampled just above the lake over a range of seasons and flow regimes (including storm events). In large watersheds, it may be appropriate to sample at several upstream locations so that contributions from individual point and nonpoint sources can be quantified. Special studies may be required to estimate groundwater input terms (for example, groundwater sampling and flow modeling, shoreline septic tank inventories). Loadings in runoff from shoreline areas and from relatively small, unsampled tributaries can be estimated indirectly, as discussed in the following paragraph. Loadings in precipitation and dustfall, usually relatively small, can be estimated from values obtained from the literature or regional sampling data.

In many cases, indirect estimates of loading from a given stream or area can be derived from information on watershed characteristics. This method is based upon the concept that two watersheds in the same region and with similar land use patterns and geology will tend to contribute the same loading of phosphorus per unit area. This permits extrapolation of data from one or more monitored watersheds to others. **EXPORT COEFFICIENTS** (pounds of phosphorus per acre a year) have been compiled for various land uses and regions (see Chapter 2, Table 2-1). The applicability of this method depends largely upon the quantity and quality of regional export coefficient data for the land uses and watersheds under study. This approach is much less costly than direct monitoring but generally less reliable. It is frequently used in preliminary studies (to get a rough handle on the lake nutrient budget before designing and conducting intensive monitoring programs) and for estimating loadings from small watersheds whose contributions to the lake's total phosphorus budget are relatively insignificant.

The term **OUTFLOW LOADING** relates to phosphorus leaving the lake in surface outlet(s); withdrawals for water supply, irrigation, or other purposes; and groundwater seepage. These parameters are usually estimated by direct measurements of flow and concentration (as described previously for stream loadings). If lake outflow is dominated by groundwater seepage, it will be difficult to determine the outflow loading term directly.

The term **NET SEDIMENTATION** defines the amount of phosphorus accumulated or retained in lake bottom sediments. It reflects the net result of all physical, chemical, and biological processes causing vertical transfer of phosphorus between the water column and lake bottom (as described in Chapter 2). For a given loading, lake water quality will generally improve as the magnitude of sedimentation increases because higher sedimentation leaves less phosphorus behind in the water column to stimulate algal growth. Because several complex processes are involved that vary spatially and seasonally within a given lake, it is generally infeasible to measure net sedimentation directly. Accordingly, this term is usually calculated by obtaining the difference from the other terms or estimated by using empirical models of the type discussed in Lake Response Models.

The **CHANGE IN STORAGE** term accounts for changes in the total mass of phosphorus stored in the lake water column between the beginning and end of the study period. Such changes would reflect changes in lake volume, average phosphorus concentration, or both. This term is positive if the phosphorus mass increases over the study period, negative otherwise.

As formulated previously, the water and phosphorus budgets provide important descriptive information on factors influencing lake eutrophication. A useful format for presenting results of budget calculations, illustrated in Table 4-1, is based on data from Lake Morey, Vermont. The table provides a complete accounting of drainage areas, flows, and loadings. The relative impor-

Table 4-1.—Water and total phosphorus (P) budgets for Lake Morey, Vermont

LAKE MOREY, VERMONT
FEB. 1, 1981 THROUGH DEC. 10, 1982

ITEM	DRAINAGE AREA (ACRES)	MEAN FLOW (AC-FT/YR)	WATER INFLOW (%)	TOTAL P LOADING (LBS/YR)	P INFLOW (%)	MEAN CONC. (PPB)	RUNOFF (FT/YR)	TOTAL P EXPORT (LBS/AC-YR)
Rutledge Inn Brook	435	664	7.3	53.5	7.2	30	1.53	0.080
Pavilion Brook	397	598	6.6	27.5	3.7	17	1.51	0.046
Glen Falls Brook	1049	1732	19.1	79.9	10.8	17	1.65	0.046
Aloha Camp Brook	134	41	0.4	8.1	1.1	74	0.30	0.201
Big Brook	908	1452	16.0	102.1	13.8	26	1.60	0.070
Gardenside Brook	237	390	4.3	75.2	10.2	71	1.65	0.193
Aloha Manor Brook	371	587	6.5	43.1	5.8	27	1.58	0.073
Bonnie Oaks Brook	179	272	3.0	56.1	7.6	76	1.52	0.206
Pine Brook	109	166	1.8	78.3	10.6	174	1.53	0.472
Shoreline Septic Systems		(negligible)		6.4	0.9			
Ungauged Direct Runoff	894	1423	15.7	125.0	16.9	32	1.59	0.088
Atmospheric	528	1727	19.1	84.7	11.4	18	3.27	0.049
Total Inflow	5239	9052	100.0	739.9	100.0	30	1.73	0.082
Evaporation		1183	13.1					
Outflow	5239	7769	85.8	639.5	86.4	30	1.48	0.082
Increase in Storage		0	0.0	−217.8	−29.4			
Water Balance Error	0	100	1.1					
Net Sedimentation				318.1	43.0			

WATER BALANCE EQUATION: WATER BALANCE ERROR TOTAL INFLOW – EVAPORATION – OUTFLOW – INCREASE IN STORAGE
PHOSPHOROUS BALANCE EQUATION: NET SEDIMENTATION TOTAL INFLOW – OUTFLOW – INCREASE IN STORAGE

tance of various sources can be readily derived from the percentage calculations and accompanying pie charts (Fig. 4-4). The mean concentrations (ppb), runoff (ft/yr), and export (lbs/acre-yr) provide the basis for comparing the unit

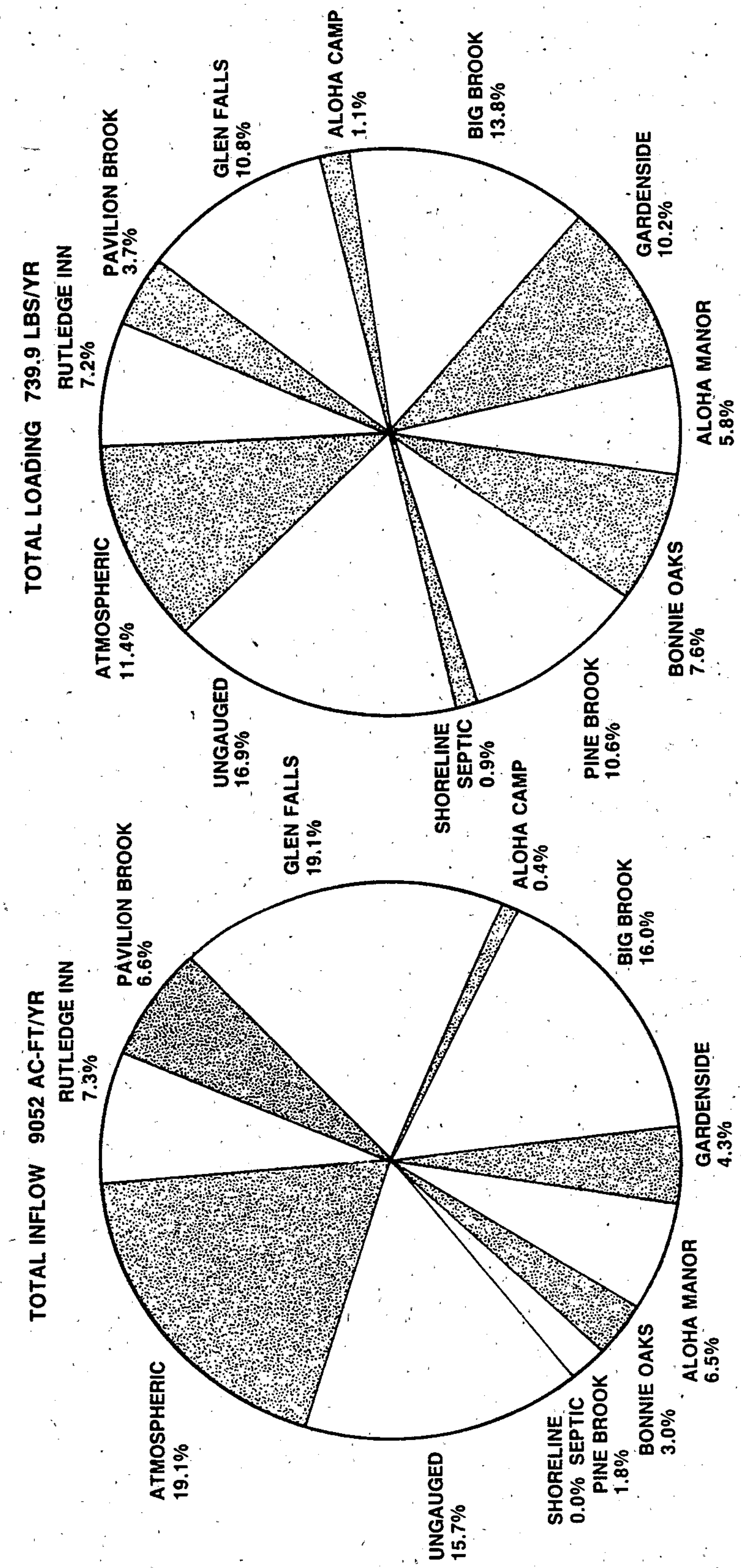


Figure 4-4.—Relative importance of various sources of water and total phosphorus for Lake Morey, Vermont.

contributions from various watersheds of different sizes. Often these values are sensitive to land uses, point sources, or geologic factors. For example, the relatively high export value for Pine Brook (.47 versus a range of .04–.21 lbs/acre-year for the other watersheds) reflects erodible soils. High export values for the Aloha Camp and Bonnie Oaks brooks reflect inputs from camp sewage treatment systems.

Comparing the magnitudes of the individual loading terms provides a basis for ranking sources and identifying possible candidates for watershed management or point source control techniques. For example, the Lake Morey phosphorus budget clearly indicates that sewering of shoreline areas would not be an effective way to reduce lake eutrophication because septic tanks currently account for less than 1 percent of the total loading.

If the net sedimentation term is unusually low (or negative) for a lake of the type being studied, it may indicate that bottom sediments are releasing significant quantities of phosphorus into the water column and thus, that an in-lake restoration technique such as sediment phosphorus inactivation (see Chapter 6) may be appropriate for lake restoration.

Lake Response Models

Having characterized water and phosphorus budgets under existing conditions, response models can be used to evaluate existing lake conditions and to predict changes in phosphorus, chlorophyll *a*, and transparency likely to result from changes in phosphorus loading. Several empirical models have been developed for this purpose. These models are based on statistical analysis of monitoring data from collections of lakes and reservoirs.

Models vary with respect to applicability, limitations, and data requirements. The consultant's choice of appropriate models for a given lake or reservoir should be based on regional experience and professional judgment. The consultant should also consider how closely the impoundment characteristics (morphometry, hydrology, natural lake versus manmade reservoir) reflect the characteristics of the lakes that were used to develop a model. It may be inappropriate, for example, to apply a model developed in a study of Canadian natural lakes to an Alabama reservoir with a very different set of conditions.

Eutrophication models are driven by three fundamental variables that are calculated from impoundment morphometry, water budgets, and phosphorus budgets:

(1) P_I = AVERAGE INFLOW PHOSPHORUS CONCENTRATION (PPB)

$$= \frac{\text{Total Phosphorus Loading (lbs/yr)}}{\text{Mean Outflow (acre-ft/yr)}} \times 368$$

This is the flow-weighted-average concentration of all sources contributing phosphorus to the impoundment. If there were no interactions with bottom sediments, the average inflow, lake, and outflow phosphorus concentrations would be approximately equal. This basic measure of inflow quality is the most important determinant of eutrophication response and the most frequent focus of long-term management efforts. It is sensitive to watershed point and nonpoint sources.

(2) T = MEAN HYDRAULIC RESIDENCE TIME (YEARS)

$$= \frac{\text{Lake Volume (acre-ft)}}{\text{Mean Outflow (acre-ft/yr)}}$$

This variable approximates the average length of time water spends in a lake or impoundment before being discharged through the outlet. Theoretically, it equals the time required for the lake to refill if it were completely drained. As residence time increases, interactions between the water column and bottom sediment have greater influences on water quality. For a given inflow concentration, phosphorus sedimentation usually increases and lake phosphorus concentration decreases with increasing residence time. At very short residence times (less than one to two weeks), algae may have inadequate time to respond to the inflowing nutrient supply.

(3) Z = MEAN DEPTH (FEET)

$$= \frac{\text{Lake Volume (acre-ft)}}{\text{Surface Area (acres)}}$$

Other factors being equal, lakes and impoundments with shallower mean depths are generally more susceptible to eutrophication problems. Shallower lakes have higher depth-averaged light intensities to support photosynthesis and greater sediment/water contact, which can encourage nutrient recycling. Since both mean depth and hydraulic residence time increase with lake volume, they are typically correlated.

Models differ with respect to how these variables are combined in equations to predict lake or reservoir responses for nutrient loading.

One set of equations based on data from northern natural lakes is presented in Table 4-2 to illustrate modeling concepts. These are only examples and not necessarily the "best" models to use in a given application; the lake consultant should determine the appropriate equation.

Two of the equations are based on the Trophic State Index (TSI) developed by Carlson (1977). This system, used by many States for classification purposes, is essentially a rescaling of phosphorus, chlorophyll *a*, and transparency measurements in units that are consistent with northern lake behavior (Fig.4-5). The Index provides a common frame of reference for comparing these measurements; its scale is calibrated so that a decrease of index units corresponds to a doubling of transparency.

Carlson's Index can be used to predict values of one variable from measurements of another. For example, a lake with a measured mean transparency of 6.6 feet (2 meters) would have a TSI of 50. Based on the scales in Figure 4-5, a mean chlorophyll *a* of 7 ppb and a mean total phosphorus concentration of 23 ppb could be predicted for this lake. These predictions are approximate, however (good roughly to within a factor of 2, assuming that the lake under study is typical of other northern lakes).

Various factors influence relationships among phosphorus, chlorophyll *a*, and transparency (Fig.4-1). Carlson's equations reflect relatively high chlorophyll *a* and transparency responses found in northern natural lakes. Turbid, rapidly flushed reservoirs tend to have lower responses and less sensitivity to phosphorus loading.

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.*

Table 4-2.—Typical phosphorus loading model equations for Northern lakes.

P_I		P		Chl. a		
INFLOW	——> (1)	PHOSPHORUS	——> (2)	CHLOROPHYLL a	——> (3)	SECCHI TRANSPARENCY

(1) A model for predicting lake phosphorus concentration was developed by Larsen and Mercier (1976) and Vollenweider (1976):

$$P \text{ (ppb)} = \frac{P_I}{1 + T^{.5}}$$

This equation predicts that average lake phosphorus concentration, P, will increase in proportion to the inflow concentration and will decrease with increasing hydraulic residence time. At low residence times, phosphorus sedimentation is negligible, and the response is controlled primarily by inflow concentration.

(2) The simplest of the chlorophyll a response models was developed by Carlson (1977):

$$\text{Chl. } \underline{a} \text{ (ppb)} = .068\ P^{1.46}$$

This equation is similar to others developed from northern lake data by Dillon and Rigler (1974) and by Jones and Bachman (1978).

(3) A similar relationship was also developed by Carlson (1977) to predict Secchi disk transparency:

$$\text{Secchi (meters)} = 7.7\ \text{Chl}\ \underline{a}^{-.68}$$

This equation is appropriate for lakes and reservoirs in which transparency is controlled primarily by algae. It will overestimate transparency in impoundments with relatively high concentrations of inorganic suspended solids, silt, or color.

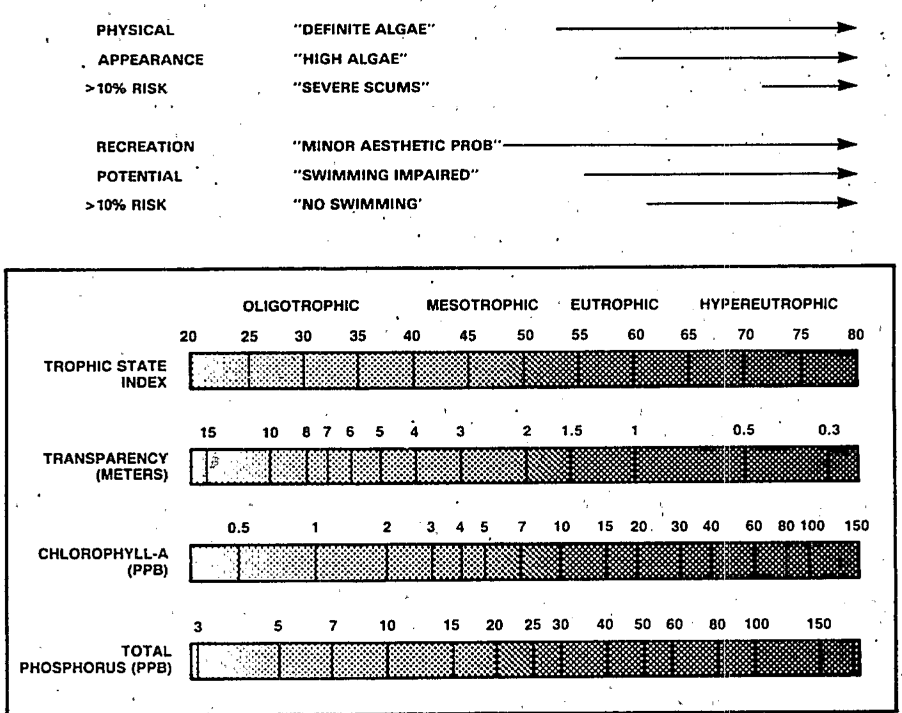
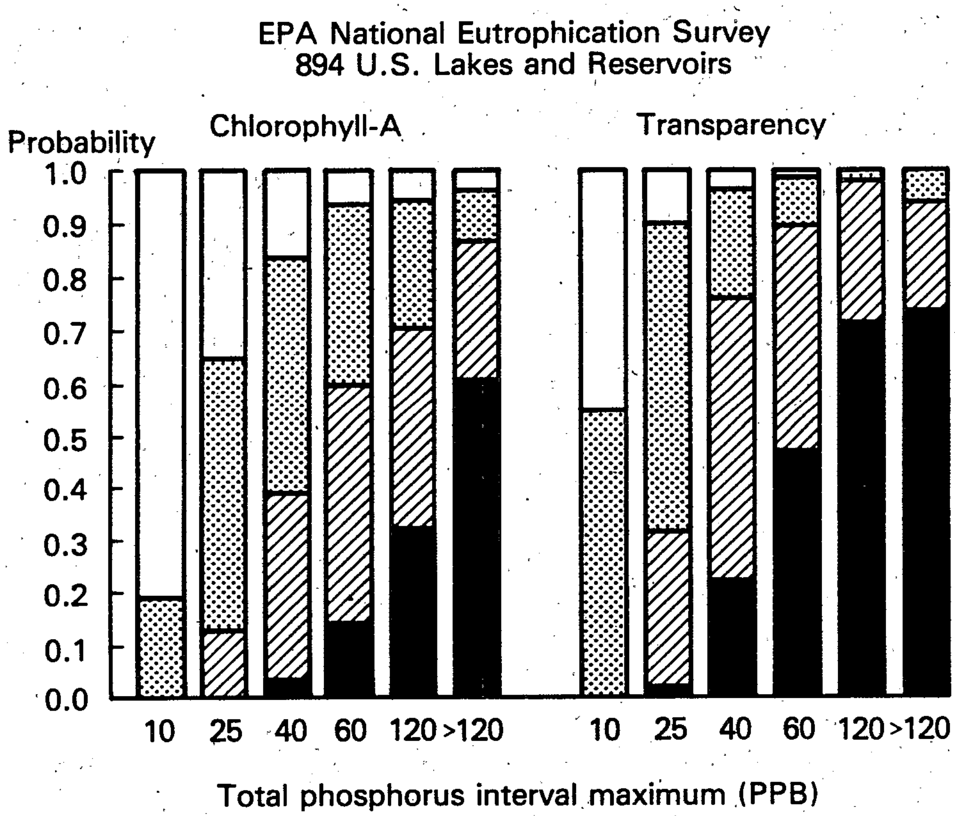


Figure 4-5.—Carlson's Trophic State Index related to perceived nuisance conditions (Heiskary and Walker, 1987). Length of arrows indicate range over which a greater than 10 percent probability exists that users will perceive a problem.

Heiskary and Walker (1987) describe a methodology for relating lake trophic state, as measured by phosphorus, chlorophyll *a*, or transparency, to user-perceived impairment in aesthetic qualities and recreation potential. The arrows in Figure 4-5 indicate measurement ranges in which the risk of perceived nuisance conditions (for example, "Swimming Impaired" or "High Algae") exceeds 10 percent, based on surveys of Minnesota lakes. These ratings may vary regionally.

Figure 4-6 provides additional perspectives on the relationship between impoundment phosphorus concentrations and eutrophication responses, as measured by mean chlorophyll *a* and transparency. The figure is based on cross-tabulations of median total phosphorus, mean chlorophyll *a*, and mean transparency values from 894 U.S. lakes and reservoirs (U.S. Environ. Prot. Agency, 1978). Phosphorus values are classified into six intervals (0-10, 10-25, 25-40, 40-60, 60-120, 120 ppb), and the probabilities of encountering mean chlorophyll *a* and transparency levels in oligotrophic, mesotrophic, eutrophic, and hypereutrophic ranges have been calculated for each phos-



Trophic State	CHL-A (PPB)	Transparency (Meters)
Oligotrophic	<4	>4
Mesotrophic	4-10	2-4
Eutrophic	10-25	1-2
Hypereutrophic	>25	<1

Figure 4-6.—Responses of mean chlorophyll *a* and transparency to phosphorus.

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.*

phorus interval. For example, if phosphorus is in the 25-40 ppb range, the probability of encountering a mean chlorophyll *a* in the eutrophic range (10 ppb) is about .4, or 40 percent, and the probability of encountering a mean transparency less than 6.6 feet (2 meters) is about .75, or 75 percent. Variations in the response factors such as depth, flushing rate, or turbidity (see Fig. 4-1) contribute to the distribution of chlorophyll *a* and transparency that can be expected for a given phosphorus load.

Tracking Restoration Efforts

Figure 4-7 illustrates a type of phosphorus loading diagram often used to depict modeling results (Vollenweider, 1976). This diagram is developed by solving the equation for phosphorus concentrations from the Secchi depth of inflowing waters and the hydraulic residence time (Equation 1 in Table 4-2.) The dotted lines (representing phosphorus concentrations of 10, 25, and 60 ppb) are not sharp boundaries of lake condition but roughly delineate trophic state categories based on average phosphorus concentrations. Corresponding chlorophyll *a* and transparency probabilities can be derived from Figure 4-5. The object of the game is to move the lake away from the HYPEREUTROPHIC (northeast) corner and toward the OLIGOTROPHIC (southeast) corner in Figure 4-7, usually by reducing watershed point or nonpoint sources and decreasing the average inflow phosphorus concentration (y-axis).

The paths of eight documented restoration efforts are also plotted in Figure 4-7, based upon data summarized in Table 4-3. These case studies provide a context for illustrating important modeling concepts. Figure 4-8 plots measured mean phosphorus, chlorophyll *a*, and transparency for each lake and time period. These are compared with predicted values derived from the models in Table 4-2. The predictions are driven by the inflow concentrations and hydraulic residence times listed in Table 4-3. These comparisons illustrate

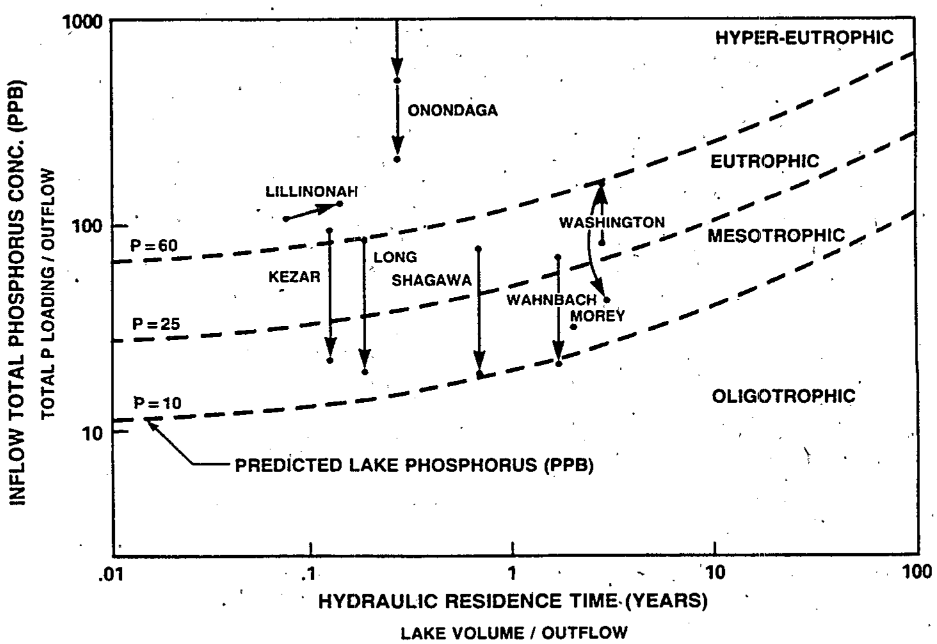


Figure 4-7.—Restoration efforts tracked on Vollenweider's (1976) phosphorus loading diagram.

Table 4-3.—Data for restoration cases discussed in Chapter 4. These data were used to plot the progress of restoration efforts on the Vollenweider curve shown in Figure 4-6

RESTORATION CASE HISTORIES									
LAKE OR RESERVOIR LOCATION IMPOUNDMENT TYPE	DURATION AND TYPE OF RESTORATION ACTIVITY	YEARS	OBSERVED WATER QUALITY RESPONSES INFLOW P (PPB)	LAKE P (PPB)	CHL-A (PPB)	SECCHI (METERS)	HYDRAULIC RES. TIME (YEARS)	MEAN DEPTH (FEET)	SURFACE AREA (ACRES)
Lake Washington		1957	94	26	13	2.2	2.84	108.0	21634
Washington[1]	1963-68 Point Source Diversion	1963	155	62	35	1.0			
Natural Lake		1978	48	19	3	6.4			
Onondaga Lake	1971 Detergent Ban & Sewer Repairs	1970	3667	2310		2.1	0.28	39.4	2889
New York[2]	1979-81 Point Source Treatment	1974	509	382	45	1.2			
Natural Lake		1985	224	143	43	0.9			
Long Lake	1978 Point Source Treatment	1972-77	85	71	15		0.19	47.9	5136
Washington[3]		1978-82	22	18	8				
Reservoir									
Shagawa Lake	1973 Point Source Treatment	1971-72	79	55	28	1.9	0.70	18.7	2272
Minnesota[4]		1974-78	20	35	26	2.4			
Natural Lake									
Kezar Lake	1970 Point Source Treatment	1970	95	70	32	1.0	0.13	9.2	180
New Hampshire[5]	1981 Point Source Diversion	1981	24	30	18	1.4			
Natural Lake	1984 Hypolimnetic Alum Treatment	1985	24	16	5	3.0			
Lake Morey	1986 Hypolimnetic Alum Treatment	1981	35	30	10	4.4	1.93	27.6	543
Vermont[6]		1986	35	12	3	6.0			
Natural Lake									
Wahnbach Reservoir	1977 River Inflow Treatment	1969-70	73	25	18	3.0	1.70	59.0	558
West Germany[7]		1978-79	21	8	5	6.0			
Reservoir									
Lake Lillinonah	1977 Point Source Treatment	1976	119	65	35	1.1	0.08	39.0	1899
Connecticut[8]		1977	136	68	33	1.6	0.14		
Reservoir									

Sources: [1] Edmonson and Lehman (1981)
[2] Devan and Effler (1983); Walker (1977)
[3] Soltero and Nichols (1984)
[4] Larsen and Malueg (1980)
[5] Connor and Smith (1983, 1986); Connor and Martin (1986)
[6] Walker (1983); Smeltzer and Swain (1985); Smeltzer (1987)
[7] Bernhardt (1980)
[8] Jones and Lee (1981)

model capabilities to predict lake conditions before and after each restoration activity.

Figure 4-9 summarizes measured phosphorus budget information (inflow, inflow-lake, and lake concentrations) for each case and time period. The difference between the inflow and lake concentrations approximately reflects the net influence of bottom sediments as a phosphorus sink (positive) or source (negative) during each time period.

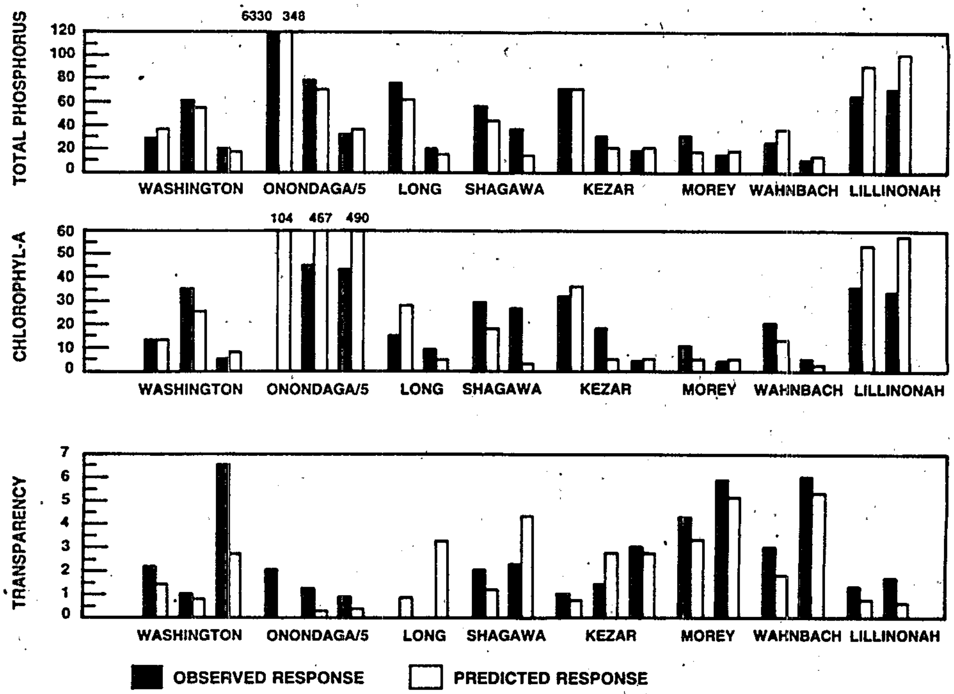


Figure 4-8.—Observed and predicted responses to restoration efforts.

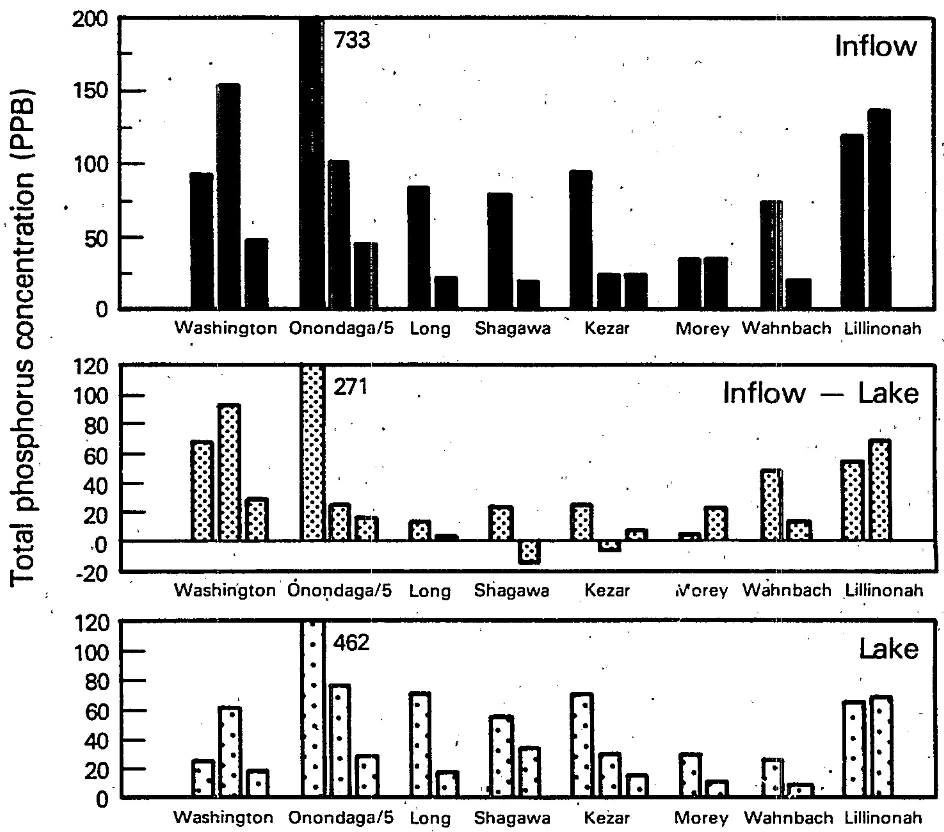


Figure 4-9.—Observed responses of phosphorus budget components to restoration efforts.

Case Studies

Each of the following sections discusses a particular case study.

Lake Washington, Washington: "You Should Be So Lucky!"

Between 1957 and 1963, eutrophication progressed with increasing sewage loadings from metropolitan Seattle. Between 1963 and 1968, sewage discharges were diverted out of the lake basin, reducing the total phosphorus loading to the lake by 69 percent, relative to 1963. Observed and predicted conditions in 1978 reflect dramatic improvements in water quality that followed within a year or two after the sewage diversion. Observed phosphorus concentrations agree well with model predictions for each time period. Decreases in chlorophyll and increases in transparency were somewhat more dramatic than predicted by the models. Lake Washington is perhaps the most successful and fully documented lake restoration project to date.

Onondaga Lake, New York: "Far Out. Ninety-three Percent Is Not Enough."

Onondaga received primary treated sewage from Syracuse for many years. Between 1970 and 1985, phosphorus loadings were reduced by over 93 percent as a result of a phosphorus detergent ban, combined sewer repairs, and tertiary treatment for phosphorus removal. Lake phosphorus levels responded in proportion to loading reductions and in agreement with model predictions (Fig. 4-8). No significant improvements in chlorophyll *a* or transparency were achieved, however.

The lack of algal response reflects the fact that pre- and postrestoration phosphorus levels were extremely high (exceeding 100 ppb; note the scale factor of 5 for this lake in Figs. 4-8 and 4-9). Phosphorus usually does not limit algal growth in this concentration range, particularly in deeper lakes. The chlorophyll model (Equation 2 in Table 4-2) does not apply and substantially overpredicts algal concentrations. Despite the substantial loading reductions as of 1985, Onondaga remained well within the hypereutrophic region of Figure 4-7 and on the flat portion of the chlorophyll response curve shown in Figure 4-1.

Onondaga illustrates the fact that some lakes subject to point source phosphorus discharges may be susceptible to nuisance algal growths, even with tertiary treatment to remove phosphorus. Although chlorophyll and transparency did not respond, the disappearance of severe blue-green algal blooms following the loading reductions was a significant water quality improvement.

Why didn't Onondaga Lake respond like Lake Washington? It started off in much worse shape (Fig. 4-7). Onondaga has much shorter hydraulic residence time (.28 versus 2.8 years) and, therefore, less opportunity for phosphorus sedimentation. The loading plot (Fig. 4-7) essentially captures the relative responses of these two lakes to restoration efforts.

Long Lake, Washington: "What's This? Reservoir Restoration?"

Beginning in 1978, tertiary treatment of sewage from Spokane reduced the average seasonal phosphorus loading to this 22-mile-long reservoir on the Spokane River by 74 percent. This impoundment has a relatively short hydraulic residence time (.19 year or 70 days). Accordingly, the inflow and reservoir phosphorus concentrations are similar, and the sedimentation term is relatively small (Fig. 4-9). Reservoir phosphorus levels responded roughly in proportion to the loading. Mean chlorophyll *a* concentrations were reduced by 45 percent and were apparently less sensitive to the phosphorus loading reductions than predicted by Equation 2 in Table 4-2. Northern lake models (such as Equation 2) tend to overestimate chlorophyll *a* sensitivity to phosphorus in some reservoirs because of effects of algal growth limitation by flushing and light (Walker, 1982,1985).

Shagawa Lake, Minnesota: "The Little Lake That Couldn't."

During 1973, external phosphorus loadings to this northern Minnesota lake were reduced by 75 percent via point source treatment. Although average lake phosphorus levels during ice-free seasons were reduced by 35 percent, mean chlorophyll *a* and transparency did not respond according to model predictions (Fig. 4-8). The lack of response has been attributed to phosphorus releases from bottom sediments. These releases reflect historical loadings and the high susceptibility of this relatively shallow lake to hypolimnetic oxygen depletion and wind mixing. The fact that lake phosphorus exceeded the inflow concentration during the postrestoration period (Fig. 4-9) is indicative of sediment phosphorus release.

Despite the fact that the phosphorus loading diagram (Fig. 4-7) places Shagawa Lake at the oligo-mesotrophic boundary following load reductions, mean chlorophyll *a* concentrations remained in the hypereutrophic range during the first few years following loading reductions. Over time, the rate of phosphorus release from bottom sediments may eventually decrease and permit the lake to respond to the change in loading. This case points out the fact that loading models of the type demonstrated here do not account for unusually high sediment phosphorus release rates, which may defer lake responses to changes in external loading.

Kezar Lake, New Hampshire: "The Little Lake That Could (With a Little Help)," Or "Shagawa Revisited . . ."

This shallow, rapidly flushed lake was subject to a municipal sewage discharge and in hypereutrophic condition for many years. Following installation of phosphorus removal facilities in 1970 and, eventually, complete elimination of the discharge in early 1981, the external loading was reduced by about 75 percent. Like Shagawa, the lake phosphorus concentration exceeded average inflow concentration during the initial period following loading reduction (Fig. 4-9).

Kezar Lake (maximum depth = 27 feet) was thermally stratified in 1981. Significant accumulations of phosphorus released from thick, phosphorus-rich bottom sediments accompanied depletion of oxygen from the hypolimnion. Surface algal blooms (chlorophyll *a* = 60 ppb) were experienced during August 1981 and were apparently triggered by escape of hypolimnetic phosphorus into the mixed layer.

Because of sediment phosphorus releases, responses of lake phosphorus, chlorophyll *a*, and transparency to the 1981 sewage diversion were less dramatic than predicted by the models (Fig. 4-8). In 1984, a hypolimnetic alum treatment was conducted to address the sediment nutrient release problem. Monitoring data from 1985 indicate that phosphorus, chlorophyll *a*, and transparency levels responded in agreement with model predictions following the alum treatment. This case illustrates use of both watershed (point source control) and in-lake restoration (alum treatment) techniques to deal with a lake problem. Decreases in transparency following 1985 indicate that the book is not yet closed on Kezar Lake, however.

Lake Morey, Vermont: "Strange Mud. . ."

Morey is a resort lake sheltered in the mountains of eastern Vermont. Aside from the shoreline, the watershed is largely undeveloped. From the late 1970s to 1985, severe algal blooms and user complaints were experienced at increasing frequency. Summer mean chlorophyll *a* concentrations ranged from 8 to 30 ppb, transparencies ranged from 2 to 5 meters, and spring phosphorus concentrations ranged from 17 to 48 ppb. These variations in water quality could not be explained by changes in land use, other watershed factors, or climate. Peak algal concentrations were usually found in the metalimnion and were supplied by phosphorus released from bottom sediments during periods of summer and winter anoxia. The hypolimnion was relatively thin (mean depth = 7 feet) and covered approximately 59 percent of the lake surface area. Bottom waters lost their dissolved oxygen early in June and remained anaerobic through fall overturn.

A two-year intensive study indicated that large quantities of phosphorus were stored in the lake water column and sediments. At peak stratification in August 1981, for example, the total mass of phosphorus in the water column was about five times the annual phosphorus loading from the watershed. Phosphorus balance calculations (see Table 4-1) indicated that the lake inflow and outflow concentrations were approximately equal, despite the relatively long hydraulic residence time of nearly two years. Equation 1 (Table 4-2) predicts that a lake with this residence time should trap 58 percent of the influent phosphorus. Study results indicated that Lake Morey was particularly susceptible to phosphorus recycling from bottom sediments because of its shape (broad, thin hypolimnion susceptible to rapid oxygen depletion) and iron-poor sediments (Stauffer, 1981).

Model predictions for the Lake Morey pre-restoration period were substantially below observed values of phosphorus and chlorophyll *a* (Fig. 4-8). This reflects the fact that phosphorus retention capacity was unusually low. Observed transparency was higher than predicted, however, because of the tendency for algae to concentrate in the metalimnion, below the mixed layer where transparencies were measured.

Because the phosphorus budget indicated that Morey's problems were primarily related to internal recycling and not to watershed loadings, a hypolimnetic alum treatment was conducted during early summer of 1986. The treatment reduced average phosphorus and chlorophyll *a* concentrations during the period following treatment down to levels that were consistent with model predictions. Despite no significant changes in external loadings, the alum treatment apparently restored Lake Morey to a mesotrophic status, consistent with its position on the phosphorus loading diagram (Fig. 4-7).

The longevity of the treatment remains to be evaluated through future monitoring. This is an example of how phosphorus budgets can be used to diagnose lake problems, regardless of whether or not the solutions involve reductions in external loading. Sewering of shoreline areas (a restoration activity previously proposed and on the drawing boards for Lake Morey) would have had little impact.

Wahnbach Reservoir, Germany: "When All Else Fails . . ."

Wahnbach Reservoir, a water supply for Bonn, Germany, was subject to high phosphorus loadings from agricultural runoff and municipal point sources during the period prior to 1977. The resulting severe blooms of blue-green algae that developed in the reservoir caused major problems for the water supply. For various reasons, the loadings from the watershed were largely uncontrollable. In response to this problem, a detention basin and treatment plant were constructed at the major inflow to the reservoir in 1977. The treatment plant was designed to remove more than 95 percent of the phosphorus inflow via sedimentation, precipitation, flocculation with iron chloride, and direct filtration. Operation of this plant reduced the average inflow phosphorus concentration to the entire reservoir by about 71 percent.

As illustrated in Figures 4-7 and 4-8, the inflow treatment restored Wahnbach Reservoir from eutrophic to oligotrophic status during 1978-1979. Observed and predicted lake phosphorus concentration dropped below 10 ppb. Chlorophyll *a* concentrations are consistently overestimated by the model, although the relative reduction in chlorophyll *a* is correctly predicted. This relatively extreme and costly restoration measure was justified in relation to the severe impacts of eutrophication on drinking water quality and water treatment economics.

Lake Lillinonah, Connecticut: "You Can't Fool Mother Nature . . ."

Data from this 10-mile impoundment on the Housatonic River in Connecticut illustrate the sensitivity of some reservoirs to hydrologic fluctuations. During 1977, phosphorus removal was initiated at a municipal point source above the reservoir. This program reduced phosphorus loading from the point source by 51 percent and reduced total loading to the reservoir by 8 percent during 1977.

Compared to the case studies just discussed, this loading reduction was relatively small, and a major change in reservoir water quality would not be anticipated. In fact, observed and predicted phosphorus and chlorophyll *a* concentrations were slightly higher during 1977 (Fig. 4-8). The concentrations increased primarily because the flow through the reservoir decreased by about 43 percent during 1977. As indicated by Equation 1 (see Table 4-2), the average inflow concentration is the most important variable determining phosphorus predictions, particularly in reservoirs with low hydraulic residence times. Inflow concentration is determined from the ratio of loading to outflow. The inflow concentration increased by 14 percent in 1977 because the small decrease in loading was more than offset by the decrease in flow.

For both time periods, the models overestimate reservoir phosphorus and chlorophyll *a* concentrations and underestimate transparency. Apparently, phosphorus sedimentation in the Lillinonah was somewhat greater than predicted by Equation 1. This is not unusual for long and narrow reservoirs with high inflow phosphorus concentrations (Walker, 1982,1985). The loading plot (Fig. 4-7) correctly predicts a hypereutrophic status for Lillinonah during both monitoring years.

Monitoring over a longer time period that includes years with flows similar to those experienced during 1976 would be required to track the response of the reservoir to the phosphorus loading reduction. Because the loading reduction is relatively small, impacts may be difficult to detect in the context of year-to-year variations. More substantial reductions in upstream point or nonpoint loadings, or both, would be required to restore the reservoir to a eutrophic or mesotrophic level.

Chapter 5

MANAGING THE WATERSHED

Introduction

The quality of lake water can be greatly influenced by watershed drainage. Therefore, restoration should start outside the lake, on the land. An entire body of land practices is aimed at exactly that: the techniques called best management practices, which are dealt with specifically in the last half of this chapter. These practices originated in the field of agriculture, mainly to prevent soil loss.

Another central concept that this chapter reemphasizes is that lake water quality is critically linked to the quality of incoming water entering the lake both from specific discharge outlets (point sources) and from general (nonpoint) sources.

The importance of the lake and watershed relationship cannot be overemphasized. While this Manual often uses the term *lake system*, it must be kept in mind that the lake is a system within a larger system, the watershed. The emphasis in this chapter is on watershed management practices that are appropriate for lake homeowners, lake associations or districts, and small lake communities.

The Lake–Watershed Relationship

Muddy waters, decreased depth, rapid filling from silt, aquatic weeds, algal blooms, and poor fishing are typical problems of many lakes. Very often, to find the cause it is necessary to look away from the lake to the surrounding land.

As Chapters 2 and 3 pointed out, the watershed contributes both the water required to maintain a lake and the majority of the pollutant loads that enter the lake. Effective lake management programs, thus, *must* include watershed management practices. Trying to solve lake problems without correcting the source or cause of the problem is not only shortsighted, it rarely works.

Pollutant loads to the lake can be contributed from the watershed as either point sources or nonpoint sources. Point sources arise from a definite or distinct source such as a wastewater (sewage) treatment plant, industrial facility or similar source that discharges through a pipe, conduit, or similar outlet. They can be identified by tracing the discharge back to a specific source. Point sources were traditionally considered to be the primary suppliers of pollution to waterbodies. This is no longer true for most lakes. Harder to identify and harder to control, nonpoint sources are more likely to be the principal contributors of nutrient and sediment loads.

Point sources are usually controlled through wastewater treatment facilities and State and federally regulated permits such as the National Pollutant Discharge Elimination System.

Nonpoint sources, by contrast, do not originate from a pipe or single source but from silt, nutrients, organic matter, and other pollutant loads that are distributed over a relatively broad watershed area. When water runs over land surfaces, it picks up these materials and transports them to the lake, either directly with runoff or through a tributary stream or groundwater system. Water running off a lawn or driveway during a heavy rain is a common sight—this is nonpoint source runoff. Although nonpoint source loadings can occur anywhere in the watershed, land uses such as agriculture, construction, and roadways contribute higher nonpoint pollutant loads than other land uses such as forests.

It is not always easy to distinguish a point source from a nonpoint source. For example, parking lot runoff is considered a nonpoint source, but the runoff typically enters the lake or stream through a drain pipe or culvert. For regulatory purposes, stormwater runoff from pipes and culverts that are required to have discharge permits is considered a point source. In this chapter, point sources are defined as homes, factories and other industrial concerns, wastewater treatment plants, and similar structures that discharge wastewater through a pipe.

For regulatory purposes, wastes from homes on septic systems are considered nonpoint sources. In this chapter we discuss home wastewaters with point sources since the discharge is discrete and easily identifiable. Nonpoint sources will include all other sources of pollutant loadings to the lake or stream, including lawns, driveways, subdivision roads, construction sites, agricultural areas, and forests.

Point Sources

Wastewaters from industrial, municipal, and household sources can be highly enriched in organic matter, bacteria, and nutrients. Wastewater pollutants can be extremely harmful to lake water quality, even when toxics or pathogens are not involved. For example, when incoming water is high in organic matter, the bacteria that decompose organic matter can consume the lake's dissolved oxygen supply more quickly than it can be replenished. The danger of this is especially strong in thermally stratified lakes, where hypolimnetic oxygen may be totally depleted. These oxygen depletions can lead to fishkills, odors, and noxious conditions.

As organic matter decomposes, it can also contribute additional nutrients to the water. The purpose of wastewater treatment is to remove the majority of the oxygen-demanding matter, bacteria, and nutrients.

Most wastewater treatment plants have low discharge rates; over 75 percent of all publicly owned treatment plants discharge less than 1 million gallons per day (mgd). Sewage treatment ponds or lagoons—the most common type of wastewater treatment facilities — typically have discharge rates of less than 1 mgd. These low discharge rates, however, do not mean the nutrient or organic loads from these systems have an insignificant effect on lakes and streams.

At just 10 to 50 parts per billion (ppb) total phosphorus concentration in the water, some lakes develop algal blooms, murkiness, and other problems. The average total phosphorus concentration of wastewater treatment plant discharges is about 100 to 500 times greater. In the summer, wastewater discharges may dominate streamflow during dry periods when total flow is lower than usual, and water cannot hold as much dissolved oxygen as it does during the cooler periods of the year.

This combination of high, oxygen-demanding organic loads and lower than normal dissolved oxygen levels is stressful enough in itself, but the problem is compounded when these high-organic, low-oxygen conditions coincide with the peak growing season for algae and macrophytes. The incoming nutrients act as a fertilizer, encouraging excessive algal and macrophyte growth, which places additional stress on the dissolved oxygen supply as these plants decompose.

Natural areas, such as wetlands around a lake, have occasionally been used for advanced wastewater treatment because they can function as a biological filter to remove silt, organic matter, and nutrients from an inflowing stream to the lake and thereby improve lake quality. Wetlands, however, can also contribute organic matter and nutrients to lakes under some conditions. Nutrients released from wetlands can fertilize algal growth and contribute to lake problems. Whether a wetland serves as a source or filter for nutrients and organic matter is a subject that needs more study. Researchers are looking at the use of constructed wetlands for wastewater treatment, which is still in an experimental stage.

The Federal Clean Water Act, which established the National Pollutant Discharge Elimination System to regulate the discharge of nutrients and organic matter from wastewater treatment facilities, provides financial incentives and authorizes punitive actions to encourage the improvement of these facilities. Wastewater treatment facilities are regulated by a State's water pollution control agency or by EPA. Many stormwater drains also are regulated through permits. Information on permitted facilities discharging into a lake or streams entering a lake can be obtained by contacting the State water pollution control agency. If a problem appears to exist with a local treatment plant discharge, this agency or the State health department should be notified.

Wastewater Treatment

Choosing the Scale of the System

If point sources are the most important contributor of organic matter, bacteria, and nutrients, good wastewater treatment will be critical to protecting the lake. The better the wastewater system, the fewer the algal blooms, aquatic weeds, and odors in the lake. Regardless of the treatment system, however, *all treatment systems require proper design, operation, and maintenance*. These requirements vary among treatment systems, but no system can be installed and then ignored. Systems *must* be maintained and properly operated.

Municipal Systems

Typical waste treatment systems for larger cities and municipalities include a conventional sewer system leading to a treatment facility such as an activated sludge treatment system. Primary wastewater treatment uses screens and sedimentation (settling) to remove the larger floating and settleable organic solids. Organic matter dissolved in the wastewater can still exert considerable oxygen demand, however, so secondary treatment is used to reduce oxygen demand before the wastewater is discharged into the lake or stream. Secondary treatment uses biological and chemical processes to remove 80 to 95 percent of the organic matter in the wastewater. Primary and secondary treatment, however, do not significantly reduce dissolved nutrient (nitrogen and phosphorus) concentrations.

Total phosphorus concentrations in untreated domestic wastewater are reduced about 4 percent by primary treatment and about 12 percent using secondary treatment. Total nitrogen has a higher removal rate, about 40 percent of the total nitrogen removal with primary treatment and about 58 percent removal with secondary treatment. This means, however, that about half the total nitrogen and almost all the total phosphorus stays in the wastewater after secondary treatment.

Another level of treatment tertiary or advanced treatment is required to significantly reduce nutrient concentrations in the wastewater. Several tertiary treatment procedures are available and more are being studied, but since this level of treatment is relatively expensive, it has not been applied to the same extent as secondary treatment.

The best procedure for handling wastewater discharges is to divert them away from the lake, out of the watershed. Lake Washington (see **Examples of Point and Nonpoint Improvement Projects**) is a classic example of how lake quality can improve after point source diversion. Another approach that has been used when diversion is not possible is dilution or flushing, which requires a relatively large source or supply of high quality (low in nutrients and organic matter) water to dilute the wastewater discharge and increase the flushing through the lake (Welch and Tomasek, 1980). These procedures have been used primarily with municipal wastewater treatment plants.

Normally, conventional treatment systems are not the best alternative for small communities and individual homeowners. Conventional treatment plants include systems such as activated sludge, biofilters, contact stabilization, sequencing batch reactors and land treatment, and large-scale lagoons. More detailed information and fact sheets can be found in the EPA Innovative and Alternative Technology Assessment Manual (EPA No. 430/9-78-009, published in February 1980).

Conventional treatment plants generally are complicated mechanical systems. They typically use large amounts of energy and are expensive for small communities to build. In addition, they require skilled operators to run and maintain them. Wastewater is collected in most conventional systems by gravity, but the cost per household of gravity sewers is high in small communities and increases greatly in rural areas or wherever the ground is hilly, rocky, or wet.

Small-scale Systems

Several small-scale treatment plants and designs are available for a small city, town, or village. Even smaller-scale treatment systems exist that are suitable for the lake homeowner or lake association. The choices can range from individual on-site systems to larger treatment and collection systems servicing several homes or small communities (Table 5-1). Characteristics of these treatment systems, including their status, application, reliability, limitations, cleaning, and treatment side effects are described in more detail in Appendix C.

On-Site Septic Systems

Individual home sewage disposal systems are referred to as on-site septic systems. The most common on-site system is the septic tank and drain field (Fig. 5-1). The septic tank provides primary treatment by trapping solids, oil, and grease that could clog the drain field. The tank stores sludge (solids that settle to the bottom) and scum, grease, and floating solids until they can be removed during

Table 5–1.—Examples of small-scale treatment plants and designs

EXAMPLE	REMARKS
1. Septic Tank	A septic tank followed by a soil absorption bed is the traditional onsite system for the treatment and disposal of domestic wastewater from individual households or establishments. The system consists of a buried tank where wastewater is collected and scum, grease, and settleable solids are removed by gravity and a subsurface drainage system where wastewater percolates into the soil.
2. Septic Tank Mound System	Can be used as an alternative to the conventional septic tank–soil absorption system in areas where problem soil conditions preclude the use of subsurface trenches or seepage beds.
3. Septic Tank – Sand Filter	Surface discharge of septic tank effluent. Can be used as an alternative to the conventional soil absorption system in areas where subsurface disposal contain an intermediate layer of sand as filtering material and underdrains for carrying off the filtered sewage.
4. Facultative Lagoon	An intermediate depth (3 to 8 feet) pond in which the wastewater is stratified into three zones. These zones consist of an anerobic bottom layer, an aerobic surface layer, and an intermediate zone.
5. Oxidation Ditch	An activated sludge biological treatment process. Typical oxidation ditch treatment systems consist of a single or closed loop channel 4 to 6 feet deep, with 45° sloping sidewalls. Some form of preliminary treatment such as screening, comminution, or grit removal normally precedes the process. After pretreatment, the wastewater is aerated in the ditch using mechanical aerators that are mounted across the channel.
6. Trickling Filter	The process consists of a fixed bed of rock media over which wastewater is applied for aerobic biological treatment. Slimes form on the rocks and treat the wastewater. The bed is dosed by a distributor system, and the treated wastewater is collected by an underdrain system.
7. Overland Flow Treatment	Wastewater is applied by gravity flow to vegetated soils that are slow to moderate in permeability and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action and also by plant uptake. An underdrainage system serves to recover the effluent, to control groundwater, or to minimize trespass of wastewater onto adjoining property by horizontal subsurface flow.

regular septic tank cleaning (every 2 to 4 years, depending on use). Solids and liquids in the tank are partially decomposed by bacteria. The wastewater that remains after solids are thus removed flows out of the septic tank and into the drain field where it seeps into the soil. The soil filters this partially treated sewage, and bacteria associated with the wastewater aid decomposition.

As wastewater flows through the drain field, phosphorus is reduced by adsorption to soil particles. Nitrogen, however, is primarily reduced by biological

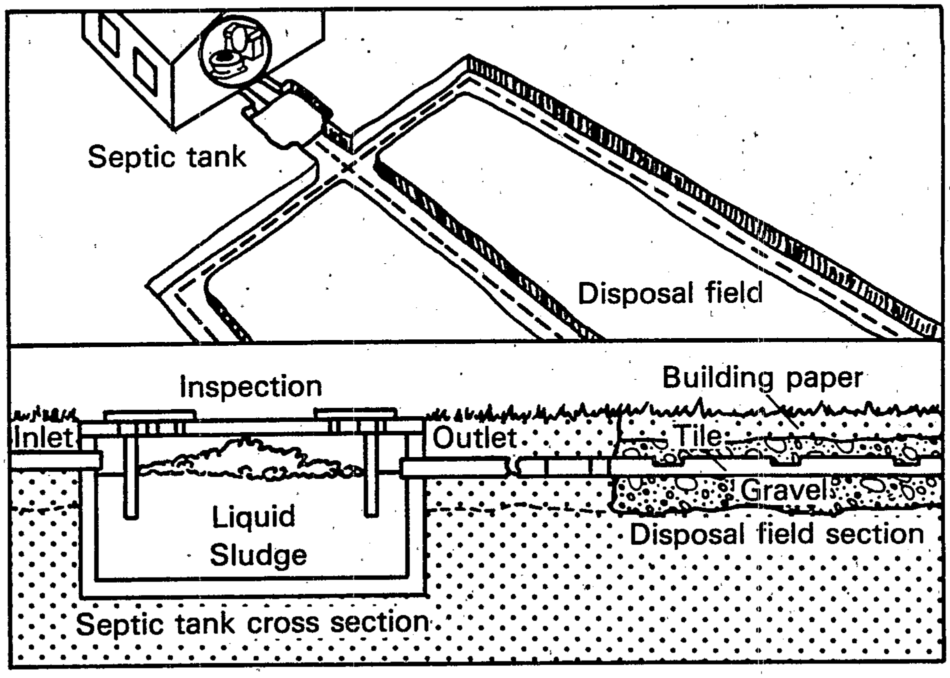


Figure 5-1.—Septic tank and drain field.

processes. Bacterial decomposition in the drain field lowers the oxygen demand of wastewater before it enters the lake or groundwater.

Some bacteria also convert ammonia nitrogen to nitrate in the drain field. While this reduces oxygen demand in the water, nitrate tends to move with the flow, eventually entering the lake in the groundwater. Since ammonia and nitrate are fertilizers, they encourage algal growth.

Septic systems can be effective in removing organic matter, bacteria, and nutrients if properly designed and maintained. They only work, however, if the proper site conditions exist. Many lakeside lots are inappropriate for septic systems, and lake problems have conclusively been associated with septic system failures. Conditions that prevent or interfere with proper function of septic systems include unsuitable soils, high water tables, and steep slopes, as well as system underdesign or improper use. Many of these soil conditions occur around lakes and can make lakeside lots unsuitable for septic systems.

Soil plays a key role in the septic system. Tightly bound and poorly drained soil types (clays) are not effective filters. At the other extreme, gravel is also a poor filter because the wastewater drains through it so rapidly.

Saturated soils also hinder treatment because they cannot adsorb nutrients well. To work properly, septic systems need good contact between the wastewater and relatively dry soil particles, which adsorb nutrients as the wastewater passes through the system. Soils that drain very slowly may be chronically saturated and the system will, therefore, be inoperative much of the time. In a poorly drained soil, the wastewater is also likely to surface and run directly to the lake. A streak of especially green grass growing over the drain field indicates that wastewater nutrients are fertilizing the lawn on the way up. High groundwater tables can also prevent treatment by periodically flooding the drain system. Steep slopes cause either rapid flow-through or surfacing of wastewater.

Frequently a septic problem can be traced to improper use and subsequent malfunction. These problems commonly arise from underdesign, that is, too small a tank or an inadequate drain field. Other problems are caused by serving more people than the system was designed for, disposing of products that contain toxics, following a poor septic tank maintenance schedule, and putting solids in the system (using a garbage disposal). Many health departments and environmental agencies have a good reference brochure on the function and design of septic systems. EPA's design manual gives information about on-site wastewater treatment and disposal systems (U.S. Environ. Prot. Agency, 1980b).

Alternative on-site wastewater treatment techniques, such as mound systems (Fig. 5-2) and sand filters (Fig. 5-3), may be more suitable for many lakeside properties. These systems use the septic tank for solids removal but not the typical soil drain field.

The mound system is suitable for rocky or tightly bound soils or areas with a high water table. Instead of a drain field, a mound is created with fill material. The wastewater from a septic tank is pumped up to the mound and allowed to seep through the soil, which provides the treatment (Fig. 5-2).

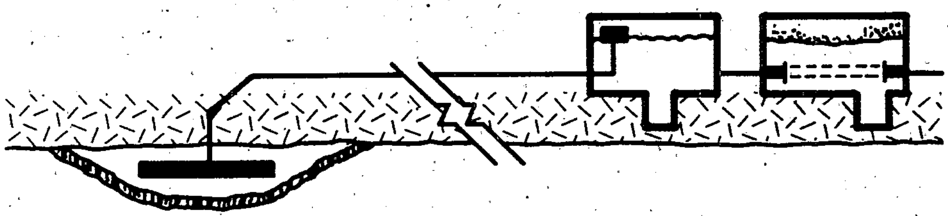


Figure 5-2.—Mound systems.

A sand filter system can also be used where soils are unsuitable for conventional drain fields. A 2- to 3-foot bed of sand is installed in the soil or aboveground to filter wastewater as it is released from the septic tank. The filtered wastewater can be disposed of through the soil as in a conventional septic drain field (Fig. 5-3).

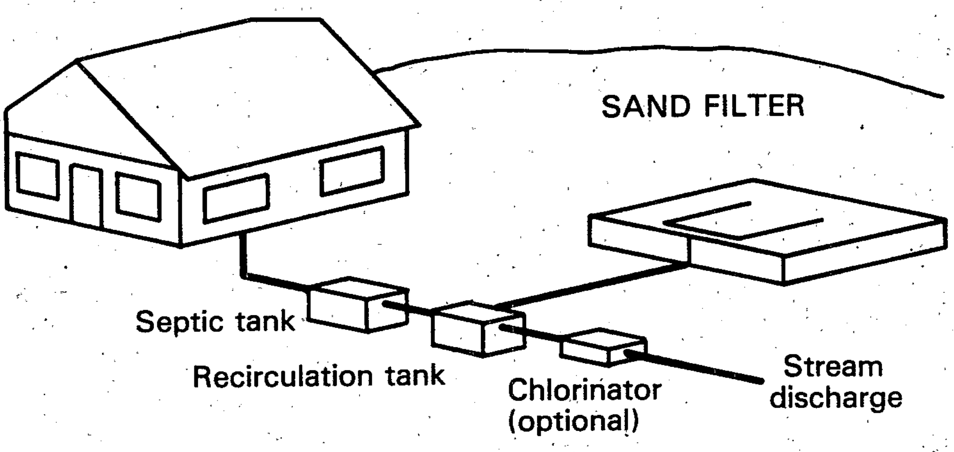


Figure 5-3.—Sand filters.

Mound and sand filter systems represent only minor modifications to the typical septic system. They do not require major construction or substantially increase the cost. However, if the groundwater movement is toward the lake, effluent from these systems will flow in that direction. For any on-site system, very careful attention must be paid to the conditions of the site (including groundwater flow), to the suitability of the system for treating the waste, and to providing proper maintenance of the system.

Holding tanks with or without chemical treatment can eliminate the discharge problem. Because they must be pumped on a regular basis to remove the wastewater, holding tanks are not as convenient as conventional systems, but for cottages or homes that receive limited weekend use, they can be an effective alternative to other treatment techniques and will reduce local lake problems.

As with the septic tank/drain field system, soil characteristics, groundwater tables, usage conditions, slope, and other factors can influence the selection, design, and operation of alternative on-site treatment methods. Local health or water pollution control agencies can assist the property owner in evaluating these conditions and selecting the appropriate treatment system, either conventional or alternative.

Community Treatment Facilities

For communities where existing sewage treatment facilities are adequate and available, the solution is simply to tie into the public sewer system. Conventional sewers are usually by far the major capital cost item of a wastewater system. However, alternative sewer system designs are available that are much cheaper than conventional systems and can also be tied into the public sewer system. These smaller sewers are installed at shallow depths. They have no manholes and fewer joints, which reduces rain and groundwater intrusion, thus reducing the treatment plant capacity required to treat this additional water. There are three general types of alternative sewer systems that might work better for small communities or individual homeowners when a major municipal or regional facility already exists and has available capacity. The first uses small-diameter gravity sewers that carry septic tank effluent away from the home. The pipes, which are usually plastic and can be four inches in diameter, are placed at less slope than a conventional sewer. Operation and maintenance requirements are low.

The second type—pressure sewer systems—use a small pump at each house to move wastewater under pressure through small diameter plastic pipes to a treatment facility or a larger interceptor sewer (Fig. 5-4).

The third general type is a vacuum sewer system (Fig. 5-5) that draws wastewater from each home through small collector pipes to a central collection station by vacuum. Wastewater entry into the system is controlled by vacuum valves at each home or at groups of homes. The vacuum collection station houses a pump that then delivers the collected wastewater to either the treatment facility or an interceptor sewer. Because of their limited ability to lift wastewater, vacuum sewers are best suited to flat areas where gravity sewers would be too expensive.

In many communities, however, small-scale treatment is the only feasible approach, but site conditions prohibit the use of on-site systems. Where lot sizes or soil conditions are not suitable for on-site systems, cluster systems can be used (Fig. 5-6). Here, wastewater is conveyed by small-diameter

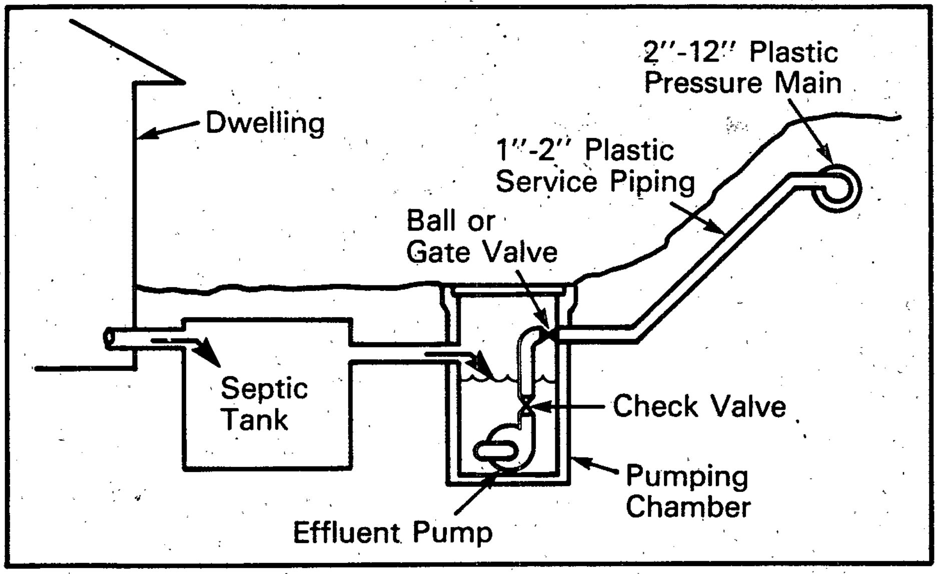


Figure 5-4.—Pressure sewer systems.

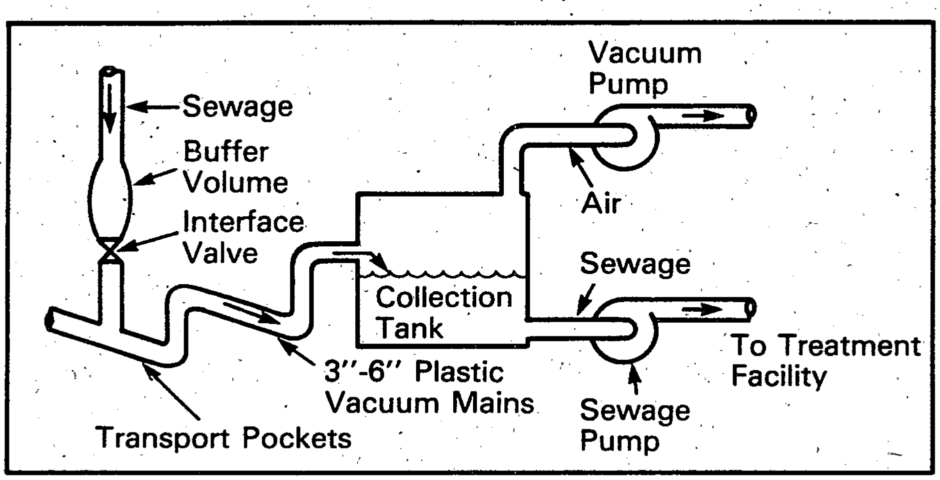


Figure 5-5.—Vacuum sewer system.

sewers to a neighborhood drainfield, mound, or sand filter. Construction and operating costs for on-site or cluster systems are usually low, and the systems can be very simple to operate. The key to their success is an efficient organization to manage their operation and maintenance.

Some treatment systems are particularly appropriate for small communities. Among the simple and reliable central treatment systems that are well suited to small community situations are ponds and lagoons, trickling filters (Fig. 5-7), oxidation ditches, and overland flow treatment (Fig. 5-8). These systems are described in more detail in Appendix C, including their advantages, disadvantages, maintenance, and cost. All of these well-established methods provide standard or better levels of treatment. In general, they cost less to build and run than the common method of treatment called activated sludge. They also use less energy and are easier to operate and maintain. When a community is starting to plan a wastewater project, it should select an engineer who has experience with these small community technologies. If the

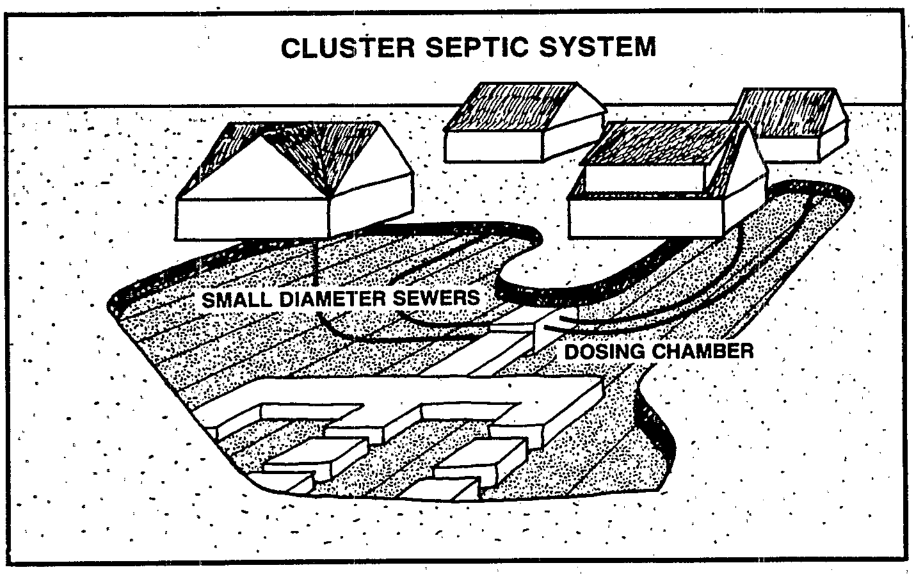


Figure 5-6.—Cluster sewer system.

ongoing project did not consider these technologies, a reevaluation of alternatives might be in order. Information on particular systems appropriate for small communities can be obtained from local contractors specializing in wastewater treatment, the local or State health departments, water pollution control agencies, or EPA. EPA has several excellent publications available, including the *Innovative and Alternative Technology Assessment Manual* (EPA No. 430/9-78-009).

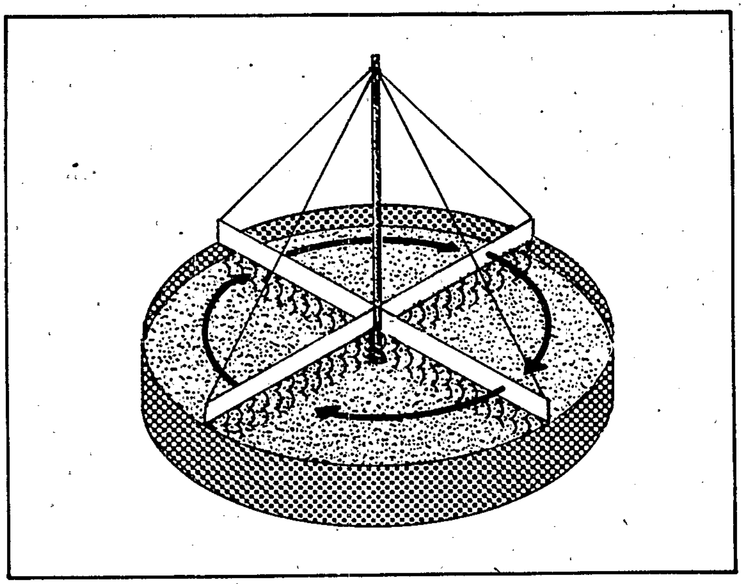


Figure 5-7.—Trickling filter.

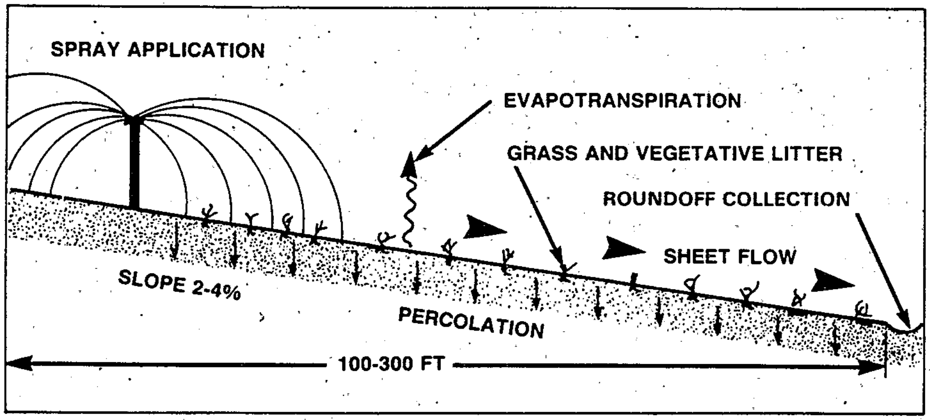


Figure 5-8.—Overland flow system.

Water Conservation to Reduce Lake Problems

With a lake nearby, conserving water might not seem critical. Reducing water usage, however, also reduces wastewater discharges. Water-saving devices such as flow-reducing showerheads and water-saving toilets can cut household wastewater flows by as much as 25 percent (U.S. Environ. Prot. Agency, 1981). Table 5-2 lists several water conservation procedures taken from a bulletin issued by the local Arkansas Cooperative Extension Service (U.S. Dep. Agric. 1984); County Extension offices have more information on this topic and others that may be of interest to lake managers and homeowners. Most of these procedures are very simple, even obvious, but the water they conserve can permit smaller wastewater treatment facilities if these procedures are followed in homes around the lake. Even if a smaller treatment facility is not possible, reducing water use can lower day-to-day operating costs for expenses such as treatment chemicals and utilities.

Water conservation is particularly appropriate in cases where existing treatment capacity is limited or near the maximum. If a community is connected to a regional sewer system, conservation measures can effectively reduce treatment charges, which are usually based on the volume of sewage treated. This volume, in most cases, is monitored through water meter readings, and the treatment charge is prorated on a household water usage basis.

Water conservation, then, not only costs less in the long run but also reduces the potential loading of organic matter and nutrients to the lake, partly as a result of reduced wastewater discharges. More careful usage may also lower nonpoint source loadings from activities such as watering lawns.

Table 5-2.—**Conscientious use of water can prevent excess run off and reduce the volume of waste water treated, both of which help protect lake water quality**

WATER CONSERVATION TECHNIQUES

- Inspect the plumbing system for leaks.
- Install flow control devices in showers.
- Turn off all water during vacations or long periods of absence.
- Check the frequency with which home water softening equipment regenerates and backwashes. It can use as much as 100 gallons of water each time it does this.
- Insulate hot water pipes to avoid having to clear the "hot" line of cold water during use.
- Check all faucets, inside and out, for drips. Make repairs promptly. These problems get worse—never better.
- Reduce the volume of water in the toilet flush tank with a quart plastic bottle filled with water (bricks lose particles, which can damage the valve).
- Never use the toilet as a trash basket for facial tissues, etc. Each flush uses 5 to 7 gallons of water. Items carelessly thrown in could clog the sewage disposal problems.
- Accumulate a full laundry load before washing, or use a lower water level setting.
- Take showers instead of baths.
- Turn off shower water while soaping body, lathering hair, and massaging scalp.
- Bottle and refrigerate water to avoid running excess water from the lines to get cold water for meals. Shake bottle before serving to incorporate air in the water so that it doesn't taste flat.
- To get warm water, turn hot water on first; then add cold water as needed. This is quicker this way and saves water, too.
- Wash only full loads of dishes. A dishwasher uses about 9 to 13 gallons to water per cycle.
- When washing dishes by hand, use one pan of soapy water for washing and a second pan of hot water for rinsing. Rinsing in a pan requires less water than rinsing under a running faucet.
- Use rinse water—"gray water"—saved from bathing or clothes washing to water indoor plants. Do not use soapy water on indoor plants. It could damage them.
- Vegetables requiring more water should be grouped together in the garden to make maximum use of water applications.
- Mulch shrubs and other plants to retain moisture in the soil longer. Spread leaves, lawn clippings, chopped bark or cobs, or plastic around the plants. Mulching also controls weeds that complete with garden plants for water. Mulches should permit water to soak into the soil.
- Try "trickle" or "drip" irrigation systems in outdoor gardens. These methods use 25 to 50 percent less water than hose or sprinkler methods. The tube for the trickle system has many tiny holes to water closely spaced plants. The drip system tubing contains holes or openings at strategic places for tomatoes and other plants that are more widely spaced.
- Less frequent but heavier lawn watering encourages a deeper root system to withstand dry weather better.
- Plan landscaping and gardening to minimize watering requirements.
- When building or remodeling, consider:
  —Installing smaller than standard bath tubs to save water.
  —Locating the water heater near area where hottest water is needed—usually in the kitchen/laundry area.

How to Assess Potential Sources

Consider the relative importance and contributions of point sources and nonpoint sources to the lake. Preparing a water and nutrient budget as discussed in Chapter 3 and described in Chapter 4 is an essential beginning.

The watershed to lake surface area ratio is also important. This ratio can indicate whether point or nonpoint sources are likely to dominate water quality. This ratio is quite simple to calculate: Lake area ratio equals the watershed area divided by lake area (computed in acres). If the watershed is small, local point sources and septic tank drainage are probably quite important. As the watershed to lake surface ratio increases, these sources might still be important, but nonpoint sources also must be considered.

Assessing Point and Domestic Wastewater Sources

With an existing on-site system, the first step is to contact the local or State health department or water pollution control agency to determine whether the system is operating satisfactorily. If it is, finding out how to maintain the system in good condition is all that is necessary. If the system is not working well, however, correcting the malfunction will be necessary. The agency that checked the system can provide advice and referrals for further information and may even offer services to correct treatment system problems.

When considering an on-site system, the individual homeowner or community should contact the local city or county agent and find out what ordinances may exist for minimum setbacks from the lake, mandatory wastewater treatment, or other requirements.

If it is absolutely necessary for a community treatment system to discharge to the lake, it is important to determine whether the additional phosphorus loading will promote algal problems. Chapter 4 describes evaluation methods; however, it is strongly recommended that wastewaters not be discharged directly to a lake.

A community treatment system may already be discharging into the lake or into a stream that enters the lake; however, information on whether it does and whether it meets permit requirements is available from the local or State water pollution control agency. When a community system does discharge directly to the lake or incoming stream, it is important to check the discharge area during the summer for problems such as algal blooms, turbid water, or other conditions. The permit for each treatment facility is periodically available for public review and comment before being reissued. If it appears that problems are occurring in the lake, the local water pollution control agency should be notified.

Remember, for any point source treatment system to be effective, it must be maintained and properly operated. This is true for all treatment systems from the septic tank on your lot to the community treatment system, if you have a sewer. You cannot install a system and then walk away and expect it to protect your lake. Point source treatment works when the systems are maintained and properly operated.

Nonpoint Sources

The importance of nonpoint sources of pollution became apparent as municipal and industrial point sources were controlled. In many cases, projected reductions in nutrients and improvements in water quality were not reached. Agencies responsible for lakes and streams attempted to find out why. Point sources, which had been perceived to contribute to the majority of water quality problems, had masked nonpoint source pollution problems. Once point sources were subjected to corrective actions, the importance of nonpoint sources became apparent. Only by stepping away from the narrow viewpoint that point sources caused nearly all water quality problems were water quality managers able to see the lake and watershed as an integrated system being affected by diverse sources of pollutants.

By approaching the management of lakes and streams from a broader perspective, water managers and scientists found that in many systems nonpoint sources were equal to or greater than point source contributions. The EPA Administrator reported to Congress that, as of 1988, 45 percent of the Nation's lakes were either impaired, partially impaired, or threatened by pollution (U.S. Environ. Prot. Agency, 1989); 76 percent of the lake impairment is related to nonpoint source pollution, and only 11 percent is related to point source pollution. The remaining sources of pollution are natural. In general, nonpoint sources were major contributors of sediment organic matter and nutrients to a lake. Although the nutrient concentrations in runoff waters or the amount of nutrients adsorbed to the sediments were not as great as the nutrient concentrations in a point source, the total load (concentration times flow) can be substantial and far exceed point source contributions.

Cultural Sources of Sediments, Organic Matter, and Nutrients

Figure 5-9 illustrates a typical scene from the window of a lakeside home. Many of the following sources of nutrients and sediments to the lake are depicted:

- **Flower and vegetable gardens**—contribute nutrients, sediments, and pesticides if not properly managed
- **Septic tank systems**—contribute nutrients and bacteria
- **A well-manicured lawn**—contributes nutrients (fertilizers) and herbicides

Although not illustrated, car maintenance can contribute nutrients to a lake from washwater and oil slicks from improperly dumped motor oil. The very presence of people on a lake conducting day-to-day activities is, in part, responsible for nutrients and sediments that accumulate in the lake.

These examples of pollutants come from an individual lot. Even if the individual contribution is insignificant, the cumulative contribution from all the individual lots surrounding a lake could be significant. It is very important that homeowners living near the lake exhibit concern for their own pollution if they wish to convince other homeowners in the watershed to improve their habits.

As explained earlier, nonpoint sources are likely to be important in large watersheds. A common method to determine the relative importance of various sources of nutrients and sediments to a lake is to determine the area of the watershed in relation to the area of the lake. For example, if there are 100 acres in the watershed and the surface area of the lake is 100 acres, then the watershed to lake surface area ratio is 1 to 1 (also represented as 1:1). In small watersheds (for example, a 1:1 ratio), the local sources of organic matter and nutrients, such as septic systems and runoff from lawns and gardens carrying nutrients, might represent the primary contributors of pollutants to the lake.

Additional sources of nonpoint source pollution in a small watershed are illustrated across the lake in Figure 5-9. Construction activities can be sig-

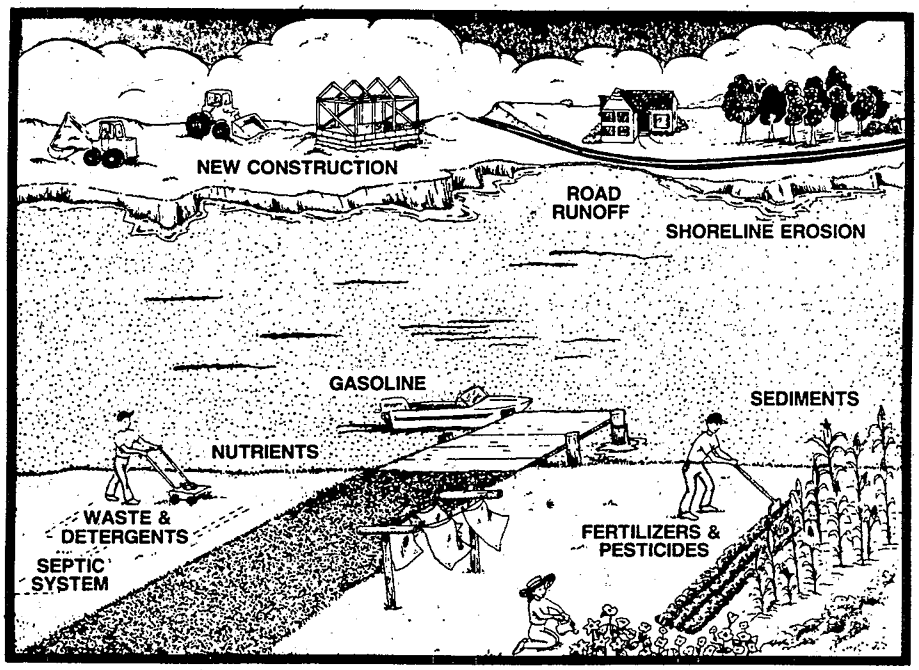


Figure 5-9.—Watershed activities as seen from individual homesite.

nificant sources of sediments, especially during rainstorms. Runoff from roads are additional sources of nutrients, sediments, and heavy metals.

As the watershed to lake surface area ratio becomes larger, other sources of pollutants such as agricultural runoff carrying animal wastes (organic matter), soil, and nutrients become increasingly important. Urban runoff from streets, storms, and rooftops will become significant sources of sediment, organics (oils and greases), nutrients, and heavy metals to lakes. Silvicultural activities also will become increasingly important as sources of sediments. In large watersheds, the contributions from urban, silvicultural, and agricultural areas are generally more significant than those from lakeshore homes.

What are Best Management Practices?

Before a discussion is initiated on how to restore a lake, background on techniques available to improve water quality must be developed.

The lake association or local residents have a number of options available to improve the water quality of the lake. They range from picking up litter around the lake to the implementation of best management practices in the watershed. Best management practices have been developed for agricultural, silvicultural, urban, and construction activities. Agricultural practices, for example, have been developed for cropland, pastures, barnyard or manure management, and pesticide control. Silvicultural practices have been developed for activities such as road construction in timberlands, timber harvest techniques, regenerating forest lands cut or killed by disease or fire, and the use of pesticides. Urban practices have been designed to keep city streets and roadsides clean, while construction practices were developed for erosion and runoff control.

In general, these best management practices were not designed with water quality protection as a goal but rather to maintain productivity on the land, reduce costs of pesticides and fertilizers, or prevent lawsuits because of mud slides or flooding on neighboring properties. Regardless of their original intent, many of these practices are useful in lake restoration projects.

Managers of lakes and streams focus on best management practices to control four primary, interactive processes: (1) erosion control, (2) runoff control, (3) nutrient control, and (4) pesticide or toxic controls. These processes are highly interactive because runoff control, for example, offers benefits for reducing sediments, nutrients, and pesticide contamination in lakes and streams. Control for other factors, however, may still be necessary. Runoff control, for example, may minimize water erosion, but wind erosion may account for 10 to 14 tons of soil loss per acre every year from croplands in some of the Great Plains States.

Table 5-3 lists various best management practices applied during different land use activities. Definitions and explanations as to their effectiveness, capital costs, longevity, confidence, adaptability, potential effects, and concurrent land management practices can be found in Appendix D. In this analysis, *effectiveness* refers to how well a practice reduces sediments, organic matter, nitrogen, phosphorus, and runoff. *Capital costs* refers to the costs that would be incurred by the farmer, forester, contractor, or municipality to implement the best management practice. *Operational and maintenance costs* refers to those costs required to keep the best management practice working properly.

Table 5-3.—A list of Best Management Practices applied during different land use activities.

BEST MANAGEMENT PRACTICES	
AGRICULTURE	**CONSTRUCTION**
Conservation Tillage	Nonvegetative Soil Stabilization
Contour Farming	Disturbed Area Limits
Contour Stripcropping	Surface Roughening
Integrated Pest Management	
Range and Pasture Management	**MULTICATEGORY**
Crop Rotation	Streamside Management Zones
Terraces	Grassed Waterways
Animal Waste Management	Interception or Diversion Practices
Fertilizer Management	Streambank Stabilization
Livestock Exclusion	Detention/Sedimentation Basins
	Vegetative Stabilization
URBAN	
Porous Pavements	
Flood Storage	
Street Cleaning	
SILVICULTURE	
Ground Cover Maintenance	
Road and Skid Trail Management	
Riparian Zone Management	
Pesticide/Herbicide Management	

Longevity is either short term or long term. For this discussion, short term means the practice is good only for a year or season. Long-term practices are those that last longer than one year. The terminology is not clear-cut because some practices have to be applied every year but are considered to be long term because the implementation of the practice is not designed to provide instant results. An example is conservation tillage. In conservation tillage, plant residue is left on the field after harvest. When a conservation tillage practice is initiated, the farmer does not expect to have significant results in the first year but will be able to maintain or protect the productivity of the land over the long haul. The benefits the lake receives are also not noticeable in the first year but will be perceived over a period of years.

Confidence is based upon how consistently a best management practice works in reducing a problem. One might have little confidence in a best management practice that works only on a hit-or-miss basis. In many cases, the scientific evidence is not yet available to assess the confidence associated with a given best management practice.

When a best management practice can be used in a variety of geographic areas and situations, it is considered to be adaptable. For example, the adaptability of conservation tillage is ranked as good instead of excellent because it is limited in northern States that experience late, cool springs or in heavy, poorly drained soils, even though it can be applied in a variety of geographic areas.

Potential treatment side effects refer to the possibility of causing another problem by treating the problem of immediate interest. For example, even though the use of conservation tillage can reduce soil erosion, runoff, and nutrient losses, the increased use of chemicals may lead to groundwater pollution.

When a best management practice is applied, there is generally a supporting best management practice that will increase the effectiveness of the primary practice. In the case of implementing a conservation tillage program, a fertilizer management and integrated pesticide management program should also be initiated as a supporting practice.

Table 5.4 summarizes the effectiveness, costs, and chance of negative side effects associated with select best management practices. In some instances, the rankings represent a range such as good (G) to excellent (E). In other instances, a particular category is ranked as unknown (U). The range of rankings and the unknowns reflect uncertainties and variable results associated with best management practices in providing benefits such as sediment nutrient reduction to a watercourse or lake. The reader should use the table as a guideline when selecting best management practices to solve a potential water quality problem. The local and regional conditions will dictate the particular combinations of best management practices that are most effective and appropriate for a particular lake. Although there is some uncertainty about the most appropriate combinations for any watershed, best management practices work! Like point source treatment systems, however, these practices must be maintained.

Table 5-4.—Summary of the effectiveness, cost and chance of negative side effects associated with select watershed best management practices.

	EFFECTIVENESS					
	SEDIMENT	NITROGEN	PHOSPHORUS	RUNOFF	COST	CHANCE OF NEGATIVE EFFECTS
AGRICULTURE						
Conservation Tillage	G-E	P	F-E	G-E	F-G	F-G
Contour Farming	F-G	U	F	F-G	G	P
Contour Stripcropping	G	U	F-G	G-E	G	P
Range and Pasture Management	G	U	U	G	G	P
Crop Rotation	G	F-G	F-G	G	F-G	P
Terraces	G-E	U	U	F	F-G	F
Animal Waste Management	N/A	G-E	G-E	N A	P	F
URBAN						
Porous Pavement	F-G	F-G	F-G	G-E	P-G	F
Street Cleaning	P	P	P	P	P	U
SILVICULTURE						
Ground Cover Maintenance	G	G	G	G	G	P
Road and Skid Trail Management	G	U	U	U	P	F
CONSTRUCTION						
Nonvegetative Soil Stabilization	E	P	P	P-G	F-G	F
Surface Roughening	G	U	U	G	F	P
MULTICATEGORY						
Streamside Management Zones	G-E	G-E	G-E	G-E	G	F
Grassed Waterways	G-E	U	P-G	F-G	F-G	P
Interception or Diversion Practices	F-G	F-G	F-G	P	P-F	P
Streambank Stabilization						
Detention/Sedimentation Basins	G	U	U	P	P-G	F

E Excellent G Good
F Fair P Poor
U Unknown

Lake Restoration Begins in the Watershed

The best place for any lake association to start a restoration project is in its own backyard. There are a number of actions individual lake homeowners can initiate, for example:

- Collecting the litter tossed in yards and along the roads.
- Leaving the grass or shrubs uncut up to the lakeshore or along roads uncut to act as a buffer strip to reduce nutrient and sediment loads to a lake.
- Modifying agricultural best management practices for flower or vegetable gardens. Although agricultural best management practices were designed for large fields (40 to 1,000 acres), they can be scaled to backyard plots.
- Adopting a form of conservation tillage, integrated pest management, and fertilizer management. Leaving after-harvest vegetable crop residue in gardens can minimize local sources of nutrients, organic matter, and sediments.

During the growing season, integrated pest management and fertilizer management may be appropriate. Integrated pest management is a practice that considers the best timing dosage and handling of pesticides for maximum effectiveness with minimal waste or overuse. Other considerations include selecting resistant vegetable varieties, optimizing vegetable/flower planting time, rotating plants, and using biological controls. Local Extension agents are good reference sources for locally suitable resistant plant varieties.

Fertilizer management considers the proper time to spread a fertilizer and the proper amount to optimize plant growth with minimal impact on the lake. Management of fertilizers and pesticides actually saves money because the proper amount is applied when it does the most good. This reduces both the amount and the number of times fertilizers and pesticides need to be used. Again, the local Extension agent can be of assistance. In addition, U.S. Soil Conservation Service personnel can provide information on locally dominant soil types and assist in determining the appropriate amount and type of fertilizer.

Once lake homeowners have initiated best management practices on their own lots, it is time to start moving outward into the watershed. By working together, lakeshore property owners can accomplish a number of small projects that will help reduce nutrient and sediment loads to a lake. For example, eliminating curbs and gutters allows the road runoff to flow over grassed areas that will filter sediments and use the nutrients. Other examples of best management practices that could be applied include vegetative stabilization, grassed waterways, streamside management zones, streambank stabilization, and detention/sedimentation basins. These practices, described in Appendix D, all help reduce the input of organic matter, silt, and nutrients to the lake.

In a streamside management zone, the natural vegetation is maintained beside the stream. If vegetation has been removed, it should be replanted. Planting erosion-resistant grasses in natural or constructed drainage channels to make a grassed waterway is another practice that lake associations might encourage. In concept, vegetative stabilization is similar to grassed waterways and streamside management zones, using erosion-resistant plants or ones that will stabilize soil in erosion-sensitive areas such as steep slopes. If a stream entering the lake is eroding its banks, however, vegetation may not suffice. Another project that a group might initiate is streambank stabilization where a layer of carefully graded rocks (riprap) is placed over the area of erosion. In some cases, a blanket of nonvegetative fiber or layer of sand must be placed before riprapping. The area may also require detention/sedimentation basins designed to slow runoff for a short time and to trap heavier sediment particles. Artificial wetlands have been created in some areas to store runoff water and decrease flooding but also to trap sediment and nutrients. Wetlands have been used in Minnesota for stormwater management and lake protection. Additional information is available from the Soil Conservation Service and local drainage improvement districts or land improvement contractors.

With a large watershed, the tasks facing the lake association become more complex. Now the organization has to work with property owners who may not live near the lake, private contractors, municipalities (such as zoning commissions), and county planning agencies that may or may not be concerned about the lake. In some cases, local ordinances or zoning regulations might need to be passed to regulate construction or other land use activities. The lake organization may require that construction areas implement best management practices such as nonvegetative soil stabilization, disturbed area limits, and surface roughening.

Nonvegetative soil stabilization includes actions such as covering disturbed areas with mulches, nettings, crushed stone, chemical binders, and blankets or mats. This best management practice is a temporary measure that should be used until a long-term cover is developed.

The best management practice known as disturbed area limits is nothing more than a common sense approach to minimize the area disturbed by the construction activity. If vegetation is removed, surface roughening can be applied on the exposed soil. Conventional construction equipment is used to scarify, or groove, the soil along the contour of a slope. In practice, the grooves spread the runoff horizontally and increase the time for water to soak into the ground.

As the watershed to lake surface area becomes larger, the task of watershed management becomes more expensive and more complex. It is important to realize that not all areas of the watershed are equally important and to identify those that are critical contributing areas so that available funds can be used effectively. A critical area is one that contributes excessive amounts of soil and nutrients to the lake, or a stream course that enters the lake. How to delineate these areas is discussed in Chapter 3, Problem Identification. An educational program on watershed management should also be considered. The only reason some individuals contribute nonpoint source loads to lakes is their lack of awareness of the impact of their actions.

The U.S. Department of Agriculture has a program on low input sustainable agriculture that is providing farmers information on more cost-effective and environmentally sound agricultural practices. This program helps farmers increase profits while maintaining and protecting the environment by building on multiple best management practices such as integrated pest management and crop rotations. This program is closely coordinated with EPA's nonpoint source programs. Additional information can be obtained from the USDA Cooperative State Research Service or the local county Extension agent. Educational approaches are critical in successfully implementing a management plan (see Chapter 8). A key to a successful lake management program is maximum local involvement.

Any one or all of the best management practices listed in Table 5-3 and in Appendix D may be applicable in the lake's watershed. The best approach is to target those areas that are concentrating the most significant sediment, organics, or nutrient loads. This may entail starting a modest monitoring program as discussed in Chapter 8.

The practices just discussed addressed the actions an association can take around the lake. Maintaining these practices and protecting lake water quality might require regulations, zoning, or ordinances. These regulatory procedures, which are discussed in Chapter 9, can be effective tools for lake and watershed management.

Guidelines and Considerations

Controlling nonpoint sources and identifying the most feasible alternatives can be considered a seven-step process.

■ **Step 1. Form a lake association or lake district.** Several voices have more strength than one. The North American Lake Management Society is an organization that can help you organize a lake association and put you in touch with other like groups. Some States have already formed a federation or congress of lake associations (Appendix E). Members from other lake associations can be a good source of information.

■ **Step 2. Identify potential problem sources.** Start with the lake home and then move around the lake and out into the watershed. This is the first step to define the extent of any problems. Refer to Chapter 3.

■ **Step 3. Identify Critical Areas.** Critical areas are those that are contributing a majority of the sediments and nutrients to the lake. Not all areas necessarily contribute equally to lake problems. Refer to Chapter 3. Part of identifying a critical area is common sense. If a farmer is plowing up to the edge of a stream, a feedlot is located on a stream or lake, or a clearcut is located close to a stream, those areas become potential candidates for critical areas. In many cases, the lake association will not be able to directly correct watershed problems created by agricultural, urban, or silvicultural activities. Ordinances or local zoning regulations might be necessary (see Chapter 9).

■ **Step 4. Initiate watershed management practices.** Common best management practices were explained earlier, and it was stated that they were initially developed for purposes besides water quality improvement. The intent of this chapter is to develop in lake associations and lake homeowners an appreciation of the relationship between the lake and the watershed. Generally no one practice is adequate by itself, and many practices must be integrated.

■ **Step 5. Determine allocation of resources.** A lake association or lake district will in all likelihood be limited by resources. The best place to start in any watershed management program is in the association's own backyard. Many of the best management practices considered for agricultural, urban, or silvicultural activities can be pursued by lake homeowners on a reduced basis: buffer strips around the lake are just as applicable to a homeowner as to a farmer, as are fertilizer management, pesticide management, conservation tillage, street cleaning, or nonvegetative soil stabilization. A lake association will probably be more effective if it corrects local problems before tackling those in the upper watershed. Common sense is the key.

■ **Step 6. Investigate regulations and zoning.** Consider regulations or zoning as time and space to resolve lake problems both of land use and lake users (see Chapter 9). A lake problem is a limitation on a desired use. In some instances, other lake uses and users are the problems. Some uses will not be compatible in all lakes, so it is important to decide which lake uses have the greatest priority and manage to achieve these uses. Regulations can assist in achieving these uses.

■ **Step 7. Employ tools in combination.** Consider an integrated program of watershed management and in-lake restoration. To develop an effective lake management plan, all the available tools should be considered and the appropriate ones incorporated in the plan. Chapter 6 discusses the third leg of the lake management triangle—lake restorations.

Examples of Point and Nonpoint Improvement Projects

Lake Washington: Point Source Diversion

Lake Washington is considered a classic example of water quality improvement with the diversion of sewage. In 1958, the public voted to divert sewage from Lake Washington, but the first diversion did not take place until 1973, and the system was not completed until 1978. With the first diversion, which stopped about 28 percent of the effluent, the lake stopped deteriorating, and during the five-year diversion period, the lake showed signs of recovery. Between 1967 and 1968, water quality changed rapidly. Edmondson (1972) reported that the content of phosphorus in the surface waters decreased about a fourth of its maximum value, microscopic plants decreased, and transparency increased (see Chapter 4).

Annabessacook Lake, Cobbossee Lake, and Pleasant Pond: Point Source Diversion/Nonpoint Source Waste Management/In-Lake Treatments

Annabessacook Lake is an example of a hit or miss approach to lake restoration. For years it was considered the most polluted lake in Maine. From 1964 to 1971, residents attempted to solve their algae problems with copper sulfate, but each year the period of effectiveness became shorter and resistant algae predominated. In 1969, steps were taken to divert sewage from the lake. The diversion resulted in an improvement, but algae growth continued to be a nuisance. To accelerate recovery, hypolimnetic aerators were installed, but there was no positive response.

After over 30 years of frustration in attempts to improve water quality in the chain of lakes (Annabessacook Lake, Cobbossee Lake, and Pleasant Pond), lakeshore property owners, local officials, and concerned citizens formed the Cobbossee Watershed District, which was to serve as a quasi-governmental agency, similar to a school district or sewer authority. Through their taxing authority, a Federal water quality management (208) planning grant, and the Agricultural Stabilization and Conservation Service, they were able to conduct a formal study of nonpoint sources of pollution to formulate a comprehensive restoration plan.

In Pleasant Pond, agriculture was the dominant source of phosphorus nonpoint pollution and the second leading cause in Annabessacook and Cobbossee lakes. Lake sediments were the primary source of nonpoint pollution in Annabessacook Lake. After careful consideration, a two-pronged approach was taken. An agricultural waste management program was started in the watershed and nutrients were removed from the lake water column. The major agricultural activities in the watershed were dairy and poultry farming; most farmers spread the manure on frozen ground and snow. To implement a waste management program, storage had to be found for six months of accumulated manure.

By using animal waste management (storage during winter months) and alum (aluminum sulfate) plus sodium aluminate to remove phosphorus, the total phosphorus loads were reduced approximately 45 percent. From the lake users' viewpoint, the improvement in water clarity has been a positive benefit (U.S. Environ. Prot. Agency, 1980a).

East and West Twin Lakes: Septic Tank Diversion

The results of septic tank diversion and alum treatment were part of a research project (Cooke et al. 1978) funded by the EPA. This study is included because it demonstrates that septic tanks can affect a lake even when sited in ideal soil.

Prior to septic tank diversion, fecal coliform levels in East and West Twin Lakes ranged from too numerous to count to 260 colonies per 100 mL. The standard for fecal coliform is 200 colonies per 100 mL, and levels above this limit resulted in the lakes being closed to contact recreation. After diversion, fecal coliform levels quickly reformed to near zero levels in groundwater, streams, and the lakes. Although the septic systems were sited in soils presumably ideal, Cooke et al. (1978) found perched water tables in the leach field that, they assumed, were the result of organic material clogging the leach field and reducing permeability. This situation allowed nutrient-rich and fecal material to be washed from the lawns to ditches and streams that entered the lakes.

A concurrent decrease in phosphorus concentrations was not observed because the lakes continued to receive untreated storm flow and runoff from diverse nonpoint sources typical of eutrophic lakes. Cooke et al. (1978) concluded that the diversion of septic tanks prevented the situation from becoming worse and potentially reaching a point where all recreation would have to cease.

Summary

Lakes receive nearly all of their silt, organic matter, nutrients, and other pollutant inputs—or loads—from their watersheds. These pollutant loads are contributed both from point sources and nonpoint sources. Point sources, discharged from a pipe, are contributed from such places as homes, offices, and factories. Point source and domestic wastewater pollutant loads are controlled with wastewater treatment systems, the most common being the septic tank and drainfield, an on-site system used by many homeowners.

Septic tanks and drainfields might not be the best on-site system for lake homes. Alternative systems, such as mound systems and sand filters, and on-site systems that can treat the wastewater from several homes, lake associations, or small communities—oxidation lagoons, trickling filters, and overland flow treatment systems—should be considered.

Nonpoint sources of pollutant loads arise from various watershed land uses such as agriculture and forestry, construction, and urban activities. These sources can be controlled by implementing best management practices in the watershed.

Watershed best management practices begin with the individual lake homeowner. Lake associations and lake districts can effectively implement best management practices in the community and promote these practices throughout the watershed. Watershed point and nonpoint source management practices implemented in the Lake Washington, Lake Annabessacook, Lake Cobbossee, Pleasant Pond, and East and West Twin Lakes demonstrate that best management practices can be used to improve and protect lake quality.

Chapter 6

LAKE AND RESERVOIR RESTORATION AND MANAGEMENT TECHNIQUES

Introduction

This chapter covers the major restoration and management techniques that are used *within* lakes and reservoirs. Somewhat like prescriptions for treating lake ailments, these techniques have benefits, side effects, and limitations. All have demonstrated and proven value, but none is suitable for every lake, for an all-inclusive range of problems, or even for a specific problem under varying circumstances.

With that warning delivered, what can the reader expect to gain from this chapter? Its threefold objective is to help the reader

- Understand the limits of lake and reservoir restoration and management methods,
- Ask the critical questions involved in choosing the most appropriate procedure, and
- Become familiar with the various methods with regard to their basic ecological principles, their mode of action, their effectiveness and potential negative impacts, and—where known—their costs.

The Principles of Restoration

The lake user needs to consider two important ideas regarding lake protection and restoration before proceeding to study and select methods appropriate to any particular lake or reservoir:

First, in the long term, the condition of a waterbody is dictated primarily by the quality and quantity of water entering it. While there are important qualifications to this, including biological interactions in the lake, sediment release of nutrients, and basin shape, it is clear that nearly all attempts at restoration will be overwhelmed by continued high incomes of silt, organic matter, and nutrients. Protection and watershed management (see Chapter 5) are therefore paramount to restoration.

Second, lake restoration is, by definition, the use of ecologically sound principles to attempt to return a lake or reservoir to the closest approximation of its original condition before disturbance. Sometimes it can be made even better than the original condition. Management, on the other hand, involves the improvement of the lake or reservoir to enhance some human use or goal such as swimming, fishing, or water supply. Of course a restored lake is likely to be very attractive for human activities and will require management to remain in that condition.

Restoration and management techniques can be divided into three general groups, based upon the ecological principles behind them.

1. Control of plant growth through control of factors such as nutrient loading or sediment nutrient release

2. Improvement of conditions for populations of desired species, including certain organisms that might control excessive vegetation

3. Removal of nuisance organisms or sediments.

Lake restoration does not include symptomatic treatments such as an herbicide or algicide application, although these chemicals can form an important part of a vegetation management program. Herbicide treatments, like some other management procedures, are not restorative because they do not treat the causes of excessive vegetation and, therefore, must be continually or frequently reapplied. Furthermore, some of them are associated with undesirable side effects.

Costs are a very important consideration, as well. The more management- and symptom-oriented the technique, the greater the likelihood that the long-term benefit-to-cost ratio will be poor. While a restoration-oriented technique usually costs more at the outset, restoration lasts. For example, it is hardly wise to consider a restoration program that provides at least 10 years' worth of benefits to be "expensive" compared to a management "bargain" that has to be repurchased 10, 20, or 30 times in the same time span without ever solving the real problem.

Some readers will be aware of specific products or procedures not mentioned here. Ultimately, some could be effective and have minimal undesirable side effects. As these techniques are thoroughly tested and proven to be effective, they will be added to this chapter. In general, the techniques and products listed in this Manual have been described in the open scientific literature and are considered to be effective.

Lake managers should ask for scientific documentation regarding a procedure, product, or technique, especially one not described here. If you are unsure, discuss a technique with a lake restoration expert not financially involved in its sale or installation. An agent of the appropriate State agency might be a good choice. There are too many cases of lake associations spending thousands of dollars on products and procedures that don't work or are unappropriate to the problem. An example would be installation of an unneccesary or under-powered aeration device.

Are Protection and Restoration Possible?

Some eutrophic lakes and many reservoirs probably cannot be restored or improved to a condition better than the current condition. Either they cannot be protected, or the users' expectations are not consistent with achievable conditions. An estimation of the degree to which a waterbody can be improved is one of the functions of the diagnostic/feasibility study (Chapter 3), which answers questions relating to sources of nutrients, silt, and organic matter loadings, and the present condition of the lake. For example, if the primary source stream is of poor quality and it is not feasible or practical to improve it, protection will be impossible and in-lake or in-reservoir procedures might have only a small effect. For another example, reducing nutrient loading won't immediately cure an algae problem if the nutrients already in the lake's sediments are available to sustain the algae. A diagnostic/feasibility study will forewarn the lake manager of these possibilities and suggest the appropriate remedies.

Reservoirs are extremely difficult to protect and therefore to improve (Cooke et al. 1986; Cooke and Kennedy, 1989). Reservoirs have features not usually found with natural lakes that can interfere with any restoration project. Reservoirs usually have a very large drainage basin, possibly covering several social or political units. In some areas, reservoirs commonly have a drainage basin with extensive areas of agricultural nonpoint nutrient, silt, and organic matter discharges, making loadings very high and the probability of improvement in stream quality low. As noted in Chapter 2, reservoirs are usually dominated by a single, high-volume, source stream. This stream may not only carry a heavy load of silt, organic matter, and nutrients but may also wash out reservoir restoration treatments, such as phosphorus inactivation, or reintroduce undesirable organisms. Reservoirs can also have extensive areas of shallow water with dense weed beds and high sediment nutrient release rates.

The current uses of the lake or reservoir, or those planned for it, may be incompatible with the implementation of some restoration techniques or may be inconsistent with achievable improvements. For example, potable water supplies must be treated with great care. Not only are most herbicides banned from water supplies, but some restoration procedures such as sediment removal may require expensive, special equipment to protect raw potable water quality.

Sometimes limited, specialized uses of a lake or reservoir can make successful management more likely. For example, weed control alone might suffice for a boating-fishing-waterskiing lake if algal blooms do not interfere with these uses. The answer might be found in a management program of harvesting or herbicide treatment. If the lake is also used for swimming, however, in-lake restoration work and an expensive stream treatment or watershed management project might become necessary.

Some lakes have always been highly productive, and no amount of money or effort will make these waterbodies crystal clear and free of algae, weeds, and shoals. Some geographic areas, or "ecoregions," have richer, more erodible soils, higher annual precipitation, and more extensive human uses of the land. Loading to lakes in these regions, even without cultural influences, is high. Therefore, the goals of lake restoration must be realistically set to limits imposed by natural background incomes of substances, to the chemistry of sediments, and to certain human uses of the land.

It is also true that high lake fertility isn't always unwanted; some lakes and reservoirs are so infertile that fish productivity is low. Management of some of these lakes can include nutrient additions to stimulate algae growth and an associated development of game fish populations.

The shape of the lake's basin is an often overlooked factor. Most natural lakes are small and shallow and thus offer ideal conditions for plant growth. Those lakes may be dominated by weed-choked areas; their low volume does little to dilute nutrient loading; and their sediments offer a rich supply of nutrients to rooted macrophytes and algae. While some of these lakes can respond well to restoration efforts, a combination of procedures may be required. In other lakes, such as those that average less than 7 feet deep, the costs of deepening might be prohibitive, and other techniques might provide primarily symptomatic relief at high cost.

The words *restoration* and *management* therefore must be considered in light of both what is desired by the lake users and what is possible. In many cases, in addition to the restoration procedure, continual maintenance work will be required to maintain water quality, and often the route to long-term improvement will extend over several years while diagnostic-feasibility studies are under way and restoration procedures are successively tested and implemented. In all cases, whether involving lakes in which long-term improvement is predicted or lakes in which it is impossible, a diagnostic-feasibility study should be undertaken before deciding on one or more in-lake restoration and management procedures.

Lake and Reservoir Restoration and Management Techniques

Most of the techniques for managing and improving lakes were developed years ago, but only in the last decade have enough well-documented data been accumulated to evaluate these methods. Much of this evaluation research was supported through the U.S. Environmental Protection Agency's Clean Lakes Program and by research grants in basic and applied limnology from EPA, the National Science Foundation, and several other governmental and private agencies and corporations. The much-needed further development of our knowledge of lakes and reservoirs will require continued support by these organizations.

Six types of lake or reservoir problems are frequently encountered by lake users. These are (1) nuisance algae; (2) excessive shallowness; (3) excessive rooted plants ("weeds" or macrophytes) and their attached algae mats; (4) drinking water taste, odor, color, and organics; (5) poor fishing; and (6) acidic conditions. For each of these major problem areas, several in-lake techniques have been found to be effective, long-lasting, and generally without significant negative impact when used properly. These procedures will be described under the appropriate problem, with regard to their underlying ecological principles and mode(s) of action, effectiveness (including brief case histories), potential negative impacts, and additional benefits and costs. The reader will be referred to further reports in the basic scientific literature. The less well-studied or less-effective procedures will also be briefly described.

Basic Assumptions

The following discussions of in-lake technique effectiveness, except where explicitly stated, always assume that loadings of nutrients, silt, and organic matter to the lake have already been controlled. Most in-lake procedures will be quickly overwhelmed by continued accumulation of these substances. To repeat the theme of Chapter 5: The lake and watershed are coupled. In-lake programs can complement watershed efforts; however, such problems as algae, turbidity, and sedimentation may persist despite load reductions or diversion projects unless an in-lake procedure is also used.

As for restoration and management techniques that are not mentioned in this Manual, in nearly every case these procedures have not been described in the open scientific literature and therefore have not had the benefit of testing, discussion, explanation, and criticism that is so vital to the development of techniques of proven effectiveness and minimal negative impact. Caution should be exercised in the use of a procedure not listed here.

Problem I: Nuisance Algae

Biology of Algae

Excessive algae growth can become a serious nuisance in all aquatic habitats. Two growth forms are most troublesome in lakes: mats of filamentous algae associated with weed beds, and free-floating microscopic cells, called phytoplankton, that form green scum on the water's surface and contribute to taste and odor problems. Algae reproduce almost exclusively through cell division. When growth conditions are ideal (warm, lighted, nutrient-rich), algae multiply rapidly and reach very high densities ("blooms") in a few days.

The factors that control the abundance of phytoplankton, including blue-green algae, form the basis for attempts to manage and limit them. Frequently the quantity of algae in a lake can be shown to be directly related to the concentration of an essential plant nutrient. In many cases this element is phosphorus. Sometimes the lake and watershed can be manipulated to lower phosphorus concentration enough to limit algal growth. Some restoration techniques therefore concentrate on controlling the income of phosphorus or on curtailing phosphorus release and cycling within the lake. Compared to phosphorus, other essential plant nutrients (such as carbon and nitrogen) are very difficult to manipulate to control algal growth. However, other factors important to algal growth can be manipulated to produce long-term control, such as light. When light and other nutrients are abundant, they can be manipulated to produce long-term controls, such as artificial circulation of algal cells into deep, dark water. In other cases, particularly where nutrients cannot be manipulated, control might be achieved by encouraging populations of animals that graze on cells. All of these procedures, and others, will be described in the following paragraphs.

Filamentous algae are difficult to control. With the exception of algicide applications, procedures to accomplish this are often associated with those to control weeds and, therefore, will be discussed in the macrophyte section.

Algae—Removal Techniques with Long-Term Effectiveness

Phosphorus Precipitation and Inactivation

■ **PRINCIPLE.** The release of phosphorus stored in lake sediments can be so extensive in some lakes and reservoirs that algal blooms persist even after incoming phosphorus has been significantly lowered, as seen in the Shagawa Lake example in Chapter 4. Phosphorus precipitation removes phosphorus from the water column. Phosphorus inactivation, on the other hand, is a technique to achieve long-term control of phosphorus release from lake sediments by adding as much aluminum sulfate to the lake as possible within the limits dictated by environmental safety (see Potential Negative Impacts).

These two techniques are most effective after nutrient diversion. Both attempt to keep phosphorus concentration in the water column low enough to limit algal growth.

■ **MODE OF ACTION.** Iron, calcium, and aluminum have salts that can combine with (or sorb) inorganic phosphorus or remove phosphorus-containing particulate matter from the water column as part of a floc. Of these elements, aluminum is most often chosen because phosphorus binds tightly to its salts over a wide range of ecological conditions, including low or zero dissolved oxygen. In practice, aluminum sulfate (alum) or sodium aluminate is added to the water, and pinpoint, colloidal aggregates of aluminum hydroxide are formed. These aggregates rapidly grow into a visible, brownish floc, a precipitate that settles to the sediments in a few hours or days, carrying phosphorus sorbed to its surface and bits of organic and inorganic particulate matter in the floc. After the floc settles to the sediment surface, the water will be very clear. If enough alum is added, a layer of 1 to 2 inches of aluminum hydroxide will cover the sediments and significantly retard the release of phosphorus into the water column as an "internal load". In many lakes, assuming sufficient diversion of external nutrient loading, this will mean that algal cells will become starved for this essential nutrient. In contrast, some untreated lakes, even with adequate diversion of nutrients, will continue to have algal blooms that are sustained by sediment nutrient release.

Good candidate lakes for this procedure are those that have had nutrient diversion and have been shown, during the diagnostic-feasibility study, to have a high internal phosphorus release. Impoundments are usually not good candidates because of an inability to limit nutrients. Treatments of lakes with low doses of alum may effectively remove phosphorus (called phosphorus precipitation) but may be inadequate to provide long-term control of phosphorus release from lake sediments (phosphorus inactivation).

Dissolved inorganic phosphorus, the phosphorus form that many scientists believe algae use for growth and reproduction, sorbs tightly to this floc. After the floc falls to the bottom of the lake, it appears to continue to sorb phosphorus as it slowly settles and consolidates with the sediments, and in this way acts as a chemical barrier to phosphorus release.

It should be clearly understood that phosphorus inactivation is not similar in any way to an algicide treatment and should not be classified or regulated with them. When carried out correctly (see section on **Potential Negative Impacts**), phosphorus inactivation provides a nontoxic, long-term control of algae through nutrient limitation. Algicides, on the other hand, provide only short-term control of algae by adding a substance that is broadly toxic to many organisms in addition to the "target" organisms.

■ **EFFECTIVENESS.** Phosphorus inactivation has been highly effective and long-lasting in thermally stratified natural lakes, especially where an adequate dose has been given to the sediments and where sufficient diversion of nutrient incomes has occurred. There has been almost no experience in using this procedure in reservoirs; there it is difficult to divert nutrients, therefore treatment effectiveness might be very brief. In addition, high flows may wash the floc out or quickly cover it with another layer of nutrient-rich silt.

Successful treatments have been made to large, deep lakes as well as to the more common smaller ones and farm ponds. Treatment longevity has extended beyond 10 years in some cases and to 5 years in many. Shallow, nonstratified lakes appear to have shorter periods of treatment effectiveness than stratified lakes. In some cases, the phosphorus-sorbing floc layer has become covered with new, phosphorus-rich sediments.

Typical lake responses to alum treatment include

- Sharply lowered phosphorus concentrations
- Greatly increased transparency (and improved conditions for weeds
- Algal blooms of much reduced intensity and duration.

■ **POTENTIAL NEGATIVE IMPACTS.** The addition of aluminum salts to lakes has the potential for serious negative impacts, and care must therefore be exercised with regard to dosage. The potential for toxicity problems is directly related to the alkalinity and pH of the lake water. pH and alkalinity must be determined in the diagnostic studies (see Chapter 3) before this treatment is implemented. When alum or aluminum sulfate ($Al_2(SO_4)_3 \cdot 14\ H_2O$) is added, aluminum hydroxide ($Al(OH)_3$) is readily formed in water at pH 6 to 8. This compound is the visible precipitate or floc described earlier. However, pH and alkalinity of the water will fall during alum addition at a rate dictated by the initial alkalinity or buffering capacity of the water. In soft water, only very small doses of alum can be added before alkalinity is exhausted and the pH falls below 6. At pH 6 and below, $Al(OH)_2$ and dissolved elemental aluminum (Al^{+3}) become the dominant forms. Both can be toxic to lake species. Well-buffered, hard water lakes are therefore good candidates for this type of lake treatment because a large dose can be given to the lake without fear of creating toxic forms of aluminum. Soft water lakes must be buffered, either with sodium aluminate or carbonate-type salts, to prevent the undesirable pH shift and to generate enough $Al(OH)_3$ to control phosphorus release. Dosage is therefore lake-specific.

Another potentially negative effect of phosphorus inactivation is the sharp increase in water transparency, which may allow an existing weed infestation to spread into deeper water.

■ **COSTS.** Phosphorus inactivation, the addition of alum to lake sediments for long-term control of phosphorus release, will have a high initial cost. For example, at West Twin Lake in Ohio a 40-acre (16-ha) area of lake sediments was dosed with 100 tons of alum (Cooke et al. 1982). At current prices, that would cost about $14,000. However, labor is the real cost and is determined by the amount of chemical to be added. More rapid, less expensive application systems have been developed. It should be noted that phosphorus inactivation is a long-term treatment so that costs are amortized. Peterson (1982a) has shown that, on this basis, phosphorus inactivation is apparently less costly than sediment removal for nutrient and algal control. If a dose sufficient to simply remove phosphorus from the water column is used, initial costs could be much lower, but long-term effectiveness may be sharply reduced.

Sediment Removal

■ **PRINCIPLE.** The release of algae-stimulating nutrients from lake sediments can also be controlled by removing the layer of the most highly enriched materials. This may produce significantly lower in-lake nutrient concentrations and less algal production, assuming that there has been adequate diversion or treatment of incoming materials.

MODE OF ACTION. Several types of dredging equipment exist for use in varying circumstances; a hydraulic dredge equipped with a cutterhead is the most common choice. The cutter loosens sediments that are then transported as a slurry of 80 to 90 percent water through a pipeline that traverses the lake from the dredging site to a remote disposal area. Figures 6-1 and 6-2, from Barnard (1978), illustrate the typical dredge and its side-to-side path across the lake.

Other types of dredges, including the grab-bucket design, are used in special situations.

Normally, a permit from the U.S. Army Corps of Engineers will be required before dredging can commence, even if a private lake is involved.

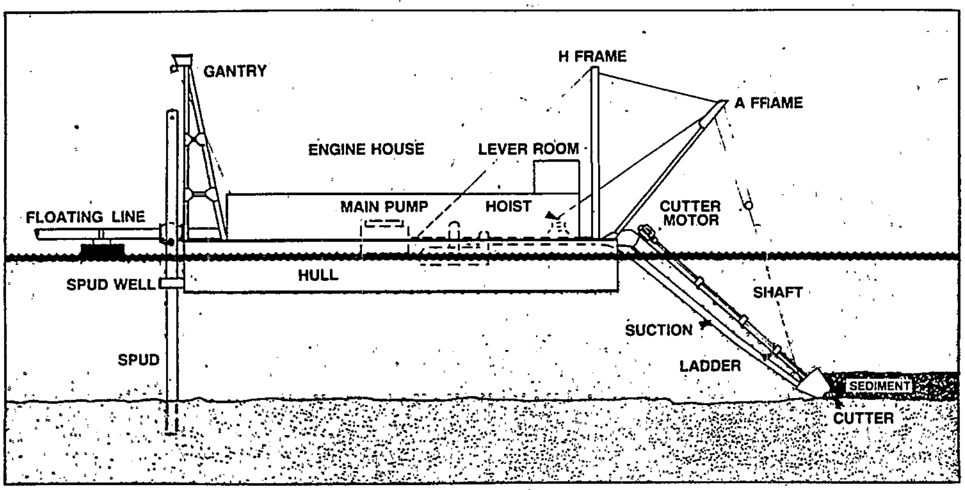


Figure 6-1.—Configuration of a typical cutterhead dredge (from Barnard, 1978).

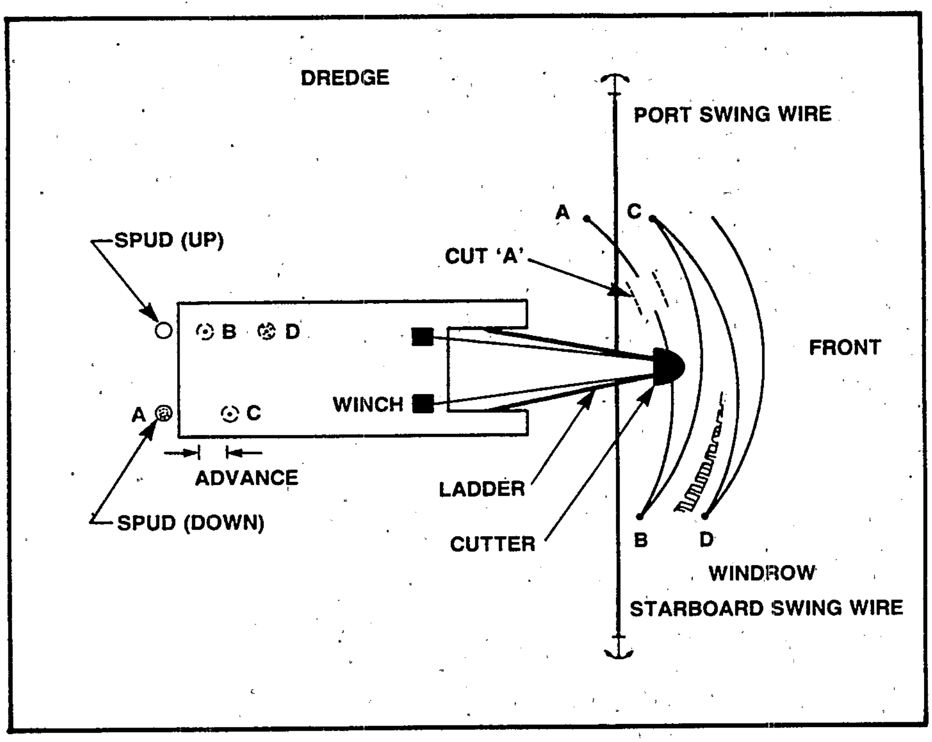


Figure 6-2.—Spud-stabbing method for forward movement and resultant patterns of the cut (from Barnard, 1978).

■ **EFFECTIVENESS.** Sediment removal to retard nutrient release can be highly effective. A good example is that of Lake Trummen in Sweden where the upper 3.3 feet of sediments were extremely rich in nutrients. This layer was removed, increasing lake mean depth from 3.6 feet to 5.8 feet, and disposed of in diked-off bays or upland ponds. Return flow from the ponds was treated with alum to remove phosphorus. The total phosphorus concentration in the lake dropped sharply and remained low for nine years (Fig. 6-3). While removing the entire nutrient-rich layer of sediment can control algae, dredging is most frequently done to deepen a lake or to remove and control macrophytes (see the section in this chapter on Macrophyte Control Techniques).

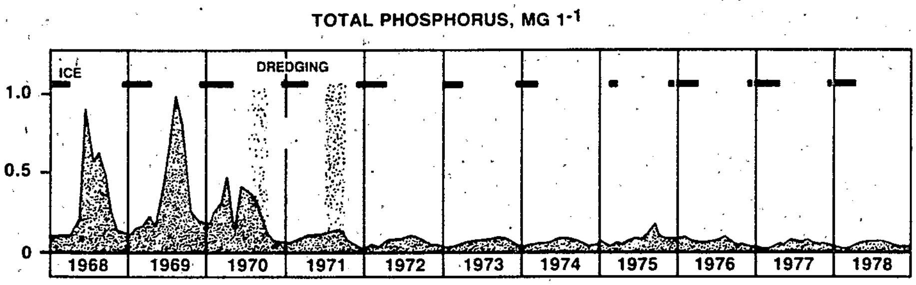


Figure 6-3.—Total phosphorus concentration in Lake Trummen, Sweden, before and after dredging (courtesy of Gunnar Anderson, Department of Limnology, University of Lund, Sweden). Shaded lines indicate period of dredging.

■ **POTENTIAL NEGATIVE IMPACTS.** The potential for serious negative impacts on the lake and surrounding area is very high. Many of these problems are short-lived, however, and can be minimized with proper planning. Among the most serious environmental problems is the failure to have a disposal area of adequate size to handle the high volume of turbid, nutrient-rich water that accompanies the sediments. Unless the sediment water slurry can be retained long enough for settling to occur, the turbid, nutrient-rich runoff water will be discharged to a stream or lake. Turbidity, algal blooms, and dissolved oxygen depletions may occur in the receiving waters. These problems may also develop in the lake during the dredging operation, but this situation is usually temporary.

Finally, an analysis of the sediments for heavy metals (particularly copper and arsenic, both of which have been extensively used as herbicides), chlorinated hydrocarbons, and other potentially toxic materials should be carried out prior to dredging. Special precautions, some of them expensive, will be required if these substances are present in high concentrations. Chapter 8 describes implementation procedures and permit procedures, which are critical to the success of a dredging project.

While the potential for negative impacts is high, proper dredge selection and disposal area design will minimize them.

■ **COSTS.** Sediment removal is expensive. Peterson (1981) reported a cost range of $0.40 per cubic yard (yd^3) to $23.35 yd^3 ($ 1988) for 64 projects and found that costs from $2 to $3 (in 1988 dollars) were common and could be considered "reasonable" for hydraulic dredging. Dredging costs are highly variable, depending upon site conditions, access, nature of the sludge, and other factors. In addition, the costs do not include disposal, transport, or monitoring. Peterson (1982a) concludes that phosphorus inactivation is somewhat less expensive than sediment removal as a method to control nutrient release.

Dilution and Flushing

■ **PRINCIPLE.** Lake waters that have low concentrations of an essential nutrient are unlikely to exhibit algal blooms. While the ideal is to divert or treat nutrient-rich waters before they empty into the lake, it is possible to lower the concentration of nutrients within the lake and flush out algal cells by adding sufficient quantities of nutrient-poor water (dilution) from some additional source. High amounts of additional water, whether low in nutrients or not, can also be used to flush algae out from the lake faster than they grow.

■ **MODE OF ACTION.** Phosphorus is often the nutrient that limits algal growth. Its concentration in lake water is a function of its concentration in incoming water, the flushing rate or residence time of the lake, and the net amount lost to the sediments as particles settle during water passage through the system. When water low in phosphorus is added to the inflow, the actual phosphorus loading will increase, but the mean phosphorus concentration will decrease, depending upon initial flushing rate and inflow concentration. Concentration will also be affected by the degree to which loss of phosphorus to sediments decreases and counters the dilution. Lakes with low initial flushing rates are poor candidates because in-lake concentration could increase unless the dilution water is essentially devoid of phosphorus (Uttormark and Hutchins, 1980). Internal phosphorus release could further complicate the effect.

Dilution also washes out cells. These facts point out the need for a water and nutrient budget, as well as a study of basin volume, before prescribing a procedure such as this one.

Flushing can control algal biomass by cell washout; however, the flushing rate must be near the cell growth rate to be effective. Flushing rates of 10 to 15 percent of the lake volume per day are believed to sufficient.

■ **EFFECTIVENESS.** Very few documented case histories of dilution or flushing exist, in part because additional water is not often available, especially water that is low in nutrients. The best documented case of dilution is that of Moses Lake, Washington (Welch and Patmont, 1980; Cooke et al. 1986), where low-nutrient Columbia River water was diverted through the lake. Water exchange rates of 10 to 20 percent per day were achieved, and in transparency and algal blooms dramatically improved, illustrating the effectiveness of this method.

■ **POTENTIAL NEGATIVE IMPACTS.** Outlet structures must be capable of handling the added discharge; also, the increased volume released downstream could have negative effects. Water used for dilution or flushing should be tested before it is introduced to the lake to be sure that no toxics are present.

■ **COSTS.** Costs will vary greatly from site to site, depending upon the need for pumps, extensive engineering, outlet structure repair, and the proximity of the new water.

Algae — Additional Procedures for Control

None of these techniques is considered completely ineffective; however, none is well enough understood or has produced enough positive results to be considered an established and effective long-term procedure.

Artificial Circulation

Artificial circulation eliminates thermal stratification or prevents its formation, through the injection of compressed air into lake water from a pipe or ceramic diffuser at the lake's bottom (Fig. 6-4). The rising column of bubbles, if sufficiently powered, will produce lakewide mixing at a rate that eliminates temperature differences between top and bottom waters. Algal blooms may be controlled, possibly through one or more of these processes:

1. In light-limited algal communities, mixing to the lake's bottom will increase a cell's time in darkness, leading to reduced net photosynthesis.
2. Introduction of dissolved oxygen to the lake's bottom may inhibit phosphorus release from sediments, curtailing this internal nutrient source.
3. Rapid circulation and contact of water with the atmosphere, as well as the introduction of carbon dioxide-rich bottom water during the initial period of mixing, can increase the water's carbon dioxide content and lower pH, leading to a shift from blue-green algae to less noxious green algae.
4. When zooplankton that consume algae are mixed to the lake's bottom, they are less vulnerable to sight-feeding fish. If more zooplankters survive, their consumption of algal cells may also increase.

Results have varied greatly from case to case. In most instances, problems with low dissolved oxygen (which can occur with deep discharge dams, for example) have been solved. In about half the cases, and where very small temperature differences from top to bottom have been maintained all summer, algal blooms have been reduced. In other cases, phosphorus and turbidity have increased and transparency has decreased. When artificial circulation is properly used in a water supply reservoir, problems with iron and manganese can be eliminated.

Failure to achieve the desired objective may be caused by lake chemistry or equipment. 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) per acre of lake surface is required to maintain oxygen within the lake. Underdesign is a major cause of failure for this technique. This is a highly specialized area; therefore, the system should be designed by a professional who is experienced in artificial circulation. Correct air flow pressure depends on site conditions. Algae control may also depend on a particular lake's water chemistry, including its pH and alkalinity.

Costs are low and will primarily be for the compressor and installation of pipes and diffuser.

Hypolimnetic Aeration

Hypolimnetic aeration is different from artificial circulation in both objective and operation. While artificial circulation injects compressed air from a diffuser located on the lake bottom, hypolimnetic aeration most commonly employs an airlift device to bring cold hypolimnetic water (the deep, stagnant water layer) up to the surface of deep lakes. The water is aerated by contact with the atmosphere, some gases such as carbon dioxide and methane are lost, and then the water is returned to the hypolimnion (Fig. 6-5). There is no intention to destratify the lake.

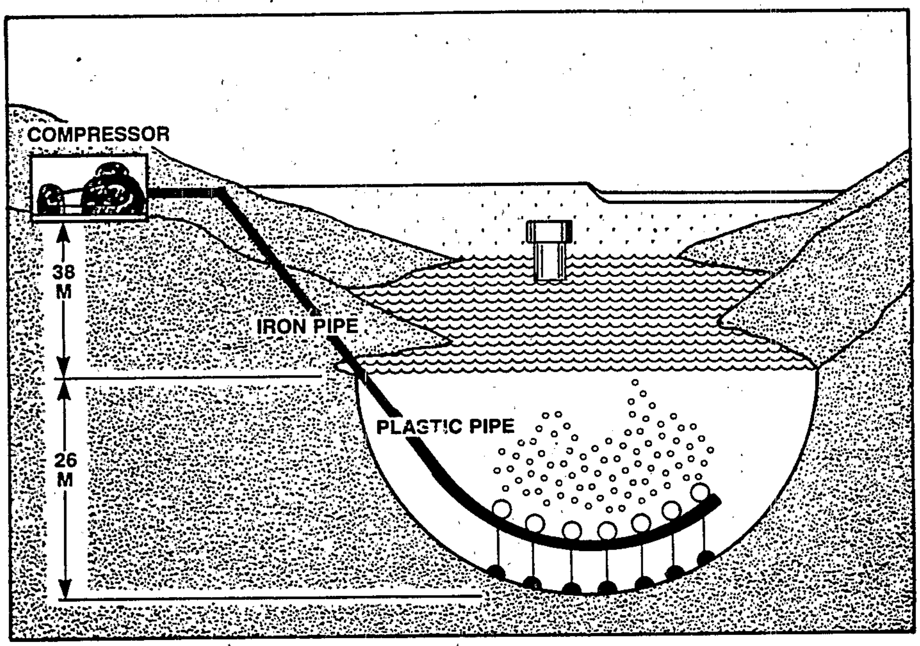


Figure 6-4.—Destratification system installed at El Capitan Reservoir, California (from Lorenzen and Fast, 1977)

A common use of this procedure is to maintain a cold water fishery in a lake where the hypolimnion is normally oxygen-free. Another use is to eliminate taste and color problems in untreated drinking water withdrawn from a hypolimnion. This is done by introducing oxygen, which will produce chemical conditions that will favor precipitation of iron and manganese, the elements most often associated with color in drinking water. Also, the procedure could be used to improve the quality of water discharged downstream from a hypolimnetic discharge.

There is little documentation of its successful use in controlling nuisance algae, although there is evidence that hypolimnetic aeration can control phosphorus release from lake sediments by promoting its combination with iron. Iron additions to the hypolimnion during aeration could enhance phosphorus removal and thereby control internal phosphorus release. Hypolimnetic aeration could become a type of phosphorus inactivation procedure under high oxygen, high iron conditions, and in this way may promote some control of algae. A case history describing use of hypolimnetic aeration to effectively improve raw drinking water and reduce algal abundance is given by Walker et al. (1989).

Hypolimnetic aerators need a large hypolimnion to work properly; consequently, any use of these aerators in shallow lakes and reservoirs should be done cautiously, if at all.

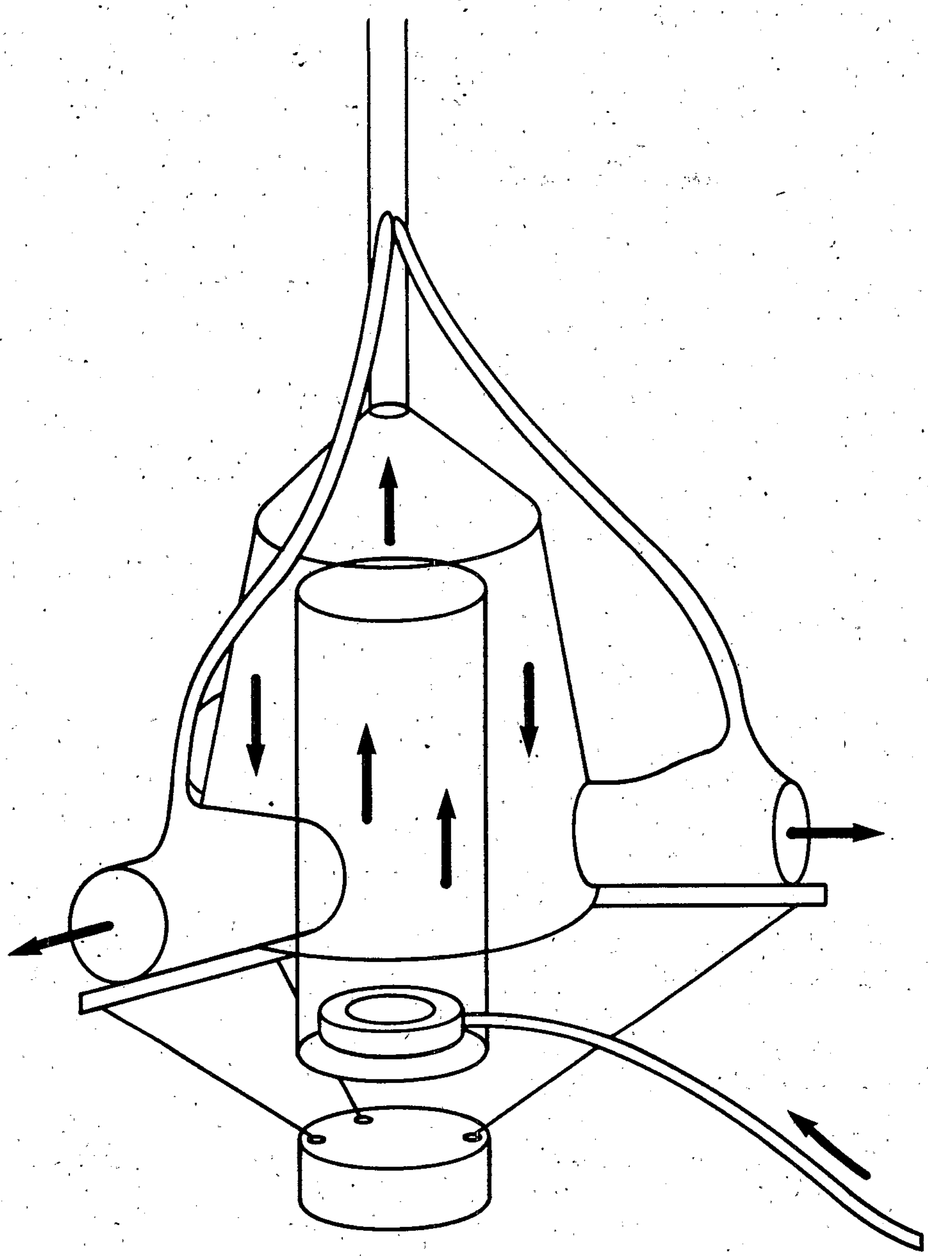


Figure 6-5.—Aqua Technique's Limno partial air-lift hypolimnetic aerator. The arrows indicate the direction of air flow. (Courtesy of Aqua Technique.)

Costs of hypolimnetic aeration are dictated by the amount of compressed air needed (a function of hypolimnion area, the rate of oxygen consumption in the lake, and the degree of thermal stratification). A procedure for calculating this is presented in Kortmann (1989).

Hypolimnetic Withdrawal

The cold, deep layers of a thermally stratified eutrophic lake or reservoir may have higher nutrient concentrations than upper layer waters. Any vertical entrainment of this water to the epilimnion will introduce nutrients to it and possibly trigger an algal bloom. This can happen naturally during the passage of a cold front and during spring and fall turnover periods. The objective of hypolimnetic withdrawal is to remove this nutrient-rich, oxygen-free water either through a deep outlet in the dam or by a siphon, thereby accelerating the lake's phosphorus loss and perhaps producing a decrease in phosphorus concentration in surface waters. There are, however, few documented case histories of this procedure (Nurnberg, 1987).

Serious negative impacts are possible. The discharge water may be of poor quality and therefore may require aeration or other treatment. State or Federal regulatory agencies may require a permit to discharge this water. Also, hypolimnetic withdrawal could produce thermal instability and thus destratification that could introduce nutrient-rich, anoxic water to the epilimnion, triggering an algal bloom. However, it is unlikely that there would be negative effects to biota.

Costs should be comparatively low and would involve a capital outlay for pump, pipe, and an aeration device.

Sediment Oxidation

This is a recent and highly experimental procedure (Ripl, 1976). The procedure's goal is to decrease phosphorus release from sediments, as with phosphorus inactivation. If sediments are low in iron, ferric chloride is added to enhance phosphorus precipitation. Lime is also added to bring sediment pH to 7.0-7.5, the optimum pH for denitrification. Then calcium nitrate is injected into the top 10 inches of sediments to promote the oxidation or breakdown of organic matter and denitrification. The entire procedure is often called RIPLOX after its originator, W. Ripl.

Lake Lillesjon, a 10.5-acre Swedish lake with a 6.6 foot mean depth, was the first to be treated. The procedure cost $112,000, primarily for equipment development and the preliminary investigation; chemical costs were about $7,000. The treatment lowered sediment phosphorus release dramatically and lasted at least two years. A portion of a Minnesota lake was also treated, but high external loading overwhelmed the effects. No negative impacts have been reported, however.

Food Web Manipulation

Shapiro et al. (1975) were the first to suggest a group of procedures, called "biomanipulation," that they believed could greatly improve lake quality without the use of expensive machines and chemicals. The following paragraphs describe their ideas.

In some lakes the amount of algae in the open water is controlled at times by grazing zooplankton rather than by the quantity of nutrients. Zooplankters are microscopic, crustacean animals found in every lake that can, as a community of several species, filter up to the entire epilimnion each day during the summer as they graze on algae, bacteria, and bits of organic matter.

The most efficient zooplankton grazers—that remove more particles over the widest range of particle sizes—are the largest-sized species. In some lakes, such as subtropical lakes in Florida, the large-bodied zooplankton species do not occur. In other lakes, large zooplankton are preferentially eaten by certain fish, including the fry of nearly every fish species and the adults of bluegill, pumpkinseed, perch, shad, and others. In lakes dominated by adults of carnivorous species such as largemouth bass, walleye, and northern pike, large-bodied zooplankton are more likely to survive because the populations of their predators have been reduced. Abundance of some species of algae will thus be reduced because grazing zooplankters can proliferate under these circumstances. Conversely, grazing on algae may be severely reduced in lakes dominated by zooplankton-eating fish, and thus there could be more extensive algal blooms.

This type of algal control by animals in the food chain is "top-down" control and differs from our usual conception of "bottom-up" algal control through nutrient limitation. Figures 6-6 and 6-7 are pictorial models of these food web interactions.

The density of zooplankton-eating fish can be reduced through the use of fish poisons, water level drawdown, winterkill, or by limiting them by stocking pred-

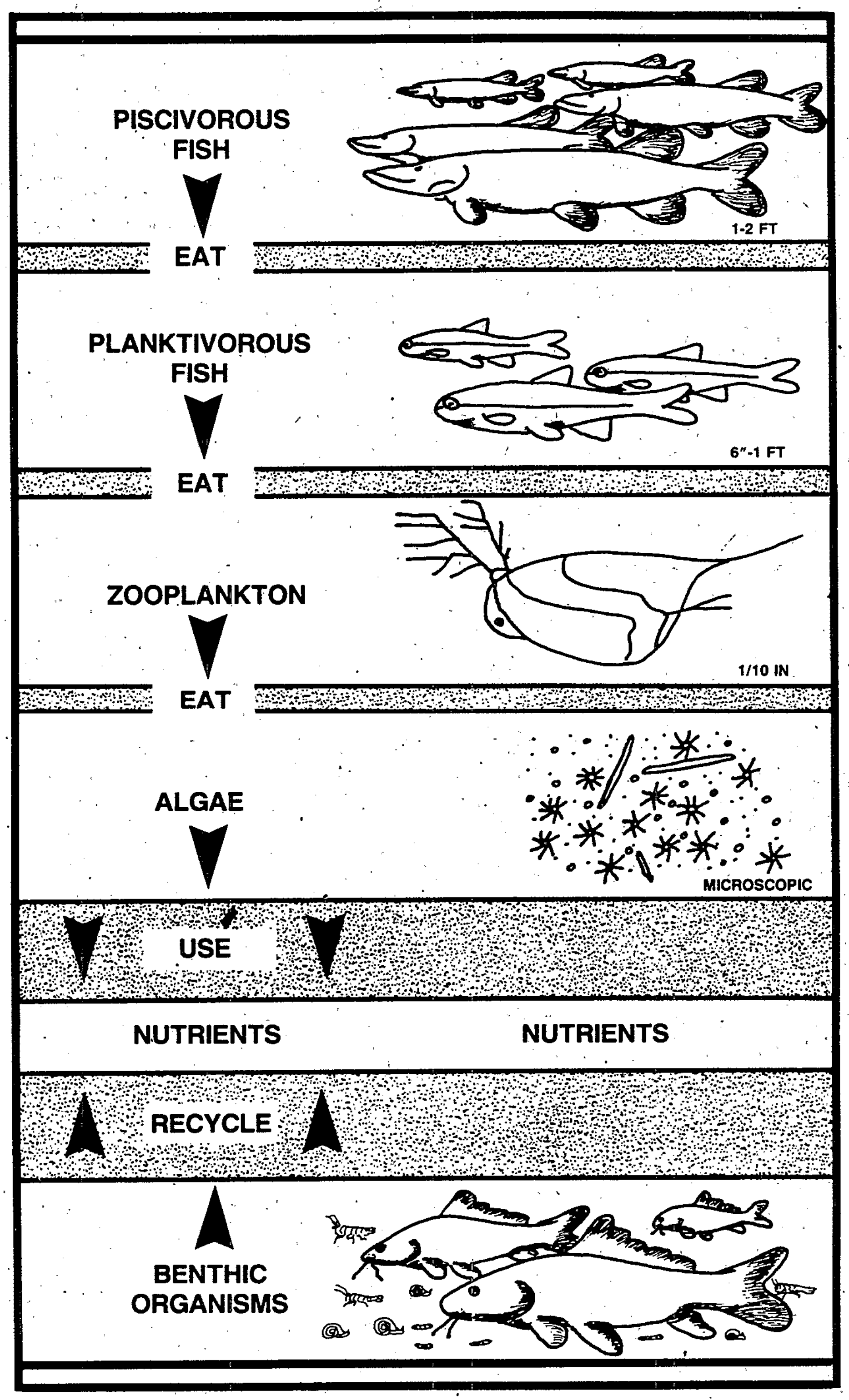


Figure 6-6.—The aquatic food chain.

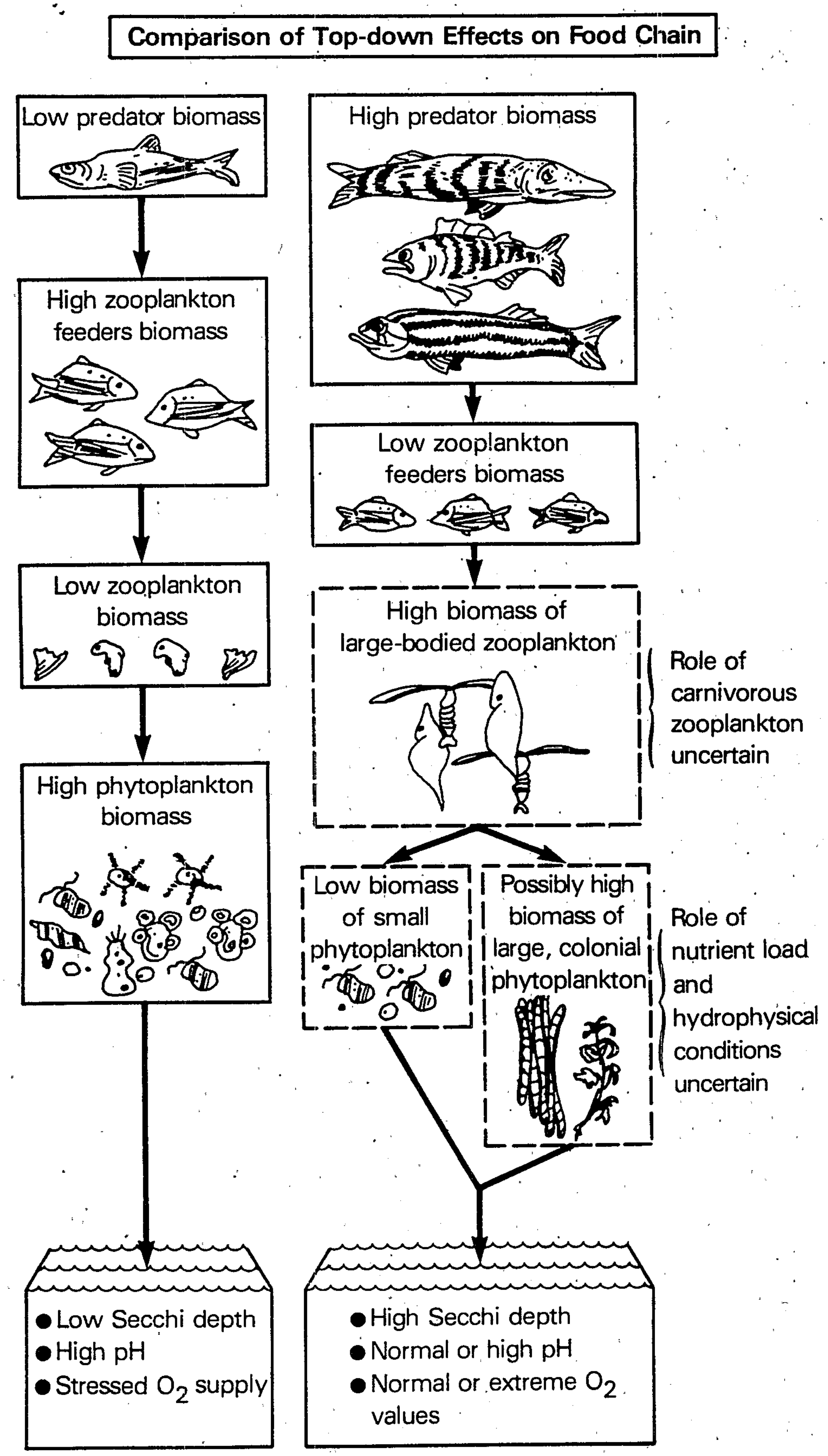


Figure 6-7.—Hypothetical scheme showing the connections involved in biomanipulation.

atory fish. However, addition of predators, such as walleyes, may not produce any measurable "top-down" control of algae when nutrient loading is high or when the algae are dominated by inedible species, such as certain blue-green algae. Allowing anglers to remove stocked predatory fish may make little ecological sense where clear water is desired. It also makes poor ecological sense to stock a lake with zooplankton-eating fish (such as gizzard shad) when clear water is a management goal. However, in lakes where sport fishing is the first priority, a planktivorous fish such as the gizzard shad is an essential foodweb link between production occurring at lower and higher trophic levels (see Fig. 2-10). The beneficial effects of controlling the density of stunted panfish are strong enough, nevertheless, to warrant these lake management projects, especially on small lakes.

Other conditions that might affect the population of zooplankton grazing on algae include an oxygen-free hypolimnion, common in eutrophic lakes, that eliminates this zone as a daytime refuge of zooplankton from sight-feeding fish and thus enhances zooplankton mortality. An aeration device might eliminate this problem. Another cause of zooplankton mortality is the toxic effects of pesticides that enter the lake with agricultural runoff. The use of copper sulfate for temporary algal control can also produce significant zooplankton mortality at doses far below those needed for algae. Severe mortality of zooplankton could explain the common "rebound" of algae following a copper treatment. Figure 6-7, from Benndorf et al. (1984), summarizes food web management.

Yet another type of biomanipulation that could improve lake transparency is elimination of fish such as the common carp or bullheads that are bottom browsers. Browsing has been shown to release significant amounts of nutrients to the water column as these fish feed and digest food. Removing such fish, however, is exceedingly difficult since they tolerate very low levels of dissolved oxygen and high doses of fish poisons.

Costs of biomanipulation are not known. Fish poisons are expensive and in many cases would entail an expensive cleanup of dead fish. The cost of restructuring a food web through enhancement of a predatory fish population will, of course, be specific to each lake. Because of the high interest in fish and fishing at most lakes, significant volunteer labor and expertise might be available. State fish and game personnel would be an excellent resource for stocking densities and species likely to survive in any given area.

Algicides

Copper sulfate ($CuSO_4$) is the most widely employed algicidal chemical. It is registered for use in potable waters, although restrictions apply in some States. Simazine is also extensively used to control algae.

Copper inhibits algal photosynthesis and alters nitrogen metabolism. In practice, copper sulfate is applied by towing burlap or nylon bags filled with granules (which dissolve) behind a boat. In alkaline waters (150 mg $CaCO_3$ (calcium carbonate) per liter, or more) or in waters high in organic matter, copper can be quickly lost from solution and thus rendered ineffective. In these cases, a liquid chelated form is often used. This formulation allows the copper to remain dissolved in the water long enough to kill algae. Both planktonic algae, including nuisance blue-green species, and species forming filamentous mats in weed beds or on the bottom will be killed by doses of 1-2 mg $CuSO_4$/L (0.8 milligrams of copper per liter (mg Cu/L)). A review of dose, effectiveness, and environmental impacts is found in Cooke and Carlson (1989).

Copper sulfate is often effective, although the response may be brief and require additional applications. There are several undesirable impacts, and it is not a lake restoration agent since no causes of the problem are addressed. Negative impacts include toxicity to fish and dissolved oxygen depletions when overly large areas are treated within a short period of time. Hanson and Stefan (1984) report that 58 years of copper sulfate use in a group of Minnesota lakes, while effective at times for the temporary control of algae, appears to have produced dissolved oxygen depletions, increased internal nutrient cycling, occasional fishkills, copper accumulation in sediments, increased tolerance to copper by some nuisance blue-green algae, and undesirable effects to fish and the fish-food community. They conclude that short-term control (days) of algae has been traded for long-term degradation of the lakes.

Costs of algicides are related to dose, to longevity of effect, and to applicator fees. The usual dose of granular copper sulfate for control of planktonic algae is about 5.4 pounds per acre-foot of water. An acre-foot is an acre of water 1 foot deep. The most commonly used chelated products are applied at 0.6 gallons per acre-foot. Current prices for chemicals are about $6 per acre-foot for granular copper sulfate at a dose of 5.4 pounds per acre-foot, and $22 per acre-foot of a chelated product at a dose of 0.6 gallons per acre-foot. Application procedures are more rapid for the liquid chelated form, and there have been claims that its effect on algae will last longer than granular copper sulfate, suggesting that annualized costs for use of the chelated form, especially in hard water lakes, may be similar to the granular form. Fees of the licensed, insured applicator are not included here.

Algae—Summary of Restoration and Management Techniques

Table 6-1 summarizes the procedures described in the preceding sections. Qualitative evaluation of the procedures with regard to short- and long-term effectiveness, costs, and potential negative impacts are presented. These judgments are the consensus of a panel of 12 lake and reservoir restoration experts.

Table 6–1.—Comparison of lake restoration and management techniques for control of nuisance algae.

TREATMENT (ONE APPLICATION)	SHORT-TERM EFFECT	LONG-TERM EFFECT	COST	CHANCE OF NEGATIVE EFFECTS
Phosphorus Inactivation	E	E	G	L
Dredging	F	E	P	F
Dilution	G	G	F	L
Flushing	F	F	F	L
Artificial Circulation	G	?	G	F
Hypolimnetic Aeration	F	?	G	F
Sediment Oxidation	G	E	F	?
Algicides	G	P	G	H
Food Chain Manipulation	?	?	E	?
Rough Fish Removal	G	P	E	?
Hypolimnetic Withdrawal	G	G	G	F

E = Excellent F = Fair
G = Good P = Poor
H = High L = Low

Problem II: Excessive Shallowness

The incomes of silt and organic matter from agricultural erosion, construction, shoreline collapse, urban drainage, and other sources can rapidly increase the area of very shallow water. Not only can this interfere with recreational activities such as boating, but shallow, nutrient-rich sediments are ideal areas for growth of nuisance aquatic plants.

Sediment removal, outlined earlier in this chapter, is the only practical way to bring about lake or reservoir improvement when shoaling is a problem. Therefore, dredging has become one of the most frequently prescribed techniques. A properly designed feasibility study of the lake and disposal sites is an essential first step, and, in nearly all cases, a permit from the U.S. Army Corps of Engineers will be required. Dredging projects are expensive and can have severe negative impacts unless correctly designed, but they are often highly effective. Continual incomes of silt will return the lake to its predredged condition; therefore, silt sources should be controlled. The reader is referred to Cooke et al. (1986), Cooke and Kennedy (1989) and Cooke and Carlson (1989) for detailed descriptions about dredge selection, disposal area design, and case histories.

Problem III: Nuisance Weeds (Macrophytes)

Biology of Macrophytes

Overabundant rooted and floating plants are a major nuisance to lake and reservoir users. In extreme cases, particularly in ponds and in shallow, warm, well-lighted lakes and waterways of the southern United States, weeds (sometimes called macrophytes) can cover the entire lake surface. Weeds obviously interfere with recreation and detract from a lake's aesthetic values. They can also introduce significant quantities of nutrients and organic matter to the water column, perhaps stimulating algal blooms and raising dissolved oxygen consumption.

Macrophytes are generally grouped into classes called emergents (represented by alligatorweed and cattails), floating-leaved (water hyacinth and water lilies), and submergents (hydrilla and pondweeds), plus the mats of filamentous algae that develop in weed beds. Understanding the factors that control weed growth is the first step in controlling weeds.

Macrophytes reproduce both by producing flowers and seeds and by asexual propagation from fragments and shoots extending from roots. Growth rates of macrophytes, especially exotic species like water hyacinth, hydrilla, and milfoil, can be very high.

Submergent plants will grow profusely only where underwater illumination is sufficient. Steep-sided lakes therefore support a much smaller development of common nuisance weeds because most of the sediments are too dark or too deep. Similarly, turbid lakes and reservoirs are unlikely to have dense beds of submerged plants. Thus, high silt incomes to a lake can create a favorable weed habitat as the lake fills in, unless the silt loading also creates severe turbidity. Significant reductions in algal blooms can also enhance light penetration and allow weeds to grow better.

Since most macrophytes obtain their nutrients via roots, they can therefore be abundant in lakes in which nutrient concentration of the water column has been reduced through diversion. When the sediments are either highly organic or inorganic (sand), macrophyte growth may be poor because it is more difficult for roots to obtain nutrients in these sediment types. In these two extremes, emergent plants may replace submergents because their more extensive root systems are better adapted to these conditions.

Texas, Louisiana, Alabama, Georgia, and especially the sub-tropical environment of Florida have lakes, reservoirs, ponds, waterways, and streams that are infested with exotic plants such as hydrilla, water hyacinth, and alligatorweed—plants that are severe economic and recreational nuisances. In Florida, plants grow throughout most of the year, often at incredible rates, so dense amounts of plants will be found. Aquatic plant management in these ecosystems often requires methods that might seem extreme in northern ecosystems.

No native animals have been found that graze on macrophytes at rates sufficient to control them. Biological controls, therefore, are confined to exotic animals.

For years macrophytes have been managed through cutting or herbicides. The development of alternative procedures to produce long-term control has lagged far behind, in part because we have, until recently, understood very little about macrophyte physiology and the environmental factors that control their growth. The following paragraphs briefly describe the procedures known to produce long-term control. Since short-term management techniques are likely to continue to be used, for example in southern waters or during implementation of a longer-term treatment, these are described in a separate section.

Macrophytes—Long-Term Control Techniques

Sediment Removal and Sediment Tilling

■ **PRINCIPLE.** Sediment removal can limit submerged weed growth through deepening, thereby limiting light, or by removing sediments favorable to growth and leaving sand. Both dredging and rototilling remove roots and thereby limit plant growth.

■ **MODE OF ACTION.** Sediment removal was described in some detail in earlier paragraphs on algal control. The amount of sediments removed, and hence the new depth and associated light penetration, is critical to successful long-term control of rooted, submerged plants. There appears to be a direct relation between water transparency, as simply determined with a Secchi disk, and the maximum depth of colonization (MDC) by macrophytes. Canfield et al. (1985) provide these equations to estimate MDC in Florida and Wisconsin from Secchi disk measurements:

STATE	EQUATION
Florida	log MDC = 0.42 log SD + 0.41
Wisconsin	log MDC = 0.79 log SD + 0.25

where SD = Secchi depth in meters

For example, suppose the Secchi transparency of a Florida lake is usually about 6 feet. How far from shore can we expect to find rooted macrophytes (the MDC)? A handheld calculator can be used to obtain the answer, which will suggest how deep nearshore areas would have to be to have minimal quantities of rooted, submerged macrophytes. In this case, transform 6 feet to meters (feet x 0.305 = meters). This will be 1.83 meters. The log of 1.83 is 0.26. Then substitute this in the equation for a Florida lake, as follows:

$$\begin{aligned} \log MDC &= (0.42 \times \log 1.83) + 0.41 \\ &= (0.42 \times 0.26) + 0.41 \\ &= 0.52 \end{aligned}$$

To obtain depth (MDC) in meters use the calculator to find the antilog of 0.52 = 3.31 meters. To convert meters to feet, multiply this answer by 3.28 = 10.9 feet. This means that for a Florida lake with a Secchi disk transparency of about 6 feet, we would expect some submerged weeds in 11 feet of water and more weeds in progressively shallower water. In this example, very large amounts of sediments might have to be removed to create large areas of the lake with depths of 10 to 11 feet. Examination of a bathymetric map (see Fig. 3-9) will indicate whether this is the case. The equation also indicates that actions that greatly improve water clarity, such as erosion control or phosphorus inactivation, may enhance weed distribution and abundance. This may be particularly true in the case of hydrilla, a nuisance exotic plant in southern waters. Hydrilla can grow at lower light intensities than native plants, making control through deepening an expensive and perhaps impossible task.

Rototilling and the use of cultivation equipment are newer procedures presently under development and testing by the British Columbia Ministry of Environment (Newroth and Soar, 1986). A rototiller is a barge-like machine with a hydraulically operated tillage device that can be lowered to depths of 10 to 12 feet (3 to 4 meters) for the purpose of tearing out roots. Also, if the water level in the lake can be drawn down, cultivation equipment pulled behind tractors on firm sediments can achieve 90 percent root removal.

■ **EFFECTIVENESS.** The use of sediment removal for long-term control of macrophytes is effective when the source of sediments is controlled. Dredging below the lake's photic zone will prevent macrophyte growth. The cost of dredging, however, often places the use of this technique in doubt. Rototilling to remove watermilfoil may be as effective as three to four harvesting operations.

■ **POTENTIAL NEGATIVE IMPACTS.** The negative impacts of sediment removal have already been discussed under algal control.

■ **COSTS.** Costs were described earlier under algal control. Newroth and Soar (1986) have studied costs of the rototiller and amphibious cultivator and found them to be similar to herbicides and harvesting, but operation speed is slower.

Water Level Drawdown

PRINCIPLE AND MODE OF ACTION. Exposing sediments to prolonged freezing and drying provides an opportunity to carry out several management procedures. Some rooted plant species are permanently damaged by these conditions and the entire plant, including roots and perhaps seeds, is killed if exposed to freezing for two to four weeks. Other species, however, are either unaffected or enhanced. Drawdown also allows repair of dams and docks, fish management, sediment removal, and installation of sediment covers to control plant growth.

EFFECTIVENESS. Cooke et al. (1986) summarize the responses of 74 aquatic plants to drawdown. Table 6-2 lists the responses of some common species.

Many case histories exist, and they illustrate three important facts:

1. Freezing and desiccation are required; wet, cold lake sediments or wet sediments covered with snow may have little negative effect on plants.
2. The technique is species-specific.
3. Successful drawdown–freezing operations should be alternated every two years with no drawdown so that resistant species do not become firmly established.

Table 6–2.—Responses of common aquatic plants to drawdown

DECREASE
Coontail (*Ceratophyllum demersum*)
Brazilian elodea (*Elodea = Egeria densa*)
Milfoil (*Myriophyllum* spp.)
Southern naiad (*Najas guadalupensis*)
Yellow Water Lily (*Nuphar lutea*)
Water Lily (*Nymphaea* spp.)
Robbin's Pondweed (*Potamogeton robbinsii*)
INCREASE
Alligator Weed (*Alternanthera philoxeroides*)
Hydrilla (*Hydrilla verticillata*)
Bushy Pondweed (*Najas flexilis*)
VARIABLE
Water Hyacinth (*Eichhornia crassipes*)
Common Elodea (*Elodea canadensis*)
Cattail (*Typha latifolia*)

Two case histories illustrate these points. Beard (1973) describes winter drawdown of Murphy Flowage, Wisconsin. Before drawdown, 75 acres were closed in spring and summer to fishing because of a dense infestation of pondweeds (*Potamogeton robbinsii, P. amplifolius*), coontail, Eurasian watermilfoil, and water lily. Drawdown opened 64 acres, and although some resistant plants increased, fishing improved. Geiger (1983) used winter drawdown in an attempt to control Eurasian watermilfoil in an Oregon lake. The mild, wet winter of the Pacific Northwest did not provide sufficient freezing; the weeds increased and had to be treated with 2,4-D.

POTENTIAL NEGATIVE IMPACTS. Algal blooms have occurred after some drawdowns. The causes are unclear but may be related to nutrient release from sediments or to an absence of competition from weeds. The most significant problem with drawdown can be loss of use of the lake.

Drying and freezing can sharply reduce the abundance of benthic invertebrates essential to fish diets. Also, oxygen can be depleted in the remaining water pool can occur, leading to a fishkill. Dissolved oxygen should be monitored in small-volume systems, and an aerator should be installed if needed.

■ **COSTS.** If the lake is controlled by a dam with drawdown capability, expenditures will be minimal. Additional costs are associated with losing the use of the lake.

Shading and Sediment Covers

The use of dyes in the water and coverings on the water surface to limit the light available to plants and the application of plastic sheets over the sediments to stop plant growth are prompted by the well-known facts that rooted plants require light and cannot grow through physical barriers. Applications of silt, sand, clay, and gravel have also been used, although plants sooner or later can root in them.

Sediment covering materials, such as polyethylene, polypropylene, fiberglass, and nylon can be used in small areas such as dock spaces and swimming beaches to completely terminate plant growth. Large areas are not often treated because the costs of materials and application are high.

■ **EFFECTIVENESS.** Engel (1982) lists the advantages of sediment covers according to their use:

1. Use is confined to a specific area.
2. Screens are out of sight and create no disturbance on shore.
3. They can be installed in areas where harvesters and spray boats cannot reach.
4. No toxics are used.
5. They are easy to install over small areas.

And these disadvantages:

1. They do not correct the cause of the problem.
2. They are expensive.
3. They are difficult to apply over large areas or over obstructions.
4. They may slip on steep grades or float to the surface after trapping gases beneath them.
5. They can be difficult to remove or relocate.
6. They may tear during application.
7. Some materials are degraded by sunlight.
8. A permit may be required.

Successful use is related to selection of materials and to the quality of the application. The most effective materials are gas-permeable screens such as Aquascreen (fiberglass), polypropylene, Dartek (nylon), and to a lesser extent, common burlap. Polyethylene and synthetic rubber trap gases beneath them. Proper application requires that the screens be placed flush with the sediment surface and staked or securely anchored. This is difficult to accomplish over heavy plant growth, therefore spring or winter drawdown are ideal times for application. Scuba divers apply the covers in deep water, which greatly increases costs. Depending upon siltation rate, sediment covers will accumulate deposits, which allows plant fragments to root. Screens then must be removed and cleaned.

Surface shading has received little attention. Polyethylene sheets, floated on the lake surface, were used by Mayhew and Runkel (1962) to shade weeds. They found that two to three weeks of cover were sufficient to eliminate all species of *Potamogeton* for the summer if the sheets were applied in spring before plants grew to maturity. Coontail was also controlled but *Chara* was not. This procedure may be a useful alternative to traditional methods of weed control in small areas such as docks and beaches.

Dyes have been applied to small areas such as ponds to light-limit algae and weeds.

■ **POTENTIAL NEGATIVE IMPACTS.** Negative features of sediment covers appear to be few. Benthic invertebrates may be eliminated (Engel, 1982), but dissolved oxygen depletions have not been a problem.

■ **COSTS.** Table 6-3, modified from Cooke and Kennedy (1989), summarizes costs of some sediment-covering materials. These costs do not include application fees.

Table 6–3.—Characteristics of some sediment covering material (revised from Cooke and Kennedy, 1989).

MATERIAL	SPECIFIC GRAVITY	COST	APPLICATION DIFFICULTY	GAS PERMEABILITY	COMMENTS
1. Black Polyethylene	0.95	$1.860 acre	High	Impermeable	Poor choice of materials. easily dislodged: "balloons"
2. Polypropyl (Typar)	0.90	$3.240 acre	Low	Permeable	Effective
3. Fiberglass-PVC (Aquascreen)	2.54	$8.700 acre	Low	Permeable	Effective
4. Nylon (Dartek)	1.0	$3.240 acre	Moderate	Impermeable	Effective if vented
5. Burlap	1.0	$1.375 acre	Moderate	Permeable	Effective up to 1 season: rots
6. Nylon-Silicone	1.5	$65.475 acre	?	Impermeable	Must be installed by dealer

Biological Controls

■ **PRINCIPLE.** Significant improvement in our future ability to achieve lasting control of nuisance aquatic vegetation in many areas of North America may come from use of plant-eating or plant pathogenic biocontrol organisms or from a combination of current procedures such as harvesting, drawdown, and herbicides with these organisms. Biological control has the objective of achieving long-term control of plants without introducing expensive machinery or toxic chemicals.

■ MODE OF ACTION

GRASS CARP (*Ctenopharyngodon idella* Val.): Grass carp are an exotic fish (imported originally from Malaysia to the United States in 1962) known to be voracious consumers of macrophytes. They have very high growth rates (about 6 pounds, or 2.5 kg per year at the maximum rate; Smith and Shireman, 1983). This combination of broad diet and high growth rate can produce control, or more likely, eradicate the plants within several seasons.

Grass carp do not consume aquatic plant species equally readily. Generally, they avoid alligatorweed, water hyacinth, cattails, spatterdock, and water lily. The fish prefer plant species that include elodea, pondweeds (*Potamogeton* spp.), and hydrilla. Low stocking densities can produce selective grazing on the preferred plant species while other less preferred species, including milfoil, may even increase. Overstocking, on the other hand, will eliminate the weeds. Feeding preferences are listed in Nall and Schardt (1980), Van Dyke et al. (1984), and Cooke and Kennedy (1989).

INSECTS: Ten insect species have been imported to the United States under quarantine and have received U.S. Department of Agriculture approval for release to U.S. waters. These insects are confined to the waters of southern States, specifically to control alligatorweed and water hyacinth. At present, neither exotic nor native insects are used against northern plants.

These 10 species have life histories that are specific to the host plants and are therefore confined in their distribution to infested areas. They are also climate-limited to southern States, with the northern range being Georgia and North Carolina.

Their reproductive rates are slower than their target plants. Therefore, control is slow, although it can be enhanced by integrated techniques wherein plant densities are reduced at a site with harvesting or herbicides, and insects are concentrated on the remaining plants.

■ EFFECTIVENESS

GRASS CARP: Grass carp are used in several States (for example, Florida, Texas, Arkansas), although they remain banned for public and private use in many others. They are undergoing a thorough evaluation throughout the United States, especially the sterile triploid variety. Most studies have found that the fish are exceptionally effective in reducing or eliminating nuisance vegetation, although there have been undesirable side effects. Two case histories illustrate their use.

Martyn et al. (1986) described the introduction of diploid (able to reproduce) grass carp into Lake Conroe, Texas, a water supply impoundment for Houston. Submersed weeds occupied about 44 percent of the

20,000 acres at maximum infestation. Most plants were hydrilla (*Hydrilla verticillata*), although milfoil and coontail were also abundant. Between September 1981 and September 1982, 270,000 grass carp, 8 inches or longer, were introduced. By October 1983, all submersed plants were gone. Associated with this eradication was an increase in planktonic algae, a decrease in transparency, and an increase in open-water fish species associated with plankton. Fish associated with weed beds declined.

Van Dyke et al. (1984) studied the effects of diploid grass carp stocking in three central Florida lakes and one reservoir. Hydrilla was eliminated for six years and may have been eradicated from the lakes. Few rooted plants remain. Illinois pondweed (*Potamogeton illinoiensis)* was eliminated from the reservoir, and milfoil was greatly reduced. Control in all four sites was slowly achieved but has been long-lasting. Eurasian watermilfoil has returned to the reservoir, apparently because the carp escaped.

Grass carp have not been successful weed management agents in the sense that small numbers could be stocked to achieve a partial elimination of plants. Shireman et al. (1983) attempted to do this in Lake Pearl, Florida, by stocking carp at low densities and using some herbicides on an infestation of hydrilla. Carp were stocked at increasing rates over a two-year period while herbicide additions continued. After two years, a carp density was finally reached that had an impact on the plants, and then eradication occurred.

Stocking rates appear to vary geographically, with the type, diversity, and coverage of plants, and with the management goal. A detailed discussion of stocking rates and food preferences is found in Cooke and Kennedy (1989); State fisheries personnel can also be an excellent source of information. Lake homeowners and managers are strongly advised not to stock a lake unless competent technical advice about the specific lake has been obtained. State fisheries personnel should be contacted prior to stocking because this practice is not legal in all States (see Table 6-4).

Table 6–4.—State regulations on possession and use of grass carp (modified from Allen and Wattendorf, 1987)

A. Diploid (able to reproduce) and Triploid (sterile) permitted			
Alabama	Hawaii	Kansas	Oklahoma
Alaska	Iowa	Mississippi	New Hampshire
Arkansas	Idaho	Missouri	Tennessee
B. Only 100% Triploids permitted			
California	Illinois	New Jersey	South Carolina
Colorado	Kentucky	New Mexico	South Dakota
Florida	Montana	North Carolina	Virginia
Georgia	Nebraska	Ohio	West Virginia
C. 100% Triploids permitted for research only			
New York	Louisiana	Oregon	Wyoming
D. Grass Carp prohibited			
Arizona	Maryland	North Dakota	Utah
Connecticut	Massachusetts	Pennsylvania	Vermont
Delaware	Michigan	Rhode Island	Washington
Indiana	Minnesota	Texas	Wisconsin
Maine	Nevada		

INSECTS: Insects have proven to be highly effective in controlling alligatorweed and water hyacinth. For example, Sanders and Theriot (1986) report that the water hyacinth weevil (*Neochetina eichhorniae*) has been responsible for at least a 50 percent decrease in the water hyacinth distribution in Louisiana since 1974. Insect control has been particularly effective when combined with another plant management technique. Two case histories illustrate this point.

Center and Durden (1986) studied the effect of the water hyacinth weevil in a Florida canal. When a canal section was harvested at the peak of the growing season, both water hyacinths and weevils were severely reduced. Subsequent plant growth was much greater than the weevil population, and control was greatly delayed. Another section was sprayed with 2,4-D at season's end, allowing plants and weevils to recover simultaneously. Insect control occurred more rapidly. Chemical or mechanical control, along with insects, will be more effective if done in early fall or winter to minimize interference with the insect.

Haag (1986) studied a Florida pond completely covered with water hyacinth. Weevils (*N. eichhornia* and *N. bruchi)* were present in small numbers. About 20 percent of the pond was isolated with a barrier while the rest was sprayed with 2,4-D in monthly increments of 25 percent of the remaining pond area. Weevil density slowly increased in the isolated area and by the following year exerted 100 percent control of water hyacinth in the entire pond. Eradication allowed alligatorweed to invade, but its spread was checked by the alligatorweed flea beetle, *Agasicles hygrophila.*

This work supports the conclusion that weed eradication with herbicides, a common strategy, will also eliminate the insects and allow a prompt return of the weeds. By leaving a reservoir of weeds and by "herding" the insects to it, sufficient insect density is achieved to produce longer-term weed control.

POTENTIAL NEGATIVE IMPACTS

GRASS CARP: Grass carp can produce a major change in the structure of a lake. When these fish are overstocked, eradication of aquatic plants is almost certain, and, as a result, increases in nutrient concentrations, bluegreen algal blooms, turbidity, and also changes in fish communities. The long-term consequences of aquatic plant eradication are poorly understood, however.

The introduction of grass carp into hydrologically open systems (reservoirs, manmade ponds) has raised important questions about escape and reproduction in habitats where vegetation is desirable. While environmental requirements for successful reproduction are stringent and were once believed to be an adequate barrier to their multiplication in North American waters, grass carp have apparently reproduced in the United States. More recently, sterile triploid grass carp have been developed and are the only type of grass carp permitted in many States. While their reproduction is not possible, their escape in large numbers from a hydrologically open system, such as a reservoir, can still pose a significant threat to a downstream habitat where aquatic vegetation is desired.

INSECTS: Significant negative environmental impacts of insects have not been observed, except for changes in aquatic habitats associated with macrophyte elimination.

■ **COSTS.** Cost comparisons for biological controls are generally not yet available, but these methods do appear to be far less costly than the traditional alternatives of chemical or mechanical treatments. These latter techniques, in addition to the costs of equipment, materials, labor, and insurance, must be reapplied frequently.

Shireman (1982) and Shireman et al. (1985) report that $117,232 had been spent on endothal for the temporary control of hydrilla in Lake Baldwin, Florida. The hydrilla problem was eliminated with grass carp at a cost of $8,499 ($43 per acre). Unlike herbicide or harvesting treatments, the grass carp exert control for many years with one treatment, so that costs are amortized. By way of comparison, harvesting costs in Florida can easily be $1,000 per acre, while chemical costs in Florida range from approximately $200 to 400 per acre (Cooke and Kennedy, 1989). Harvesting and herbicide costs in northern climates are essentially the same. Also, Shireman (1982) points out that, in 1977, the cost of chemical treatment of 37,000 acres of hydrilla in Florida was $9.1 million; the cost of grass carp to provide long-term control would have been about $1.71 million if stocked at a density of 14 fish of 8 inches or longer per acre. Table 6-5 compares the costs of using harvesting, herbicides, and grass carp to manage aquatic weeds.

Table 6–5.—Cost comparisons, in 1984 dollars, of three symptomatic treatments for nuisance aquatic weeds (Florida data for grass carp).

PROCEDURE	COST RANGE	
Harvesting		
Midwest	$140–310	per acre
Florida	$310–5,200	per acre
Herbicides		
Midwest	$210–415	per acre
Florida	$210–415	per acre
Grass Carp*	$90	per acre
	(cost is also amortized due to long-term effectiveness	

*12 inch or greater fish. stocked at 14–20 per acre.

Macrophytes—Techniques with Shorter-Term Effectiveness

Harvesting

■ **PRINCIPLE.** Harvesting is a procedure to cut and remove nuisance rooted plants and associated filamentous algae. Unlike herbicide applications where plants are left in the lake to die, decompose, and release nutrients and organic matter, harvesters may have some restorative value in lakes with dense infestations and low external loading because plants and the associated organic matter and nutrients are removed. Some potable water supply systems use them to reduce the concentration of organic molecules in raw water, which, when chlorinated in the treatment plant, produce potentially carcinogenic molecules such as trihalomethanes. Harvesters can clear an area of vegetation without the post-treatment waiting period associated with herbicides and without significant danger to nontarget species.

■ **MODE OF ACTION.** The typical harvester is a highly maneuverable, low-draft barge designed with one horizontal and two vertical cutter bars, a conveyor to remove cut plants to a hold on the machine, and another conveyor to rapidly unload plants (Fig. 6-8). Some manufacturers sell shore conveyor units to assist loading from harvester to truck and high-speed barges to carry cut plants from the harvester to shore. Harvesters vary in size and storage capacity from about 200 ft^3 (6 m^3) of cut vegetation to 800 ft^3 (23 m^3). Cutting rates range from about 0.2 to 0.6 acres per hour, depending on machine size. The barge itself can be very useful with other lake improvement procedures, including alum applications.

Weed disposal is usually not a problem, in part because lakeshore residents and farmers often will use the weeds as mulch and fertilizer. Also, since aquatic plants are more than 90 percent water, their dry bulk is comparatively small.

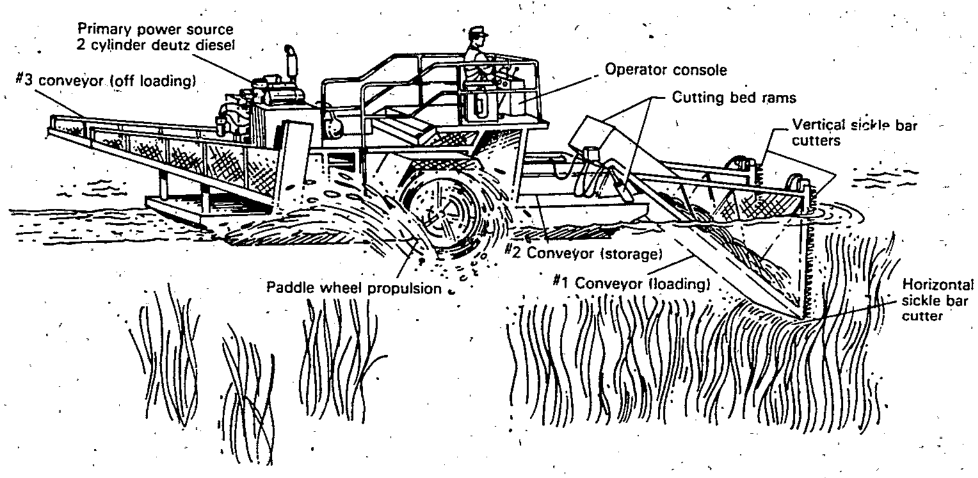


Figure 6-8.—The Aquamarine Corporation's H650 harvester. (Courtesy of Aquamarine Corporation.)

■ **EFFECTIVENESS.** Most harvesting operations are successful in producing at least temporary relief from nuisance plants and in removing organic matter and nutrients without the addition of a potentially deleterious substance. Plant regrowth can be very rapid (days or weeks), especially in southern waters where midsummer growth rates of water hyacinth can exceed the rate at which they can be harvested. Several case histories illustrate the effectiveness of harvesting in northern waters.

A bay of LaDue Reservoir (Geauga County, Ohio) was harvested in July 1982 by the traditional method in which the operator treats the weed bed like a residential lawn and simply mows the area. Stumps of Eurasian watermilfoil plants about 0.5 to 3 inches in height were left, and complete regrowth occurred in 21 days. In contrast, the slower method of lowering the cutter blade about 1 inch into the soft lake mud will produce season-long control of milfoil by tearing out roots (Conyers and Cooke, 1983). Of course this cutting technique is of little value where sediments are very stiff or in deeper water where the length of the cutter bar (usually 5 to 6 feet) cannot reach the mud. When only plant tops are cut, regrowth may be rapid. There is evidence of a carry-over effect (less growth in the subsequent year), especially if an area has had multiple harvests in one season.

Some weed species are more sensitive to harvesting than others. Nicholson (1981) has suggested that harvesting was responsible for spreading milfoil in Chautauqua Lake, New York, because the harvester spreads fragments of plants from which new growths can begin. On the other hand, he considers pondweeds to be far more susceptible because these species emphasize sexual reproduction and regenerate poorly from fragments. Harvesting therefore could mean that milfoil could replace the pondweeds.

There are few data on the actual restorative effects of harvesting, in the sense of removing significant amounts of nutrients or in reducing the release of nutrients and organic matter to the water column. If nutrient income is moderate and weed density high, as much as 40 to 60 percent of net annual phosphorus loading could be removed with intense harvesting. This would be a significant nutrient removal in many cases. Milfoil may be a large contributor of phosphorus to the water column throughout the summer, which strongly suggests that removing this plant through harvesting could curb this source of nutrients to algae. An herbicide application would leave the plants to decompose and release nutrients and organic material to the water column. On the other hand, harvesting itself can increase water column phosphorus concentration either through mechanical disturbance of sediments or by enhancing conditions for phosphorus release from sediments.

Effective use of a harvester to manage aquatic plants and to minimize regrowth during the season includes the purchase of a machine of sufficient size to handle the affected areas, the use of proper cutting techniques, and the siting of disposal areas near the areas to be harvested.

■ **POTENTIAL NEGATIVE IMPACTS.** The following are some of the possible negative effects of harvesting:

1. Cutting and removing vegetation can be energy- and labor-intensive and therefore expensive.
2. Only relatively small areas can be treated per unit time, which may create lake user dissatisfaction.
3. A high capital outlay for equipment is required.
4. Plants may fragment and spread the infestation.
5. Small fish may be removed.
6. Operating depths are limited.
7. Favorable weather is required.
8. Machine breakdown can be frequent, especially if an undersized piece of equipment is purchased.

■ **COSTS.** Harvesting costs in the Midwest have ranged from $140 to $310 per acre when costs from extreme situations are omitted (Table 6-5), making the technique somewhat less expensive than herbicide treatments; costs in

Florida have routinely exceeded $1,000 per acre. Expenditures of a particular project will be for machine cost, labor, fuel, insurance, disposal charges, and the amount of downtime. Estimates of manpower time and costs can be obtained from the HARVEST model developed by the U.S. Army Corps of Engineers (Hutto and Sabol, 1986), which runs on a personal computer. The program is available from the program manager of the Aquatic Plant Control Research Program at the U.S. Army Engineers Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39181-0631.

Herbicides

■ **PRINCIPLE AND MODE OF ACTION.** Poisoning nuisance aquatic weeds is perhaps the oldest method used to attempt their management. Few alternatives to herbicides existed until recently. The pesticide industry has grown and has been more carefully regulated so that some of the most dangerous and toxic herbicides, such as sodium arsenite, have been replaced with chemicals that have much lower toxicity to nontarget biota and leave degradable residues.

An herbicide treatment can be an effective short-term management procedure to produce a rapid reduction in vegetation for periods of weeks to months. Pesticide use cannot be equated with lake restoration, since causes of the weed problem are not addressed nor are nutrients or organic matter removed. Plants are left to die and decompose. New plants will shortly regrow, sometimes to densities greater than before.

The use of herbicides remains controversial and emotion-charged, in part because they have been promoted as, and confused with, restoration procedures, and in part because their positive and negative features have been poorly understood by both proponents and opponents. For example, as pointed out by Shireman et al. (1982), herbicide treatments are presently the only means of opening the vast acreage of water infested with the exotic water hyacinth (*Eichhorniae crassipes*) in Florida and other southeastern States. This is a case in which chemicals for management are a necessity until some other more long-term control, such as plant-eating insects, can be established. Their broad-scale use in other climates, often for the purpose of seasonal eradication of weeds, is more controversial, especially since equally cost-effective alternatives have smaller environmental impacts.

Many opponents of herbicides fear their effects on fish and fish-food organisms. Some chemicals can be toxic at high doses, but most have low toxicity to aquatic organisms. The impacts of herbicides on humans is poorly understood, and there is almost no information on the long-term ecological consequences of their use.

Lake managers who choose herbicidal chemicals need to exercise all proper precautions. As shown in Table 6-6, some chemicals are specific to certain species and therefore the nuisance plants must be carefully identified. Users should follow the herbicide label directions exactly, use only an herbicide registered by EPA for aquatic use, wear protective gear during application, and be certain to protect desirable plants. Most States require applicators to be licensed and to have adequate insurance. Among the important factors to be considered before adopting a management program with herbicides are the following questions:

1. What is the acreage and volume of the area(s) to be treated? Proper dosage is based upon these facts.

Table 6–6.—Common aquatic weed species and their responses to herbicides (adapted from Nichols, 1986).

	DIQUAT	ENDOTHAL	2,4-D	GLYPHOSATE (RODEO)	FLURIDONE (SONAR)
EMERGENT SPECIES			YES	YES	YES
Alternantherca philoxeroides (alligatorweed)					
Dianthera americana (water willow)			YES		
Glyceria borealis (mannagrass)	YES	NO	NO		
Phragmites spp (reed)				YES	
Sagittaria sp (arrowhead)	NO	NO	YES		YES
Scirpus spp (bulrush)	NO	NO	YES	YES	YES
Typha spp (cattail)	YES	NO	YES	YES	YES
FLOATING SPECIES					
Brasenia schreberi (watershield)	NO	YES	YES		NO
Eichhornia crassipes (water hyacinth)	YES[1]		YES		NO
Lemna minor (duckweed)	YES	NO	YES		YES
Nelumbo lutea (American lotus)	NO	NO	YES	NO	
Nuphar spp (cowlily)	NO	YES	YES	YES	YES
Nymphaea spp (water lily)	NO	YES	YES	YES	YES
SUBMERGED SPECIES					
Ceratophyllum demersum (coontail)	YES	YES	YES		YES
Chara supp (stonewort)	NO[2]	NO[2]	NO[2]	NO[2]	
Elodea spp (elodea)	YES	?	NO		YES
Hydrilla verticillata (hydrilla)	YES	YES			YES
Myriophyllum spicatum (milfoil)	YES	YES	YES	NO	YES
Najas flexilis (naiad)	YES	YES	NO	NO	YES
Najas guadalupensis (southern naiad)	YES	YES	NO		YES
Potamogeton amplifolius (large-leaf pondweed)	?	YES	NO		
P. crispus (curly-leaf pondweed)	YES	YES	NO		
P. diversifolius (waterthread)	NO	YES	NO		
P. natans (floating leaf pondweed)	YES	YES	YES		YES
P. pectinatus (sago pondweed)	YES	YES	NO		YES
P. illinoiensis (Illinois pondweed)					YES
Ranunculus spp (buttercup)	YES		YES		

YES = Controlled NO - Not Controlled
BLANK - Information unavailable ? Questionable Control

[1] plus chelated copper sulfate [2] controlled by copper sulfate

Source: Anonymous. 1979; Arnold. 1979; McCowen et al. 1979; Nichols. 1986; Pennwalt Corp., 1984; Schmitz. 1986; Westerdahl and Getsinger. 1988

2. What plant species are to be controlled? This will determine the herbicide and dose to be used.

3. What will the long-term costs of this decision be? Herbicides must be reapplied annually, or in some cases, two to three times per season.

4. How is this waterbody used? Many herbicides have restrictions (days) on water use, following application.

5. Is the applicator licensed and insured, and has a permit been obtained from the appropriate regulatory agency?

There are several useful and well-written reference manuals to facilitate plant identification and the determination of the proper chemical and its dose. These include *Aquatic Weeds*, 1979, Fisheries Bulletin No. 4, Department of Conservation, Springfield, IL 62706; and especially the *Aquatic Plant Identification and Herbicide Use Guide* by Westerdahl and Getsinger (1988).

■ **EFFECTIVENESS.** Table 6-6 lists some aquatic weeds and the herbicides known to control them. The following paragraphs briefly describe each commonly used herbicide.

- **Diquat.** The effectiveness of diquat is inactivated in turbid water because of its sorption to particles. It does not persist in the water but can remain toxic in lake sediments for months. Many users combine it with copper sulfate, producing a potent, broad-scale herbicide–algicide. The reader is cautioned to note the toxic features of copper, described in an earlier section.

- **Endothall.** Endothall is sold in several formulations: liquid (Aquathol K), granular dipotassium salt (Aquathol), and the di (N, N-dimethylalkylanine) salt (Hydrothal) in liquid and granular forms. Effectiveness can range from weeks to months. The potassium salt forms have been shown to persist in the water for 2 to 46 days.

- **2,4-D.** 2,4-D is sold in liquid or granular forms as sodium and potassium salts, as ammonia or amine salts, and as an ester. Doses of 18 to 36 pounds per acre are usual for submersed weeds, most often of the dimethylamine salt or the butoxyethanolester (BEE). This herbicide is particularly effective against Eurasian watermilfoil (granular BEE applied to roots early in the season) and, in a foliage spray against water hyacinth. 2,4-D has a short persistence in the water but can be detected in the mud for months.

- **Glyphosate.** This herbicide is effective against floating leaves and emergent aquatic plants but not against submersed species.

- **Fluridone.** Fluridone is sold in liquid and pellet formulations as an herbicide for emersed and submersed weeds. It is a persistent compound and will not exert effect until 7 to 10 days after application. Control may be evident for an entire season, and sediments may remain toxic to plants for more than a year.

Label registration restrictions on water use following treatment are very important and should be followed carefully regardless of the herbicide chosen. Each State has its own regulations, as well.

■ **POTENTIAL NEGATIVE IMPACTS.** Many, but not all, nontarget aquatic organisms appear to have high tolerances to the herbicides just discussed. Diquat is a notable exception because of its toxicity to some crustacea, a staple of fish diets.

The primary environmental impacts include release of nutrients to the water column and consumption of dissolved oxygen during plant decomposition. Algal blooms, dissolved oxygen depletions, and nutrient release from sediments can follow a treatment. Another significant problem is that a species unaffected by the herbicide may replace the target species. Stonewort and pondweeds often invade a treated area. When a target weed is replaced by an algal bloom or a resistant weed, another chemical may have to be used, making herbicide treatment even more expensive.

Shireman et al. (1982) caution that the following lake or pond characteristics almost invariably produce undesirable water quality changes after treatment with an herbicide for weed control:

1. High water temperature
2. High plant biomass to be controlled
3. Shallow, nutrient-rich water
4. High percentage of the lake's area to be treated,
5. Closed or nonflowing habitat.

Competent applicators will be cautious in treating a lake with these conditions.

There has been a long-standing debate over the effects of 2,4-D on humans. Men exposed to 2,4-D and/or 2,4,5-T for more than 20 days per year may face an increased risk of non-Hodgkins' lymphoma (Hoar et al. 1986).

■ **COSTS.** Herbicide treatments are expensive for what they accomplish. They produce no restorative benefit, show no carryover of effectiveness to the following season, and may require several applications per year. The short-term benefit-cost ratio can be desirably high, but the long-term benefit-cost ratio is likely to be very low.

The ranges of per-acre costs for harvesting and herbicide treatments are similar in northern climates, but grass carp treatments cost significantly less than either (Table 6-5). It should be recalled, however, that harvesters remove nutrients and organic matter—a potential source of trihalomethane (THM) precursors and of dissolved-oxygen consumption—that can have a carryover effect to subsequent seasons.

One study of harvesting and herbicide (Diquat and copper sulfate) costs showed that harvesting was more expensive only in the initial year when the machinery was purchased. In the following years, maintenance, operation, insurance, and weed disposal costs were lower than those for chemicals alone. Harvesting, in this case history, cost $115 per acre and herbicides $266 per acre, so that over a five-year period, not including herbicide price inflation or applicator fees, the use of chemicals would have been 2.6 times more expensive than harvesting and without the benefits of nutrient and organic matter removal (Conyers and Cooke, 1983).

Shireman (1982) has compared the costs of chemical and biological (grass carp) control of hydrilla in Florida. A chemical treatment of 37,000 acres in 1977 cost $9.1 million, whereas a grass carp introduction would have cost $1.71 million. Of course the grass carp exert control slowly while herbicides provide prompt, though short-term relief.

Regional cost ranges can be expected for herbicides (see Table 6-5). Variations in costs are brought about by size of area to be treated, density of the infestation, species, and problems unique to a particular lake.

Macrophytes—Summary of Restoration and Management Techniques

Table 6-7 is a summary of the procedures described in this section. Qualitative evaluations about short- and long-term effectiveness, costs, and potential for negative side effects are presented. These judgments are the consensus of 12 lake and reservoir restoration experts.

Table 6–7.—Comparison of lake restoration and management techniques for control of nuisance aquatic weeds.

TREATMENT ONE APPLICATION	SHORT-TERM EFFECT	LONG-TERM EFFECT	COST	CHANCE OF NEGATIVE EFFECTS
Sediment Removal	E	E	P	F
Drawdown	G	F	E	F
Sediment Covers	E	F	P	L
Grass Carp	P	E	E	F
Insects	P	G	E	L
Harvesting	E	F	F	F
Herbicides	E	P	F	H

E Excellent F Fair G Good P Poor H High L Low

Problem IV: Eutrophic Drinking Water Reservoirs

Nature of the Problem

Those who drink water from surface water supply reservoirs often detect unpleasant tastes, odors, and color. They may be unaware of more serious problems that are unknown to the user but are of concern to potable water treatment plant managers and State and Federal EPA officials: the presence of potentially toxic materials in treated water. Toxic material can enter drinking water supplies directly by runoff from the land (for example, herbicides). They can also be created in the treatment process when treatment plant chemicals interact with naturally occurring organic molecules in the raw water to form potentially dangerous compounds such as trihalomethanes (THMs).

Many of the problems in potable water treatment are caused by eutrophic conditions in the water supply reservoir. Poor taste and odor are associated with algal blooms. Some of these algae, the blue-greens, produce toxins lethal to domestic animals and may be linked to certain summer illnesses in humans.

Colored drinking water is usually caused by a high concentration of iron and manganese in the raw water. This occurs when the raw water intake is deep and withdraws oxygen-free hypolimnetic water. THMs are a class of organic molecules—chloroform is in this class—that are produced through an interaction between the disinfectant (chlorine) added to raw water to kill microbes and certain organic molecules in the raw water. The organic molecules come from the watershed, primarily in the form of plant decay products, and from weeds and algae in the reservoir. The concentrations of these organic molecules are expected to be higher in more eutrophic waterbodies. THMs are believed to be carcinogenic. The U.S. EPA has set an upper average amount (0.1 ppm) past which finished water should not go.

Other eutrophication-related problems in water supply systems include a gradual loss of water storage as silt deposits increase, rapidly escalating costs connected with increased chemical use to clean the raw water, and such in-plant problems as clogged filters.

Water Supply Reservoir Management

The traditional approach to improving drinking water quality is to upgrade the in-plant treatments. Sometimes this is effective, particularly where the water supply is in good to excellent condition. In other cases, however, a costly increase in chemical use is required or additional equipment may have to be installed. Treatments with granulated active carbon, which may be needed to remove pesticides and other organics from the raw water, might cost a modest-sized city millions of dollars in initial capital costs plus the high costs of operation.

The better the incoming raw water, the less it will cost to make it into acceptable drinking water. Ultimately, watershed and reservoir protection and reservoir management or restoration may be less costly than extensive in-plant modifications and increased chemical uses. As already pointed out, however, reservoirs are very difficult to protect because their drainage basins, which are often large relative to reservoir area, usually include several political and economic units and may have extensive and uncontrollable human uses. The city or controlling authority may have to embark on a long-term effort to buy land, encourage or subsidize wastewater treatment plant upgrades, improve municipal storm water discharges, and help land users employ modern agricultural practices.

One alternative or an addition to drainage basin management is the use of chemicals (such as alum) in the river to strip phosphorus from the water before it enters the reservoir. This can involve a prereservoir detention basin or the addition of a chemical to the stream.

Another option is to divert river water into a smaller, square-sided, weedless basin where silt deposition and additions of flocculent could occur. Wahnbach Reservoir, an example of this, was described in Chapter 4. The basin can be periodically drained and dredged.

Water supply reservoirs near highways, railroads, and within industrial areas are vulnerable to accidental spills of toxic materials. Few reservoirs are protected or prepared for this. The silt basin described above, built large enough to hold a three- to five-day supply, could also serve as an emergency raw water supply.

Theoretically, most of the techniques described earlier in this chapter could be used to improve water quality, or to actually restore the reservoir after poor quality waters are diverted. In practice, however, restoration techniques are not easily applied to reservoirs because of their size and the difficulty of reducing loadings. The following paragraphs list drinking water quality problems and possible in-reservoir solutions.

Color

Iron and manganese appear in oxygen-free raw water. Three solutions are common: artificial circulation, hypolimnetic aeration, or elevating the intake from the hypolimnion to the epilimnion. Drawing water from the epilimnion can introduce taste and odor, and the aerator could destratify a shallow reservoir, triggering an algal bloom.

Taste and Odor

Algal blooms, particularly blue-green algae, not only can impart an unacceptable taste and odor but can also increase the demand for treatment chemicals and decrease filter runs. There are few solutions if nutrient diversion is not adequate. Artificial circulation could reduce productivity of planktonic algae in deep reservoirs but is unlikely to be effective in shallow ones. Sediment removal and especially phosphorus inactivation—both procedures to curtail sediment nutrient release—will be eventually overwhelmed by high loading but offer the possibility of improvement for several years. Copper sulfate, an algicide, can be used for short-term relief, but applications are often followed by more severe blooms and release of substances that add to THM production.

Loss of Storage Capacity

This problem can be solved only by removing silt and curtailing its income. A stringent permitting process may be imposed by the U.S. Army Corps of Engineers if dredging is chosen because the reservoir is a potable water supply.

Trihalomethane Production

A search for sources of organic THM precursor molecules in the drainage basin must be undertaken, followed by appropriate land management to curtail their generation. Marshes are known to be important sources. A substantial fraction of the organics can come from sediments, weeds, and algae, which strongly suggests that in-reservoir management of these sources could produce a significant decrease in THM production. Harvesting would be an effective procedure. Another possibility is to add clean well water to dilute the raw water at the intake. A book on reservoir management for water quality and THM precursor control is available (Cooke and Carlson, 1989).

Problem V: Fish Management

Nature of the Problem

Most lakes and reservoirs are used to some extent for fishing, and some (according to fishermen) are considered unsatisfactory. Problems with fishing usually fall into the following categories:

1. **Conflicts between users**—including high fishing pressure
2. **Interference with fishing by weeds**
3. **Overabundance and population imbalances**—especially of "stunted" fish or undesirable species
4. **Poor reproduction and die-off** of desirable species
5. **Low lake fertility and fish production.**

User conflicts are not trivial. Chapter 9 addresses the problem of regulating these conflicts.

Fish production is directly related to lake or reservoir fertility. This fact is also the source of many fishery problems. In nutrient-rich waters, such as those often encountered in the lakes and reservoirs of the North or Midwest ecoregions or in situations of heavy wastewater or agricultural inflows, high fish biomass is likely to be found. But high fertility may also promote intense algal blooms, encourage heavy fishing pressure that can limit other lake uses such as waterskiing, and ultimately give rise to lakes and reservoirs with serious imbalances in fish species and to the complaint that the lake is "fished out."

In other ecoregions, such as some of those in the West and Southwest, lake and reservoir fertility may be so low that there is little fish production, so stocking efforts fail, and the lake must be fertilized. Lake Mead, Nevada–Arizona, is a case in point (Axler et al. 1988). Thus, both low and high fertility situations are likely to require fish management and lake or reservoir manipulations.

Improvement of a lake or reservoir for fishing requires both lake and fish management. Bennett (1970), citing Leopold (1933), defines fish management as "the art and science of producing sustained crops of wild fish for recreational and commercial uses." Competent programs include a diagnostic study of the lake or reservoir and its fish community and then implementation of management options that are ecologically sound and within financial constraints.

Diagnosis and Management

Just as with lake restoration, a diagnosis of the condition of the fish community is the first step in a fish management program. For most situations, this involves fish sampling to provide an assessment of the condition of the lake's present fish community. Various sampling methodologies and strategies are available, the specific approach being dependent upon the region in the country where the lake is located, the type of fish to be sampled, the purpose of the sampling, and the characteristics of the particular lake. Before attempt-ing to diagnose a fishery condition, consultation with State or local fisheries professionals is strongly recommended.

Additional studies will usually be required, including determinations of temperature and dissolved oxygen profiles and many of the other factors related to diagnosing and solving problems related to eutrophication, or its absence, as described in Chapters 3 and 4. Management may then proceed at several levels, including the physical-chemical level (e.g., hypolimnetic aeration, whole lake fertilization), the habitat level (e.g., installation of artificial reefs, aquatic plant control), and biological level (e.g., fish removal or stocking). Bag or slot length limits can be imposed so that management also involves the fishing population as well. A good description of some of these possibilities is found in the summary of a NALMS Workshop (McComas et al. 1986). Their implementation should involve the advice of knowledgeable professionals, including State agency personnel.

Fisheries management, as described earlier, is often an integral part of a lake restoration plan. It is important to remember that lake ecosystems are complex and highly interconnected. Fishermen may urge a lake manager to stock predators, such as walleye, muskie, or bass to improve fishing or even a lake's water quality. However, corrective stocking can fail. Often the lake is at or near its productive capacity. Game fish fry stocked in a poor quality lake may not survive the many sources of mortality, including intense predation. The stocking of significant numbers of older fish is expensive and the animals are more difficult to obtain. High fishing pressure can quickly reduce their numbers once stocked. Similarly, some lake managers have heeded advice to stock forage species, such as shad, only to discover later that shad reproduction exceeded predation by top predators or shad grazing on zooplankton was sufficient to relax grazing pressure on algae. The problem of poor fishing might then have been traded for nuisance quantities of forage fish or excessive growths of algae.

There are several valuable sources of information about fish management. Each State has a fisheries unit that can provide important guidelines specific to that geographic area.

Problem VI: Acidic Lakes

Acidic waters are detrimental to many aquatic organisms. High concentrations of hydrogen and aluminum ions in acidic waters adversely affect ion regulation in aquatic organisms (a condition known as osmoregulatory failure). The principal detrimental effect on fish and other organisms is the leaching of sodium chloride from bodily fluids. The general types of changes in fish species expected to occur with increasing surface water acidity at 0.5 pH intervals are summarized in Table 6.8. Loss of important sport fish species generally occur at pH levels below 6.

Acidic lakes occur in areas where the soils have no natural buffer capacity and where acid rain and other manmade or natural processes cause acidification of waterbodies. Many of these lakes are unable to support a healthy, reproducing fishery. Some waters are mildly acidic because of their passage through naturally acidic soils. Acidic drainage from abandoned mines affects thousands of miles of streams and numerous lakes throughout Appalachia and in other coal and metal mining areas.

Table 6-8.—General effects on fish species anticipated with surface water acidification, expressed as a change in pH (source: J. Baker et al. 1990).

pH DECREASE	GENERAL BIOLOGICAL EFFECTS
6.5 to 6.0	Some adverse effects (decreased reproductive success) may occur for highly acid-sensitive fish (e.g., fathead minnow, striped bass)
6.0 to 5.5	Loss of sensitive species of minnows and dace, such as blacknose dace and fathead minnow; in some waters, decreased reproductive success of lake trout and walleye, which are important sport fish species in some areas
5.5 to 5.0	Loss of several important sport fish species, including lake trout, walleye, rainbow trout, and smallmouth bass, as well as additional nongame species such as creek chub
5.0 to 4.5	Loss of most fish species, including most important sport fish species such as brook trout and Atlantic salmon; few fish species able to survive and reproduce below pH 4.5 (e.g., central mudminnow, yellow perch, and, in some waters, largemouth bass)

Lakes can be effectively restored and managed to support desired fisheries by addition of neutralizing materials or by other related techniques. The following sections describe five techniques that have been used to restore acidic lakes. Most techniques rely on addition of limestone materials to upland streams, the lake surface, or the lake watershed. Two other techniques, injection of base materials into lake sediments and pumping of alkaline groundwater into lakes, are also described. There is very little experience with the latter two neutralization methods. The five methods and some others are described in more detail by Olem (1990).

Limestone Addition to Lake Surface

■ **PRINCIPLE.** Limestone, a naturally occurring mineral product, is often the major component of surface water buffering systems; it is a basic material that neutralizes acidity when applied to waterbodies. Limestone works in the same way that common antacid tablets neutralize excess stomach acids. The active ingredient in most antacids is calcium carbonate, the same compound in limestone. Because it is used extensively for agricultural liming, limestone is easily available at a low cost.

■ **MODE OF ACTION.** When added to surface water, limestone dissolves slowly, resulting in a gradual increase in pH. It is often desirable to add enough limestone so that some settles to the bottom of the lake. This "sediment" dose results in continued slow dissolution over time. Limed waterbodies typically increase in pH to levels between pH 7 and 9. These pH levels are best for growth and reproduction of some aquatic organisms. When limestone is added to acidic surface waters, dissolved aluminum concentrations are lowered because aluminum is less soluble in neutral waters. Also, the toxic forms of aluminum—$Al+^3$ and $Al(OH)_2$—are no longer dominant at pH levels above 6. Lake water dissolved aluminum is thus reduced to nontoxic levels for fish and other aquatic organisms.

The most common method of adding alkaline materials is spreading a slurry of limestone and water to the lake surface by boat. Helicopters are often used to lime lakes that may be inaccessible by boat.

■ **EFFECTIVENESS.** Application of limestone over the lake surface has been shown to be effective for lakes with water retention times over about six months. The effects typically last about twice the lake retention time. For instance, a lake with a retention time of 6 years will normally maintain neutral conditions for up to 10 years after liming. Other techniques are recommended for lakes with very short retention times because the effects of direct lake liming are too short-lived. The direct liming method has been the most widely applied technique to mitigate acidic conditions in lakes. It has been widely adopted to neutralize acidic lakes in Scandinavian countries. For example, about 5,000 lakes have been treated with limestone in Sweden since 1977.

■ **POTENTIAL NEGATIVE IMPACTS.** There have been few instances where liming has caused mortalities in resident fish populations. A few isolated incidents of fish mortality have occurred because of metal toxicity. These cases have often been due to improper treatment and stocking of fish after liming. Also, treatment of lakes high in metal concentrations may result in fish mortality. For example, during the liming of a lake near a Canadian metal smelter, metal hydroxides were observed to precipitate onto fish gills.

Injection of Base Materials into Lake Sediment

This is an experimental procedure that has been applied to only a few lakes (Lindmark, 1982, 1985). The technique consists of injecting neutralizing materials such as limestone, hydrated lime, or sodium carbonate into the sediments of acidic lakes. Calcium or sodium ions in the sediment are released in exchange for hydrogen ions in the water column. This results in a gradual change in lakewater pH and an increase in acid neutralizing capacity to the water column during spring and fall lake turnover. The technique has also been shown to release phosphorus from the sediments to the water column, resulting in increased productivity and subsequent benefits to the fish. The technique is generally limited to small, shallow lakes with soft organic sediments and adequate road access for transport of materials and application equipment. In laboratory experiments, this treatment was shown by Ripl (1980) to last about five to seven times longer than adding limestone to the lake surface. The technique has the potential to disrupt the benthic community and increase water column turbidity, and it may cost more than liming lake water.

Mechanical Stream Doser

It is possible to neutralize acidic lake water by continuously adding limestone to upland streams using mechanical dosing equipment. Several types of stream dosing devices exist. The more common dosers are automated devices that release dry powder or slurried limestone directly into streams. The distribution of limestone from dosers powered by electricity or by battery is controlled automatically by microprocessors programmed to calculate appropriate dosing rates from remotely monitored water quality or hydrological parameters. Dosers powered by water flow distribute neutralizing material at rates that vary with the flow.

Few streams have been treated using these devices because they have not been well developed and there are several inherent difficulties in treating flowing systems. For instance, it is difficult to accommodate rapidly changing flow conditions and ensure proper operation of mechanical equipment, particularly during storms and freezing temperatures. The treatment is continuous, expensive, and is not generally recommended unless all other alternatives are ruled out.

Limestone Addition to Watershed

The addition of limestone to portions of the lake watershed, also known as soil or watershed liming, is considered an experimental procedure in the United States. A viable alternative to the direct addition of base materials to surface waters, its principal advantage is that the effects of this type of treatment are more sustained. The slower response of lakes to watershed liming also reduces the likelihood of rapid changes in acid-base chemistry and its effects on metal solubility and fish toxicity.

Soils are used here in a broad sense to mean areas other than the lake or stream water surface and include dry soils and wetland areas.

Experience with watershed liming has indicated that it is very important to apply the limestone to major water pathways. This practice avoids treatment of the entire watershed and reduces the amount of limestone required.

Although watershed liming has been relatively uncommon, it has increased in recent years. For example, about 2 percent of the total limestone used in liming treatments in Sweden was applied to soils in 1983; by 1987, 15 percent was used in this practice (Nyberg and Thornelof, 1988).

Watershed liming may be particularly applicable to lakes with short retention times (less than six months) because its effects are much longer lasting than direct lake liming. Also, watershed liming can reduce the severity of episodic acidic conditions and the leaching of toxic aluminum from the soils to the lake water.

Although the cost of one application is higher than direct lake liming, the overall costs may be similar or lower because of the more sustained effects. Rosseland and Hindar (1988) calculated that the watershed liming of Lake Tjonnstrond, Norway, in 1983 would last 30 years compared to less than one year for direct lake liming.

Pumping of Alkaline Groundwater

Pumping of water from a nearby source that contains alkalinity has been suggested as a viable technique for neutralizing acidic surface waters. It is possible to pump deep groundwater to an acidic lake because these sources often contain more alkalinity than nearby surface waters. This method has been tested in Pennsylvania and Wisconsin. In Pennsylvania, groundwater was successfully pumped from wells to neutralize an acidic section of Linn Run to help the stream sustain a put-and-take trout fishery. The Wisconsin experiments have not been reported.

An important consideration is the possible depletion of groundwater reserves by continuous pumping. It is not known whether the method has wide applications or whether the costs of treatment compare favorably to other mitigation methods for acidic surface waters.

Acidic Lakes—Summary of Restoration and Management Techniques

Table 6-9 summarizes the procedures described in the preceding sections for mitigation of acidic conditions in lakes. A qualitative comparison of the methods is presented with regard to short- and long-term effectiveness, costs, potential negative impacts, and relative use.

Table 6–9.—Comparison of lake restoration and management techniques for neutralization of acidic lakes.

TREATMENT (ONE APPLICATION)	SHORT-TERM EFFECT	LONG-TERM EFFECT	COST	NEGATIVE EFFECTS	RELATIVE USE
Limestone addition to lake surface	E	F	G	E	E
Injection of base materials into lake sediment	E	G	F	G	P
Mechanical stream doser	E	E	P	G	P
Limestone addition to watershed	G	E	G	G	G
Pumping of alkaline groundwater	E	?	?	G	P

E Excellent G Good F Fair P Poor

Chapter 7

HYPOTHETICAL CASE STUDY

Purpose of Case Study

Armed with all the explanations, guidance, instructions, and information in the preceding chapters, could a lake user or lake association group "do lake management?" The answer is yes. These associations are the driving force behind the many lake restoration and management programs in the United States. They may hire experts, but the burden of making the critical decisions and bearing the responsibility for organizing and sustaining a restoration program is typically borne at the grass roots level. The hypothetical case study in this chapter illustrates how a lake management or restoration program can be carried out. This case study integrates the information and material from the previous sections, including problem definition, in-lake restoration techniques, watershed management, data analysis, and the evaluation and selection of management alternatives.

Lynn Lake—a hypothetical waterbody—suffers from excessive algae, aquatic weeds, and siltation. Like most lakes that are managed and restored to good condition by involved citizens, Lynn Lake is extremely popular locally. It is not one of the largest or most important lakes in the State, or even well known outside the State. Restoration will take major effort and a considerable dedication of local citizens—but it can be done. The rest of the case study will demonstrate how restoration is accomplished.

Lynn Lake—A Case Study

Lynn Lake is located completely in Kent County. There is a county park on the western side of the lake, but the entire perimeter is accessible to the public. The lake is used heavily for fishing, swimming, and boating; well-used jogging and walking trails circle it. Swimming is often prohibited because of high levels of algae and bacteria. Boating is impaired by macrophytes that cover 50 percent of the lake. Siltation of the inlet areas of the lake has also limited the use of these areas for boating. Lynn Lake (Fig. 7-1) has two major tributaries: Kimmel Creek and Tag Run. The city of Middletown is located on Kimmel Creek and has a secondary wastewater treatment plant that discharges to the creek. Upstream of Middletown is Blue Ridge, a 200-unit subdivision that is presently under construction. Tag Run, the other tributary, is surrounded mostly by wetlands, ponds, and undeveloped land.

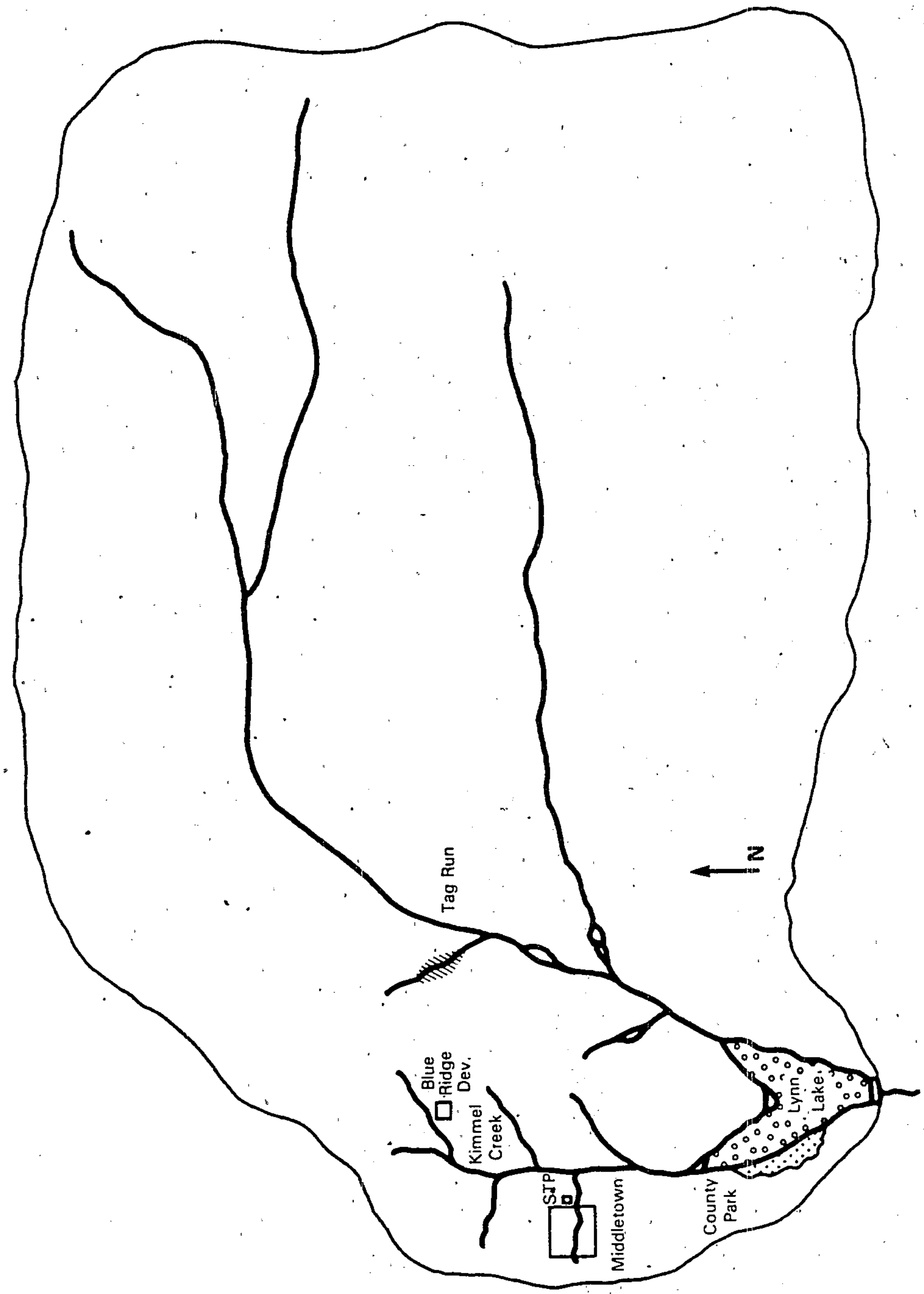


Figure 7-1.—Lynn Lake — a hypothetical waterbody — and its watershed.

Problem Definition

Because of concern over the declining condition of the lake, the county collected several water samples and analyzed them for nutrients (phosphorus and nitrogen) and algae. The results indicated that the lake has high levels of phosphorus and nuisance blue-green algae. County officials decided to conduct a survey (Table 7-1) over Fourth of July weekend to ask residents who used the lake what problems they had observed and to gage the degree of concern and potential support for restoring the lake to better condition. Interest in the lake proved high because 70 percent of the households in the Lynn Lake basin responded to the questionnaire. Results of this informal survey, summarized in Table 7-2, indicated that the public participated in all recreational aspects of the lake, with walking, picnicking, fishing, and boating being the dominant uses. Results also showed that 98 percent of those who answered the questionnaire supported a lake restoration project if partially funded by State or Federal grants, and 74 percent supported the program if funded solely by the county.

Table 7–1.—Public opinion questionnaire.

1. How often do you visit Lynn Lake? __________

2. How far do you travel to visit Lynn Lake? __________

3. When you visit Lynn Lake, what activities do you participate in?
   - ☐ Picnicking ☐ Jogging ☐ Swimming
   - ☐ Walking ☐ Boating ☐ Other ________
   - ☐ Fishing

4. Since Lynn Lake appears to be suffering from excessive algae, aquatic weeds, and siltation, do you support a lake restoration program that would include a study of the lake and the implementation of a program to eliminate the lake problems?
   - ☐ Yes ☐ No ☐ Undecided

5. Restoration of Lynn Lake will require the expenditure of county funds. Partial funding of the restoration program may be obtained from a State or Federal grant. Realizing this, do you still support the implementation of a lake restoration program for Lynn Lake?
   - ☐ Yes, only if State or Federal funds are available to offset the cost of the program.
   - ☐ Yes, even if only county funds are used.
   - ☐ No ☐ Undecided

It should be noted at this point, that while Lynn Lake meets all of the criteria for an EPA Clean Lakes grant, including the fact that it is a publicly owned waterbody with several recreational water uses available to everyone, many lakes do not meet these criteria. Furthermore, many problem lakes do not require the infusion of Federal funds to accomplish an effective lake protection and restoration program. The approach to the diagnosis and development of a management plan provided here, moreover, is more comprehensive but generally applicable to most lake situations, including private lakes and others for which Clean Lakes Program funds are not available. However, the approach can be modified, depending on existing information and resources, for effective lake restoration.

Based on the results of the survey, the county held a special meeting in August to discuss a restoration program for Lynn Lake. County staff presented the results of the questionnaire and outlined a proposed study of the lake. During the discussion period, the citizens repeated their support for the proposed restoration project. Many users believed that the lake's problems were caused by discharges from the Middletown treatment plant, erosion and runoff from new construction (especially the Blue Ridge Development), erosion from farmland,

Table 7–2.—Public opinion questionnaire results.

1. How often do you visit Lynn Lake?

TIME	PERCENT
Daily	3
Weekly	32
Monthly	56
Annually	9

2. How far do you travel to visit Lynn Lake?

MILES	PERCENT
0–2	29
2–5	33
5–10	36
>10	2

3. When you visit Lynn Lake, what activities do you participate in?

78 Picnicking	32 Jogging	2 Swimming
59 Walking	61 Boating	__ Other Model Boats: 1
101 Fishing		Necking: 1

4. Since Lynn Lake appears to be suffering from excessive algae, aqatic weeds, and siltation, do you support a lake restoration program that would include a study of the lake and the implementation of a program to eliminate the lake problems?
   100% Yes 0% No 0% Undecided

5. Restoration of Lynn Lake will require the expenditure of county funds. Partial funding of the restoration program may be obtained from a State or Federal grant. Realizing this, do you still support the implementation of a lake restoration program for Lynn Lake?
   98 Yes, only if State or Federal funds are available to offset the cost of the program.
   74 Yes, even if only county funds are used.
   2 No 0 Undecided

and nutrients leaching from failing septic systems. They also suggested that erosion from roadway construction and maintenance being performed by the State Highway Department was contributing to the sedimentation problem. Several lake users indicated that a few areas of the shoreline were sloughing or caving in. Green algal scums and weeds, however, were universally agreed to be the major problem.

At the end of the meeting, the county formally formed a special committee to investigate the possibility of restoring Lynn Lake. The committee was made up of the County Engineer, the Director of the County Planning Department, the Director of Middletown Public Works, and four interested lake users. The County Commissioners also approved a motion to hire a consultant if help could not be found through the county staff or State office first. It was agreed that the special committee would seek out recommendations of firms capable of helping with the restoration project, review qualifications, and recommend a consultant.

In the next month, members of the special committee sought information and sources of help in lake restoration. They asked the State Water Control Board, the State Game and Fish Commission, and the State Health Department whether any programs existed that could be used to study or restore Lynn Lake. Since no State program or funding dedicated to lake preservation or management existed, the committee asked for general information on lake restoration and as much guidance as possible. A staff member of the State Water Control Board collected names of lake associations and municipalities in the State that were involved in lake restoration, and the committee contacted these groups to find out how they had carried out their projects and who they might recommend as a consultant.

One member of the special committee, who was also a member of the North American Lake Management Society, suggested that they call the NALMS office in Washington, D.C. The committee ordered a booklet on lake restoration and explained the types of problems Lynn Lake was having. The NALMS office sent a list of consultants in Lynn Lake's area who specialized in lake restoration and a list of NALMS members who had agreed to help lake associations and municipalities with general questions such as how to find help and how to establish a public information program to support the work.

The committee contacted lake associations and municipalities in the State that had begun restoration projects and asked them who they had used to carry out the work, how they had paid for it, what the consultant had done for them, how much the program had cost, whether it had been effective, and whether they were satisfied with the results.

At the next meeting, the special committee reported its findings. The committee voted to initiate a lake restoration program that would include the following activities:

1. Forming a lake restoration advisory committee;
2. Selecting a consultant to perform the lake study, evaluate the management alternatives, assist in implementing the restoration program, and help the association find funding to support the work and prepare any grant application packages;
3. Developing a detailed work plan;
4. Submitting a grant application to the EPA for a Phase I Diagnostic/Feasibility Study;
5. Performing a study of Lynn Lake that would quantify the problems and problem sources and result in the development of a comprehensive lake and watershed management program;
6. Submitting a grant application to EPA for a Phase II Lake Restoration Program if Lynn Lake qualified for a Phase I grant; and
7. Implementing the restoration program.

Lake Restoration Advisory Committee

The first step in the restoration program was to form an advisory committee representing various interests in the watershed that would be responsible for providing direction throughout the program. It was recognized that for the project to be successful all interests in the watershed would need to represented and their concerns and desires addressed. A committee was formed that consisted of representatives from the following municipalities, agencies, and groups:

- ❑ Friends of Lynn Lake—a fund-raising organization
- ❑ Lynn Lake Fishing Club
- ❑ Kent County
- ❑ The Kent County Homebuilders Association
- ❑ Kent County Soil and Water Conservation District
- ❑ U.S. Soil Conservation Service
- ❑ Middletown Sewer Authority
- ❑ State Water Control Board
- ❑ State Health Department
- ❑ State Highway Department
- ❑ East Kent Garden Club
- ❑ State Game and Fish Commission
- ❑ Farm Bureau

Responsibilities of the Lake Restoration Advisory Committee included:

- Reviewing consultant qualifications and recommending a consultant to the County Commissioners;
- Providing direction throughout the project by frequently meeting with the consultant;
- Reviewing the consultant's work including data analysis, conclusions, and recommendations;
- Obtaining public input to the proposed management alternatives;
- Approving the final lake and watershed management plan prepared by the consultant;
- Recommending the acceptance and implementation of the management plan to the County Commissioners; and
- Assisting in the implementation of the lake and watershed management plan.

Consultant Selection

Since no one involved in the project was experienced in lake studies and restoration, the county decided to retain a consultant to assist in developing a lake restoration program. Realizing that it would be applying for Federal funds from the EPA's Clean Lakes Program, the county followed the Federal procurement guidelines provided in 40 CFR Part 33—"Minimum Standards for Procurement Under EPA Grants." It recognized that the procurement guidelines would be useful whether or not Federal funds were available. The county then decided to use the negotiation method of procurement. The Advisory Committee mailed requests for qualifications to eight firms, reviewed the qualifications, and interviewed three that were asked to indicate specific experience in several of the lake management areas, as listed in Table 3-3 of Chapter 3.

The Advisory Committee selected a consultant who demonstrated the necessary qualifications and experience, which included the successful completion of projects involving algae and weed problems similar to those experienced at Lynn Lake. The consultant was selected to provide the following services:

1. Develop a detailed work plan that would meet all requirements of an EPA Phase I Diagnostic/Feasibility Study;
2. Develop a Phase I grant application;
3. Perform a diagnostic study, with or without Clean Lakes funding;
4. Assist in the selection of a cost-effective restoration program;
5. Develop a grant application for the Phase II Lake Restoration Program if Lynn Lake appears to be eligible for such funding or develop a fund-raising program if Lynn Lake were not eligible;
6. Design in-lake and watershed management practices; and
7. Implement the restoration program.

By including all of these tasks in the consultant selection process, the Advisory Committee ensured that one consultant would be involved from start to finish and that further consultant selection procedures would not be required.

Detailed Work Plan

The consultant developed a work plan that included the following activities:

1. Study of lake and watershed characteristics
2. Study of lake and watershed aesthetics and recreational characteristics
3. Limited lake monitoring
4. Limited watershed monitoring
5. Data analysis
6. Development and evaluation of management alternatives
7. Selection of a watershed management and lake restoration program
8. Projection of benefits
9. Environmental evaluation
10. Presentation to the homeowners association
11. Progress reports and final report

In developing the detailed work plan, the consultant reviewed the limited existing water quality data on Lynn Lake and evaluated the natural characteristics of the lake and watershed. The consultant also met several times with the Advisory Committee to discuss project goals, potential problem areas in the watershed (such as Middletown treatment plant, erosion from agriculture, construction and roadway maintenance, and septic system leachate), and the availability of local resources (in-kind services) that could be used during the study.

In-kind services from local sources and State offices may be counted as part of the State's contribution for Clean Lake Program funding. See Chapter 8 for suggestions regarding Federal agencies that may support lake restoration or watershed management (nonpoint source control) programs.

To keep the diagnostic study costs to a minimum, the consultant decided that the following local resources could be used as in-kind services:

1. KENT COUNTY

- Provide boat for lake monitoring
- Provide land use data for study
- Assist in the installation of watershed monitoring stations
- Assist in the evaluation and selection of management alternatives
- Assist in public participation activities
- Review and comment on final report
- Attend project meetings

2. SOIL CONSERVATION SERVICE

- Identify agricultural problem areas
- Assist in the identification and evaluation of agricultural control measures, attend project meetings
- Provide cost information
- Provide technical information
- Advise on funding through other U.S. Department of Agriculture programs

3. MIDDLETOWN SEWER AUTHORITY

- Provide wastewater treatment plant effluent data
- Analyze lake and stream samples in treatment plant laboratory

4. STATE WATER CONTROL BOARD

- Review progress reports and final report
- Attend project review meetings

5. STATE GAME AND FISH COMMISSION

- Conduct a fish population survey
- Review progress reports and final report
- Attend project review meetings

The final work plan included a detailed description of study tasks, project responsibilities, the project budget (cash and in-kind services), and the project schedule. Costs for in-kind services were calculated using an hourly cost rate based on salary plus overhead.

Phase I Grant Application

The county decided to apply for EPA Clean Lakes financing because the Lynn Lake project appeared to be an ideal candidate. It not only met the criteria for public access but was also the most heavily used public lake within a three-hour commuting radius. Furthermore, the lake's deterioration was pronounced; without restoration, the lake was likely to become unusable for several recreational pursuits within a few years. The enthusiastic public support for restoration was also in the lake's favor. Clean Lakes funding provides a matching form of grant (that is, 70 percent Federal, 30 percent State funds); both the county and the general public were willing to support the cost of a restoration project through in-kind services and direct contributions. Many lake restoration projects, however, are conducted using only local funds and volunteer help and services.

The consultant developed a Phase I grant application that consisted of the completed EPA application forms along with the detailed work plan. Although the consultant developed the grant application for the county, the official applicant was the State Water Control Board since EPA regulations allow Clean Lakes Program grants to be given only to State agencies. The State Water Control Board, therefore, reviewed the grant application and submitted it along with their priority ranking of the project.

After both the EPA regional and headquarters offices had reviewed and evaluated the application, EPA approved the application and offered the State a Phase I grant. The State then subcontracted with Kent County to perform the Phase I study. Kent County in turn contracted with the consultant to perform the technical tasks of the Phase I study.

Lake and Watershed Study

Study of Lake and Watershed Characteristics

The study of lake and watershed characteristics was performed primarily by collecting and analyzing secondary data—data already available from other sources including the State Water Control Board's 208 Water Quality Management Plans, U.S. Geological Survey maps, aerial photographs, and State and local publications. Using these sources, the consultant obtained the following information:

1. Physical lake characteristics (area, depth, mean flow)
2. Some general chemical and biological characteristics of the lake (temperature, dissolved oxygen, nutrients, algal population, fish population)
3. Watershed characteristics (drainage area, land use, topography, geology, and soils) and
4. Possible pollutant sources (wastewater treatment plant discharge, construction sites, agricultural areas, and failing septic systems).

Insufficient existing data were available to clearly define the lake's mean depth, its volume, or its chemical and biological condition. The work plan was designed to fill in these and other gaps in information. Also, although the consultant, working with the input from the Advisory Committee, was able to identify potential pollutant sources, not enough information was available to quantify and rank them.

The products of this task were some basic information about the lake and a set of watershed maps illustrating land use, topography, geology, soils, and possible pollutant sources.

Study of Previous Uses and Recreational Characteristics

Using existing reports and information, the consultant identified the following information on the lake and watershed:

1. Historical uses (walking, jogging, boating, swimming, fishing, and picnicking)
2. Past lake problems (excessive algae, aquatic weeds, poor fishing success, and siltation leading to loss of recreational uses)
3. Public access locations

The product of this task was basic information on lake uses and users, information useful for clarifying project goals and developing a management program. Much of this information may already be available for local projects and not require much time. Compiling this information is required for a Clean Lakes grant.

Lake Monitoring

Because of the lake's shape, three sampling stations were located on it, as shown in Figure 7-2. One station was located over the deepest part of the lake while the other two stations were located in the two arms of the lake to adequately characterize water quality. Samples were collected monthly from September through April and biweekly from May through August. Besides meeting EPA monitoring requirements, the sampling program was designed to obtain more samples during the warm weather period (May through August) when the biological activity and chemical changes are at their maximum.

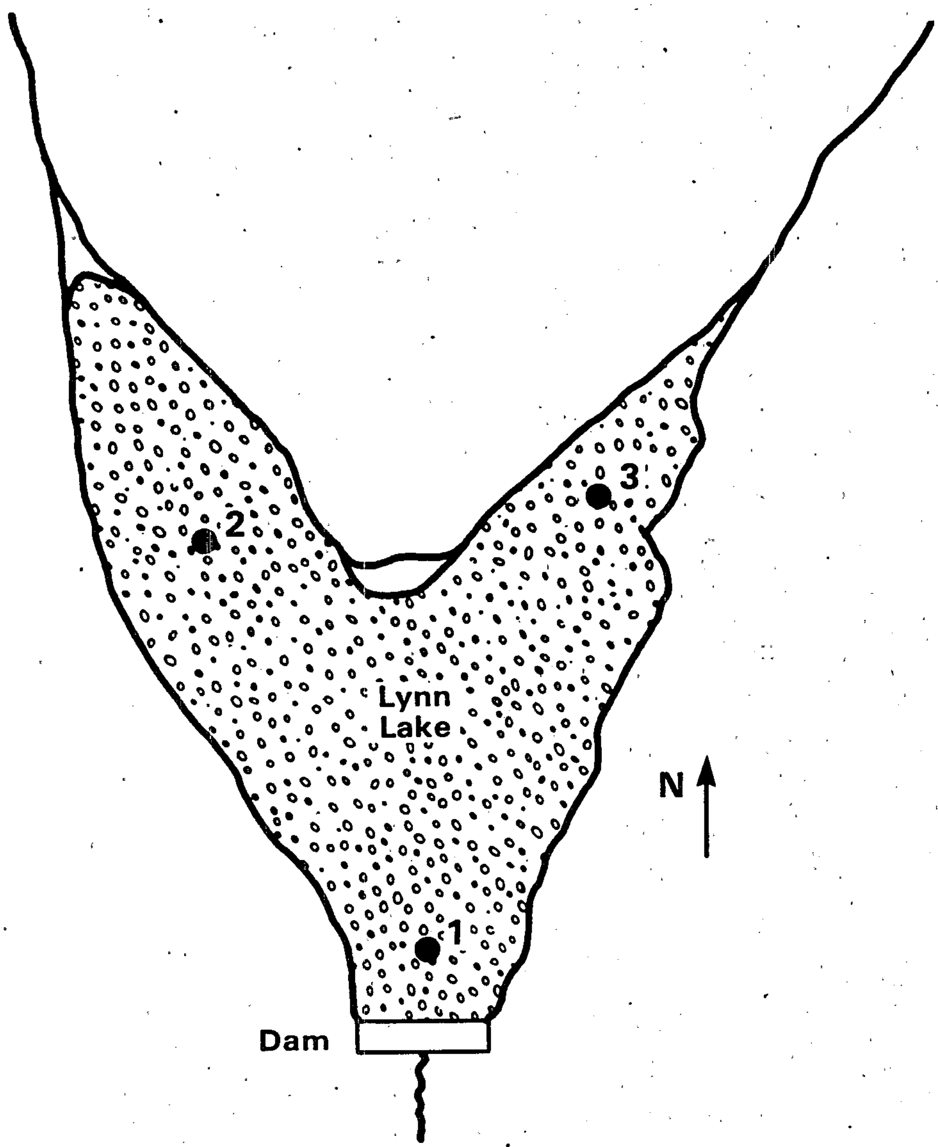


Figure 7-2.—Lynn Lake monitoring stations.

Three depths were sampled at each station because the lake *stratified*. Water samples were collected at half a meter below the surface, half a meter above the bottom, and near middepth. The mid-depth station was located within the metalimnion, the water stratum where temperature and dissolved oxygen change the most.

Each water sample was analyzed in the laboratory for the following chemical parameters:

Total Phosphorus	Total Suspended Solids
Soluble Reactive Phosphorus	Alkalinity
Organic Nitrogen	Iron
Ammonia Nitrogen	Manganese
Nitrate Nitrogen	

Field measurements at each sampling station included a temperature and dissolved oxygen profile with measurements taken at intervals of 1 meter (using a combined temperature-dissolved oxygen meter). Field measurements also included pH, conductivity, and Secchi depth. The Secchi depth measures the transparency of the water.

Water samples collected from the half-meter depth were also analyzed for chlorophyll *a*, phytoplankton, and zooplankton. Chlorophyll *a* measures the algal biomass in the surface waters of the lake. The phytoplankton (floating algae) and zooplankton (floating microscopic animals) analyses consisted of identifying and counting the various algae and microscopic animals in the samples.

The State Game and Fish Commission's District Fish Biologist conducted a creel census in the spring. To determine the type of fish being caught, the physical condition of the fish, and the catch per unit effort or how long it takes to catch a fish.

A macrophyte (aquatic weed) survey was performed in August and consisted of identifying the type and distribution of aquatic plants in the lake. Since siltation of the lake is a problem, bathymetric (bottom contour) and sediment depth surveys of the lake were performed to determine the water and sediment depth of the entire lake. The surveys consisted of measuring the water depth with a depth recorder and the depth of the unconsolidated (loose) bottom sediments by probing with a steel rod at cross sections throughout the lake. A survey crew was used to pinpoint the location of the cross sections.

At each of the three lake stations, a sediment sample was collected and analyzed for the following parameters:

SEDIMENT SAMPLE PARAMETERS

Total Phosphorus	Iron
Total Nitrogen	Manganese
Percent Solids	EP Toxicity Test
Percent Organic Solids	

The products of this task were physical, chemical, and biological data on the lake water and sediments. These data would be analyzed later to determine the present ecological condition of the lake. Another product of this task was bathymetric data that would be used to calculate the volume of the lake and to determine whether dredging was a feasible management alternative. This information is critical in any lake restoration project to formulate a cost-effective plan.

Watershed Monitoring

As discussed in Chapter 4, the first step in analyzing and modeling a lake is to establish a water balance and budget of materials (for example, nutrients, sediment, organic matter). Chapter 4 also indicated that a water balance and materials budget could be obtained either indirectly by comparing the watershed to a similar watershed or directly by monitoring the streamflow and pollutant loads over a one-year period. The direct measurement method is obviously more accurate and reliable than the indirect estimate method, but it also requires more resources. Since sufficient funds and resources were available, the direct measurement method was used to calculate an annual water balance and pollutant budget.

To calculate an annual sediment and nutrient budget for Lynn Lake, the consultant (with assistance from Kent County) installed stream monitoring stations on Kimmel Creek, Tag Run, and the lake's outlet, as shown in Figure 7-3. Each stream station consisted of an automatic water level recorder and sampler. Volunteers serviced the stations as part of in-kind services. The consultant measured cross-sectional area and velocity of the stream during selected rain events, data that was used to develop a stream rating curve correlating stream water level with streamflow. This information was used in conjunction with the water level readings to calculate streamflows throughout the study period. A staff gage was also installed in the lake to monitor changes in lake level and thus water storage (or loss) to or from the lake.

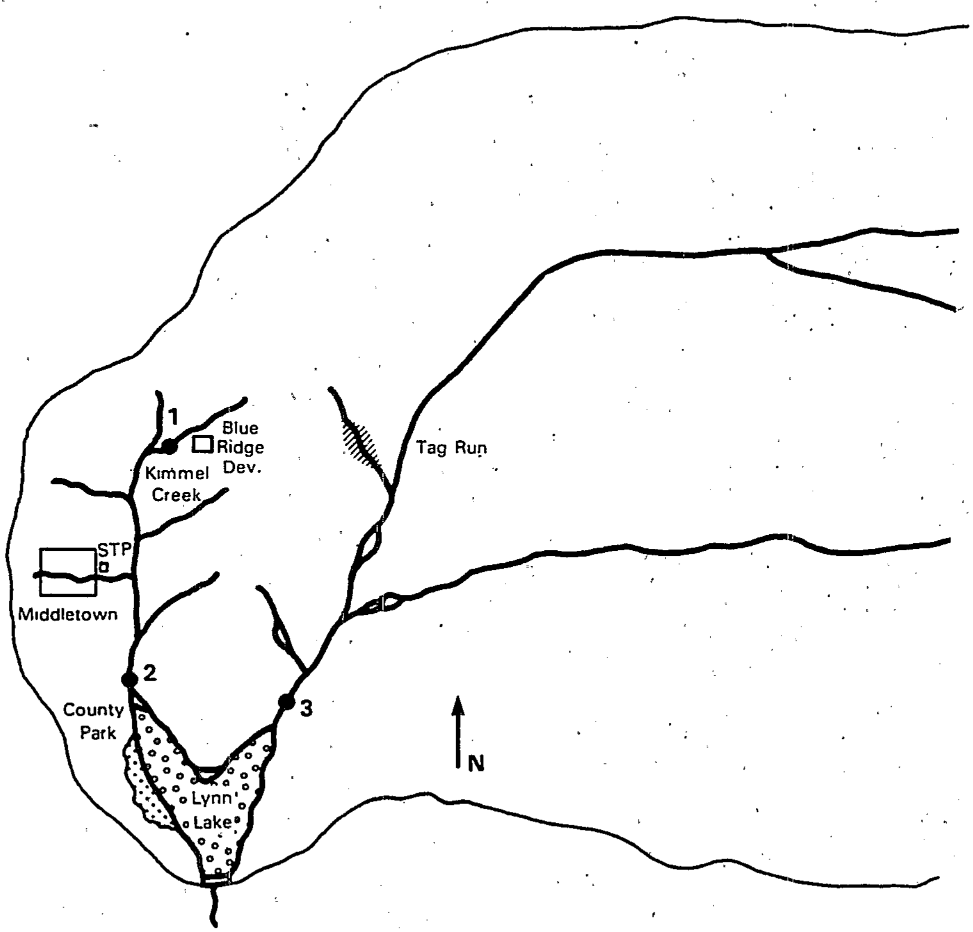


Figure 7-3.—Location of stream monitoring stations.

In some lakes, groundwater income can be a very important source of water and, sometimes, of nutrients. Because Lynn Lake had a very high income of water via the two streams, it was believed that groundwater was an insignificant component of the overall water budget. In reservoirs, this may often be the case. In many natural lakes, stream inflow is small and groundwater may be very important. In these cases, wells could be placed around the lake and groundwater inflow determined if sufficient funds were available. At the same time, nutrient concentration in groundwater would also be determined. However, if insufficient funds had not been available, groundwater contributions for both water and nutrients could have been estimated by assuming any water and nutrient contributions not accounted for in the water; nutrient budgets are attributable to groundwater.

An automatic water sampler (Fig. 7-4) was electrically connected to the water level recorders and programmed to collect water samples when the stream level increased during rain events. These are water level changes that occur very rapidly, often (it seems) during the night or on holidays when volunteers cannot be present to note them. During each rain event, discrete water samples were collected at half-hour intervals over the stream hydrograph as shown in Figure 7-5. (Depending on the size of the stream and land use in the watershed, the sampling time interval can be adjusted from 15 minutes to several hours.) After each storm event, selected water samples were taken to characterize sediment and nutrient loading at various times during the storm. One or more samples were taken as the flow increased, near the peak discharge, and as the flow decreased.

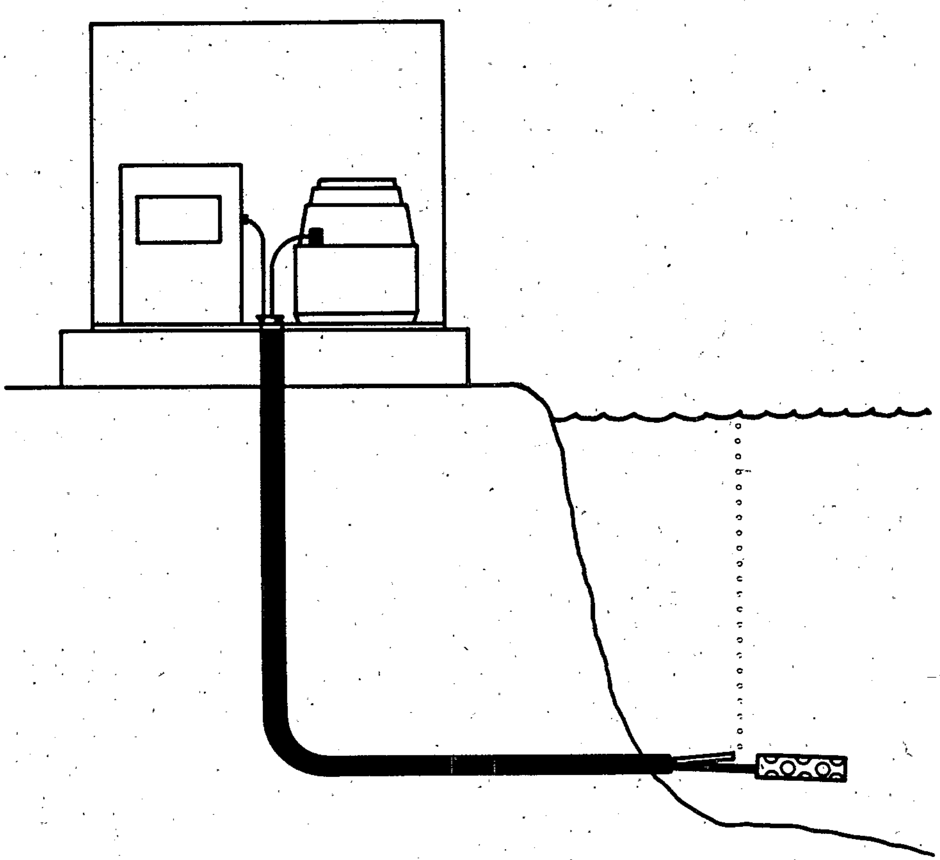


Figure 7-4.—Automated stream monitoring station used to collect flow and water quality data.

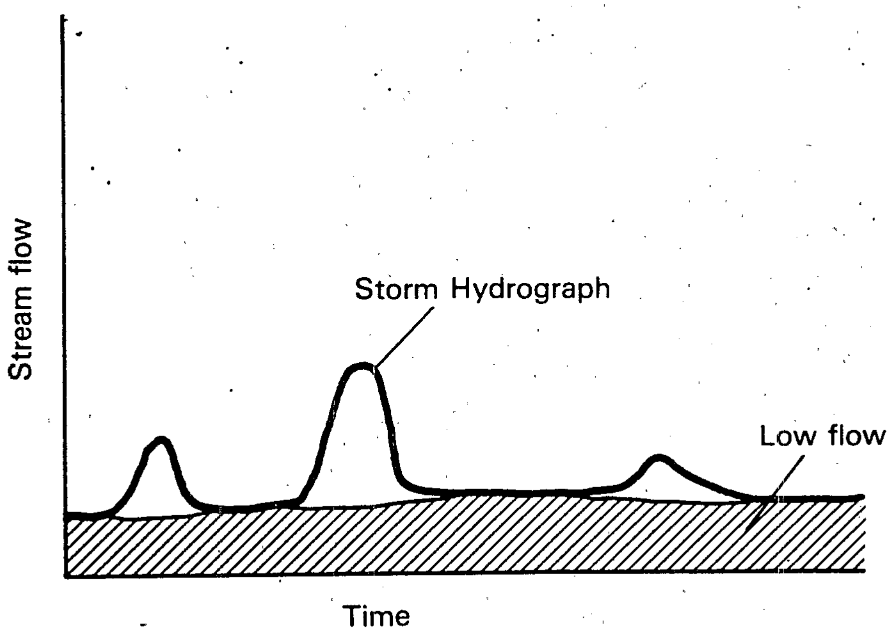


Figure 7-5.—Typical stream hydrograph showing increase in stream water level during a rain event and showing how an automatic sampler collects water samplers at select time intervals.

Each selected sample was analyzed for the following parameters:.

Total Phosphorus	Ammonia Nitrogen
Soluble Reactive Phosphorus	Nitrate Nitrogen
Total Nitrogen	Total Suspended Solids

These selected samples permitted the development of a nutrient to sediment concentrations versus flow relationship that was used to estimate loads during nonsampled storms, based on the flow records.

A total of nine storm events were monitored, which provided sediment and nutrient loading data representative of nonpoint source pollution such as watershed erosion and runoff. Dry weather stream monitoring was also performed to obtain baseflow stream loading data. Dry weather stream monitoring consisted of collecting grab samples from the two tributaries and the lake's outlet once each month during the study. Each sample was analyzed for the same variables as the wet weather samples.

The products of this task were flow and water quality data for both dry and wet weather conditions for the two tributaries and the lake's outlet as well as changes in water storage in the lake. Precipitation directly on the lake and water loss through evaporation were estimated from data obtained at a nearby National Oceanic and Aeronautic Administration weather station.

Data Analysis

Lake Analysis

The lake's mean and maximum depths and volume were calculated for the bathymetric survey data. The hydraulic residence time—the theoretical time required to displace the lake volume as explained in Chapter 2—was calculated using the lake volume and the mean annual discharge from the lake. The limiting nutrient was suggested by the nitrogen to phosphorus ratio in the lake during the study period. If the total nitrogen to total phosphorus ratio is greater than 10 to 1, phosphorus is usually the limiting nutrient. Throughout most of the study, the nitrogen to phosphorus ratio was generally greater than 17 to 1 indicating that phosphorus was generally the limiting nutrient and that the in-lake and watershed management program should be concentrated on reducing phosphorus loads entering and within Lynn Lake.

Figure 7-6 illustrates some summer temperature and dissolved oxygen profiles for Lake Station 1. Temperature stratification began in late May and became progressively more pronounced over the summer. In most cases, a shallow lake with as large a surface area as Lynn Lake's would destratify frequently from summer storms. Lynn Lake, however, is sheltered from prevailing winds by high bluffs and trees so that it remains stratified all summer. Cool weather in September, however, allowed enough heat loss from the lake to make destratification possible.

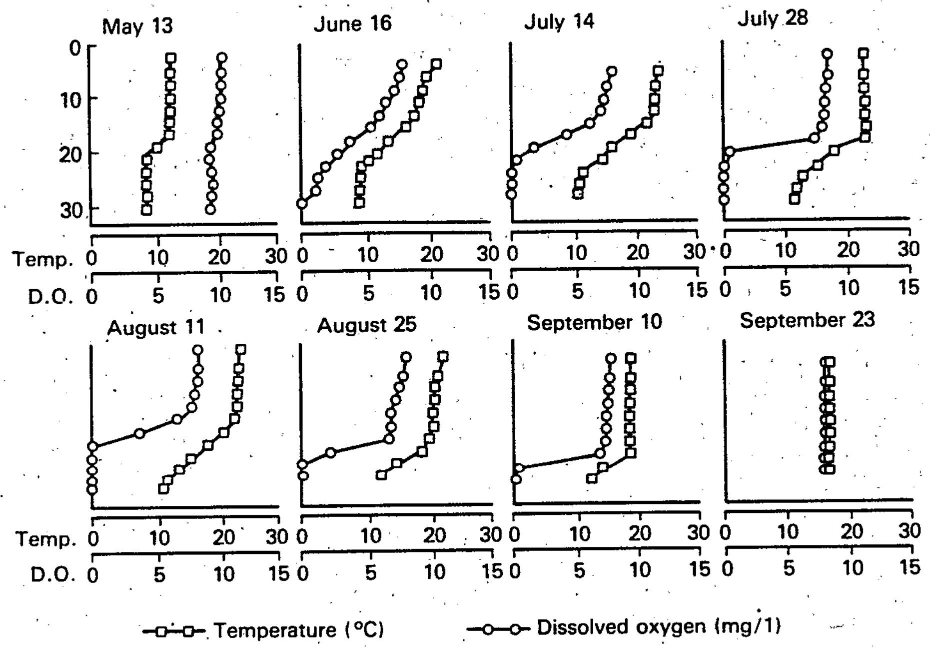


Figure 7-6.—Representative temperature and dissolved oxygen profiles for Lake Station 1. Thermal stratification and dissolved oxygen depletion occurred from June through mid-September. Zero dissolved oxygen conditions in the bottom waters adversely affect the cold water fishery and cause the release of phosphorus from the lake sediments.

Dissolved oxygen began to deplete in the bottom waters of Lynn Lake right after the lake stratified. By mid-July, the entire hypolimnion was devoid of oxygen, a common symptom in a eutrophic lake. An absence of dissolved oxygen in waters overlying the sediments provides ideal conditions for release of phosphorus from the sediments to the water column. In Lynn Lake, summer-long monitoring of phosphorus concentrations from surface to bottom demonstrated that the hypolimnion had greatly elevated concentrations, and studies before and after summer storms demonstrated that small mixing events circulated some of this phosphorus to surface waters and stimulated immediate growths of algae. A calculation of the rate of internal phosphorus release, using phosphorus income–outgo data and changes in the amount of phosphorus in the water column, revealed that 118 pounds of phosphorus were released between the end of May and the middle of September when Lynn Lake destratified. An introduction of dissolved oxygen to bottom waters when the lake mixed in the fall changed chemical conditions there, and more phosphorus was precipitated to the sediments than was released.

Chlorophyll *a* and phytoplankton levels varied during the study. However, the mean summer chlorophyll *a* concentration was 18 ppb, which is indicative of eutrophic conditions. During the summer and early fall, the phytoplankton was dominated by nuisance blue-green algae. Except for periods after rain events, the Secchi depth decreased with increased phytoplankton levels. A comparison of Lynn Lake data to EPA eutrophication criteria is presented in Table 7-3. This comparison indicated that Lynn Lake is eutrophic. A summary of Lynn Lake characteristics, based on study results, is presented in Table 7-4.

Table 7–3.—Comparison of Lynn Lake data to eutrophic classification criteria (EPA, 1980)

PARAMETER	EUTROPHIC CRITERIA	LYNN LAKE CONCENTRATION
Total Phosphorus (ppb as P) (winter)	greater than 25	50.0
Chlorophyll *a* (ppb) (summer)	greater than 10	18.0
Secchi Depth (m)	less than 2.0	1.1

Table 7–4.—Characteristics of Lynn Lake

Lake Area (acres)	500
Watershed Area (acres)	4400
Watershed to Lake Area Ratio	9:1
Mean Depth (feet)	20
Maximum Depth (feet)	45
Volume (acre-ft)	10000
Outflow (acre-ft/yr)	4501
Mean Hydraulic Residence Time (years)	2.2
Tropic Condition	Eutrophic
Limiting Nutrient	Phosphorus

Another indication of Lynn Lake's eutrophic condition was found in Carlson's index. This index, as Chapters 3 and 4 explain, can be a valuable tool for quantifying lake trophic status from basic, readily attainable data. Indices calculated from Lynn Lake range from 58 to 61, indicative of eutrophic conditions (see Fig. 7-7).

Evaluation of the lake data indicated that Lynn Lake was suffering from the following problems:

- Excessive algal growth
- Excessive weed growth in the inlet area
- Excessive siltation in the inlet area
- Phosphorus release from the lake sediments.

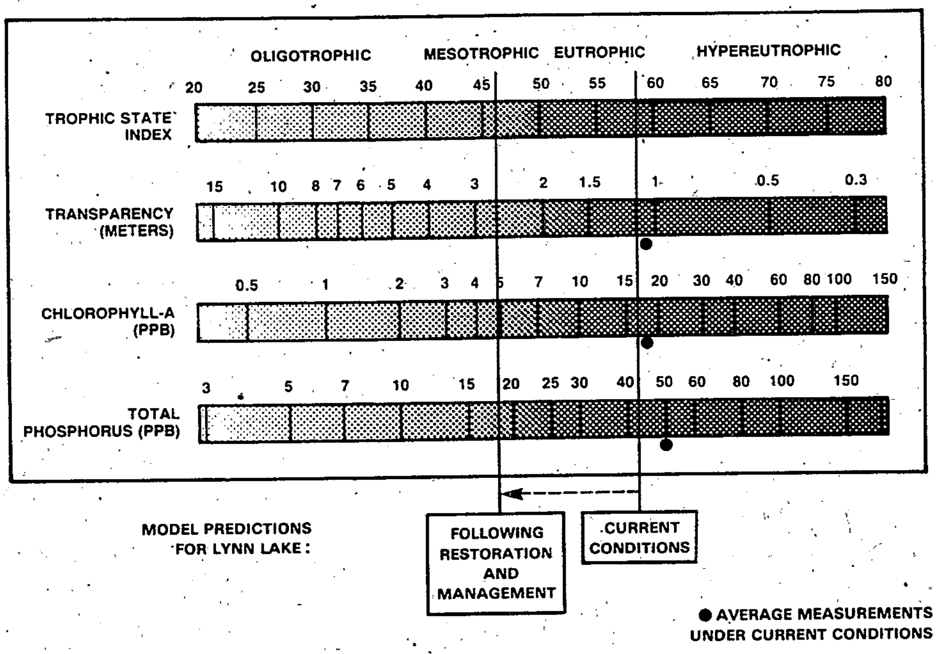


Figure 7-7.—Carlson's Trophic State Index for Lynn Lake, indicating that Lynn Lake is eutrophic.

Watershed Analysis

The lake and stream data were used to calculate an annual water balance and nutrient budget, using the techniques discussed in Chapter 4. In addition to the stream and outlet monitoring, data were also collected for the Middletown treatment plant and for the quantity and quality of rainfall in the watershed. The annual water balance was calculated using the equations provided in Chapter 4.

Stream and lake data collected over a one-year period consisted of water quality data for 12 monthly dry-weather samples and 9 composite storm samples. The annual stream phosphorus load to Lynn Lake was calculated by adding both the dry weather and wet weather loads. The dry weather or baseflow load was calculated using the 12 monthly phosphorus concentrations and the continuous streamflow data.

Since the nine monitored storms only represented a portion of the total storms that occurred during the monitoring period, a statistical relationship between the total phosphorus concentrations and flow was used with other storm flows to calculate the annual wet weather phosphorus load. The phosphorus load for the area draining directly into Lynn Lake was extrapolated using the stream load data.

The annual point source load from the Middletown treatment plant was calculated from daily flow records and biweekly chemical data. The annual direct rainfall phosphorus load was calculated from rainfall quantity and quality data collected during the study.

Table 7-5 lists the annual water balance and phosphorus budget for Lynn Lake. This table follows the format provided in Table 4-1 of Chapter 4. It provides a complete accounting of drainage areas, flows, and loading. Similar tables were developed for nitrogen and sediment budgets.

Table 7-5.—Annual water balance and external phosphorus loading for Lynn Lake

ITEM	AREA ACRES	FLOW AC-FT/YR	% PF TOTAL INFLOW	TOTAL P LOADING LBS/YR	% PF TOTAL LOADING	RUNOFF FT/YR	TOTAL P EXPORT LB/AC-YR
Kimmel Creek	300	375	6.6%	180	14.4%	1.25	0.600
Tag Run	3500	3885	68.1%	315	25.2%	1.11	0.090
Ungauged Area	100	111	1.9%	9	0.7%	1.11	0.090
WWTP		80	1.4%	655	52.5%		
Atmosphere	500	1250	21.9%	89	7.1%	2.50	0.178
Total	4400	5701	100.0%	1248	100.0%	1.30	0.284
Evaporation	500	1200	21.0%		0.0%	2.40	
Outflow	4400	4501	79.0%	612	49.0%	1.02	
Net Phosphorus Retention				636	51.0%		

phosphorus loading model predictions for Lynn Lake:

T = mean hydraulic residence time (years)
= Lake volume (ac-ft) / mean outflow (ac-ft/yr)
= 10,000 ac-ft / 4,501 ac-ft/yr
= 2.22 years

PI = average inflow p concentration (ppb)
= total p loading (lbs/yr) × 368 / lake outflow (ac-ft/yr)
= 1,248 lbs/yr × 368 / 4,501 ac-ft/yr
= 102 ppb

P = predicted lake phosphorus concentration (ppb)
= $PI / (1 + \sqrt{T})$
= $102 / (1 + \sqrt{2.22})$ = 41 ppb

observed lake phosphorus concentration = 50 ppb

Application of the phosphorus loading model described in Chapter 4 (Table 4-2) to Lynn Lake yielded a predicted lake phosphorus concentration of 41 ppb, as compared with the average measured concentration of 50 ppb. The higher measured value suggested the presence of an additional external or internal phosphorus source that is not considered in Table 7-5. The consultant concluded that, based upon geologic factors and lake water balance information, significant groundwater contributions were unlikely. Review of lake monitoring data indicated that soluble phosphorus was released from bottom sediment during periods when the bottom waters were devoid of oxygen. Severe algal blooms often followed periods of high winds, which caused mixing of phosphorus-rich bottom waters into the surface layer. Based upon these considerations, it was concluded that lake bottom sediments were likely to be important internal sources of phosphorus that should be addressed in a restoration program.

Since the external loads listed in Table 7-5 do not indicate specific land uses or activities that produced these loads, the consultant performed field investigations throughout the watershed to identify specific nonpoint source problem areas that indicated that Tag Run is in good condition. The Soil Conservation Service provided specific information on problem agricultural areas in the watershed, and active construction sites were surveyed to estimate the magnitude of soil erosion occurring during rain events. Based on the external phosphorus budget and an evaluation of the field investigation, the consultant concluded that the following phosphorus sources were significant and should be controlled:

- Middletown wastewater treatment plant
- Agricultural activities (Tag Run),
- Construction activities (Kimmel Creek).

Evaluation of Management Alternatives

Management alternatives for Lynn Lake were divided into watershed management and in-lake management alternatives. The first priority was to determine whether watershed management practices were needed to reduce the pollutants entering the lake. After all, the best in-lake management program will not succeed if there still is an excessive inflow of nutrients, silt, and organic matter. Therefore, it is important to determine whether the annual pollutant load to the lake is excessive. For Lynn Lake, the significance of annual phosphorus loading to the lake was estimated by using the Vollenweider Phosphorus Loading Diagram shown in Figure 7-8, and explained in Chapter 4. This curve, which relates the average inflow phosphorus concentration to the ratio of mean depth to hydraulic residence time, indicates that the annual phosphorus loading to Lynn Lake is probably excessive and should be controlled.

Future projections for Lynn Lake shown in Figures 7-7 and 7-8 assume implementation of the recommended management strategies, to be described. Advanced treatment of the Middletown wastewater discharge would reduce annual external phosphorus loading by 491 pounds per year. The consultant estimated that implementation of the recommended watershed management practices would reduce the phosphorus loading from Kimmel Creek by approximately 25 percent, or 45 pounds per year. Overall, the external phosphorus loading would be reduced by 43 percent from 1,248 to 741 pounds per year. Figures 7-7 and 7-8 indicate that this reduction would restore Lynn Lake to a mesotrophic status. Average water transparency would increase from 1.1 to 2.7 meters and average chlorophyll *a* concentrations would decrease from 16 to 5 ppb. The selection of specific alternatives to achieve these results is described in the next section.

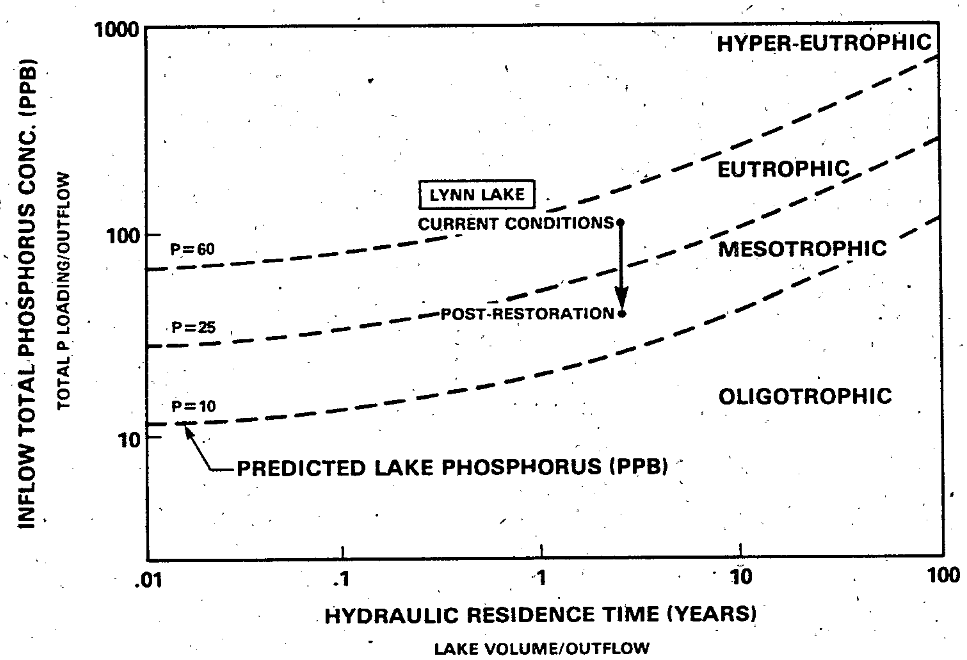


Figure 7-8.—Vollenweider phosphorus loading curve for Lynn Lake indicating that Lynn Lake is eutrophic and receiving excessive phosphorus loading.

Evaluation Criteria

The following criteria were used in the evaluation of lake and watershed management alternatives:

- Effectiveness
- Longevity
- Confidence
- Applicability
- Potential negative impacts
- Capital costs
- Operating and maintenance costs.

Effectiveness

Effectiveness relates to how well a specific management practice meets its goal. For instance, dredging would be considered effective if it met the identified goals of increasing the lake's depth and capacity, removing excessive nutrients from the lake, and eliminating weed problems. A management practice may be partially effective in that goals may be incompletely met. For instance, dredging may increase the depth and capacity, but excessive nutrients may still exist in the remaining sediments, or algae may continue to be a problem in some areas of the lake.

For some management practices, such as dredging, initial determinations of effectiveness can be based on the specific design and extent of the practice. If all the loose sediments are removed from the lake, all goals will be met. However, if funds are limited and only partial dredging is carried out, only partial effectiveness will be obtained. The decision, therefore, becomes a trade-off between effectiveness and other factors such as costs, available funds, negative impacts, and public acceptability.

For other management practices such as alum treatment or sedimentation basins, effectiveness is not straightforward and cannot be completely defined prior to implementation. Alum treatment, for example, depends upon many factors that could influence its effectiveness. If, following alum addition, high sediment or nutrient loads continue to enter the lake, the beneficial effects of alum treatment would be negated. Similarly, a detention basin is designed to treat a specific streamflow. If rain events occur that produce a streamflow in excess of the design flow, the effectiveness of the basin will be reduced. Effectiveness of management practices, therefore, must be evaluated based on the past experience of the effectiveness of the practice, the commitment to implement part or all of the required practice, and an analysis of the risks and variabilities involved.

Longevity

Longevity reflects the duration of treatment effectiveness. Treatments are usually categorized as short term or long term. A treatment or management practice is defined as short term if it is effective for one year or less. Weed harvesting, for example, is usually a short-term technique that is immediately effective but may only last for a period of several weeks or a single growing season. The short-term longevity of a treatment or management practice, however, is not inherent in the process; it usually varies with specific environmental conditions. Three copper *sulfate treatments* might control algal blooms on one lake for an entire growing season, while on another lake, weekly treatments would be necessary to overcome the effects of a high flushing rate and incomes of new nutrient-laden water. Treatment or management practices that produce short-term effects will result in long-term effectiveness if they are reapplied each year. For example, a farmer may use conservation tillage each year to produce a long-term benefit from the method.

A treatment or management practice is usually defined as long term if it is effective for more than a year. The long-term effectiveness, like short-term effectiveness, depends on both environmental conditions and the specific management practice. A sedimentation basin will provide long-term treatment effectiveness if it is properly designed for specific environmental conditions, such as streamflow fluctuations and pollutant loadings, and if it is properly maintained. If, however, the basin was designed too small, it will not continue to remove pollutants effectively. If the accumulated sediments are not periodically removed, the long-term effectiveness will be decreased by poor maintenance. Dredging will provide long-term effectiveness if the dredging program was properly designed and if watershed management practices have already been implemented. If excessive siltation still occurs, the long-term effectiveness of dredging will be decreased. Construction of grass waterways on farmland will provide long-term effectiveness if properly designed and if maintained each year.

Confidence

Confidence refers to the number and quality of reports and studies supporting the effectiveness rating of a treatment. Some in-lake procedures such as dredging have been extensively applied and studied. Confidence in the effectiveness of dredging is high, based on its record of successful application. Other techniques such as lake aeration have not been studied as extensively, and their confidence evaluation is therefore lower. In addition, poor confidence can arise from a variable record. It is not currently understood, for example, why aeration works well in some lakes and does not in others.

Applicability

Treatment applicability refers to whether or not the treatment directly affects the cause of the problem and whether it is suitable for the region in which it is considered for application. For example, nutrient concentrations in runoff from midwestern agricultural fields are often high and promote noxious algal blooms. The perceived problem is algal blooms, but the cause is excessive nutrients. Nutrient inactivation with alum can temporarily reduce nutrient levels in the lake water but cannot address the true origin of the problem—upstream agricultural watersheds. Nutrient inactivation, therefore, is not applicable to the problem of incoming nutrients; it can be applicable, however, to the problem of nutrient release from sediments into the water column. Flushing may be highly applicable where water is plentiful, but not in a region where water is scarce.

Potential Negative Impacts

Lakes are dynamic ecosystems; changing one element of the lake ecosystem may cause a beneficial or adverse change in another element. In developing a lake management program, the lake manager should take a holistic view of the ecosystem to ensure that a proposed management practice does not cause a negative impact on the lake ecosystem. For example, control of algae may bring about an expansion of the submersed macrophyte problem. On the other hand, the excessive removal of macrophytes may affect fishing by eliminating spawning and nursery areas, which would result in a decline in fish production. Obviously, some practices have short-term negative impacts that cannot be eliminated. Dredging usually destroys the bottom-dwelling organisms, but new organisms can recolonize within a year.

Capital Costs

Standard approaches should be used to evaluate the cost effectiveness of various alternatives. In evaluating costs of alternative methods, the lake manager must balance the other factors already described; namely, effectiveness, longevity, confidence, applicability, and potential negative impacts. It is rare that the benefits of different management practices are equal. Furthermore, limited funds and resources often force the lake manager to select the most affordable rather than the most cost-effective alternative. Many municipalities and lake associations elect to treat their lake's weed problem annually with a herbicide rather than dredge their lakes because they do not have sufficient funds for dredging.

Assuming, however, that the benefits of alternative management practices are equal or nearly equal, the annual cost method should most likely be used to determine the most cost-effective alternative. In this method, all costs must be calculated using the same discount rate, and the annual cost must be based on the same period of analysis.

An example of the annual cost method is provided for comparing dredging and alum treatment of Lynn Lake. The targets of dredging and alum treatment are almost the same—to reduce phosphorus in the lake.

Cost Comparison: Alum Treatment Versus Dredging

Assume:

1. Dredging has a lifespan of 20 years, assuming that 1 foot of sediment is uniformly removed over 150 acres and that external loading is reduced.
2. Alum treatment has a lifespan of 6 years.
3. Benefits are equal.
4. Dredging has a one-time cost of $500,000 ($2 per yd^3).
5. Alum treatment costs $35,000 every 6 years, assuming that the entire area beneath the metalimnion (100 acres) is treated at a cost of $350 per acre.

The annual cost method is often used to compare alternatives. The main advantage of this method over all other methods (such as present worth) is that it does not require making the comparison over the same number of years when the alternatives have different lives. The equivalent annual cost is calculated as follows:

Equivalent Annual Cost = Present Cost (Capital Recovery Factor)

The capital recovery factor is obtained from standard interest tables for various interest rates and time periods. Figure 7-9 shows a typical table for an interest rate of 6 percent. Based on the assumptions described above, the cost analysis is as follows:

Discrete Cash Flow
6.00% Discrete Compound Interest Factors

	Single payments		Uniform series payments				
N	Compound Amount P/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	N
1	1.0600	0.9434	1.00000	1.000	1.06000	0.9434	1
2	1.1236	0.8900	0.48544	2.060	0.54544	1.8334	2
3	1.1910	0.8396	0.31411	3.184	0.37411	2.6730	3
4	1.2625	0.7921	0.22859	4.375	0.28859	3.4651	4
5	1.3382	0.7473	0.17740	5.637	0.23740	4.2124	5
6	1.4185	0.7050	0.14336	6.975	0.20336	4.9173	6
7	1.5036	0.6651	0.11914	8.394	0.17914	5.5924	7
8	1.5938	0.6274	0.10104	9.897	0.16104	6.2098	8
9	1.6895	0.5919	0.08702	11.491	0.14702	6.8017	9
10	1.7908	0.5584	0.07587	13.181	0.13587	7.3601	10
11	1.8983	0.5268	0.06679	14.972	0.12679	7.8869	11
12	2.0122	0.4970	0.05928	16.870	0.11928	8.3838	12
13	2.1329	0.4688	0.05296	18.882	0.11296	8.8527	13
14	2.2609	0.4423	0.04758	21.015	0.10758	9.2950	14
15	2.3966	0.4173	0.04296	23.276	0.10296	9.7122	15
16	2.5404	0.3936	0.03895	25.673	0.09895	10.1059	16
17	2.6928	0.3714	0.03544	28.213	0.09544	10.4773	17
18	2.8543	0.3503	0.03236	30.906	0.09236	10.8276	18
19	3.0256	0.3305	0.02962	33.760	0.08962	11.1581	19
20	3.2071	0.3118	0.02718	36.786	0.08718	11.4699	20
22	3.6035	0.2775	0.02305	43.392	0.08305	12.0416	22
24	4.0489	0.2470	0.01968	50.816	0.07968	12.5504	24
25	4.2919	0.2330	0.01823	54.865	0.07823	12.7834	25
26	4.5494	0.2198	0.01690	59.156	0.07690	13.0032	26
28	5.1117	0.1956	0.01459	68.528	0.07459	13.4062	28
30	5.7435	0.1741	0.01265	79.058	0.07265	13.7648	30
32	6.4534	0.1550	0.01100	90.890	0.07100	14.0840	32
34	7.2510	0.1379	0.00960	104.184	0.06960	14.3681	34
35	7.6861	0.1301	0.00897	111.435	0.06897	14.4982	35
36	8.1473	0.1227	0.00839	119.121	0.06839	14.6210	36
38	9.1543	0.1092	0.00736	135.904	0.06736	14.8460	38
40	10.2857	0.0972	0.00646	154.762	0.06646	15.0463	40
45	13.7646	0.0727	0.00470	212.744	0.06470	15.4558	45
50	18.4202	0.0543	0.00344	290.336	0.06344	15.7619	50
55	24.6503	0.0406	0.00254	394.172	0.06254	15.9905	55
60	32.9877	0.0303	0.00188	533.128	0.06188	16.1614	60
65	44.1450	0.0227	0.00139	719.083	0.06139	16.2891	65
70	59.0759	0.0169	0.00103	967.932	0.06103	16.3845	70
75	79.0569	0.0126	0.00077	1300.949	0.06077	16.4558	75
80	105.796	0.0095	0.00057	1746.600	0.06057	16.5091	80
85	141.579	0.0071	0.00043	2342.982	0.06043	16.5489	85
90	189.465	0.0053	0.00032	3141.075	0.06032	16.5787	90
95	253.546	0.0039	0.00024	4209.104	0.06024	16.6009	95
100	339.302	0.0029	0.00018	5638.368	0.06018	16.6175	100

Figure 7-9.—(From Blank and Tarquin, 1983.)

Annual Cost for Dredging Lake: From Figure 7-9 for a time period of 20 years (N=20), the capital recovery factor is 0.08718. Therefore, the equivalent annual cost is calculated as follows:

Equivalent Annual Cost = $500,000 (0.08718) = $43,590/year

Annual Cost for Alum Treatment: From Figure 7-9 for a time period of 6 years (N=6), the capital recovery factor is 0.20336. Therefore, the equivalent annual cost is calculated as follows:

Equivalent Annual Cost = $35,000 (0.20336) = $7,118/year

From this comparison, it is obvious that alum treatment is the more cost-effective alternative since the equivalent annual cost is $7,118 for alum treatment and

$43,590 for dredging. Cost estimates for these treatments, while based on an average of some actual case histories, cannot be applied, even as estimates, to any other real lake situations. Each lake will have important and unique features that will produce unique unit costs.

Watershed Management Alternatives

Watershed management practices, described in Chapter 5, include controlling runoff from agriculture and silviculture, stabilizing eroding shorelines, controlling construction runoff, and repairing failing septic systems. Watershed management also includes nonstructural practices such as the development of model erosion and runoff control ordinances.

To be cost effective, watershed management practices should be directed toward priority areas. Priority rating systems usually include factors such as proximity to lake, existing pollutant loadings, potential reductions in pollutant loadings, and costs. For small watersheds where specific, limited watershed management alternatives can be identified, the evaluation and selection process is relatively straightforward and can be performed as described later in this chapter. However, for large watersheds where only large-scale generic watershed management alternatives such as agricultural practices or streambank erosion control can be identified, the selection process is more complicated. For small watersheds, the costs and effectiveness of management practices can be readily estimated, but for large watersheds neither can be easily identified. Therefore, selection of a management program for a large watershed is much more subjective and qualitative than for a small watershed.

By its very nature, a large watershed management program must be evolutionary and long term: first, priority areas are identified; then the most suitable management practices are selected and implemented.

The watershed management information contained in Chapter 5 was used to evaluate the effectiveness, longevity, and applicability of various watershed management practices.

Based on the results of the diagnostic portion of the study, the consultant for Lynn Lake identified specific priority areas in the watershed. These areas included the Middletown wastewater treatment plant, specific agricultural areas in the watershed, and several developing areas of the watershed. Various management practices for each high-priority area were identified and evaluated using the criteria discussed previously. An evaluation matrix, shown in Table 7-6, was developed to evaluate the various management practices. Information from Chapter 5 and other reference sources was used to develop a rating based on conditions specific to Lynn Lake such as land use, activity, soil conditions, topography, and pollutant loadings. This matrix format can be used for decisionmaking on any lake. The evaluations in Table 7-6, however, apply *only* to Lynn Lake.

Wastewater Treatment Plant Upgrade

Table 7-5, the annual phosphorus budget for Lynn Lake, indicates that the Middletown treatment plant (listed as WWTP) contributes 52.5 percent of the annual total phosphorus income to Lynn Lake. In addition to being the dominant phosphorus source, the treatment plant discharges phosphorus primarily in the form of soluble reactive phosphorus, a form readily available for algal and weed growth. Also, the plant discharges this highly available phosphorus throughout the year, even during summer low flow conditions. It is important, therefore, that this phosphorus source be significantly reduced.

There are two alternatives for eliminating or reducing the phosphorus entering the lake from the treatment plant: diverting the plant effluent to another watershed that is not adversely affected by high phosphorus levels or providing tertiary treatment to remove a significant portion of the phosphorus from the plant's effluent. Diversion of the treatment plant's effluent to another watershed was rejected because the pipeline and pumping station needed for the diversion would cost approximately $400,000—more than the cost of adding tertiary treatment to the plant. It was also rejected because the citizens in the adjacent watershed opposed the diversion of effluent to their watershed.

The addition of tertiary treatment facilities to the existing secondary treatment plant would reduce the effluent phosphorus concentration by 75 percent, from 2 ppm to 0.5 ppm. The tertiary treatment facilities would include the addition of a sand filter and alum treatment to the existing plant. Addition of the tertiary facilities would cost approximately $300,000 for the 100,000 gallon-per-day treatment plant. Operation and maintenance costs would increase by about 25 percent primarily because of increased chemical and sludge disposal costs.

As shown in Table 7-6, the addition of tertiary treatment facilities to the Middletown plant was rated excellent for all categories except capital cost and operations and maintenance cost. Although the cost of tertiary treatment is high, this approach must be implemented to reduce the dominant phosphorus load to Lynn Lake.

Sedimentation Basins

An effective practice for controlling sediment and phosphorus loads to Lynn Lake is the construction of sedimentation basins on the major tributary streams, just upstream of the lake. As shown in Table 7-6, the basins were rated "good" overall, except for the costs, which were rated "fair." Construction of the basins would be cost effective only if upstream watershed management practices were not implemented or were not effective. Construction of the basins, therefore, was rejected and postponed until upstream management practices could be implemented and evaluated. If additional sediment and phosphorus load reductions were required after upstream management practices were implemented, then the construction of the sedimentation basins should be reconsidered.

Agricultural Practices

The ratings of agricultural practices, shown in Table 7-6, were developed in conjunction with the U.S. Soil Conservation Service and the County Conservation District. Priority management practices were determined based on these ratings and included animal waste management, grassed waterways, buffer strips, and conservation tillage. Secondary emphasis was given to pasture management, crop rotation, and runoff diversion. The Soil Conservation Service was contacted for information on the low input-sustainable agriculture program and this information was given to the farmers in the watershed. The Soil Conservation Service worked with the farmers to develop multiple use programs that would actually sustain yields while reducing erosion and nutrient input to the streams feeding Lynn lake.

Construction Controls

Construction–development controls were divided into three general categories:

- Erosion control ordinance
- Runoff control ordinance
- Field inspections.

Table 7-6.—Watershed management evaluation matrix

PRACTICE	EFFECTIVENESS	LONGEVITY	CONFIDENCE	APPLICABILITY	POTENTIAL NEGATIVE IMPACTS	CAPITAL COST	O&M COST
Addition of Tertiary Treatment to Middletown Treatment Plant	E	E	E	E	E	F	F
Construction of Sedimentation Basins at Inlets to Lake	G	E	G	G	G	F	F
AGRICULTURAL PRACTICES							
—Conservation Village	F-E	G	G	G	F	F	F
—Contour Farming	F-G	P	F	G	E	E	E
—Pasture Management	F-G	E	E	G	E	E	E
—Crop Rotation	F-G	G	G	G	E	E	E
—Terraces	F-G	G	G	G	E	F	G
—Animal Waste Management	E	E	E	E	E	F	F
—Grass Waterways	E	E	G	G	E	G	E
—Buffer Strips	E	E	E	E	E	G	E
—Diversion of Runoff	G	G	F-G	F	E	F	G
CONSTRUCTION CONTROLS							
—Erosion Control Ordinance	E	E	E	E	E	E	E
—Runoff Control Oridnance	E	E	E	E	E	E	E
—Field Inspections	E	E	E	E	E	E	E

Legend: E = Excellent G = Good F = Fair P = Poor

An erosion control ordinance provides rules and guidelines to regulate the control of erosion from an active construction site. Although the State has an ordinance to control erosion on construction sites, the Advisory Committee recommended that the county enact a county-wide erosion control ordinance more restrictive and enforceable than the State ordinance. In general, control of erosion should be a local, not a State regulated function.

A runoff control ordinance, in contrast to an erosion control ordinance, provides rules and guidelines for controlling runoff and erosion from new developments after construction is completed. The consultant developed a runoff control ordinance that required that the peak postdevelopment stormwater runoff rate not exceed the peak predevelopment runoff rate. It also contained an equation for estimating the phosphorus load from the new development and stipulated that the postdevelopment phosphorus load not exceed the predevelopment load.

No ordinance is effective if it is not adequately implemented and inspected. Field inspections of all construction sites during and after construction are necessary to ensure that all ordinance conditions are being met. All three construction–development controls (that is, erosion control ordinance, runoff control ordinance, and field inspections) were rated excellent in all categories in Table 7-6. Implementation of all three controls will eliminate or significantly reduce runoff and erosion problems for new developments.

In summary, the watershed management program recommended by the Advisory Committee consisted of the following:

- Addition of tertiary treatment facilities to the Middletown treatment plant;
- Implementation of priority agricultural practices in priority agricultural areas;
- Development and adoption of erosion control and runoff control ordinances; and
- Development of a field inspection program for construction and development sites.

After these practices are implemented, the annual sediment and phosphorus loads to Lynn Lake would be re-evaluated to determine whether additional practices, such as the construction of sedimentation basins, are needed.

In-Lake Management Alternatives

In-lake management practices applicable to the control of excessive algal and weed growth and loss of depth were identified and evaluated using the information contained in Chapter 6. Each management technique was evaluated based on the lake and watershed data collected during the study. The results of this evaluation, presented in Table 7-7, indicate that the most feasible and cost-effective in-lake management practices include the following:

- Alum treatment to precipitate and inactivate phosphorus
- Dredging of the lake inlet areas.

Alum treatment, after the addition of tertiary treatment to the Middletown treatment plant, was selected because the study data indicated that internal cycling of phosphorus from the lake sediments was a source of phosphorus to Lynn Lake.

Table 7-7.—In-Lake management evaluation matrix

PRACTICE	EFFECTIVENESS	LONGEVITY	CONFIDENCE	APPLICABILITY	POTENTIAL NEGATIVE IMPACTS	CAPITAL COST	O&M COST
Alum Treatment to Precipitate and Inactivate Phosphorus	E	G	G	E	F-G	G	G
Dredging of Whole Lake	P	E	E	P	F-G	P	E
Dredging of Lake Inlet Areas	E	E	E	E	G	F	E
Dilution	F	F	F	P	F	P	P
Flushing Artificial Circulation	F	F	P	F	F	P	F-P
Hypolimnetic Aeration	F	F	F	F	F	P	F-P
Sediment Oxidation	G	G	P	F	G	F	G
Addition of Algicides	G	P	E	F	P	G	P
Food Chain Manipulation	G	Unknown	P	F	Unknown	E	E
Hypolimnetic Withdrawal	G	G	G	G	F-P	G	E
Water Level Drawdown to Remove Weeds	F	F	F	P	F-P	F	G
Weed Harvesting	G	P	G	G	F	F	P
Biological Controls to Reduce Weeds	G	G	F	G	F-P	G	G
Addition of Herbicides	G	P	G	F	P	G	P

Legend: E = Excellent G = Good F = Fair P = Poor

The lake characteristics are conducive to alum treatment: the flushing rate is low (0.45 times per year) and the annual phosphorus loading after watershed management practices are implemented will be relatively low. Lab studies were performed to determine the alum dosage required to both remove phosphorus from the lake water and to inactivate (seal) the phosphorus in the sediments. Additional alum treatments may be required every six years based on case studies of other similar lakes treated with alum.

Alum treatment on a three- to five-year basis was compared to dredging of the whole lake using the cost comparisons described earlier. Alum treatment was judged the most cost-effective method of controlling phosphorus from lake sediments. If, however, a secondary benefit—lake deepening—was added, dredging of the whole lake may be the most cost-effective alternative. However, since Lynn Lake is deep enough for its intended recreational uses, lake deepening was rejected as a benefit, and alum treatment was selected as the practice to inactivate phosphorus in the sediment.

Dredging of lake inlet areas, however, was selected as a feasible management practice since the siltation of the lake primarily affected the inlet areas that were shallow and unusable for boating. Many of the aquatic weeds also grow in these inlet areas.

Other in-lake practices were rejected for a variety of reasons. Dilution and flushing were rejected because a source of dilution water was not available. Pumping of groundwater to flush and dilute the lake was rejected because of high costs and the potential depletion of groundwater. Aeration of the whole lake was rejected because of the lack of confidence in the practice and the high capital and operation costs. Insufficient data are available on the effectiveness of whole lake aeration. Hypolimnetic aeration (aerating only the bottom waters) was rejected because it was evaluated "fair" in all categories except costs, which were rated "poor." Sediment oxidation was rejected because of the "poor" confidence rating; insufficient data are available on the effectiveness of sediment oxidation.

The addition of algicide was rejected because it is a "Band-Aid" approach that has poor longevity and produces negative environmental impacts. Algicide, however, can be added on a temporary basis while the watershed management program is being implemented but should not be used as a long-term management program. Weed harvesting and the addition of herbicides were also rejected for similar reasons.

Food chain manipulation was rejected because the longevity and negative impacts are unknown and the confidence level was rated "poor." Biological controls to reduce weeds were rejected to avoid introducing exotic species to the lake. Water-level drawdown, although it was rated "good" for effectiveness, was rejected because the citizens did not want the lake water lowered.

Hypolimnetic withdrawal, the discharge of nutrient-laden bottom waters, was temporarily rejected because of concern over potential downstream impacts and possible in-lake effects on the thermal stratification of the lake. Discharge of bottom waters high in nutrients and low in dissolved oxygen could adversely affect water quality downstream of Lynn Lake. The Advisory Committee decided that these potential impacts should be further investigated before a bottom discharge would be allowed.

In summary, the in-lake management program recommended by the Advisory Committee consisted of the following:

- Alum treatment to precipitate and inactivate phosphorus
- Dredging of the lake inlet areas.

Public Hearing

Prior to the final selection of watershed and in-lake management alternatives, the Advisory Committee held a formal public hearing. The consultant presented an overview of the study along with a description of the conclusions and proposed management plan. In describing the proposed management program, the consultant clearly explained the evaluation criteria used in developing the plan. Comments from the public on all aspects of the study and management plan were solicited by the Advisory Committee.

In general, the public comments were positive and supported the proposed management program. Some questioned whether the restoration program would cause an increase in county taxes. Others wanted to know whether their sewerage fees would increase when the treatment plant was upgraded to tertiary treatment. They were told that county taxes would not increase but that the sewerage hookup fees and user fees would increase by a small amount. Some wondered if fishing would be adversely affected by the proposed plan. It was explained that the alum treatment and inlet dredging would shift the lake from an eutrophic to a mesotrophic state. Although less productive, the mesotrophic lake conditions would primarily benefit game fish production and would enhance fishing.

Several citizens recommended that the monthly monitoring results for the treatment plant's effluent be sent to the county and the Advisory Committee to ensure that the plant met its treatment requirements. Others recommended that the Advisory Committee be maintained until the management plan was completely implemented and that the county hire a full-time lake manager to oversee the program. The Advisory Committee directed the consultant to include these recommendations in the final management plan.

Selection of Management Plan

The Advisory Committee, in conjunction with the consultant, presented the final lake and watershed management plan to the County Commissioners for review. After they revised the plan, the Commissioners approved the plan and directed the County Engineer to forward the Phase I Study Report and Management Plan to the State Water Control Board and EPA for their reviews. The plan was approved by both the State and EPA.

Chapter 8

IMPLEMENTING A MANAGEMENT PLAN

Management Means Implementation

A well-evaluated and carefully designed management plan is useless if it is never carried out and may be either useless or disastrous if it is poorly followed. Management includes not only diagnosing problems and evaluating alternative solutions but also putting the chosen plan into action.

Proper implementation requires money, manpower, planning, scheduling, and permission. Even on private lakes, various permits and regulations must be satisfied before many lake restoration techniques can be applied. If the watershed is not entirely owned by a single lake user, coordination among parties becomes a sizable task in itself. And, in all cases, education is a necessary counterpart to accomplishment. Never assume that the majority of residents will be aware of the major and minor disruptions to their tranquil lake environment that will occur once implementation begins. Publicity on not only the goals of the project but the procedures used to reach them will foster both public support and patience during the implementation phase.

Who Does the Work?

For many lake managers, homeowners, and other interested persons, the most important step in implementation is the selection of a knowledgeable and experienced consultant or contractor. It is at the implementation stage that the benefits of experience become obvious. There can be frequent opportunities for delays, minor accidents, misunderstandings, and oversights in a restoration project. Experienced contractors are more likely to foresee these problems and be better prepared to handle unexpected ones.

The person who pays the contractor has responsibilities as well. For example, an association may hire a lake manager or consultant, who, in turn, hires contractors to carry out various tasks and represents the owners' interests. The manager's responsibilities include overseeing the budget, monitoring progress to ensure the project is on schedule, and acting as liaison between the association and the contractor to be sure that both sides understand each other's intentions and that work is not delayed while the contractor awaits important decisions.

Selecting Consultants or Contractors

Selecting the right consultant or contractor involves a number of considerations. The criteria used in Chapter 3 will ensure that the selection process identifies qualified contractors who have a responsible record and the right background to solve the particular problem. Table 3-3 in Chapter 3 also includes criteria for selecting a consultant who will be able to assist in other phases of lake management such as identifying the problem, evaluating watershed and lake management practices, and formulating the lake management plan as well as implementing the plan once it is developed.

Consulting services can range from assistance in one specific area such as lakeshore erosion, to the design, execution, and implementation of the entire lake management program. The expertise required for lake management can be specialized or broad, depending on the specific services requested, but should include limnology or aquatic ecology, watershed management practices, lake restoration techniques, economic analysis, planning, engineering, and water quality evaluations. Many lake associations prefer to work with a single firm from the preliminary study to project completion, but it may be wise in some cases to hire more than one consultant to take advantage of the strengths and specialties offered by different providers.

Experts on lake restoration can be found at universities, public and private research organizations, environmental consulting firms, or engineering firms specializing in lake management. Many firms or groups that specialize in lake management can put together teams of skilled individuals with special experience who can target a specific set of lake problems. In this case, the consultant or contractor may change team members as needed to accomplish the work most efficiently. The members of this team and the consultant should be familiar with local and State regulations, local and regional lake problems, and the management options that work in your type of lake and region of the country. The North American Lake Management Society has a list of members who can provide services by area of specialty and section of the United States.

Initially, candidate consultants and contractors can be identified by contacting (1) other lake associations to find out who they have used previously, (2) local and State environmental agencies and groups to find out who has conducted similar studies in the past, (3) a referral service offered through NALMS, or (4) societies for professionals in these trades. Appendix E provides more detailed information on various lake management programs in the States and Canadian Provinces. Because of the importance of the consultant or contractor in properly implementing the lake management program, several individuals or groups should be interviewed. The criteria listed in the case study in Chapter 7 can be used as a starting point for questions related to their expertise and capabilities.

Asking for references is imperative. The hiring agency should write, or better yet call, these references in addition to evaluating the responses of candidates to interview questions. Lake management is not a cookbook process; there is some art to lake management as well as engineering and science. Innovation should be an important criterion. There are, however, certain important components in implementing any lake management program. These are discussed in the remainder of this chapter. This information also can be used to initiate questions for the consultant during the evaluation and selection process.

Institutional Permits, Fees, and Requirements

Every State and many Federal agencies have institutional requirements (for example, permits, fees, and notifications) that must be met before lake restoration or watershed management practices can be implemented. Some of these requirements are briefly summarized in Appendix E. DO NOT assume this is a complete list of all the agencies that need to be contacted. Local, city, and county agencies might also require various permits or fees or fulfillment of necessary conditions, and these requirements and agencies change through time. Obtain a recent list of permits, fees, or other requirements.

These institutional requirements, in many instances, are technique specific as well. The requirements for dredging, for example, will be quite different from those for herbicide application or harvesting. The U.S. Army Corps of Engineers is authorized, after proper notice and public hearings, to issue general permits to permit dredging or fill procedures if, in the Corps' determination, the dredging operation will have minimal adverse environmental effects.

If a State has assumed permit responsibility, a copy of every permit application is forwarded to the U.S. Army Corps of Engineers. Copies also are forwarded to the Secretary of the Interior and the Fish and Wildlife Service. Some States may have additional requirements, such as the State of Washington, where an application must be made to the State Department of Game for a hydraulic permit for any alteration of the stream or lake bed, including the installation of a flow- or temperature-measuring device.

In a lake restoration plan that calls for dredging, taking the sediment out of the lake represents only one part of the implementation process. The dredged material, or spoils, must be properly disposed of as fill or taken to an approved disposal area. Disposal procedures must conform with local, State, and Federal requirements, which might require monitoring of the runoff (leachate) from the disposal area.

In addition to requirements for implementation of the various techniques, there are also various Occupational Safety and Health Administration requirements to protect the health, well-being, and safety of the individuals working on the project. Ear protection and safety shoes might be required for the dredge workers, for example, or special safety precautions might be mandated to protect workers while they are mixing chemicals for alum applications or dispersing herbicides for weed control. An example of the language that can be included in contracts to promote and ensure a safe implementation program is shown in Appendix F. DO NOT assume this language will satisfy the legal requirement in your State or county. Contact a local attorney to be sure you are adequately covered.

The institutional requirements for each lake management program will depend on the specific restoration and management practices proposed. If the lake management plan is well organized and detailed beforehand, the various agencies will be able to indicate the specific procedures and guidelines that must be followed. Even if the lake manager or association is researching and filing for all permits and fulfilling other requirements, it makes sense to ask consultants and contractors if they are familiar with the appropriate regulations and agencies for the proposed lake management project. The degree of help and completeness of information may be excellent in some government offices. Other offices give out pertinent information more grudgingly, and only if the right questions are asked. The contractor's previous experience will be especially valuable if this latter situation is the case.

Implementation Costs Money

Two questions that arise from this statement are "How much will it cost?" and "Is there funding available to implement this project?"

Plans and Specifications

The first question can be addressed by having the consultant or contractor, lake manager, or interested groups or individuals develop a set of plans and specifications for the various lake management techniques that are feasible. Economic considerations were part of the evaluation that preceded choosing a management alternative, so a rough approximation of cost is already available. At implementation, this estimate can be refined by pricing materials and manpower needed; calculating the cost of the time required for implementation, equipment needs, and any construction prior to implementation; and, finally, estimating the cost of a postrestoration monitoring program.

The cost of postrestoration monitoring should be factored directly into the overall cost of implementation because it is the only approach for evaluating whether treatments are effective.

The preliminary set of plans and specifications does not have to be extremely detailed because it will be revised before it is let for bids, but it should provide sufficient information to approach potential funding agencies for money.

Funding Sources

Federal Agencies

For lakes with public access, the Clean Lakes Program, administered through the U.S. Environmental Protection Agency (EPA), is a source of funds both for diagnosis and evaluation of lake problems and also for implementation of lake management programs. Section 314 of the Clean Water Act provide for Phase I (Diagnostic/Feasibility Studies) and Phase II (Implementation) management programs to improve lake water quality. Much of the work discussed in this Manual came out of Clean Lakes studies.

Contact the State agencies listed in Appendix E for information on their programs.

Funds also might be available from other Federal agencies for various aspects of lake management:

- ❑ One of the most innovative Federal programs has been the Rural Clean Water Program, which began in 1980 as a 15-year experiment to control agriculturally generated nonpoint source pollution at the local level. Many lakes have benefitted from the RCWP's objective of improving water quality. Based on interagency cooperation, the program is administered by the U.S. Department of Agriculture's (USDA) Agricultural Stabilization and Conservation Service (ASCS) in consultation with EPA. The Soil Conservation Service has contributed technical expertise, with national, State, and local committees making the major program decisions.

- Soil and water conservation are encouraged by grants and cost sharing through the ASCS. Cost sharing enables communities to design management systems to improve water quality and stabilize runoff of nutrients or soils. Longer-term agreements would allow for preservation of wetlands areas. An advisory service to improve flood prevention, streambank protection, and wildlife protection is also available.

- Guaranteed and insured loans also are available through USDA's Farmers Home Administration to improve farmland and watersheds through soil conservation, treatment of farm wastes, and reduction of runoff into receiving waters.

- The Department of Agriculture's Forest Service offers research grants and financial assistance to improve watershed management. Studies that determine the fate of pesticides and fertilizers after they have been applied to forests. Reforestation and habitat improvement research studies are also funded.

- Loans and project grants are available through the Economic Development Administration of the Department of Commerce to encourage economic improvements in financially depressed areas. Support for better water and sewage facilities helps to improve the water quality of lakes and streams. In some instances, cities or regions that have strong, organized offices of economic development have sponsored or provided assistance in lake projects.

- The Department of Housing and Urban Development supports a broad range of planning and management activities to improve land management and protect natural resources.

- The Department of Interior's Office of Surface Mining Reclamation and Enforcement makes available grants to States to restore lands and waters affected by pre-1977 coal mining. The 1977 Federal Surface Mining Law makes mine operators responsible for protecting the environment during coal mining and reclaiming the land afterward.

- Interior's Bureau of Reclamation improves recreation development and flood control and aids in protecting municipal and industrial water supplies through project grants and loans.

- The U.S. Fish and Wildlife Service oversees habitat development and enhancement of fisheries resources and researches the effect of pesticides on fish and wildlife through formula grants.

- The U.S. Geological Survey offers help to the States through cooperative programs that provide 50 percent matching grants to investigate the physicochemical properties of the State waters as well as the geology and quantity of streamflow from watersheds and basins. This agency also manages the State Water Resource Research Institute Program, which can be of great assistance to lake restoration efforts.

State Agencies

EPA's Clean Lakes Program has encouraged the development of lake management programs in many States. Most are modeled after the Clean Lakes Program; some administer the Federal program for their States, others fund projects independently. The funding status of state programs is shown in Appendix E. Funding varies annually, so these agencies need to be contacted well in advance of deadlines for submittal of grant requests to determine their current or projected funding status.

Each State and territory has a designated State Water Resource Research Institute or Center on the campus of at least one land grant university. Nearly all these universities have staff and libraries that can be of great assistance to individuals or groups seeking information about restoration programs such as the State agencies involved, the rules and regulations involving shoreline development, in-stream and lake manipulations, dredging, and application of chemicals to lakes. In most instances staff will be aware of assistance programs to implement a restoration project. Each institution or center also has contact with, or directories of, the more prominent lake researchers and agency personnel in the State or territory.

Local Funding Sources

In some States, lake management districts have been authorized with enabling legislation that permits millage or tax assessments. Watershed management districts, irrigation districts, conservation districts, or sewer districts may have the authority to fund watershed or lake management plans that will improve lake quality. Private foundations might have funds available for particular aspects of lake management such as nature conservancy (for example, preserving or enhancing wetlands around a lake) or other considerations.

Local clubs, organizations, or community agencies might provide funds or sponsor fundraising activities. For example, if fishing is a desired lake use, local fishing clubs might be interested in sponsoring a fishing tournament, community dance, or other activity to raise money.

Local activities can raise significant amounts of money. The small community of Republic, Washington, raised $25,000 in direct contributions to meet a State matching requirement to fund studies on nearby Curlew Lake.

For many grants or awards, a fund-matching arrangement requires the recipient to raise a percentage of revenue to qualify. This matching money, however, does not have to be out-of-pocket cash. Often, in-kind services are credited with a value in lieu of actual monies. Contributed time at an approved, audited rate can satisfy the matching requirements. City, county, or State agencies, for example, might provide an in-kind match by filing permit applications, coordinating public meetings, or monitoring restoration activities or other aspects of the project.

Volunteer help from lake association members or interested citizens is invaluable, particularly where Federal or State funds cannot be obtained. Many lake restoration projects have been effectively conducted by using volunteers and equipment donated by local contractors: a flotilla of fishing boats for alum treatment; local contractors with backhoes and dump trucks for dredging; and youth groups to plant sod or other vegetation to stabilize stream banks or shoreline. Every option should be considered for lake restoration.

Once funding sources have been identified, the project can be submitted to prospective consultants and contractors for bids.

Implementation Requires Contracts

Invitations to bid can be announced locally, but because lake management is a specialized area, it is generally better to announce the invitation to bid at the State or regional level. Various organizations have newsletters that are read by lake management contractors and consultants, so it is a good idea to also consider placing an announcement there. Potential contractors or consultants should include a list of their qualifications with their bids. In the invitation to bid, a minimum set of qualifications should be specified as a prerequisite to consideration. Prequalification prevents contractors from wasting their time submitting bids on projects for which they are not competitive and reduces the time the lake manager has to spend reviewing bids.

Evaluation of the bids and selection of the contractor should be based on the quality of the proposed work as well as price. The lowest cost will not always result in the desired lake quality. A local attorney familiar with engineering contracts can be used to prepare a contract or review the contract submitted by the individual or firm selected.

The person preparing the contract should consider including a requirement for a contract bond and liability insurance. A contract bond guarantees that the work or implementation of the lake management plan will be completed in accordance with the contract documents (that is, the lake management plan with associated specifications) and that all costs will be paid. Examples of a bid bond, payment bond, and performance bonds are included in Appendix F. These are examples *only*; contact a local attorney for a legal contract.

Implementation Takes Time

Inclement weather, unanticipated obstacles, and other factors can delay the implementation of the lake management program. Some of these delays may be unavoidable, but their impact can be minimized. One of the first products the successful contractor or consultant should deliver is a detailed project schedule and contingency options for every critical activity. A critical activity is one that must be completed before another can proceed or be finished. For example, a restoration plan that includes dredging will come to a complete stop if the business of acquiring and preparing an approved disposal site is not begun early enough. Until the disposal site is ready, nothing can come out of the lake.

Smooth implementation depends on careful scheduling. Not only do critical activities need to be timed to one another, but convenience, ideal operating conditions, and maximal efficiency should also be kept in mind. It is better to plan dredging to coincide with a time of year when usage is low but the lake is accessible, such as fall or early winter, which allows for maximum boating safety, as well. In colder climates, dredging can occur in the winter using conventional construction equipment such as bulldozers and drag lines. The lake can be drawn down in the fall and the sediments allowed to consolidate and freeze before removal. This permits the use of volunteer labor and local construction contractors or operators for sediment removal, which can decrease expenses. Alum treatment can be scheduled (1) for late spring following the major spring thaw to aid in inactivation of new nutrient input, (2) in the fall to intercept the release of nutrients from decaying macrophytes, or (3) after dredging to inactivate suspended phosphorus and reduce exposure of rich sediments to overlying water columns. Watershed manipulation such as streambank revetment or levee construction can best be accomplished when water flow is low. Implementation of streamside management zones should coincide with the peak growing season so that vegetation can become established before winter.

Scheduling programs are available for personal computers that permit daily, weekly, or monthly tracking of the project's progress. These programs can be revised quickly to determine the impact of delays on project implementation and reschedule other activities to minimize these delays. The lake manager should review these schedules on a weekly basis during peak construction or implementation periods.

The lake manager, contractor, or other interested party should audit the project's progress and expenditures at least quarterly to determine if the budget is living up to the schedule.

Monthly progress reports should be required for the contractor.

Public Education is Critical for Sound Lake Management

Public education must begin before implementation ever occurs, but it is particularly critical *during* implementation. Various desired lake uses generally are partially restricted while restoration is in progress. Activities such as shoreline stabilization, alum treatment, and dredging restrict lake usage. People typically respond positively when they understand what is occurring and why. People react negatively when they are uninformed.

In many States, public meetings are a requirement for lake restoration projects. Every opportunity should be used to discuss progress in all phases of lake restoration at lake association and lake homeowner meetings. It is essential to prepare lake residents and users for what may take place during the implementation phase.

Materials, including slides, films, and videotapes of other projects, may be used to familiarize the public with the type of equipment and procedures that will be used during lake restoration. NALMS can provide a videotape or slide show on lake management for use in a public information program.

Postrestoration Monitoring is an Integral Part of Implementation

The greatest current deficiency in lake management is the lack of information on treatment longevity and effectiveness; postrestoration monitoring can supply this data.

Results from lake management and restoration projects are not always obvious to the naked eye; monitoring can help identify changes in the lake and whether or not the trend is toward improvement. If monitoring shows that an improvement is not occurring, the data can be used to help diagnose the cause. In addition, restoration projects can result in a short-lived improvement because some factor not accounted for in the restoration plan is counteracting the work that was done. By maintaining a continuing monitoring program, such problems can be detected as they develop.

Monitoring is one of the most cost-effective activities of the entire lake management program. Monitoring, however, does cost money; the amount is directly related to the number of stations, the number of samples, the number of variables, and the sampling frequency. The number of stations and depths was discussed under Sampling Sites in Chapter 3. In general, for oval or round lakes a single station over the deepest point in the lake might be satisfactory. Additional stations will be required as the lake or reservoir becomes more irregular, with multiple coves and embayments, or much longer and narrower.

To assist in the design of a postrestoration-monitoring program (for example, parameters to measure, the frequency of measurement, location and depth in the lake, inflow and outflow), a technical supplement on monitoring, *Monitoring Lake and Reservoir Restoration* (Wedepohl et al. 1990), was prepared to complement this Guidance Manual. The technical monitoring supplement discusses appropriate parameters to measure for different types of lake problems and management techniques, the relative cost of these parameters, and how to prioritize parameters. The supplement also provides guidance on interpreting and presenting the monitoring results.

Regardless of the question asked or problem addressed, there is no substitute for data. Table 8-1 explains briefly where samples are taken for commonly measured chemical and physical data.

The reliability of the conclusions drawn from monitoring data is directly related to its quality. There are well-established and accepted methods and procedures for chemical analysis of water samples as well as for quality assurance and quality control of the analyses. It is imperative that the laboratory, consultant, or contractor who collects and analyzes these samples use accepted methods and standard quality assurance/quality control procedures. Inquire about their methods and ask to see the quality assurance/quality control results from previous water quality analyses on lakes or streams. Laboratories that analyze sewage might not be able to analyze lake water samples because the constituent concentrations may be 100 to 1,000 times less than wastewater. Test kits are appropriate for some analyses but should not be used for most routine water quality examinations. Water quality analyses cost money; make sure the quality of the data warrants the expense.

Table 8-1.—Long-term monitoring requires proper siting and appropriate selection of parameters

LONG-TERM MONITORING CONSIDERATIONS	
SITING	
Ambient Water Quality	Generally, one site over the deepest part of the lake. Should not be near a dam, close to shore, or near stream inflows or point source influents. Lakes with distinctive subbasins, coves, fingers, or multiple inlets may require additional sampling sites (see Chapter 3)
Budgets	Flow rates, water levels, and concentrations can be measured on major tributaries and estimated on minor inflows. Accurate assessment of lake volume be necessary to account for nonpoint source loading and runoff volume entering the lake. Nonpoint sources are difficult to monitor; a professional will base siting on lake-specific hydrology, basin morphometry and other factors. Reference land-use-based export coefficients can provide a good first approximation, often sufficient to disguise problems. Budgets are usually limited to diagnostic studies, but long-term monitoring may be employed to track success of a restoration project or management technique.
Sources	Monitoring sites can usually be limited to major inflowing streams or point source outfalls to the lake or tributary—particulary near suspected sources of sediment, nutrients, organic matter, or chemicals. Unless a special problem or land use exists, rates from these stations can be used to interpolate rates from minor inflows. In seepage lakes, groundwater observation wells may be necessary.
PARAMETERS	
Complete Water Chemistry	Samples taken from two depths (1 ft below surface and 2 ft above lake bottom) The following constituents are commonly measured, but a professional may recommend additional (or fewer) constituents: **Priority Group** Dissolved oxygen Total phosphorus Total nitrogen pH Total alkalinity Turbidity Total suspended solids **Other Parameters Commonly Measured** Ammonia nitrogen; Kjedahl nitrogen Nitrate-nitrite nitrogen; Chlorine Dissolved phosphorus; Calcium Magnesium; Sodium Potasium; Sulfates Iron; Manganese Total dissolved solids; Volatile solids Color
Total Phosphorus	Sampled at two depths (1 ft below surface, 2 ft above bottom) during late winter to spring turnover; during growing season sampled at three depths (surface, bottom, and at top of hypolimnion). Multiple measurements near the surface are a priority
Water Temperature pH Conductivity	These parameters are profiled, or recored along a vertical axis (the water column), from 1 ft below surface and at 3-6 ft intervals to the bottom. Meter is required to measure pH and conductivity
Chlorophyll-a	Measured at 1 ft below lake surface, and as important as phosphorus
Secchi Transparency	Extremely useful and simple measurement; minimal sampling schedule can be inexpensively upgraded to weekly sampling with volunteer observers

Table 8-1.—Long-term monitoring requires proper siting and appropriate selection of parameters (cont.)

LONG-TERM MONITORING CONSIDERATIONS	
OTHER USEFUL MEASUREMENTS	
Lake Water Level	Frequency can be increased to weekly observations at low cost by using volunteer observers; volunteer programs to observe water levels during storm events, however, are difficult to conduct. If intensive sampling is required for a diagnostic study, automated equipment is generally used
Fish Survey	Netting during spawning season, boom shocking after Sept. 1. Electroshocking every other year. Gill netting every sixth year. Obtain advice from State or local agency or fish and wildlife department
Macrophytes	Surveyed every third year for abundance and location by species during peak growing season, late summer
Phytoplankton	Water collected at 1 ft depth with water bottle to identify species and general abundance
Zooplankton	A vertical tow is made with a plankton net for identification and general bundance
Macro-invertebrates	Sampling is conducted in late winter in the lake and inflowing streams
Watershed Map	Inventory of existing land use with field verification (on-site observation and walking tours). Updated every 3 to 5 years, as necessary, can provide an excellent record of potential sources both for tracing the origin of problems and planning to prevent problems

Chapter 9

LAKE PROTECTION AND MAINTENANCE

Introduction

Fishing, swimming, boating, hiking, watching a sunset or a sunrise over the water, sitting on the shore—all are activities that occur in and around lakes. Water attracts people, and, if uncontrolled, this attraction can eventually result in impairment of water-based recreation. This Manual is directed primarily at restoring these desired lake uses. Obviously, the best solution would have been to prevent the degradation from occurring. Now, the object is to prevent these problems from occurring again once the lake is restored.

This chapter discusses some of the approaches that can be used to protect and maintain desired lake uses. These approaches range from informal backyard discussion of lakeshore maintenance or aquatic weeds to the passage of laws to protect lakes. The key to lake protection and maintenance in all of the approaches, however, is public involvement and organization.

Lake Organizations

The protection and maintenance of lakes depends on the ability of lakefront property owners and lake users to identify their own interests and form an association to pursue these interests. Many lake associations are organized in response to lake crises such as nuisance weeds, fishkills, foul odors, or pollution from watershed development. People recognize that they can accomplish more as an organized group than they can individually, and this rationale holds true for lake protection and maintenance. Preservation of a lake, its water quality, and the desired lake uses is far more prudent than restoration, and it is certainly more cost effective.

Lake organization activities range from holding informal meetings of homeowners to share information about the lake, to monitoring the passage of enabling legislation to form special districts to protect and improve lakes. Wisconsin lake districts, for example, have the power to tax, levy special assessments, borrow and bond to raise money, make contracts, and other like authority to protect and improve their lakes. The critical element is the formation of the lake association. If your lake does not have a lake association, identify several people who share your interest and concerns and form a steering committee. There is a pamphlet available from the North American Lake Management Society (NALMS)—*Starting and Building an Effective Lake Association*—that can help you get started.

Two of the primary purposes of all lake organizations, however, should be educating the public and promoting increased involvement in lake management. The more informed people are about lake problems, alternative management procedures, and watershed effects, the more intelligent their decisions will be about selecting and implementing appropriate protection and maintenance procedures. This information is available from a variety of sources including those listed in Chapter 8 and Appendix E. State Departments of Natural Resources or Environment, Game and Fish staff, and county Cooperative Extension agents generally are willing to provide written information or talks to organizations about various aspects of lake or watershed management practices. Local university professors, consulting firms, or members of environmental groups can discuss ongoing or completed projects at other lakes in the area. Video cassettes, slide presentations, brochures, and other information on lake protection and restoration can be obtained from EPA and NALMS, which can also provide the name of the NALMS State contact and a list of members who have volunteered to speak about lake management and restoration. Local, State, and Federal officials also can be called upon to discuss some of the regulatory procedures available for protecting and maintaining lakes.

Regulations for Lake and Watershed Protection and Management Activities

Reasonable and appropriate regulations can be an important part of a watershed–lake protection and management plan. These regulations can be adopted for three general purposes: (1) protecting the lake by regulating watershed activities that cause erosion and pollution problems (the point and nonpoint source controls discussed in Chapter 5); (2) controlling development to protect the aesthetics and benefits of the shoreland; and (3) regulating the lake usage to reduce conflicts among swimmers, boaters, fishermen, and others (Born and Yanggen, 1972). Some of the most serious lake problems occur because of conflicts among lake users.

Controlled Development

Many of the same regulatory activities developed for other situations such as urban areas can be adapted to protect or maintain lake quality. Zoning, for example, was developed to minimize conflicts between potentially incompatible land uses such as heavy industry–commercial areas and residential homes in urban areas. Zoning also can be used to protect lake quality. Setback zones or areas typically are used to protect highway corridors. Setback regulations for piers, boathouses, wharves, and homes can help preserve shore cover, vegetation, and aesthetics. Some lake communities have a minimum setback of 75 to 100 feet for all buildings, including homes.

A variety of zoning regulations are available for lake management and protection; some are listed in Table 9-1. Many of these procedures were summarized by public Technology, Inc., in its report on land management (1977).

Some communities protect lakes with regulations and ordinances that require best management practicesbest management practices (BMPs) for existing uses and planned development of the lakeside community. In the State of Washington, for example, the community of Mountlake terrace regulates construction to minimize nonpoint source pollution.

Planned development of the lake's watershed is an effective means of minimizing lake problems while maintaining economic growth in the community. Subdivision regulations including minimum lot sizes, minimum frontage requirements, minimum floor area, height restrictions, and land use intensity ratings also are applicable for lakefront property or the community around a lake. Several development approaches are listed in Table 9-2. Planned unit developments that are clustered (Fig. 9-1) can be combined with special protection, critical, or environmentally sensitive area designations to provide lots and homes for people in a lake environment and setting while avoiding direct pollution of lakes and protecting important environmental resources or unique aquatic habitats. Clustered developments allow much greater flexibility in arranging lots and use more economical and efficient small-scale water systems and waste treatment systems.

Cluster development

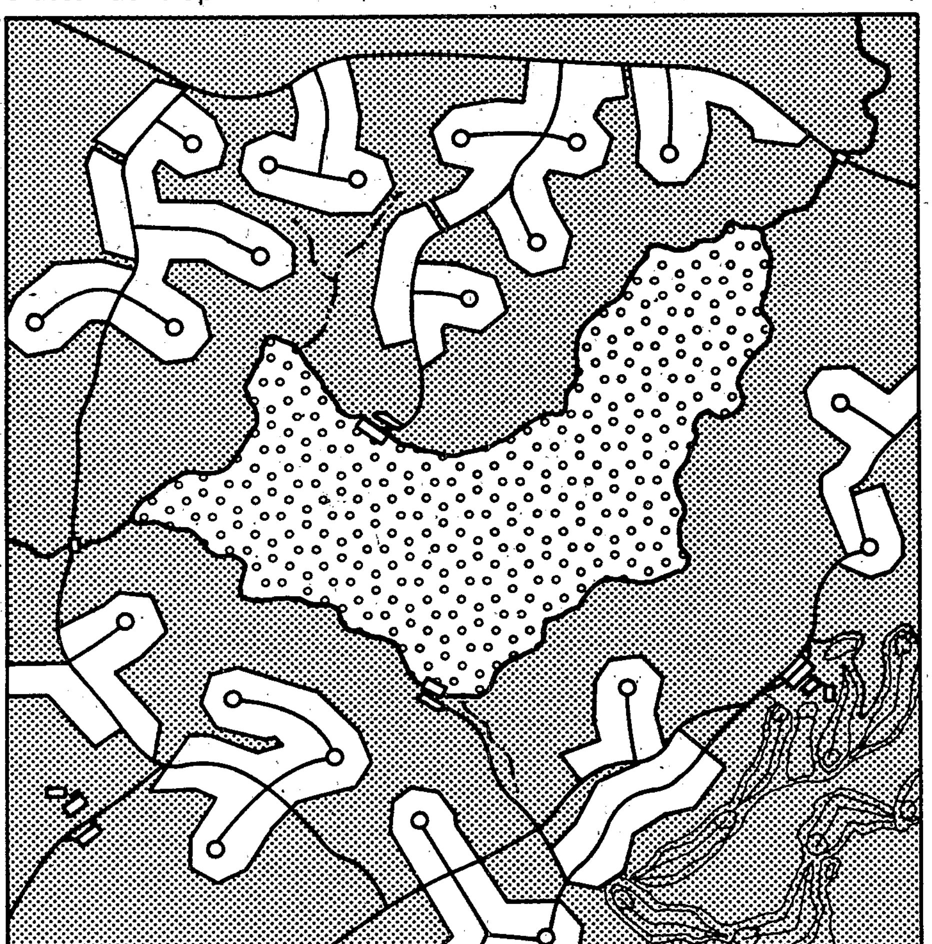


Figure 9-1.—Clustering of lots or homes in the portion of the watershed best suited to development reduces problems in the lake and maintains economic development in the watershed. The same number of lots can be developed using the cluster approach but water supply and waste treatment can be more efficient and effective. (After Fulton et al. 1971.)

Table 9-1.—A variety of zoning techniques

TOPIC	DEFINITION
Zoning	The regulation of building types, densities, and uses permitted in districts established by law.
Special Permits/ Special Exceptions/Conditional Use Permits	Administrative permits for uses that are generally compatible with a particular use zone, but that are permitted only if certain specified standards and conditions are met.
Variances	Administrative permits for uses that are generally compatible with a particular use zone, but that are permitted only if certain specified standards and condition are met.
Floating Zones	Use zones established in the text of a zoning ordinance, but not mapped until a developer proposes and the legislative body adopts such a zone for a particular site.
Conditional Zoning	An arrangement whereby a jurisdiction extracts promises to limit the future use of land, dedicate property, or meet any other conditions. The arrangement is either stated in general terms in the zoning ordinance or imposed on a case-by-case basis by the legislative or administrative body, prior to considering a request for a rezoning.
Contract Zoning	An arrangement whereby a jurisdiction agrees to rezone specified land parcels subject to the landowner's execution of restrictive covenants or other restrictions to dedicate property or meet other conditions stated in the zoning ordinance or imposed by the legislative or administrative body.
Cyclical Rezoning	The periodic, concurrent consideration of all pending rezoning applications, generally as part of an ongoing rezoning program, focusing upon one district at a time.
Comprehensive Plan Consistency Requirement	Provisions that require all zoning actions, and all other government actions authorizing development, to be consistent with an independently adopted comprehensive plan.
Zoning Referendum	Ratification of legislatively approved land use changes by popular vote, before such changes become law.
Prohibitory Zoning	The exclusion of all multifamily, mobile, modular, industrialized, prefabricated, or other "undesirable" housing types from an entire jurisdiction, or from most of the jurisdiction.
Agricultural Zoning/Large Lot Zoning/Open Space Zoning	The establishment of "permanent" zones with large (that is multiacre) minimum lot sizes and/or a prohibition against all nonagricultural development (with the exception of single-family residences and, possibly selected other uses).
Phased Zoning/ Holding Zones/ Short-Term Service Area	The division of an area into (1) temporary holding zones closed to most nonagricultural uses and/or with large minimum lot sizes, and (2) service areas provided with urban services and open for development in the near term (for example 5 years).
Performance Zoning/Performance Standards	An arrangement whereby all or selected uses are permitted in a district if they are in compliance with stated performance standards, that is, if they meet stated community and environmental criteria on pollution, hazards, public service demands, etc.
Flexible Zoning/ Cluster Zoning/ Density Zoning	Freedom from minimum lot size, width, and yardage regulations, enabling a developer to distribute dwelling units over individual lots in any manner the developer desires, provided (usually) that the overall density of the entire subdivision remains constant.

Table 9–2.—A variety of development options

TOPIC	DEFINITION
Planned Unit Development (PUD)	A conditional use or floating zone regulated through specific design standards and performance criteria, rather than through the traditional lot-by-lot approach of conventional subdivision and zoning controls.
Subdivision Regulations	Procedures for regulating the division of one parcel of land into two or more parcels—usually including a site plan review, exactions, and the application of aesthetic, bulk, and public facility design standards.
Minimum Lot Size	The prohibition of development on lots below a minimum size.
Minimum Lot Size Per Dwelling Lot	A limitation on the maximum number of dwelling units permitted on a lot, based on the land area of that lot (usually applied to multifamily housing).
Minimum Lot Size Per Room	A limitation on the maximum number of rooms (or bedrooms) permitted on a lot, based on the land area of that lot (usually applied to multifamily housing).
Setback, Frontage, and Yard Regulations	The prohibition of development on lots without minimum front, rear, or side yards or below a minimum width.
Minimum Floor Area	The prohibition of development below a minimum building size.
Height Restriction	The prohibition of development above a maximum height.
Floor Area Ratio (FAR)	The maximum square footage of total floor area permitted for each square foot of land area.
Land Use Intensity Rating	Regulations that limit the maximum amount of permitted floor space and require a minimum amount of open space (excluding parking areas) and recreation space, and a minimum number of parking spaces (total and spaces reserved for residents only).
Adequate Public Facilities Ordinance	The withholding of development permission whenever adequate public facilities and services, and defined by ordinance, are lacking, unless the facilities and services are supplied by the developer.
Permit Allocation System	The periodic allocation of a restricted (maximum) number of building permits or other development permits first to individual districts within a jurisdiction and then to particular development proposals.
Facility Allocation System	The periodic allocation of existing capacity in public facilities, especially in sewer and water lines and arterial roads, to areas where development is desired while avoiding areas where development is not desired.
Development Moratorium/ Interim Development Controls	A temporary restriction of development through the denial of building permits, rezonings, water and sewer connections, or other development permits until planning is completed and permanent controls and incentives are adopted, or until the capacity of critically overburdened public facilities is expanded.
Special Protection Districts/ Critical Areas/ Environmentally Sensitive Areas	Areas of local, regional, or State-wide importance—critical environmental areas (for example, wetlands, shorelands with steep slopes); areas with high potential for natural disaster (for example, floodplains and earthquake zones); and areas of social importance (for example, historical, archaeological, and institutional districts)—protected by a special development review and approval process, sometimes involving State-approved regulations.

Permits and Ordinances

Public facilities ordinances and sanitary permits can help minimize problems with septic systems or housing growth that exceeds the capacity of existing waste treatment systems. Sanitary permits can be required prior to building any structure for human occupancy, to determine if sites are suited for septic systems. Ordinances can be developed to limit building growth to a pace within the treatment system's capacity to adequately handle increased wasteloads. These ordinances can also provide for the orderly and timely expansion of waste treatment facilities.

Both time and zoning can be used to reduce use conflicts by prohibiting certain uses during a specified time of day or in selected areas (Fig. 9-2). For example, pleasure motorboating and waterskiing could be restricted 10 a.m. to 6 p.m., which would minimize conflicts with anglers.

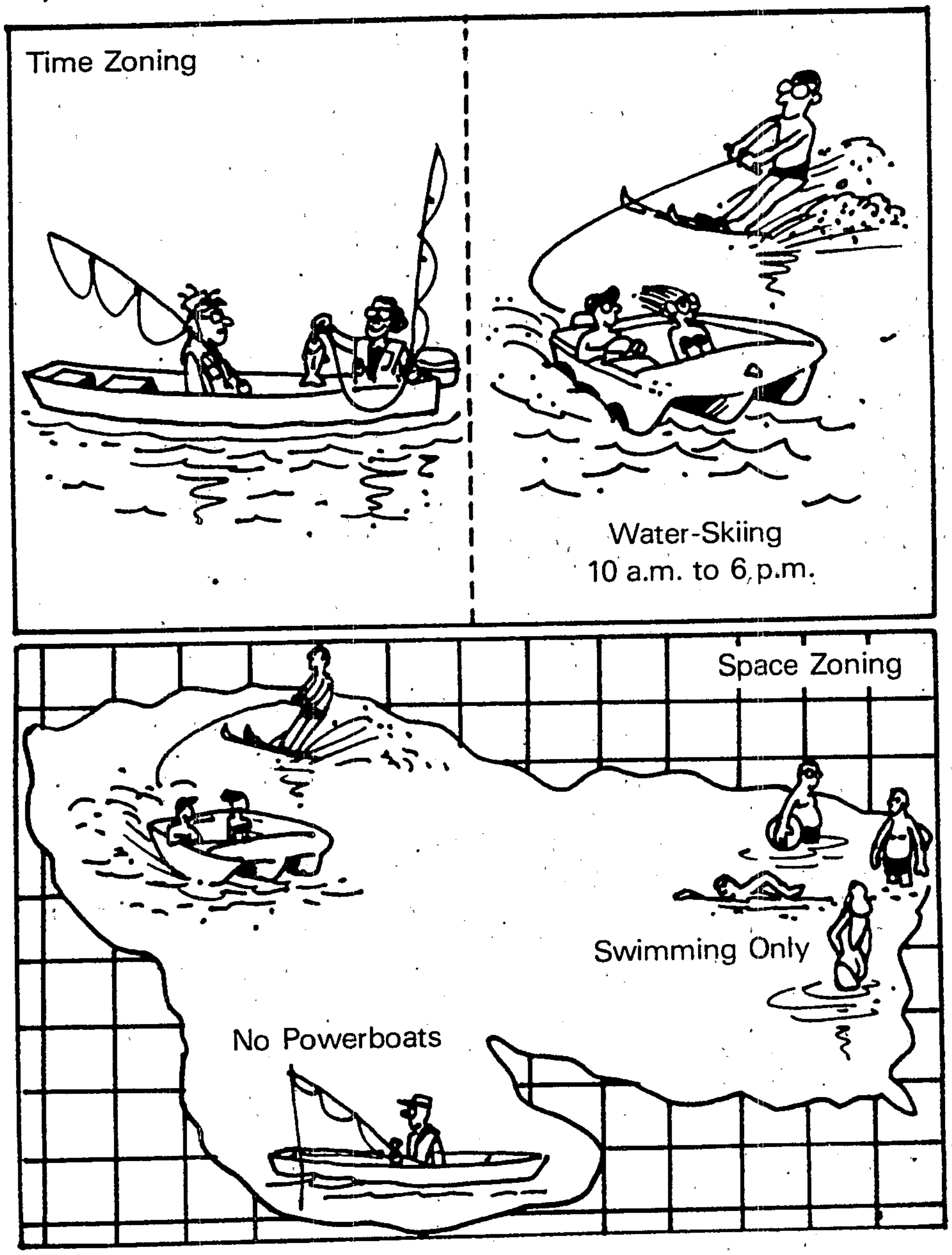


Figure 9-2.—Conflicts among multiple users can sometimes be avoided by restricting the space in which the activities occur or the time of day for these activities. After Fulton, et al. 1971.

For space zoning, certain shore areas of the lake could be limited to particular uses such as swimming or fishing, with powerboating and waterskiing restricted to open water areas. A minimum distance and speed could be specified; for example, a powerboat should be at least 100 feet away from an anchored fishing boat or moving at no more than 5 mph. Restrictions on motor sizes (no motors on some lakes, only electric motors, or only motors less than 10 hp) are commonly used on small lakes or lakes in pastoral settings.

All of these regulatory procedures can be combined to provide the most suitable approach for a particular lake or specific set of lake uses. Regardless of the regulations or restoration practices employed, however, it is critical that lake management be an integrated program of watershed and lake management that is tailored to the particular uses and priority problems of the lake user.

Lake Monitoring

Monitoring programs have been outlined in previous chapters. Lake monitoring is discussed here to emphasize its importance. It is easier and much more cost effective to treat problems as they develop rather than when they have reached a crisis or nuisance level. Monitoring is the only approach for determining whether protection and maintenance approaches are effective.

Lakes are dynamic systems that age through time. As the lake ages, the efficiency and effectiveness of various management techniques can change. Monitoring programs can record these changes and determine either that management procedures should be altered to maintain the same lake uses or that the lake no longer can support these uses. Investment precedes dividends; investing in monitoring pays dividends by ensuring lake management techniques are providing effective protection or maintenance of the desired lake uses.

Chapter 8 provides guidance for establishing a monitoring program to obtain the most important information possible based upon financial resources.

The Lake Watch

Lake protection and maintenance is a continuous process, an organized effort to ensure the wisest use of the resource and to record what happens in that resource and relate those developments intelligently to past records and future potential.

More than the process, lake protection and maintenance is also a responsibility. A responsibility that does not stop with hiring a lake manager or volunteering to participate in the monitoring program. Every lake user must be aware of the individual's role in protecting the resource.

That role can be as minor as tossing a gum wrapper on the lake shore, as irresponsible as failing to keep a septic system operating properly, as dangerous as exceeding the speed limit for boats. Multiplied by many such user actions, this repudiation of individual responsibility can bring trouble to any lake.

But the opposite can also be true. Educated, caring users — each assuming responsibility for the lake — ensure that this resource will continue to meet their expectations.

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Appendix A

METRIC UNITS

COMMON UNITS OF MEASURE IN LAKE MANAGEMENT

Limnology, the primary science upon which lake management is based, uses metric units in professional publications. Although most units in this Manual are expressed in British/U.S. form, the reader is strongly encouraged to become more comfortable with common metric units—they are far easier to manipulate, and any further encounter with the literature and books on lake management will entail the metric system of measurement.

The following table compares the two systems; to convert English units to metric, use the conversion factors supplied in this table.

METRIC TO ENGLISH CONVERSIONS

METRIC UNIT	SYMBOL	ENGLISH UNIT	CONVERSION FACTOR*
LENGTH			
Millimeter	mm = 0.001 m	inch	0.03937
Centimeter	cm = 0.01 m	inch	0.3937
Meter	m = 1.0 m	yard	1.094
Kilometer	km = 1000 m	mile	0.6214
WEIGHT			
Microgram	µg = 0.000001 g	(no reasonable equivalent)	
Milligram	mg = 0.001 g	grain	0.015432
Gram	g = 1.0 g	ounce(avoir)	0.03527
Kilogram	kg = 1000 g	pound	2.205
VOLUME			
Milliliter	mL = 0.001 L	ounce	29.57
Liter	L = 1.0 L	quart	1.057
Kiloter	kL = 1000 L	cu. yard	1.308
(cubic meter)	(m^3)		

* To convert metric to English units, multiply by factor.

OTHER USEFUL CONVERSIONS

1 gallon =	3.785 liters
1 milligram/liter =	1 part per million
1 hectare =	2.47 acres
1 acre-foot =	32,590 gallons
1 cubic meter =	264 gallons

Appendix B

GLOSSARY

Acid neutralizing capacity (ANC): the equivalent capacity of a solution to neutralize strong acids. The components of ANC include weak bases (carbonate species, dissociated organic acids, alumino-hydroxides, borates, and silicates) and strong bases (primarily, OH^-). In the National Surface Water Survey, as well as in most other recent studies of acid-base chemistry of surface waters, ANC was measured by the Gran titration procedure.

Acidic deposition: 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.

Allochthonous: Materials (e.g., organic matter and sediment) that enter a lake from atmosphere or drainage basin (see autochthonous).

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.

Autochthonous: Materials produced within a lake; e.g., autochthonous organic matter from plankton versus allochthonous organic matter from terrestrial vegetation.

Bathymetric map: A map showing the bottom contours and depth of a lake; can be used to calculate lake volume.

Benthos: Macroscopic (seen without aid of a microscope) organisms living in and on the bottom sediments of lakes and streams. Originally, the term meant the lake bottom, but it is now applied almost uniformly to the animals associated with the substrate.

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.

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. Often measured in terms of grams per square meter of surface.

Biota: All plant and animal species occurring in a specified area.

Chemical oxygen demand (COD): Nonbiological uptake of molecular oxygen by organic and inorganic compounds in water.

Chlorophyll: A green pigment in algae and other green plants that is essential for the conversion of sunlight, carbon dioxide, and water to sugar. Sugar is then converted to starch, proteins, fats, and other organic molecules.

Chlorophyll *a*: A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae.

Cluster development: Placement of housing and other buildings of a development in groups to provide larger areas of open space.

Consumers: Animals that cannot produce their own food through photosynthesis and must consume plants or animals for energy (see producers).

Decomposition: The transformation of organic molecules (e.g., sugar) to inorganic molecules (e.g., carbon dioxide and water) through biological and non-biological processes.

Delphi: A technique that solicits potential solutions to a problem situation from a group of experts and then asks the experts to rank the full list of alternatives.

Density flows: A flow of water of one density (determined by temperature or salinity) over or under water of another density (e.g., flow of cold river water under warm reservoir surface water).

Detritus: Nonliving dissolved and particulate organic material from the metabolic activities and deaths of terrestrial and aquatic organisms.

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.

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 this Manual, the ecosystem is usually defined 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.

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 nutrient, organic matter, and silt enrichment and sedimentation of a lake or reservoir. If the process is accelerated by man-made influences, it is termed cultural eutrophication.

Fall overturn: The autumn mixing, top to bottom, of lake water caused by cooling and wind-derived energy.

Fecal coliform test: Most common test for the presence of fecal material from warm-blooded animals. Fecal coliforms are measured because of convenience; they are not necessarily harmful but indicate the potential presence of other disease-causing organisms.

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.

Groundwater: Water found beneath the soil's surface; saturates the stratum at which it is located; often connected to lakes.

Hard water: Water with relatively high levels of dissolved minerals such as calcium, iron, and magnesium.

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.

Influent: A tributary stream.

Internal nutrient cycling: Transformation of nutrients such as nitrogen or phosphorus from biological to inorganic forms through decomposition, occurring within the lake itself.

Isothermal: The same temperature throughout the lake.

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.

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).

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.

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).

Macroinvertebrates: Aquatic insects, worms, clams, snails, and other animals visible without aid of a microscope, that may be associated with or live on substrates such as sediments and macrophytes. They supply a major portion of fish diets and consume detritus and algae.

Macrophytes: Rooted and floating aquatic plants, commonly referred to as waterweeds. These plants may flower and bear seed. Some forms, such as duckweed and coontail (*Ceratophyllum*), are free-floating forms without roots in the sediment.

Mandatory property owners association: Organization of property owners in a subdivision or development with membership and annual fee required by covenants on the property deed. Association will often enforce deed restrictions on members' property and may have common facilities such as bathhouse, clubhouse, golf course, etc.

Marginal zone: Area where land and water meet at the perimeter of a lake. Includes plant species, insects, and animals that thrive in this narrow, specialized ecological system.

Metalimnion: Layer of rapid temperature and density change in a thermally stratified lake. Resistance to mixing is high in the region.

Morphometry: Relating to a lake's physical structure (e.g., depth, shoreline length).

Nekton: Large aquatic and marine organisms whose mobility is not determined by water movement—for example, fish and amphibians.

Nominal group process: A process of soliciting concerns/issues/ideas from members of a group and ranking the resulting list to ascertain group priorities. Designed to neutralize dominant personalities.

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.

Ooze: Lake bottom accumulation of inorganic sediments and the partially decomposed remains of algae, weeds, fish, and aquatic insects. Sometimes called muck; see sediment.

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.

Pathogen: A microorganism capable of producing disease. They are of great concern to human health relative to drinking water and swimming beaches.

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.

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.

Phytoplankton: Microscopic algae and microbes that float freely in open water of lakes and oceans.

Plankton: 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.

Primary productivity: The rate at which algae and macrophytes fix or convert light, water, and carbon dioxide to sugar in plant cells. Commonly measured as milligrams of carbon per square meter per hour.

Producers: Green plants that manufacture their own food through photosynthesis.

Profundal zone: Mass of lake water and sediment occurring on the lake bottom below the depth of light penetration.

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.

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 ooze).

Seepage lakes: Lakes having either an inlet or outlet (but not both) and generally obtaining their water from groundwater and rain or snow.

Soil retention capacity: The ability of a given soil type to adsorb substances such as phosphorus, thus retarding their movement to the water.

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.

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 contours of 2, 5, 10, or 20 feet. Can be used to delineate the watershed.

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.

Voluntary lake property owners association: Organization of property owners in an area around a lake that members join at their option.

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 lakewater.

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.

Zooplankton: Microscopic animals that float freely in lake water, graze on detritus particles, bacteria, and algae, and may be consumed by fish.

Appendix C

POINT SOURCE TECHNIQUES

Facultative Lagoons: Facultative lagoons are intermediate depth (3 to 8 feet) ponds in which the wastewater is stratified into three zones. These zones consist of an anaerobic bottom layer, an aerobic surface layer, and an intermediate zone. Oxygen in the surface stabilization zone is provided by reaeration and photosynthesis. In general, the aerobic surface layer serves to reduce odors while providing treatment of soluble organic by-products of the anaerobic processes operating at the bottom.

CRITERIA	REMARKS
1. Status	Fully demonstrated and in moderate use especially for treatment of relatively weak municipal wastewater in areas where real estate costs are not a restricting factor.
2. Applications	Used for treating raw, screened, or primary settled domestic wastewaters. Most applicable when land costs are low and operation and maintenance costs are to be minimized.
3. Reliability	The service life is estimated to be 50 years. Little operator expertise is required. Overall, the system is highly reliable.
4. Limitations	In very cold climates, facultative lagoons may experience reduced biological activity and treatment efficiency. Ice formation can also hamper operations. In overloading situations, odors can be a problem.
5. Cleaning	Settled solids may require cleaning out and removal once every 10 to 20 years.
6. Treatment Side Effects	Potential seepage of wastewater into groundwater unless lagoon is lined.

Overland Flow Treatment: Wastewater is applied by gravity flow to vegetated soils that are slow to moderate in permeability and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action and also by plant uptake. An underdrainage system consisting of a network of drainage pipe buried below the surface serves to recover the effluent, to control groundwater, or to minimize trespass of wastewater onto adjoining property by horizontal subsurface flow. Vegetation is a vital part of the process and serves to extract nutrients, reduce erosion and maintain soil permeability.

CRITERIA	REMARKS
1. Status	Has been widely and successfully used for more than 100 years.
2. Applications	Can provide the following benefits: 1) an economic return from the reuse of water and nutrients to produce marketable crops or forage; 2) water conservation when used for irrigating landscaped areas; 3) a means of recovering renovated water for reuse or for discharge; 4) a means of controlling groundwater.
3. Reliability	Extremely reliable.
4. Limitations	Process is limited by soil type and depth, topography, underlying geology, climate, surface and groundwater hydrology and quality, crop selection and land availability. Graded land is essential; excessive slope increases runoff and erosion. Climate affects growing season and application ceases during periods of frozen soil conditions. Prolonged wet spells limit application by Gulf states and the Pacific Northwest coastal region.
5. Cleaning	
6. Treatment Side Effects	Minimal, when properly operated.

Oxidation Ditch: An oxidation ditch is an activated sludge biological treatment process. Typical oxidation ditch treatment systems consist of a single or closed loop channel 4 to 6 ft. deep, with 45° sloping sidewalls. Some form of preliminary treatment such as screening, comminution or grit removal normally precedes the process. After pretreatment, the wastewater is aerated in the ditch using mechanical aerators that are mounted across the channel. The aerators provide mixing and circulation in the ditch, as well as sufficient oxygen transfer. A high degree of nitrification may occur in the process without special modification because of the long detention times and high solid retention times (10 to 50 days). Secondary settling of the aeration ditch effluent is provided in a separate clarifier. Ditch loops may be oval or circular in shape. "Ell" and "horseshoe" configurations have been constructed to maximize land usage.

CRITERIA	REMARKS
1. Status	There are nearly 650 shallow oxidation ditch installations in the U.S. and Canada. Numerous shallow and deep oxidation ditch systems are in operation in Europe. The overall process is fully demonstrated for carbon removal, as a secondary treatment process.
2. Applications	Applicable in any situation where activated sludge treatment is appropriate. The process cost of treatment is generally less than other biological processes in the range of wastewater flows between 0.1 and 10 Mgal/d.
3. Reliability	The average reliability is good with adequate removal of oxygen-demanding material and solids.
4. Limitations	Oxidation ditches are relatively expensive and require skilled operators for good performance.
5. Cleaning	Requires weekly to monthly sludge removal.
6. Treatment Side Effects	Solid waste, odor, and air pollution impacts are similar to those encountered with standard activated sludge processes.

Septic Tank: A septic tank followed by a soil absorption bed is the traditional on-site system for the treatment and disposal of domestic wastewater from individual households or establishments. The system consists of a buried tank where wastewater is collected and scum, grease, and settleable solids are removed by gravity and a subsurface drainage system where wastewater percolates into the soil.

CRITERIA	REMARKS
1. Status	Most widely used method of on-site domestic waste disposal (almost one-third of the U.S. population).
2. Applications	Used primarily in rural and suburban areas. Properly designed and installed systems require a minimum of maintenance and can operate in all climates.
3. Reliability	Properly designed, constructed, and operated, septic tank systems are efficient and economical. System life may equal or exceed 20 years.
4. Limitations	Dependent on soil and site conditions, the ability of the soil to absorb liquid, depth to groundwater, nature of and depth to bedrock, seasonal flooding, and distance to well or surface water.
5. Cleaning	The sludge and scum layers in tank must be removed every 3 to 5 years.
6. Treatment Side Effects	Groundwater contamination when pollutants are not effectively removed by the soil. Increasing nitrate in groundwater. Soil clogging may result in surface ponding with potential health problems.

Septic Tank Mound System: A septic tank and mound system is a method of on-site treatment and disposal of domestic wastewater that can be used as an alternative to the conventional septic tank-soil absorption system. In areas where problem soil conditions preclude the use of subsurface trenches or seepage beds, mounds can be installed to raise the absorption field aboveground, provide treatment, and distribute the wastewater to the underlying soil over a wide area in a uniform manner.

CRITERIA	REMARKS
1. Status	Proven successful alternative for difficult soil conditions.
2. Applications	Alternative to septic tank-soil absorption system in problem soil conditions. Increases amount of soil for purification before effluent reaches groundwater.
3. Reliability	Septic tank-mound systems are viable alternatives to centralized treatment facilities. Dosing equipment should be routinely maintained, and septic tanks must be periodically pumped out for systems to operate effectively.
4. Limitations	Requires more space and periodic maintenance than conventional subsurface disposal system, along with higher construction costs. Cannot be installed on steep slopes.
5. Cleaning	Septage requires disposal every 3 to 5 years.
6. Treatment Side Effects	Visual impact particularly in suburban areas. Drainage patterns and land use flexibility may also be affected.

Septic Tank–Sand Filter: Surface discharge of septic tank effluent is a method of on-site disposal of domestic wastewater that can be used as an alternative to the conventional soil absorption system. Where permitted by code, surface discharge units can be employed in areas where subsurface disposal systems are not feasible. Sand filter trenches are similar to absorption trenches but contain an intermediate layer of sand as filtering material and underdrains for carrying off the filtered sewage. Buried sand filters, which required less area than trenches, also can be used.

CRITERIA	REMARKS
1. Status	Sand filtration has traditionally been employed to treat septic tank effluent and has had success.
2. Applications	Surface discharge systems are alternative designs to be used where site conditions, including geology, hydrology, and lot size, preclude the use of the soil as a treatment and disposal medium. Operation by communities, rather than homeowners, is normally required to be successful.
3. Reliability	Sand filters perform well, unless overloaded. Periodic inspection is required to obtain proper functioning of chlorination units.
4. Limitations	These systems are more expensive than conventional on-site systems. Filter surfaces and disinfection equipment require periodic maintenance. Buried sand beds are inaccessible. Power is required for pumping and some disinfection units. State or Federal discharge permits along with sampling and monitoring are required.
5. Cleaning	Sand with organic waste must be removed from intermittent and recirculating filter surfaces when clogging occurs and may be buried on-site or require off-site disposal.
6. Treatment Side Effects	Treated effluents are discharged to surface waters. Odors may emanate from open filters.

Trickling Filter: The process consists of a fixed bed of rock media over which wastewater is applied for aerobic biological treatment. Slimes form on the rocks and treat the wastewater. The bed is dosed by a distributor system, and the treated wastewater is collected by an underdrain system. Primary treatment is normally required to optimize trickling filter performance. The low rate trickling filter media bed generally is circular in plan, with a depth of 5 to 10 feet.

CRITERIA	REMARKS
1. Status	This process is highly dependable in moderate climates.
2. Applications	Treatment of domestic and compatible industrial wastewaters amendable to aerobic biological treatment in conjunction with suitable pretreatment.
3. Reliability	Highly reliable under conditions of moderate climate. Mechanical reliability high. Process operation requires little skill.
4. Limitations	Vulnerable to climate changes and low temperatures, filter flies and odors are common, periods of inadequate moisture for slimes can be common. High land and capital cost requirements.
5. Cleaning	Sludge is withdrawn from the secondary clarifier at a rate of 3,000 to 4,000 gal/Mgal of wastewater, containing 500 to 700 lb dry solids.
6. Treatment Side Effects	Odor problems; high land requirement relative to many alternative processes; and filter flies.

Appendix D

BEST MANAGEMENT PRACTICES

Much of the material in this appendix was taken from EPA's Guide to Nonpoint Source Pollution Control, Published by the Office of Water in 1987.

Animal Waste Management: A practice where animal wastes are temporarily held in waste storage structures until they can be utilized or safely disposed. Storage units can be constructed of reinforced concrete or coated steel. Wastes are also stored in earthen ponds. Also includes diverting runoff to pass barnyard areas, elimination of winter manure spreading, applying manure at P requirement rates, and not applying manure to poorly drained areas.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Not applicable.
b) Nitrogen (N)	Good to excellent.
c) Phosphorus (P)	Good to excellent. Reduction of P to surface waters of 80 to 90 percent.
d) Runoff	Not applicable.
e) Bacteria	Good to excellent. Reduction of bacteria to surface waters by 80 to 90 percent.
2. Capital Costs	High because of the necessity of construction and disposal equipment. Control of feedlot runoff costs approximately $7500 yearly for every 50 animals. Manure storage averages $2844 for each storage facility.
3. Operation and Maintenance Costs	Unknown.
4. Longevity	Good.
5. Confidence	Fair to excellent if properly managed.
6. Adaptability	Good.
7. Potential Treatment Side Effects	The use of earthen ponds can possibly lead to groundwater contamination.
8. Concurrent Land Management Practices	Fertilizer management.

Conservation Tillage: A farming practice that leaves stalks or stems and roots intact in the field after harvest. Its purpose is to reduce water runoff and soil erosion compared to conventional tillage where the topsoil is mixed and turned over by a plow. Conservation tillage is an umbrella term that includes any farming practice that reduces the number of times the topsoil is mixed. Other terms that are used instead of conservation tillage are (1) minimum tillage where one or more operations that mixed the topsoil are eliminated and (2) no-till where the topsoil is left essentially undisturbed.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good to excellent, decreases sediment input to streams and lakes (60 to 98 percent reduced tillage, 80 to 98 percent no tillage).
b) Nitrogen (N)	Poor, no effect on nitrogen input to streams and lakes.
c) Phosphorus (P)	Good to excellent, can reduce the amount of phosphorus input to streams and lakes (40 to 90 percent reduced tillage, 50 to 95 percent no tillage).
d) Runoff	Fair to excellent, decreases amount of water running off fields carrying sediment and phosphorus up to about 61 percent.
e) Pesticides	Good; atrazine and alachlor losses reduced 80 to 90 percent.
2. Capital Costs	High, because requires purchase of new equipment by farmer.
3. Operation and Maintenance Costs	Less expensive than conventional tillage. Potential increase in herbicide costs. Potential increase in net farm income. As of 1984, the average cost per acre was $31.
4. Longevity	Good; approximately every five years the soil has to be turned over.
5. Confidence	Fair to excellent.
6. Adaptability	Good, but may be limited in northern areas that experience late cool springs, or in heavy, poorly drained soils.
7. Potential Treatment Side Effects	Potential increase in herbicide effects and insecticide contamination of surface and groundwater. Nitrogen contamination of groundwater. On some soils, yields are reduced. Phosphorus concentration in runoff may increase.
8. Concurrent Land Management Practices	Consider fertilizer management and integrated pesticide management.

Contour Farming: A practice where the farmer plows across the slope of the land. This practice is applicable on farmland with a 2–8 percent slope.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good on moderate slopes (2 to 8 percent slopes), fair on steep slopes (50 percent reduction). Reported range in reduction of sediments is 15 to 55 percent.
b) Nitrogen(N)	Unknown.
c) Phosphorus (P)	Fair.
d) Runoff	Fair to good, depends on storm intensity.
2. Capital Costs	No special effect.
3. Operation and Maintenance Costs	No special effect.
4. Longevity	Poor, it must be practiced every time the field is plowed.
5. Confidence	Poor, not enough information.
6. Adaptability	Good, limited by soil, climate, and slope of land. May not work with large farming equipment on steep slopes.
7. Potential Treatment Side Effects	Side effects not identified.
8. Concurrent Land Management Practices	Fertilizer management, integrated pesticide management, possibly streamside management.

Contour Stripcropping: This practice is similar to contour farming where the farmer plows across the slope of the land. The difference is that strips of close-growing crops or meadow grasses are planted between strips of row crops like corn or soybeans. Whereas contour farming can be used on 2–8 percent slopes, contour stripcropping can be used on 8–15 percent slopes.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good, 8 to 15 percent slopes, provides the benefits of contour plowing plus buffer strips. Reduces water erosion 40 to 60 percent and wind erosion 40 to 50 percent.
b) Nitrogen (N)	Unknown, assumed to be fair to good.
c) Phosphorus (P)	Unknown, assumed to be fair to good.
d) Runoff	Good to excellent.
2. Capital Costs	No special effect unless farmer cannot use the two crops. Implementation costs average $24 per acre.
3. Operation and Maintenance Costs	$3 to $5 per acre.
4. Longevity	Poor, must be practiced year after year.
5. Confidence	Poor, not enough information.
6. Adaptability	Fair to good, may not work with large farming equipment on steep slopes.
7. Potential Treatment Side Effects	Side effects not identified.
8. Concurrent Land Management Practices	Fertilizer management, integrated pesticide management.

Crop Rotation: Where a planned sequence of crops are planted int he same area of land. For example, plow-based crops are followed by pasture corps such as grass or legumes in two- to four-year rotations.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good when field is in grasses or legumes.
b) Nitrogen (N)	Fair to good.
c) Phosphorus (P)	Fair to good.
d) Runoff	Good when field is in grasses or legumes.
2. Capital Costs	High if farm economy reduced. Less of a problem with livestock that can use plants as food.
3. Operation and Maintenance Costs	Moderate, increased labor requirements. May be offset by lower nitrogen additions to the soil when corn is planted after legumes, and reduction in pesticide application.
4. Longevity	Good.
5. Confidence	Fair to good.
6. Adaptability	Good, but some climatic restrictions.
7. Potential Treatment Side Effects	Reduction in possibility of groundwater contamination.
8. Concurrent Land Management Practices	Range and pasture management.

Flood Storage (Runoff Detention/Retention): Detention facilities treat or filter out pollutants or hold water until treated. Retention facilities provide no treatment. Examples of detention/retention facilities include ponds, surface basins, underground tunnels, excess sewer storage and underwater flexible or collapsible holding tanks.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Fair to excellent, design dependent (56–95% efficient).
b) Nitrogen (N)	Very poor to excellent, design dependent.
c) Phosphorus (P)	Very poor to excellent, design dependent.
d) Runoff	Fair to excellent, design dependent.
2. Capital Costs	Dependent on type and size. Range from $100 to $1,000 per acre served, depending on site. These costs include capital costs and operational costs.
3. Operation and Maintenance Costs	Annual cost per acre of urban area served has ranged from $10 to $125 depending on site.
4. Longevity	Good to excellent, should last several years.
5. Confidence	Good, if properly designed.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	Groundwater contamination with retention basins.
8. Concurrent Land Use Practices	Porous pavements.

Grassed Waterways: A practice where broad and shallow drainage channels (natural or constructed) are planted with erosion-resistant grasses.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good to excellent (60 to 80 percent reduction).
b) Nitrogen (N)	Unknown.
c) Phosphorus	Poor to good; 5 to 40 percent.
d) Runoff	Fair to good.
e) Pesticides	Poor to good, 5 to 40 percent reductions.
2. Capital Costs	Moderate, about $22 per acre.
3. Operation and Maintenance Costs	Low, but may interfere with the use of large equipment. Average maintenance costs range from $1 to $14 per acre per year.
4. Longevity	Excellent.
5. Confidence	Good.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	None identified.
8. Concurrent Land Management Practices	Conservative tillage, integrated pest management, fertilizer management, animal waste management.

Haul Roads and Skill Trails: This practice is implemented prior to logging operations. It involves the appropriate site selection and design of haul road and skid trails. Haul roads and skid trails should be located away from streams and lakes. Recommended guidelines for gradient, drainage, soil stabilization, and filter strips should be followed. Routes should be situated across slopes rather than up or down slopes. If the natural drainage is disrupted, then artificial drainage should be provided. Logging operations should be restricted during adverse weather periods. Other good practices include ground covers (rock or grass), closing roads when not in use, closing roadways during wet periods, and returning main haul roads to prelogging conditions when logging ceases.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good if grass cover is used on haul roads (45 percent reduction); Excellent if crushed rock is used as ground cover (92 percent reduction).
b) Nitrogen (N)	Unknown.
c) Phosphorus (P)	Unknown.
d) Runoff	Unknown.
2. Capital Costs	High, grass cover plus fertilizer $5.37/100 ft roadbed, crushed rock (6 in) $179.01/100 ft roadbed. Costs may be offset by reducing road miles and decreased construction maintenance costs.
3. Operation and Maintenance Costs	High, particularly with grass that may have to be replenished routinely and may not be effective on highly traveled roads.
4. Longevity	Unknown.
5. Confidence	Good for ground cover, poor for nutrients.
6. Adaptability	Good.
7. Potential Treatment Side Effects	Potential increase in nutrients to water course if excess fertilizers are applied.
8. Concurrent Land Management Practices	Maintain natural waterways.

Integrated Pest Management: Pests are any organisms that are harmful to desired plants, and they are controlled with chemical agents called pesticides. Integrated pest management considers factors such as how much pesticide is enough to control a problem, the best method of applying the pesticides, the appropriate time for application, and the safe handling, storage, and disposal of pesticides and their containers. Other considerations include using resistant crop varieties, optimizing crop planting time, optimizing time of day of application, rotating crops, and biological controls.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	No effect, but pesticides attached to soil particles can be carried to streams and lakes.
b) Nitrogen (N)	No effect.
c) Phosphorus (P)	No effect.
d) Runoff	No effect, but water is the primary route for transporting pesticides to lakes and streams.
e) Pesticides	Fair to good, 20 to 40 percent reductions.
2. Capital Costs	No effect.
3. Operation and Maintenance Costs	Farming cost, potential reduction in pesticide costs and an increase in net farm income.
4. Longevity	Poor, as pesticides are applied one or more times per year to address different pests and different crops.
5. Confidence	Fair to excellent, reported pollutant reductions range from 20–90 percent.
6. Adaptability	Methods are generally applicable wherever pesticides are used: forest, farms, homes.
7. Potential Treatment Side Effects	Potential for groundwater and surface water contamination. Toxic components may be available to aquatic plants and animals.
8. Concurrent Land Management Practices	See crop rotation, conservation tillage.

Interception or Diversion Practices: Designed to protect bottomland from hillside runoff, divert water from areal sources of pollution such as barnyards, or to protect structures from runoff. Diversion structures are represented by any modification of the surface that intercepts or diverts runoff so that the distance of flow to a channel system is increased.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Fair to good (30 to 60 percent reduction).
b) Nitrogen (N)	Fair to good (30 to 60 percent reduction).
c) Phosphorus (P)	Fair to good (30 to 60 percent reduction).
d) Runoff	Poor, not designed to reduce runoff but divert runoff.
2. Capital Costs	Moderate to high, may entail engineering design and structures.
3. Operation and Maintenance Costs	Fair to good.
4. Longevity	Good.
5. Confidence	Poor to good, largely unknown.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	None identified.
8. Concurrent Land Management Practices	Since the technique can be applied under multiple situations (i.e., agriculture, silviculture, construction), appropriate best management practices associated with individual situations should be applied.

Maintain Natural Waterways: rrhis practice disposes of treetops and slash in areas away from waterways. Prevents the buildup of damming debris. Stream crossings are constructed to minimize impacts on flow characteristics.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Fair to good, prevents acceleration of bank and channel erosion.
b) Nitrogen (N)	Unknown, contribution would be from decaying debris.
c) Phosphorus (P)	Unknown, contribution would be from decaying debris.
d) Runoff	Fair to good, prevents deflections or constrictions of stream water flow that may accelerate bank and channel erosion.
2. Capital Costs	Low, supervision required to ensure proper disposal of debris.
3. Operation and Maintenance Costs	Low, if proper supervision during logging is maintained, otherwise \$160–\$800 per 100 ft stream.
4. Longevity	Good.
5. Confidence	Good.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	None identified.
8. Concurrent Land Management Practices	Proper design and location of haul and skid trails; streamside management zones.

Nonvegetative Soil Stabilization: Examples of temporary soil stabilizers include mulches, nettings, chemical binders, crushed stone, and blankets or mats from textile material. Permanent soil stabilizers include coarse rock, concrete, and asphalt. The purpose of soil stabilizers is to reduce erosion from construction sites.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Excellent.
b) Nitrogen (N)	Poor.
c) Phosphorus (P)	Poor.
d) Runoffs	Poor on steep slopes with straw mulch, otherwise good.
2. Capital Costs	Low to high, depending on technique applied.
3. Operation and Maintenance Costs	Moderate.
4. Longevity	Generally a temporary solution until a more permanent cover is developed. Excellent for permanent soil stabilizer.
5. Confidence	Good.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	No effect on soluble pollutants.
8. Concurrent Land Management Practices	Runoff detention/retention.

Porous Pavement: Porous pavement is asphalt without fine filling particles on a gravel base.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Fair to good, depends on pore size.
b) Nitrogen (N)	Fair to good, depends on pore size.
c) Phosphorus (P)	Fair to good, depends on pore size.
d) Runoff	Good to excellent, depends on pore size.
2. Capital Costs	Moderate, slightly more expensive than conventional surfaces. May be high when old pavement must be replaced.
3. Operation and Maintenance Costs	Potentially expensive, requires regular street maintenance program and can be destroyed in freezing climates.
4. Longevity	Good, with regular maintenance (i.e., street cleaning), in southern climates. In cold climates, freezing and expansion can destroy.
5. Confidence	Unknown.
6. Adaptability	Excellent.
7. Potential Treatments Side Effects	Groundwater contamination from infiltration of soluble pollutants.
8. Concurrent Land Management Practices	Runoff detention/retention.

Range and Pasture Management: The objective of range and pasture management is to prevent overgrazing because of too many animals in a given area. Management practices include spreading water supplies, rotating animals between pastures, spreading mineral and feed supplements, or allowing animals to graze only when a particular plant food is growing rapidly.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good, prevents soil compaction, which reduces infiltration rates.
b) Nitrogen (N)	Unknown.
c) Phosphorus (P)	Unknown.
d) Runoff	Good, maintains some cover, which reduces runoff rates.
2. Capital Costs	Low, but may have to develop additional water sources.
3. Operation and Maintenance Costs	Low.
4. Longevity	Excellent.
5. Confidence	Good to excellent. Farmer must have a knowledge of stocking rates, vegetation types, and vegetative conditions.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	None identified.
8. Concurrent Land Management Practices	Livestock exclusion, riparian zone management, and crop rotation.

Riprap: A layer of loose rock or aggregate placed over a soil surface susceptible to erosion.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good, based on visual observations.
b) Nitrogen (N)	Unknown.
c) Phosphorus (P)	Unknown.
d) Runoff	Poor.
2. Capital Costs	Low to high, varies greatly.
3. Operation and Maintenance Costs	Low.
4. Longevity	Good, with proper rock size.
5. Confidence	Poor to good.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	In streams, erosion may start in a new, unprotected place.
8. Concurrent Land Management Practices	Streamside (lake) management zone.

Sediment Traps: Sediment traps are temporary structures made of sandbags, straw bales, or stone. Their purpose is to detain runoff for short periods of time so heavy sediment particles will drop out. Typically, they are applied within and at the periphery of disturbed areas.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good, coarse particles.
b) Nitrogen (N)	Poor.
c) Phosphorus (P)	Poor.
d) Runoff	Fair.
2. Capital Costs	Low.
3. Operation and Maintenance Costs	Low, require occasional inspection and prompt maintenance.
4. Longevity	Poor to good.
5. Confidence	Poor.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	None identified.
8. Concurrent Land Management Practices	Agricultural, silviculture or other construction best management practices could be incorporated depending on situation.

Streamside Management Zones (buffer strips): Considerations in streamside management include maintaining the natural vegetation along a stream, limiting livestock access to the stream, and, where vegetation has been removed, planting buffer strips. Buffer strips are strips of plants (grass, trees, shrubs) between a stream and an area being disturbed by man's activities that protects the stream from erosion and nutrient impacts.

CRITERIA	REMARKS
1. Effectiveness	
1) Sediment	Good to excellent, reported to reduce sediment from feedlots on 4 percent slope by 79 percent.
b) Nitrogen (N)	Good to excellent, reported to reduce nitrogen from feedlots on 4 percent slope by 84 percent.
c) Phosphorus (P)	Good to excellent, reported to reduce phosphorus from feedlots on 4 percent slope by 67 percent.
d) Runoff	Good to excellent, reported to reduce runoff from feedlots on 4 percent slope by 67 percent.
2. Capital Costs	Good, moderate costs for fencing material to keep out livestock and for seeds or plants.
3. Operation and Maintenance Costs	Excellent, minimal upkeep.
4. Longevity	Excellent, maintains itself indefinitely.
5. Confidence	Fair, because of the lack of intensive scientific research.
6. Adaptability	May be used anywhere. Limitations on types of plants that may be used between geographic areas.
7. Potential Treatment Side Effects	Shading may alter the diversity and number of organisms in the stream.
8. Concurrent Land Management Practices	Conservation tillage, animal waste management, livestock exclusion, fertilizer management, pesticide management, ground cover maintenance, proper construction, maintenance of haul roads and skid trails.

Street Cleaning: Streets and parking lots can be cleaned by sweeping, which removes large dust and dirt particles, or by flushing, which removes finer particles. Sweeping actually removes solids so pollutants do not reach receiving waters. Flushing just moves the pollutants to the drainage system unless the drainage system is part of the sewer system. When the drainage system is part of the sewer system, the pollutants will be treated as wastes in the sewer treatment plant.

CRITERIA	REMARKS
1. Effectiveness	
1) Sediment	Poor, not proven to be effective.
b) Nitrogen (N)	Poor, not proven to be effective.
c) Phosphorus (P)	Poor, not proven to be effective.
d) Runoff	No effect.
2. Capital Costs	High, because it requires the purchase of equipment by community.
3. Operation and Maintenance Costs	Unknown but reasonable vehicular maintenance would be expected.
4. Longevity	Poor, have to sweep frequently throughout the year.
5. Confidence	Poor.
6. Adaptability	To paved roads, might not be considered a worthwhile expenditure of funds in communities less than 10,000.
7. Potential Treatment Side Effects	Unknown.
8. Concurrent Land Management Practices	Detention/sedimentation basins.

Surface Roughening: On construction sites, the surface of the exposed soil can be roughened with conventional construction equipment to decrease water runoff and slow the downhill movement of water. Grooves are cut along the contour of a slope to spread runoff horizontally and increase the water infiltration rate.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Good.
b) Nitrogen (N)	Unknown.
c) Phosphorus (P)	Unknown.
d) Runoff	Good.
2. Capital Costs	Low, but require timing and coordination.
3. Operation and Maintenance Costs	Low, temporary protective measure.
4. Longevity	Short-term.
5. Confidence	Unknown.
6. Adaptability	Excellent.
7. Potential Treatment Side Effects	None identified.
8. Concurrent Land Management Practices	Nonvegetative soil stabilization.

Terraces: Terraces are used where contouring, contour strip cropping, or conservation tillage do not offer sufficient soil protection. Used in long slopes and slopes up to 12 percent; terraces are small dams or a combination of small dams and ditches that reduce the slope by breaking it into lesser or near horizontal slopes.

CRITERIA	REMARKS
1. Effectiveness	
a) Sediment	Fair to good.
b) Nitrogen (N)	Unknown.
c) Phosphorus (P)	Unknown.
d) Runoff	Fair, more effective in reducing erosion than total runoff volume.
2. Capital Costs	High initial costs, an average of $73 per acre.
3. Operation and Maintenance Costs	Maintenance costs are $16 per acre annually but may be offset by increased income.
4. Longevity	Good with proper maintenance.
5. Confidence	Good to excellent.
6. Adaptability	Fair, limited to long slopes and slopes up to 12 percent.
7. Potential Treatment Side Effects	If improperly designed or used with poor cultural and management practices, they may increase soil erosion. Subsurface nitrogen losses may increase.
8. Concurrent Land Management Practices	Fertilizer and pesticide management.

Appendix E

STATE AND PROVINICIAL LAKE MANAGEMENT

Appendix E represents perhaps the most dramatic change in this, the second edition of the Manual. Its size alone has nearly doubled — from 22 programs in the first edition to more than 50 in this volume. Forty-two States and eight Provinces reported lake-oriented programs: at times, involving several agencies.

Two major reasons account for this growth: increasing interest (and knowledge) at the citizen level and, in the United States, the nurturing by the Federal Clean Lakes Program.

This Manual itself is evidence of the thrust of the Clean Lakes Program: EPA is clearly committed to helping citizens take care of their own lakes. This Manual provides the information necessary to that task; its supplements guide the technical manager in support of citizen efforts. And the Program's ongoing support for Clean Lakes projects and their assessment provide the framework that States can use to establish their own programs.

The citizens' own organization, the North American Lake Management Society, works closely with the Clean Lakes Program in this technical transfer effort, enabling citizens and scientists to share information essential to the wise management of this continent's lake resources.

Updated by letters and phone calls just prior to publication, this appendix is still incomplete. For example, several States and Provinces did not furnish information, but that doesn't necessarily mean they don't have some type of lakes program. Please, if you can fill in some of those blanks — or add to/correct/change existing information — contact the Clean Lakes Program, Nonpoint Sources Branch (WH-583), U.S. Environmental Protection Agency, 401 M St. SW, Washington, DC 20460.

ALABAMA

Department of Environmental Management
Field Operations Division
1751 Cong. W.L. Dickinson Drive
Montgomery, AL 36130
205/271-7935

Purpose To determine compliance with water use classification and associated water quality criteria.

Emphasis The department's lake program is primarily involved with water quality assessment and prioritization of waterbodies for additional diagnostic/feasibility studies. The majority of the State's lakes are actually multi-use reservoirs created initially for electrical power and/or navigation purposes.

Program Elements

1. **Lake assessment:** Major publicly accessible lakes are monitored on a rotating basis, about 12-14 per year, during the growing season to assist in documenting trophic status and compliance with water use classification.

2. **Federal Clean Lakes Program:** Phase I Diagnostic/Feasibility Study grants are used for appropriate lakes when available.

Assistance/ Services Technical cooperation and information are provided to States and Federal agencies, the public, and others.

Funding Sources U.S. EPA (majority funding source) and State legislature.

Staff Lake assessments and diagnostic/feasibility studies are conducted by departmental surface water monitoring staff and by contract. No one staff member is dedicated full time to a lake program.

Other Lake-Related Programs

1. Alabama Nonpoint Source Program administered by the ADEM.

2. Reservoir Fisheries Management and Aquatic Plant Control programs administered by the Alabama Department of Conservation and Natural Resources, 64 N. Union Street, Montgomery, AL 36130.

3. Others involved in lake management/monitoring activities include the Tennessee Valley Authority, U.S. Army Corps of Engineers, and the Alabama Power Company.

ARIZONA

Department of Environment Quality
Water Assessment Section, 2655 E. Magnolia, Suite 2
Phoenix, AZ 85034
602/392-4006

Purpose

To protect public health and to preserve, protect, and enhance the environment of Arizona.

Emphasis

Current emphasis of the Arizona Clean Lakes program is to develop and implement a program for expanded monitoring and assessment of Arizona's lakes and to increase the level of protection, restoration, and management of these water resources.

Program Elements

1. Monitoring and assessment of lake water quality.
2. Environmental review and comment on land and water use activities to address point and nonpoint source pollution sources affecting lakes.
3. Promulgation of surface water quality standards.
4. Implementation of a nonpoint source pollution program including watershed demonstration projects and development of best management practices.
5. Administration of Phase I diagnostic/feasibility studies on Roosevelt and Painted Rocks lakes.
6. Development of a riparian/wetlands habitat management program.

Funding Sources

Base funding (65%) for the Arizona Clean Lakes program has been provided through Federal grants pursuant to Section 314 of the Clean Water Act and the remainder by State match (35%).

Staff

Arizona Clean Lakes staff includes one permanent full-time employee, two part-time State-service interns. Sixteen staff members from the Water Quality Standards, Nonpoint Source, and Point Source and Monitoring units also contribute support and assistance to the Clean Lakes program (backgrounds in fisheries, aquatic biology, engineering, hydrology, and agricultural sciences).

Interactions

Public: Not listed

Private: Not listed

Governmental: Federal — Army Corps of Engineers, Fish and Wildlife Service, Geological Survey, Bureau of Reclamation, National Park Service, Forest Service, Bureau of Land Management

State: Dept. of Health Services, State Parks, Game and Fish Department, Salt River Project

Academic: University of Arizona, Arizona State University

ARKANSAS

Arkansas Department of Pollution Control and Ecology
8001 National Drive, P.O. Box 9583
Little Rock, AR 72209
501/562-7444

Purpose

Implementation of the provisions of the Clean Water Act and the Arkansas Water and Air Pollution Control Act.

Program Elements

1. Development and implementation of surface water quality standards.

2. Control of point source pollution through NPDES permitting procedures.

3. Assessment of nonpoint source impacts for guidance in implementation of best land management practices by designated management agencies.

4. Operation of statewide waterbody monitoring network.

Assistance Service

Report available to the public: Water Quality Assessment of Arkansas' Publicly Owned Lakes.

Funding Sources

Projects funded through Federal 314 grants and State legislative appropriations. Staff is federally funded through water quality program grants.

Staff

One part-time technical support staff person.

Other Lake-Related Programs

Statewide monitoring network periodically monitors water quality of reservoirs.

COLORADO

Colorado Department of Health
Water Quality Control Division
4210 E. 11th Avenue
Denver, CO 80220
303/331-4578

Purpose To protect the classified beneficial uses of lakes and reservoirs.

Emphasis Responsible for regulatory issues of eutrophication control by managing point and nonpoint sources of nutrients in specific lakes. Although there is no specific lake program, activities are conducted as part of the whole water quality program.

Program Elements

1. Coordinate and manage the Federal Clean Lakes Program Phase I and Phase II projects with council of governments, local governments, and district or other organizations within the State.
2. Lake monitoring program funded through the Federal Lake Water Quality Assessment Grant.
3. Water quality sampling and monitoring of pollutants in fish tissue on specific lakes and reservoirs.
4. Other elements include wastewater discharge permits, water quality standards, and general water quality management and planning activities.

Assistance/ Service Technical guidance on request.

Funding Sources Combination of Federal and State.

Staff For specific lake activities, there are three staff with backgrounds in aquatic biology, planning, and engineering who assist in the program.

Interactions Variety of local, State, and Federal government agencies.

CONNECTICUT

Department of Environmental Protection
Bureau of Water Management
Division of Planning and Standards, Lakes Management Section
165 Capitol Avenue, Hartford, CT 06106
203/566-2588

Purpose

To develop and implement water quality management strategies and policies that will deal with the problem of lake eutrophication, particularly excessive algae, aquatic plant growth, and dissolved oxygen depletion.

Emphasis

The program focuses on management of both statewide concerns (nonpoint source management policy and construction grants program) and individual lake projects. Grants are used as a key aspect of management.

Program Elements

1. **Trophic status assessment:** A study completed in the late 1970s is presently being updated. This study will analyze trends in eutrophication and acidification.
2. **Municipal/industrial discharge management:** evaluation of lake water quality benefits attained after the implementation of advanced wastewater treatment through State construction grants.
3. **Water quality standards:** No discharges to Class A lakes. Discharges to certain Class B lakes can't raise phosphorus levels above 0.03 mg/L. A lake trophic classification system is included.
4. **Nonpoint source control:** Development and distribution of a guide to best management practices for controlling nonpoint sources in lake watersheds.
5. **Federal Clean Lakes Program:** Administration of grants from Section 314 Program for Phase I studies and Phase II implementation projects.
6. **Administration of cost-sharing grant program** for diagnostic feas-ibility studies and eutrophication abatement projects to muni-cipalities and eligible lake associations for lakes with public access.
7. **Special projects:** State appropriations have been made for projects to (a) purchase a hydraulic dredge for lake management projects and (b) develop individual lake management projects.

Assistance/ Service

Handbooks on best management practices for nonpoint source controls, algae and weed control methods, and nuisance aquatic vegetation control; cost-sharing grant programs to municipalities and eligible lake associations for qualified lakes; and technical assistance to towns, lake associations, and private pond owners.

Funding Sources

Individual projects are funded through Federal 314 grants, State grant program, State legislative appropriations, and local sources. Staff is federally and State funded.

Staff One full-time and one part-time professional contribute to the program.

Interactions **Public:** Provide information to public.

Governmental: Grants/cost-sharing grant program to municipalities and eligible lake associations for qualified lakes.

Other Lake-Related Programs DEP, Pesticides Section, Hazardous Materials Management Unit; DEP, Fisheries Bureau; DEP, Water Resources Unit, Department of Health Services.

DELAWARE

Department of Natural Resources & Environmental Control
Division of Fish and Wildlife
89 Kings Highway, P.O. Box 1401
Dover, DE 19903
302/736-4590

Purpose Provide maximum fishing opportunity for freshwater anglers.

Emphasis Applied research and management dealing primarily with individual problem lakes. Some problems (e.g., *Hydrilla*) deal with multiple waterbodies.

Program Elements

1. **Fisheries management** through (a) evaluation of fish introductions, (b) investigation of largemouth bass regulation changes, (c) impact of advanced fingerling stocking, (d) restoration of herring runs into freshwater impoundments, and (e) evaluation of freshwater fishing by mail creel survey.
2. **Investigation of vegetation removal in ponds** by (a) evaluation of partial aquatic vegetation removal, (b) evaluation of biological control including the use of triploid grass carp, (c) Hydrilla investigations.
3. **Evaluation of dredging on a freshwater community** including the impact of wetlands loss on a pond and sediment mapping of public ponds.

Assistance/ Services Biologist available to assist owners on all ponds (private or public).

Funding Sources Federal funds through the Dingell-Johnson Program and State funds through license receipts.

Staff Six (primarily biology/ecology/fisheries background).

Interactions **Public:** Creel interviews and angler diaries.

Private: None listed.

Governmental: Technical assistance to State/county parks and recreation departments and soil conservation services.

Other Lake-Related Programs Soil Conservation Service: Technical aid to private owners; University of Delaware Extension Service; Delaware State College Cooperative Fisheries Unit; Division of Water Resources, DNREC — Clean Lakes Grant, contact Mark Blosser — Water Quality Parameters; eutrophication land use controls for surface water runoff.

FLORIDA

Florida Department of Environmental Regulation
2600 Blair Stone Road
Tallahassee, FL 32399-2400
904/488-0782

Purpose

The program's purpose is to maintain and improve lake water quality for the propagation of wildlife, fish, and other aquatic life, for public recreational and other beneficial uses.

Emphasis

The program focuses on providing monetary assistance to State, county, and municipal agencies and water management districts for lake assessment and restoration activities.

Program Elements

1. **Clean Lakes Program:** The Department administers the Clean Lake Program for the State of Florida.
2. **Information Dissemination:** Provide information on lake and reservoir management and restoration.
3. **Technical Assistance:** Provide consultation and advice to public organizations and citizens groups.

Assistance/ Services

Refer to program elements.

Funding Sources

Projects are federally funded through Section 314 Clean Water Act and through various State programs such as the Surface Water Improvement and Management Program.

Staff

One program administrator and one program coordinator.

Interactions

Public: Assist by providing information and participation on citizens task forces.

Private: Disseminate information.

Governmental: Administrate U.S. EPA Clean Lakes Program.

Florida Game and Fresh Water Fish Commission
Lake Management Section
207 West Carroll Street
Kissimmee, FL 34741
904/488-0782

Emphasis

Primarily management oriented; dealing with problem lakes or watersheds. Discharge of sewage has been the major statewide problem. Current emphasis shifting more toward controlling agricultural runoff and surface water runoff from developed watersheds. Primary emphasis of fish and habitat management. Normally, grants are not pursued but assistance is provided for local governments to apply.

Program Elements

1. Development of lake restoration plans based on needs of aquatic habitat, fisheries, and wildlife and considering such factors as water quality and quantity, lake level manipulation, and aquatic plant management.
2. Point and nonpoint source considerations.
3. Many plans have been developed using mechanical removal of organic sediments, drawdown, or pumpdown along with mechanical removal to restore aquatic habitat and associated fish and wildlife values.
4. Cooperation with Federal, State, and local agencies and elected officials to implement planned programs.

Assistance/ Services

Develop or assist in development of restoration plans for public lakes of greater than 5 acres. Also provide services by recommending management techniques to enhance fish and wildlife values.

Funding Sources

Entirely from sale of fishing licenses.

Staff

One limnologist; two fish management specialists; nine fisheries biologists; two technicians; two secretaries (strong backgrounds in lake drawdown, pollution control methodologies, and surface water hydrology).

Interactions

Public: Considerable, from phone calls to formal public hearings.

Private: Work with consultants during project planning and implementation.

Governmental: Work with many other agencies during the planning and implementation of projects.

SWIM Act: Passed by 1987 legislative action.

GEORGIA

Georgia Department of Natural Resources
Environmental Protection Division
Water Protection Branch
205 Butler Street, SW
Atlanta, GA 30334
404/636-4708

Purpose

To protect and enhance the quality of Georgia's waters for their designated uses.

Emphasis

Efforts primarily focus on water quality assessment and resolution of problem issues. Lake programs are part of integrated approach to State waters that concentrates on assessing and maintaining water quality standards.

Program Elements

1. **Lake classification:** As part of a Clean Lakes Classification Grant, 175 lakes and reservoirs were evaluated in 1980-81. Subsequent Clean Lakes funding in 1989 has been used to further evaluate and classify 14 major reservoirs.
2. **Lake monitoring:** Ongoing lake monitoring is conducted on major reservoirs in the annual Major Lakes Monitoring Project and on sites included in the Trend Monitoring Network.
3. **Special studies and intensive surveys** are conducted on reservoirs on an as-needed basis to evaluate problem issues. Federal Clean Lakes funds used for a portion of these studies. Continued monitoring on lakes where EPD has required point sources to reduce nutrient loading.
4. Comprehensive studies are beginning or planned for publicly owned reservoirs greater than 1,000 acres. These studies will be used to set nutrient and chlorophyll *a* standards in addition to current standards for dissolved oxygen, pH, and fecal coliform bacteria.

Assistance/ Services

Coordination and management of Clean Lakes Program grants; technical guidance on request; response to water quality concerns.

Funding Sources

State appropriations and Federal grants.

Staff

Water Protection Branch monitoring personnel are assigned projects on an as-needed basis.

Other Lake-Related Programs

Game and Fish Division manages fisheries and aquatic plant programs and responds to fish kill incidents.

IDAHO

Idaho Division of Environmental Quality
1410 North Hilton
Boise, ID 83706
208/334-5860

Purpose

The Division of Environmental Quality (DEQ) is responsible for protecting all ground and surface waters of the State. In the last decade, Idaho has actively participated in the Federal Clean Lakes Program and designed and implemented a citizen volunteer monitoring program. A State lake protection program was established in 1989 through passage of the Nutrient Management Act. A second piece of legislation, the Clean Lakes Act, was also passed in 1989, establishing a pilot lake coordination program in the five northern countries.

Emphasis

The Nutrient Management Act focuses on two areas: completing a statewide nutrient management plan emphasizing lakes and reviewing locally developed plans for consistency with criteria set forth in the act. Individual nutrient management plans are to be developed for each of the State's six hydrologic basins. These hydrologic basin plans will be compiled into a State nutrient management plan by January 1995.

The Clean Lakes Act authorized a pilot program in north Idaho and formation of a council to coordinate all lake-related activities. The council is empowered to conduct baseline studies, develop management plans, conduct informational activities, and provide technical assistance to lake associations. Existing resource agencies and governments are relied upon for implementation and enforcement.

Program Elements

The State Nutrient Management Act, North Idaho Pilot Program, and Federal Clean Lakes Program together include the following elements:

1. Prioritization of lakes for study.
2. Lake water quality assessment and management plan completion.
3. Technical assistance to lake associations.
4. Public involvement through advisory committee formation and public meetings.
5. Public information and education.
6. Volunteer lake monitoring program.

Assistance/ Services

DEQ and the Panhandle Health District work through the Clean Lakes Council in north Idaho to provide technical assistance and information and education support to local lake associations. Elsewhere in the State, DEQ works with lake association, local units of government, and private foundations to help solve lake water quality problems.

Funding Sources

A funding source to implement the plans developed under the Nutrient Management Clean Lakes Act was not established. Solving lake water quality problems occurs primarily through other complementary programs. The State municipal facilities grants and loans program addresses sewage problems. The State Agricultural Water Quality Program provides grants to farmers to install best management practices. The Centennial Adopt-A-Stream pilot project, funded under Clean Water Act Section 319, provides small grants for local water quality protection and restoration projects. Other Section 319 demonstration projects address tributary problems that affect lakes. The Federal Clean Lakes Program also provides funding for implementing in-lake and watershed restoration activities.

Staff

DEQ supports three staff with Federal project funds and one person with State funds. The Panhandle Health District supports one person with State funds to staff the Clean Lakes Council in north Idaho.

Interactions

Public and private interaction is extensive through local lake associations, advisory committees, and public meetings. Governmental interactions are extensive through advisory committees and cooperative projects.

ILLINOIS

Illinois Environmental Protection Agency
Division of Water Pollution Control
Planning Section
2200 Churchill Road
Springfield, IL 62706
217/782-3362

Purpose To protect, enhance, and restore the quality and usability of lake ecosystems.

Emphasis An integrated, multidisciplinary approach to lake use enhancement involving watershed protection and in-lake management to mitigate past damage.

Program Elements

1. **Monitoring and lake classification to guide decisionmaking:** (a) Volunteer Lake Monitoring Program (VLMP): 260+ lakes monitored for Secchi disk transparency, 50 for nutrients and suspended solids, (b) Ambient Lake Monitoring Program (ALMP): about 30 lakes/year monitored by division personnel.

2. **Development and implementation of lake/watershed management plans for public lakes under the Federal Clean Lakes Program:** Administration of the CLP-funded protection/restoration projects. Currently, three projects ongoing; two completed.

3. **Technical assistance and coordination to promote planning and implementation initiatives funded by other sources:** Interactions with other Federal, State, and local groups and agencies.

Assistance/ Services Information and training for VLMP volunteers, other educational and technology transfer information, development of lake/watershed implementation plans.

Funding Sources Federally funded through Sections 314, 106, and 205(j) of the Clean Water Acts.

Staff Four full time staff (Springfield HQ) plus regional office technicians and aquatic biologists.

Interactions **Public:** Citizen volunteers (VLMP), Illinois Lake Management Association, Northeastern Illinois Planning Commission.

Private: Not listed.

Governmental: Federal — U.S. EPA, USDA.

State: Dept. of Agriculture, Dept. of Conservation, State Water Survey.

Development of an administrative framework plan as authorized by the Illinois Lake Management Program Act (Nov. 1, 1989). The plan, if funded, would provide for an enhanced State Lakes Management Program in Illinois.

INDIANA

Indiana Department of Environmental Management
Office of Water Management
5500 West Bradbury Avenue
Indianapolis, IN 46241
317/243-5028

Purpose

Protection and management of water quality in State lakes.

Emphasis

A comprehensive, multidisciplinary program involving data acquisition, public education, and citizen involvement.

Program Elements

1. Lake water quality assessment and classification to guide decisionmaking
2. Volunteer Monitoring Program — citizens monitor 100 public lakes for Secchi transparency.
3. Fish tissue and sediment toxics monitoring.
4. Technical assistance to lake associations and local government. Also assist local governments in applying for U.S. EPA Section 314 grants.
5. Public education: sponsor annual lake management conference, publish quarterly newsletter, prepare lake management guidance materials.

Assistance/ Services

Technical assistance; training of volunteer monitors; prepare annual fish consumption advisories; public education.

Funding Sources

State budget and Federal funds through Sections 205(j) 314 and 319 of the Clean Water Acts.

Staff

Three staff members implement the statewide fish tissue and sediment monitoring program. A portion of their time is spent on lakes.

Two additional staff members with biological background work part-time on program coordination. The program is implemented by the School of Public and Environmental Affairs of Indiana University under contract with the Department of Environmental Management.

Interactions

Public: Volunteer Monitoring Program; annual lake management conference.

Private: Work with consultants involved in studies.

State government: Work with the Department of Natural Resources to coordinate lake and wetlands programs; with DNR and State Board of Health on fish consumption advisories.

Federal: U.S. EPA.

Division of Soil Conservation
FLX 1 Building, Purdue University
West Lafayette, IN 47907
317/243-5028

Purpose To ensure the continued viability of Indiana's public access lakes.

Emphasis Control of sediment and nutrient inflows from nonpoint sources. Where appropriate, remedial actions may be taken to forestall or reverse the impacts of such inflows.

Program Elements Administration of the "T by 2000" Lake Enhancement Program, a cost-share (grant) program to assist local entities in funding feasibility studies and the design and construction of sediment and nutrient control measures.

Assistance/ Services Technical and financial assistance can be provided for qualifying projects.

Funding Sources State government funds and money raised locally by project sponsors.

Staff Five individuals with solid conservation, engineering, and aquatic biology backgrounds.

Interactions **Public:** Extensive inquiries for lake management information and technical and financial assistance from individuals and local organizations.

Private: Deal with consultants on feasibility and design studies.

Governmental: Federal EPA, USDA Soil Conservation Service, ASCS.

State: Indiana Department of Environmental Management (IDEM)

Indiana Department of Natural Resources (IDNR) — Divisions of Fish and Wildlife, Nature Preserves, Outdoor Recreation, Water.

Local: Soil and Water Conservation districts, park and recreation boards, planning agencies, drainage boards.

Other Lake-Related Programs **IDEM:** Indiana Clean Lakes Program, water quality regulations, nonpoint source pollution programs permitting.

IDNR: Division of Water — permitting, lake level.

IDNR: Division of State Parks — limited sediment removal from lakes in State parks.

IDNR: Division of Fish and Wildlife — fisheries management in public waters.

IOWA

Iowa Department of Natural Resources
Fish and Wildlife Division
Wallace State Office Building, 900 East Grand
Des Moines, IA 50319
515/281-8663

Purpose

The lakes program is designed to protect and enhance the State's valuable lake resources. The primary goal of the program is maintenance of high quality lakes for swimming, fishing, and other recreational uses.

Emphasis

Program focuses on data acquisition, development, and implementation of lake watershed protection and lake restoration projects; implementation of lake management plans, development, and implementation of new management techniques; and public information and education.

Program Elements

1. **Investigations and surveys of publicly owned lakes:** monitor lake use and fish populations, physical and chemical conditions, and watershed use to detect changes that require management strategies to be implemented; classification of lakes.
2. **Research:** conduct research that will provide new methods and techniques to manage and protect lake environments and fisheries.
3. **Lake protection/restoration projects:** develop and implement watershed protection/lake restoration projects, using Federal Clean lakes Program or other Federal/State/local program funds.
4. **Technical assistance:** provide information to aid owners of private impoundments manage their lakes and lake fisheries.
5. **Fish stocking:** stock number, size, and species of fish as recommended in lake management plan.
6. **Information dissemination:** publish and distribute results of research findings, technical lake management reports, and information to the public and lake managers regarding fishing opportunities, new lake management techniques, and lake management plans.

Assistant/ Services

Problem analyses, technical assistance, management plans, fish stocking, dissemination of information materials, and development/implementation of lake watershed protection and lake restoration plans.

Funding Sources

Federal Aid (Dingell-Johnson); Fish and Wildlife Trust Fund; Sections 205(j), 314, & 319 of Federal Clean Water Act.

Staff

Central office and field staff of DNR Fisheries Bureau and other DNR Divisions.

Interactions

Public: extensive response to inquiries for information.

Private: consultation with lake protection associations.

Governmental: work closely with other DNR Divisions, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, County Conservation Boards, and other local governmental agencies.

Other Lake-Related Programs

County Conservation Board lake programs; Iowa Water Resources Research Institute — research into lake management problems; DNR Stream Fisheries Research and Management Program; Iowa Water Quality Management Program; Iowa Nonpoint Pollution Management Program; Iowa Publicly-owned Lakes Cost Share Program; USDA – various ASCS and SCS Programs.

KANSAS

Department of Health and Environment
Bureau of Environmental Quality
Forbes Field
Topeka, KS 66620
913/296-5575

Purpose

To provide water quality information on lakes and address current concerns of the public and the department.

Emphasis

Program stresses data acquisition and investigation to address individual lake problems and to assess generic problems such as eutrophication or nonpoint sources. Response to public concerns is a key focus of the program.

Program Elements

1. **Routine lake monitoring:** 15-30 lakes/year.
2. **Special investigations:** Performed in-house or in cooperation with other State, Federal, or local agencies, these studies include: (a) the formation of trihalomethanes in drinking water supply reservoirs; (b) the occurrence and persistence of pesticides in drinking water reservoirs; (c) the effects of nonpoint source pollutants on lake water quality; and (d) the causes and control of taste and odor problems reported by the public or treatment plant operators.

Assistance/ Services

Special investigative surveys in response to public notifications of observed lake problems.

Funding Sources

The lake monitoring program is funded by the Federal and State governments.

Staff

Four staff with aquatic biology backgrounds assist in the lake monitoring program. Also, three to five part-time environmental technicians assist (20% time, total).

Interactions

Public: Extensive response to public requests.

Private: Little to none.

Governmental: Grants for special studies.

Academic: Grants for special studies.

KENTUCKY

Department of Environmental Protection
Division of Water
Fort Boone Plaza
18 Reilly Road
Frankfort, KY 40601
502/564-3410

Purpose To provide lake water quality data for making management decisions on the use of point and nonpoint source controls to alleviate use impairments.

Emphasis Data acquisition.

Program Elements

1. **Ambient monitoring program:** Six lakes are monitored for eutrophication trends on a revolving basis and three lakes for long-term potential acid precipitation impacts.

2. **Lake classification survey:** A new survey of 99 lakes will be completed in 1990 using Federal Clean Lakes Program funds. This information is used to make decisions on new point source discharges in lake watersheds and for 305(b) reporting purposes.

3. **Citizens participation program (Water Watch):** Designed to actively educate the public about water quality problems. One element ("adopt a lake" program) allows local groups to learn about their lakes and watersheds.

4. **Program staff review all NPDES permits** for lake discharges and recommend appropriate discharge limits, discharge location, or denials based on trophic status and use support, or potential use impairments.

Assistance/ Service Staff assistance in educating volunteer groups on lake sampling and limnology; advice on private lake management problems.

Funding Sources Mainly Federal (Section 205j) funds.

Staff Two part-time employees (aquatic biologists).

Interactions

Public: Local volunteer groups through the monitoring/education program. Response to inquiries on lake problems.

Private: Consulting firms, developers.

Governmental: Federal — Army Corps of Engineers, Soil Conservation Service.

Interstate: Tennessee Valley Authority.

State: Department of Fish and Wildlife Resources.

Local: City officials.

Department of Environmental Quality
Office of Water Resources
Natural Resources Building
P.O. Box 44091
Baton Rouge, LA 70804
504/342-6369

Purpose

Responsible for protecting and preserving the quality of all surface waters in the State. Lake water quality problems are handled within the framework of the whole program; there is no separate lake program.

Emphasis

This water quality management and planning program is designed to be flexible so that a variety of activities can be used to deal with whatever problems arise. Grant aid has been used for both general and specific lake investigations.

Program Elements

1. **Monitoring:** Establishment and implementation of monitoring networks.
2. **Water quality data assessment:** On a case-by-case basis for any waterbody.
3. **Wastewater discharge permits:** Development, issuance, and enforcement of permits for discharges to any waterbody.
4. **Lake classification:** An inventory of lakes and their trophic indices was completed using Federal Clean Lakes Program funds.

Assistance/ Services

Technical expertise and databases available. Field staff respond to water quality complaints and fishkills.

Funding Sources

Combination of Federal grants and self-generated fund from permit fees and fines.

Staff

About 100 members for all water quality issues.

Interactions

Public: Attend public meetings on water quality issues.

Private: With consultants and private industry regarding the permitting process.

Governmental: Regulatory agreement with Louisiana Department of Wildlife and Fisheries.

Other Lake-Related Programs

Louisiana Department of Agriculture: Nonpoint sources; Soil and Water Conservation Commission: Nonpoint sources; Department of Transportation: Water sources and quantity; Department of Health: Water quality (coliforms); Department of Wildlife and Fisheries: Fish resources; Soil and Conservation Service: Nonpoint sources, irrigation; U.S. Geological Survey: Flow and hydrology

Department of Environmental Protection
State House #17
Augusta, ME 04333
207/289-3901

Purpose

To direct long-term planning, protect lake water quality, and inform and educate the public so as to maintain or improve the present water quality of Maine's 5,000 lakes and ponds.

Program Elements

1. **Vulnerable Lake Identification:** Determining which lakes need protection or restoration using vulnerability indices, value indices, lake benthic indices, volunteer monitoring programs, critical area program, and LURC wildlands lake assessment.
2. **Priority List:** Included on the list are lakes (a) with declining water quality; (b) sensitive for phosphorus loading; (c) in critical areas; and (d) with cultural stress but stable water quality.
3. **Protection Plans:** Plans are formulated taking into account water quality data from volunteer monitoring and diagnostic studies, land use trends, lake associations (lobby), town officials, local ordinances, soils information, subdivision reviews, and conservation easements. Develop town comprehensive plans.
4. **Best Management Practices:** Encouragement in the use of BMPs at the State level through site and subdivision review, and the Natural Resource Protection Act. DEP assistance is provided for municipalities on development review, ordinances and zoning, watershed districts, and town enforcement roles.
5. **Development of a broad base of support** through general public and school education programs.
6. **Lake Restoration:** Problem lakes that deviate from their natural state are marked for efforts to control cultural activities.
7. **Nonpoint Source Reduction:** Efforts are aimed at agriculture, forestry, and transportation.
8. **Other issues being studied include** conflicting policies, cumulative impact guidelines, scenic values, open space for lakes, conflicting uses, and aquatic plant issues.

Assistance/ Services

Technical guidance to municipalities, lake associations, and other State agencies such as the Bureau of Land Quality.

Funding Sources

State funds, Federal funds through Section 314.

Staff

Six biologists, One civil engineer, One environmental specialist, One part-time support staff.

Interactions

Public: Extensive response to public requests, watershed districts, municipalities.

Governmental: Other State and Federal agencies; SCS/EPA.

University: Joint research with University of Maine.

MASSACHUSETTS

Department of Environmental Protection
Division of Water Pollution Control
Lyman School, Westview Building
Westborough, MA 01581
508/366-9181

Purpose To restore, preserve, and maintain publicly owned lakes and ponds for recreation and enjoyment.

Emphasis The program focuses on providing monetary and technical assistance to communities for lake restoration and on water quality data acquisition.

Program Elements

1. **State Clean Lakes Program:** Administration of a matching grant aid program to provide funds for diagnostic/feasibility studies, long-term restoration/preservation projects, and short-term in-lake maintenance projects.

2. **Federal Clean Lakes Program:** Administration of federally funded CLP implementation projects.

3. **Water quality monitoring:** Limnological sampling to obtain lake water quality data (a) to determine baseline lake conditions; (b) to monitor post-implementation project changes; and (c) to respond to public concerns about lake problems.

4. **Aquatic Herbicide Application Licensing:** Administration of legislatively mandated license program for application of chemicals in lakes.

Assistance/ Services Staff is funded by a combination of State and Federal money. Matching grants were provided from State funds only or a combination of State and Federal funds. Currently, no new State funds are available for the grant program.

Staff Three (backgrounds in aquatic biology, aquatic chemistry, and geology).

Interactions **Public:** Extensive response to public requests for grants, surveys, and information.

Private: Dealings with consultants and contractors working on studies and implementation projects.

Governmental: Federal — Clean Lakes Program grants.

State: Cooperation with other DEP agencies, Division of Fisheries and Wildlife, and Dept. of Environmental Management.

Local: Grant contracts with communities.

Other Lake-Related Programs Division of Fisheries and Wildlife: Manages fisheries resources; lake liming program; Department of Environmental Management: Manages lakes in State parks; DEP, Division of Water Supply: Water supply reservoirs; DEP, Division of Wetlands: Wetlands Protection Act.

Department of Natural Resources
Land and Water Management Division
Inland Lake Management Unit
Box 30028
Lansing, MI 48909
517/373-8000

Purpose

The Inland Lake Management Unit serves as a focal point and information source for lake and watershed management activities.

Emphasis

Lake management through the administration of regulatory and public assistance programs dealing with both specific lakes and broad lake issues.

Program Elements

1. **Aquatic nuisance control:** Provide information to the public on nuisance aquatic macrophyte and algae control and on swimmer's itch control (including oversight of a research grant on swimmer's itch control). Responsible for issuing permits for herbicide use in surface waters.

2. **Lake Improvement Boards:** Serve as Department of Natural Resources representatives on Lake Boards formed to undertake lake restoration/management projects. Boards have authority to tax riparian owners to fund projects. Currently there are 75 active boards.

3. **Federal Clean Lakes Program:** Classification of all lakes over 50 acres was completed in 1982. CLP grants have been administered for two demonstration projects, four Phase I studies, and two Phase II projects.

4. **Inland Lake Self-help Monitoring Program:** Established in 1974, the program involves volunteers in measuring Secchi transparency. Until 1982 chlorophyll *a* was also measured.

5. **Technical reviews:** Staff are called on to review (a) NPDES permit effluent limits for phosphorus discharges to lakes or within 20 miles upstream of lakes; (b) recommendations on the establishment of legal lake levels; and (c) dredge and fill permits that might impact lake water quality.

6. **Nonpoint source management:** The ILMU provided input (with the Surface Water Quality Division) to a recently established State nonpoint source control incentives grant program.

Assistance/ Services

Public information bulletins and assistance, Self-help Monitoring Program, technical assistance to other agencies.

Funding Sources

Combined Federal (50%) and State (50%).

Staff

Four (backgrounds in limnology).

Interactions

Public: Extensive inquires for information from public; work with Self-help Program volunteers and Lake Boards.

Private: Deal with consultants on Lake Board feasibility studies.

Governmental; Federal — EPA Clean Lakes Program.

State: Coordinate with Dept. of Agriculture, Surface Water Quality Div. (DNR), Engineering-Water Management Div. (DNR), Fisheries Div. (DNR), and other Div. of Land Resource Programs units (DNR).

Other Lake-Related Programs

Michigan Department of Agriculture: licensing of herbicides and herbicide applicators; DNR, Surface Water Quality Division: NPDES permits and nonpoint source control; DNR, Land and Water Management Division: Lake level control; DNR, Fisheries Division: Fisheries management; DNR, Division of Land and Water Management Division: Dredge and fill permits.

MINNESOTA

Minnesota Pollution Control Agency
520 Lafayette Road
St Paul, MN 55155
612/296-7217

Purpose

To preserve and protect Minnesota's lakes and to increase and enhance their public use and enjoyment.

Emphasis

The Minnesota Pollution Control Agency (MPCA) stresses protection and management through lake data collection, public education, and interpretation, and the use of grants on specific lakes.

Program Elements

1. **Minnesota Clean Lakes Program:** Since 1977 the MPCA has administered and supplemented the Federal Clean Lakes Program. Because the MPCA feels that local leadership, control, and coordination play a key role in a project's success, most projects are initiated at the local level and the local project is responsible for implementing the project and meeting the grant objectives. The MPCA evaluates and prioritizes grant proposals before submitting them to the U.S. EPA Region V office. To date, 48 lakes have been involved in the program.

2. **Clean Water Partnership Program (CWP):** The CWP is Minnesota's nonpoint source program. This program provides local units of government with resources to protect and improve lakes, streams, and groundwater. A two-phase process is used as in the Clean Lakes Program. Grants were made available to 14 projects in February 1989.

3. **Lake classification:** About 1,400 of Minnesota's approximately 12,000 lakes have been classified.

4. **Reference lakes:** About 35 to 45 lakes are monitored annually to characterize lake water quality in each of Minnesota's ecoregions.

5. **Citizen Lakes Monitoring Program:** About 400 Lakes are enrolled in this program. The MPCA initiated a program to assist lake associations collect and interpret water quality data.

6. **Lake Assessment Program (LAP):** LAP was initated in 1985 to assist lake associations collect and interpret water quality data. Approximately 35 lake studies have been completed through LAP.

7. **Public education:** MCPA staff routinely speak to interested public groups about lake protection. The handbook "Citizens Guide to Lake Protection" was drafted in conjunction with the Gray Freshwater Biological Institute and is available for distribution. The report "Trophic Status of Minnesota Lakes" provides water quality data on over 1,000 lakes.

Assistance/ Services

Grants and grant administrative assistance are available on request. Technical expertise and educational materials are available to respond to public requests and complaints. Citizen Lakes Monitoring Programs and Lake Assessment Programs are available.

Funding Sources

Federal for staff and grants. State for grants.

Staff

Six positions to administer the Clean Lakes Program, Lake Assessment Program, Citizen Lake Monitoring Program, and reference lake monitoring.

Interactions

Public: Extensive interaction with lake associations and other public groups.

Private: Consultants dealing with Clean Lakes Program.

Governmental: Federal — U.S. EPA, USDA SCS.

State: DNR, Soil and Water Conservation Board.

Local: Municipalities and counties

Academic: University of Minnesota Limnological Research Center, Freshwater Foundation, University of Minnesota Water Resources Research Center.

Department of Natural Resources
Division of Environmental Quality
Water Pollution Control Program
P.O. Box 176
Jefferson City, MO 65102
314/751-1300

Purpose To project the beneficial uses listed in the State water quality standards.

Emphasis The program acts as a clearinghouse for lake monitoring and management activities.

Program Elements Limited review of monitoring and lake management activities of publicly owned lakes (50 acres).

Funding Sources There are no Federal or State funds specifically available for lakes.

Staff One limnologist/aquatic biologist available.

MONTANA

Montana Department of Health and Environmental Sciences
Capitol Station
Helena, MT 59601
406/444-2406

Purpose Management of both coldwater and warmwater fisheries.

Program Elements

1. **Routine stocking:** Trout and salmon are stocked in coldwater lakes. Walleye, northern pike, and largemouth bass are stocked in cool/warmwater lakes.
2. **Reproducing populations:** Considerable effort is being given to establish reproducing sport fish populations in lakes and reservoirs of all types, from high mountain lakes to lowland lakes and from ranch ponds to large (200,000 acre) reservoirs.

Assistance/ Services Public education programs through written documentation and through project WILD and education programs working with the public school system.

Funding Sources From State license dollars, and Federal government through Dingle/Johnson Programs.

Staff 108 staff members working in fisheries department, many of whom are involved with lake management.

Interactions

Public: None listed.

Private: Trout Unlimited, Walleye Unlimited, Montana Wildlife Federation, Montana Alliance Nature Conservancy.

Government: Federal — Army Corps of Engineers, Bureau of Reclamation.

State: Department of Natural Resources.

Contacts

Administrator, Fisheries Division (above address).

Department of Natural Resources.

Department of Agriculture.

NEBRASKA

Nebraska Department of Environmental Control
Water Quality Division, Surface Water Section
301 Centennial Mall South, Lincoln, NE 68509-8922
402/471-4700

Purpose

The mission of Nebraska's Clean Lakes Program is to protect, enhance, and restore the quality and beneficial uses of lake ecosystems.

Program Elements

1. Physical, chemical, and biological monitoring to evaluate existing conditions and determine water quality trends.
2. Establish priorities through lake and watershed monitoring and assessments.
3. Administration of lake and watershed projects.
4. Integrate Nonpoint Source and Clean Lakes programs.
5. Technology transfer and interaction with other Federal, State and local agencies and groups.

Funding Sources

Federal funding through Section 314 of the Clean Water Act. Clean Lake Phase I grants have been awarded by EPA.

Nebraska Game Parks Commission
Fisheries Division
2200 North 33rd Street
Lincoln, NE 68503
402/471-0641

Purpose

To perpetuate and enhance the fish and wildlife resources of Nebraska for recreational, aesthetic, educational, and scientific use by Nebraskans and their visitors.

Emphasis

The program involves management planning based on data collection, analysis, and public input.

Program Elements

1. **Investigations and Surveys:** Monitoring of fish populations and habitats through standard survey techniques.
2. **Management Planning:** Development of lake management plans designed to provide an optimum sustained yield.
3. **Technical Assistance:** Provide assistance to owners of private waters in the proper management of their lakes and ponds.

Assistance/ Services

Technical assistance, management plans, published informational material.

Funding Sources

Permit fees, Federal aid (Sport Fish Restoration Act).

Staff

Division chief, administrative assistant, and 14 district fish managers.

Interactions

Public: extensive response to inquiries for information.

Other Lake-Related Programs

Nebraska Game and Parks Commission, Fisheries Research Section and Parks Division; Nebraska Department of Environmental Control; Nebraska Natural Resources District.

Water Supply and Pollution Central Commission
Biology Division
6 Hazen Drive, P.O. Box 95
Concord, NH 03301-6528
603/271-3503

Purpose

To provide limnological services through planning, research, and water quality monitoring to protect and restore the water quality of the State's lakes and ponds in accordance with legislated uses.

Emphasis

The program focuses on water quality protection through monitoring efforts and public information and technical assistance.

Program Elements

1. **Lake trophic surveys:** Sampling of 40 to 50 lakes and ponds each year, winter and summer, for baseline, long-term trends, and water quality compliance information.

2. **Volunteer Lake Assessment Program:** Use of citizen volunteers to monitor the water quality of lakes and ponds during the growing season for short- and long-term analysis.

3. **Acid rain studies:** Sampling of 20 low elevation lake outlets at spring and fall overturn) and about 30 high elevation remote ponds (by helicopter) in spring for acid rain parameters to provide short- and long-term trend information on acidic deposition impacts. Precipitation events are analyzed for pH, sulfate, and nitrate.

4. **Federal Clean Lakes Program (Section 314):** conduct Phase I, II, and III studies to determine causes and recommend solutions for impaired lakes, to implement restoration procedures, and to monitor the effectiveness of the restoration procedures.

5. **New Hampshire Clean Lakes Program:** Investigate and control aquatic nuisances, manage exotic aquatic plants by providing information material, eradicating small new infestations, and granting matching funds to manage existing infestations, and provide matching funds for the Section 314 program.

6. **Special projects:** Periodically, special lake projects are conducted that don't fall into one of the above-listed categories. Presently, lake sediment cores are being analyzed for heavy metal content.

7. **Public education/technical assistance:** The lakes program provides educational material and technical assistance to towns, lake associations, schools, and the general public.

Assistance/ Services

Education material for the public (exotic weed control manual, answers to lake questions booklet, volunteer lake assessment manual and newsletter, numerous technical bulletins on various lake-related topics, and best management practices information);

lake water quality data, summaries, and reports; presentations and slide shows to the public; lake education program for the schools; lake development model for town planning boards; investigation for citizen complaints; microscopic identifications for the public; matching funds for aquatic nuisance control and lake restoration.

Funding Sources State general funds and Federal Clean Lakes (Section 314) funds.

Staff Six State-funded and two federally funded limnologists/aquatic biologists; one State-funded secretary; three to four seasonal (State and Federal funds).

NEW JERSEY

Department of Environmental Protection
Division of Water Resources
35 Arctic Parkway
Trenton, NJ 08638
609/292-0427

Emphasis

The division uses a grant aid-oriented approach to deal with individual lake programs.

Program Elements

1. **State Grants Aid:** Funds provided for Phase I and II type activities.
2. **Federal Clean Lakes Program:** The Division acts as official applicant and administrator of Federal CLP funds when available.
3. **Herbicide application:** Administration of State funds for annual herbicide applications to State-owned lakes (about $50,000/yr; about 12 lakes/yr).

Assistance/ Services

Grant aid for studies, restoration, and herbiciding.

Funding Services

Federal CLP (when available) and State budget appropriations for specific lakes.

Staff

One person with experience in lake issues.

Other Lake-Related Programs

New Jersey Division of Coastal Resources.

NEW MEXICO

New Mexico Environmental Improvement Division
Surface Water Quality Bureau
Surveillance and Standards Section
1190 St. Francis Drive
Santa Fe, NM 87503
505/827-2822

Purpose

Monitor and assess the quality of publicly owned lakes and make recommendations for best management practices for control of nonpoint source pollution.

Emphasis

The program's principal objective is to inventory and classify, according to trophic status, the State's approximately 150 publicly owned lakes and reservoirs.

Program Elements

The Clean Lakes program assesses and reports the physical, chemical, and biological quality of New Mexico's public lakes and reservoirs through intensive lake studies. The information is reported in the biennial 305(b) Report to the U.S. Congress as required by the Clean Water Act, Section 305(b). The information includes:

1. Classification according to trophic status of the State's public lakes.
2. Description of methods to control pollution of impaired lakes.
3. Description of methods to restore the quality of impaired lakes.
4. Description of methods to mitigate effects of acid precipitation in impacted lakes.
5. Listing of impaired lakes not meeting water quality standards.
6. Assessment of status and trends of water quality and sources of pollution of impaired lakes not meeting water quality standards.

Assistance/ Services

Develop recommendations for water quality standards for State Water Quality Control Commission and provide material and analytic support for interactive agencies.

Funding Sources

Federal funding through Section 314 of the Clean Water Act.

Staff

Two full-time aquatic biologists.

Interactions

Government: Federal — U.S. EPA, USDA–U.S. Forest Service, U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Bureau of Land Management, Bureau of Reclamation, Soil Conservation Service.

State: Department of Game and Fish, Water Quality Control Commission, Department of Agriculture, Energy, Minerals and Natural Resources Department, State Universities.

NEW YORK

Department of Environmental Conservation
Bureau of Technical Services and Research
50 Wolf Road
Albany, NY 12233
518/457-7470

Emphasis

The program uses a wide variety of methods to address both project-specific and statewide issues (such as acid precipitation impacts).

Program Elements

1. **Financial assistance:** State appropriations (about $1.5 million) and Federal funds ($100,000) are primarily used on lake restoration measures, such as dredging and harvesting, with lesser amounts spent on watershed work, monitoring, and research.
2. **Citizens Statewide Lake Assessment Program:** The DEC conducts this monitoring program using volunteers to aid general statewide efforts.
3. **Restoration projects:** The program conducts and monitors restoration projects.
4. **Fish hatcheries:** The DEC operates hatcheries and conducts a fish stocking program.
5. **Public accesses:** The Department strives to improve public access through land acquisition for new sites and development of existing facilities (fish piers, boat ramps, etc.).
6. **Statewide surveys:** Surveys conducted to monitor acid precipitation impacts and general lake water quality.

Assistance/ Services

Financial and technical assistance.

Funding Sources

Federal and State.

Staff

Six people in the Central Office (Albany) with backgrounds in environmental engineering or aquatic biology. Most of the nine regional offices have a designated Regional Lake Manager.

Other Lake-Related Programs

Local and county health departments; county governments may conduct restoration or water quality monitoring programs; Federation of Lake Associations: public information and citizen monitoring programs (273 Hollywood Ave., Rochester, NY 14618).

NORTH CAROLINA

Department of Environment, Health, and Natural Resources
Division of Environmental Management
512 N. Salisbury Street, P.O. Box 27687
Raleigh, NC 27611
919/733-5083

Because lake management in North Carolina involves a number of programs in various agencies, universities, and companies, the following summary focuses on efforts by the Division of Environmental Management but includes other programs.

Program Elements

1. **Lake classification:** Surveying and trophic classification of lakes began in 1981 using Federal Clean Lakes Program funds. The State continued monitoring lakes after Federal funds ran out. Algal Growth Potential tests conducted by EPA's Ecological Support Branch (Athens, GA) aided in determining limiting nutrients.

2. **Intensive Water Quality Investigations:** Major sampling efforts are ongoing for several multipurpose reservoirs. Evaluations focus on various management issues, including eutrophication, impacts from point and nonpoint sources of pollutants, and water supply suitability.

3. **Federal Clean Lakes Program:** Funding has been received for both Phase I and Phase II projects dealing with sedimentation, hydrilla, and persistent mercury contamination.

4. **Algal Bloom Program:** This program was initiated in 1984 to document suspected blooms with reliable algal taxonomy and quantification. Results are used to identify overly enriched waterbodies that qualify for Nutrient Sensitive Waters designation or merit special nutrient management plans.

5. **Aquatic Weeds Program:** This program involves the identification of aquatic plant problems and the initiation of corrective measures. Hydrilla infestation is a major concern.

6. **Lake Assessment Modeling:** Efforts have focused on nutrient loading, and permitting of wastewater discharges to lakes and reservoirs and their tributaries.

7. **Public participation:** Although no program currently exists targeting lake management, the Stream Watch Program (coordinated by the Division of Water Resources) involves some groups with lake management interests. The program provides a network of public education and participation in environmental programs for groups such as schools, community and fish clubs, Sierra and Audubon chapters, and river basin associations.

Assistance/ Services

Technical assistance, educational materials.

Funding Sources Federal EPA and State legislature.

Staff Five to six people in the Division of Environmental Management participate in lake monitoring and assessment efforts. Lake monitoring, data evaluations, modelling, and management plan development are coordinated by Steve Tedder, Water Quality Section Chief (919/733-5083)

NORTH DAKOTA

Department of Health
Division of Water Supply & Pollution Control
1200 Missouri Avenue, Box 5520
Bismark, ND 58505-5520
701/224-2354

Purpose To restore lakes for beneficial uses through the Federal program.

Emphasis The program deals with projects on natural and manmade lakes with public recreational facilities.

Program Elements Under the Lake Restoration Program grants are provided for projects designed to reduce lake eutrophication through watershed and/or in-lake treatments.

1. Provide technical help to local governments to aid in restoration (Lake Improvement Associations).
2. Ambient water quality monitoring special projects, bioassays; anything dealing with water quality standards.
3. Investigation of unusual aquatic phenomenan.

Assistance/ Services State grants of up to 25% of eligible project costs may be made when Federal funds are available.

Funding Sources Currently the program has $150,000 available for 2 years.

Staff Part-time, as needed.

Interactions State Fish and Game Department.

NEVADA

Department of Conservation and Natural Resources
Division of Environmental Protection
123 West Nye Lane
Carson City, NV 89710
702/687-4670

Emphasis

The purpose of the program may at times be site-specific (water quality model development) or for developing baseline limnological data to aid in water quality management decisions.

Program Elements

1. **Routine lake monitoring:** three to four lakes per year.
2. **Special investigations:** (a) effects on point and nonpoint source nutrient loading; (b) experimental fertilization to enhance fishery production; and (c) model development to aid in wasteload allocation.
3. **Provide technical support** by participating in cooperative studies and providing laboratory support to other State and local agencies.

Funding Sources

Federally funded through Sections 314, 106, and 205(j) grants with partial funding from the State.

Staff

Two staff devote part of their time to the program. One has extensive limnological experience.

Interactions

Cooperation with municipalities and their consultants; interaction with EPA, U.S. Fish and Wildlife Service, Bureau of Reclamation, Corps of Engineers, U.S. Geological Survey, Nevada Department of Wildlife, State Parks, and Tahoe Regional Planning Agency.

Other Lake-Related Programs

Nevada Department of Wildlife – Fisheries Management Agency.

OHIO

Environmental Protection Agency
Division of Water Quality Monitoring & Assessment
1800 Water Mark Drive
P.O. Box 1049
Columbus, OH 43266-0149
614/644-2131

Emphasis

Efforts deal primarily with water quality assessment, U.S. EPA Clean Lakes Program; lake/watershed management plans, Section 305(b) water quality inventory report.

Program Elements

1. **Lake monitoring/classification:** From 1975-80 a cooperative program with the U.S. Geological Survey sampled 85 public lakes. Additional lake monitoring during 1990-81 and 1989-90 as part of a U.S. EPA Clean Lakes Program Assessment Grants.
2. **Developed Ohio Lake Condition Index** to classify use impairment in public lakes for the Section 305(b) report.
3. **Received four U.S. EPA Clean Lakes Program Phase I grants** (Summit Lake, Winton Woods-West Fork Mill Creek Lake. Indian Lake, Sippo Lake). Submitted one Phase I, two Phase II, and one Phase III projects in 1990.
4. **Partially funded a four-county citizen volunteer Secchi disk monitoring program** (NEFCO planning agency). Potential for the program to be expanded statewide.
5. **Water Quality Standards:** all public lakes and wetlands classified as State Resource Waters for protection of aquatic life and recreational use.
6. **Nonpoint Source Assessment and Management Plan.** Targeted lakes potentially affected by nonpoint sources of pollution for the Section 319 report. Cooperative efforts with Federal, State, and local agencies to address nonpoint watershed management plans throughout the State.

Assistance/ Services

Cooperative projects to develop lake/watershed management plans. Citizen complaints and spills. U.S. EPA Clean Lakes Program for public lakes.

Funding Sources

Minimum of State general funds. Federally under through Sections 314, 319, 205(j) and 106.

Staff

Several people from Central Office and District Offices.

Interactions

Public: Citizen complaints, citizen volunteer monitoring program, Ohio Lake Management Society, areawide planning agencies.

Government: U.S. EPA, U.S. Geological Survey, Soil Conservation Service, Cooperative Extension Service, Ohio Department of Natural Resources, County Soil and Water Conservation Districts.

OREGON

Department of Environmental Quality
Executive Building, 811 SW Sixth Avenue
Portland, OR 97204
503/229-5284

Emphasis

The State's program is fairly small and tailored toward the Federal Clean Lakes Program. Projects are aimed at problems in specific lakes.

Program Elements

Specific projects are managed according to the Federal Clean Lakes Program guidelines. They seek solutions for long-term control of weeds, nutrient inputs, and improving flow and watershed management.

Currently there are two projects. Devils Lake in Lincoln City has a nuisance aquatic weed problem, and Sturgeon Lake in North Portland has an excessive sedimentation problem.

Assistance/ Services

Coordination and management of Federal Clean Lakes Program grants; sampling and technical guidance to local communities.

Funding Sources

Primarily Federal Clean Lakes Program funds.

Staff

One part-time (limnology/environmental assessment background).

PENNSYLVANIA

Department of Environmental Resources
Bureau of Water Quality Management
P.O. Box 2063
Harrisburg, PA 17120
717/787-9633

Purpose

To provide for a consistent and effective statewide approach to controlling nutrients (phosphorus) to impounded waters so as to maintain an acceptable trophic level that will not adversely impact on designated water uses.

Emphasis

The program focuses on regulatory issues as they affect individual priority lakes. Some technical input and funding are provided for broader issues (nonpoint source control and acid deposition).

Program Elements

1. **Regulation of phosphorus discharges to lakes, ponds, and impoundments:** The regulations provide a systematic method for protecting lakes and impoundments that are undergoing eutrophication. It relies on empirical lake models to estimate phosphorus loadings and to determine the appropriate level of protection or water quality improvement, considering both point and nonpoint sources.
2. **Data acquisition:** Conduct lake surveys to obtain data that support the imposition of phosphorus controls on wastewater discharges.
3. **Federal Clean Lakes Program:** Coordinate the CLP with interested and qualified lake watershed management districts or organizations within the State.

Assistance/ Services

Technical guidance on request.

Funding Source

Combination of Federal and State.

Staff

Eight (backgrounds in water pollution biology/ecology).

Other Lake-Related Programs

DER, Bureau of State Parks: Lake treatment program for State park lakes.

SOUTH CAROLINA

Department of Health and Environmental Control
Bureau of Water Pollution Control
2600 Bull Street
Columbia, SC 29201
803/734-5296

The Department (SCDHEC) has no particular agency or staff responsible solely for lake management. Issues relating to lake quality and management are dealt with as part of program areas that have a larger overall function.

Program Elements

1. **Water quality sampling:** Extensive sampling is conducted on the major lakes and special intensive surveys are conducted to evaluate specific waterbodies.

2. **Classification:** All of the State's lakes are actually reservoirs created for electrical power. They are classified for primary recreation (highest freshwater category excluding trout habitat), and management strategies are developed based on that classification.

3. **Other elements involve** wastewater discharge permits, water quality standards, and general water quality management strategies.

4. **Reservoir management:** Management of the major reservoirs is by the organization that holds the license for its operation.

   a. Duke Power Co. (P.O. Box 33189, Charlotte, NC 28242) L. Jocassee, L. Keowee, L. Wylie, L. Greenwood, L. Wateree.

   b. U.S. Army Corps of Engineers (P.O. Box 899, Savannah, GA 31402) Hartwell Reservoir, Strom Thurmond Reservoir, Russell Reservoir.

   c. S.C. Electric & Gas (Palmetto Center, 1420 Main St., Columbia, CS 29201) Lake Murray, Montecello Reservoir.

   d. Public Service Authority (P.O. Box 398, Moncks Corner, SC 29461) Lake Marion, Lake Moultrie.

   e. Carolina Power and Light Company (P.O. Box 327 New Hill, NC 27652).

Funding Sources

314, (106 rent fund supported State dollars; two to one match, State to Federal).

Staff

Two working under 314 Clean Lakes grants but no position dedicated to lakes.

Other Lake-Related Programs

Dept. of Wildlife & Marine Resources: Manages lake fisheries; Water Resources Commission: Manages Lake Robinson's aquatic plants.

SOUTH DAKOTA

South Dakota Department of Water and Natural Resources
Division of Water Resources Management
Clean Lakes/Nonpoint Source Section
Joe Foss Bldg. Room 425
523 East Capital
Pierre, SD 57505-3181
605/773-4907

Purpose

The Clean Lakes Program is responsible for diagnostic/feasibility studies and restoration activities on publicly owned lakes. The Nonpoint Source Program is an inter-agency and inter-organizational program to control nonpoint sources of water pollution.

Emphasis

Individual lake restoration activities and nonpoint source pollution control. Statewide lakes assessment activities. Lake protection.

Program Elements

1. Conducts both State-funded and federally funded diagnostic/feasibility studies on publicly owned lakes' watersheds.
2. Development of restoration alternatives for impaired lakes and streams.
3. Management of the operation of four State-owned dredges for sediment removal on impaired lakes.
4. Nonpoint source pollution control on a statewide basis.

Assistance / Services

Technical assistance to local governments and associations to conduct studies and restoration activities. Information and education program. Nonpoint source project development and implementation.

Funding Sources

Federal funding through Sections 314, 319, and 205(j) of the Clean Water Act. State funding through Consolidated Water Facilities construction grants and general appropriations.

Staff

Seven full-time biologists, one civil engineer, one geologist, eight seasonal employees, one summer intern, clerical personnel, and regional personnel.

Interactions

Local lake associations, citizens groups, Conservation Districts, U.S. EPA, USDA, U.S. Fish and Wildlife Service, Forest Service, S.D. Game, Fish and Parks, S.D. Dept. of Agriculture.

Department of Health and Environment
Division of Water Pollution Control
150 9th Avenue, N.
Nashville, TN 37247-3420
615/781-6643

Emphasis

The program is primarily focused at regulatory issues of water quality management including numerous impoundments (i.e., statewide scope). Research efforts are toward program support and enforcement. The State has no specific lake projects; however, lake water quality is addressed as a part of the whole regulatory program.

Program Elements

1. Water quality regulation.
2. Implementation and enforcement of the Tennessee Water Quality Control Act.
3. NPDES primacy for State and Federal facilities and coal mining.
4. Certifying agency for the 404 process.
5. Permitting: Wetlands, non-coal mining, and habitat alteration.

Assistance/ Services

Technical cooperation with other agencies.

Funding Sources

Mainly State with some Federal appropriations.

Staff

About 100 (backgrounds in engineering, biology, and water quality).

UTAH

Department of Health
Division of Environmental Health
Bureau of Water Pollution Control
288 North 1460 West
P.O. Box 16690
Salt Lake City, UT 84116
801/538-6146

Purpose To preserve, protect, and restore the water quality of Utah's lakes to enhance and assure their public use and enjoyment.

Emphasis Provide technical assistance and guidance in development of programs for evaluation, implementation, or management for water quality.

Program Elements

1. Routine lake monitoring and assessment in support of 305b reporting.
2. Special lake and watershed evaluation investigations in conjunction with other agencies.
3. Implementation of Federal Clean Lakes program.
4. Provide technical assistance on local task force or water quality management units.
5. Lake classification and inventory.
6. Public education.

Funding Sources State and Federal revenues for program element. Federal grants with local match monies for project implementation.

Staff One position to administer program with additional support staff to conduct monitoring activities.

Other Lake-Related Programs Utah Division of Wildlife Resources:

Tim Provan: Bureau of Reclamation: Jerry Miller; Utah Department of Natural Resources

Paul Gillette; Local Water Quality Management Agencies; Local Water Improvement Districts.

Department of Natural Resources
Division of Wildlife Resources
1596 West North Temple
Salt Lake City, UT 84116
801/538-4700

Emphasis

The program focuses on solving individual lake problems, but some work is done on problems of a broader scope (acidic deposition). Some research is also done.

Program Elements

1. **Fisheries management:** Aspects of this program deal with predator-prey relations; exploitation; trout strain evaluations; recovery of native trout populations; recovery or development of black bass populations; studies to determine trout stocking rates, times, and sizes; chemical renovation; population monitoring; and development of management plans.

2. **Acid deposition:** Management of 650 soft water lakes in the High Uintas region that could be affected by acidic deposition.

3. **Trout research:** Limited study of sterile and hybrid trout.

Funding Sources

Mainly funded from fishing license sales and Federal aid (Wallup-Breaux).

Staff

About 27 full-time in fisheries management (backgrounds in fisheries science). Most spend 2% of their time on lake management.

Other Lake-Related Programs

Utah Department of Health: Richard Denton; Bureau of Reclamation: Jerry Miller; Utah State Cooperative Fisheries Unit: Tim Modde; Utah State University: Wayne Wurtsbaugh.

VERMONT

Department of Environmental Conservation
Water Quality Division
103 South Main Street
Waterbury, VT 05676
802/244-5638

Purpose

The Lakes and Ponds Program is responsible for planning and managing in the best public interest all activities dealing with Vermont's lakes.

Emphasis

The primary objective is to assure the maximum sensible recreational potential of lakes through sound water quality management practices.

Program Elements

1. **Monitoring and surveillance:** The department keeps abreast of existing lake water quality conditions and detects changes in lake quality conditions through the following six data collection programs.

   a. **Spring Phosphorus Program:** Sampling once a year in the spring to monitor a large number of lakes for trends in total phosphorus to determine existing trophic status and detect impending water quality problems.

   b. **Acid Deposition Program:** This program collects chemical and biological data on lakes located in low alkalinity (acid-sensitive) regions of the State to determine the effects of acid deposition.

   c. **Lay Monitoring Program:** Equipment and training are provided under this program so that local residents may collect lake water quality data weekly during the summer. Secchi transparency, chlorophyll *a* and total phosphorus (on Lake Champlain only) are collected. This program provides the majority of the summer water quality data presently available on Vermont lakes.

   d. **Aquatic Plan Survey Program:** Detailed qualitative aquatic plant surveys are conducted on selected lakes each summer. The surveys are used to provide baseline data to document future changes in the extent and/or species composition of aquatic plant communities in Vermont lakes.

   e. **Milfoil Watcher's Program:** Volunteers are trained to identify Eurasian watermilfoil and to search for new infestations in presently infested lakes. It is hoped that, through this program, new infestations will be found early enough to make eradication possible.

   f. **Cooperative Bacteriological Sampling Program:** Under this program, local volunteers sample a limited number of lakes for near-shore fecal coliform bacteria levels during July or August. This program serves the dual purpose of involving lake residents in the monitoring of septic systems and ensuring that the high bacteriological quality of Vermont's lakes is maintained.

2. **Special studies:** For various reasons a specific lake may be chosen for detailed water quality study. Lake studies may involve long-term extensive data collection or limited data collection and sophisticated lake modelling techniques. Studies have been funded through the Federal Clean Lakes Program and/or State funds. Special studies may also be initiated to address particular areas of statewide concern (such as a toxics monitoring program) or to gather additional data in certain areas (such as periphyton or user perceptions).

3. **Management/restoration activities:** Lakes with water quality problems may undergo either maintenance or restoration activities. Maintenance activities are control measures to manage aquatic nuisances on a yearly basis. Restoration activities are aimed at eliminating causes of lake problems to achieve long-term benefits. Maintenance efforts currently underway include the Lake Champlain Aquatic Nuisance Control Program (harvesting of water chestnut) and the Aquatic Nuisance Control Program (nuisance control in other lakes). Restoration projects have been dealt with through the CLP (both studies and implementation) and the U.S. Soil Conservation Service (agricultural best management practices).

4. **Lake Protection Program:** Lake protection is promoted through (a) monitoring and surveillance (described above), (b) educational activities (slide shows; brochures; newsletters; manuals and short workshops), and (c) regulation.

   The Management of Lakes and Ponds Statute (permitting of encroachment into waters), the Phosphate Detergent Ban, the Water Quality Standards, and the Land Use Control Law, as well as a variety of department regulations, provide regulatory protection mechanisms.

Assistance/ Services

Technical and educational assistance; grant aid for restoration and maintenance projects.

Funding Sources

Federal funds are provided for grants through the EPA (Clean Lakes Program) and Army Corps of Engineers (Lake Champlain Aquatic Nuisance Control). The State legislature provides other funds.

Staff

Six full-time (backgrounds in limnology, biology/botany engineering, and environmental education), three part-time (statistics and administration), four limited time, and six seasonal.

VIRGINIA

Water Control Board
2111 Hamilton Street, P.O. Box 11143
Richmond, VA 23230-1143
804/367-6406

Emphasis

The program centers on monitoring publicly owned lakes to determine lake trophic status and accelerated eutrophication problems.

Program Elements

1. **State Lake Monitoring Program:** 15 to 20 publicly owned lakes are tested each year for general water quality parameters. Data are used to update trophic status information that was originally obtained under an EPA Clean Lakes Program classification grant.
2. **Federal Clean Lakes Program:** Three lakes (Big Cherry-Phase I; Chesdin, and Rivanna Reservoir receiving Phase II funding.
3. **Lay monitoring:** The VWCB assists volunteer sampling efforts by identifying algal samples.

Assistance/ Services

Technical assistance on sampling methods and algal identification; educational materials.

Funding Sources

Primarily Federal (106) with minor State appropriations.

Staff

One person oversees the Lake Monitoring Program, which is carried out by one to two people in each of six regional offices. They have biology, chemistry, and environmental analysis backgrounds; another person administers the Clean Lakes Grant.

Other Lake-Related Programs

Occoquan Watershed Monitoring Laboratory: Water quality assessment in the suburban Washington, D.C., area.

Department of Ecology
Mail Stop PV-11
Olympia, WA 98504-8711
206/459-6062

Purpose

The Department's lake restoration program endeavors to restore to lakes those beneficial uses that have been lost or impaired in the recent past (i.e., 50 years).

Emphasis

The program is primarily grant-aid oriented toward individual problem lakes with public access. Remedial and preventive projects are eligible for grant assistance. Some amount of applied research is accomplished indirectly from grant projects and some of the developments of these projects can be applied to other lakes with similar projects.

Program Elements

1. **Diagnostic/Feasibility Studies (Phase I):** Develops a water and nutrient budget, identifies water quality problems and their causes, and recommends restoration alternatives. Cost estimates for the proposed Phase II project are developed and an environmental assessment may be prepared.

2. **Implementation Projects (Phase II):** Implements the findings and recommendations of Phase I.

Assistance/ Services

Grants of up to 75% of eligible project costs to public entities; technical assistance on limnological questions, study requirements, lake association organization, aquatic macrophyte control, etc.

Funding Sources

Primarily State funds matched by local resources.

Staff

One full-time and two part-time people.

Other Lake-Related Programs

Washington Department of Wildlife (600 N. Capitol Way, Olympia, WA 98504).

West Virginia Division of Natural Resources
Water Resources Section
Planning Branch
1201 Greenbrier Street
Charleston, WV 25311
304/348-5902

Purpose

To preserve, protect, and restore the physical, chemical, and biological integrity of the State's publicly owned lakes.

Emphasis

Mitigation of current impacts primarily through control of local nonpoint source pollution (watershed management) and secondarily through in-lake restoration.

Program Elements

1. **Lake Water Quality Assessment:** 70 "non-priority" lakes field monitored by summer interns for a variety of physical and chemical parameters: 12 "priority" lakes targeted for intensive quarterly water quality monitoring by division personnel.
2. **Coordination with local government agencies** to develop lake and watershed management plans under the Federal Clean Lakes Program (CLP): Administration of CLP projects. Currently, one Phase I project ongoing and one with preliminary approval.
3. **Interactions with Federal, State, and local agencies** to generate interest and participation in the Federal Clean Lakes Program.

Assistance/ Services

Technical assistance/training for CLP participants. Guidance for preparation and submittal of grant applications as well as assistance with project implementation.

Funding Sources

Federally funded through Section 314 of the Clean Water Act with appropriate matching funds from State and/or local sponsoring agencies.

Staff

One full-time aquatic biologist (Charleston HQ) plus a part-time field assistant. Temporary summer employees are hired as needed.

Interactions

Federal: U.S. EPA, U.S. Forest Service, U.S. Soil Conservation Service.

State: Dept. of Agriculture, Dept. of Energy, Division of Wildlife Resources, Soil Conservation Commission.

Local: Regional planning councils, county governments, city governments.

Department of Natural Resources
P.O. Box 7921
Madison, WI 53707-7921
608/267-7513

Purpose

To protect and maintain Wisconsin's lake resources for our own and future generations; to help carry out measures that protect and maintain lakes; and to strive for active coordination between the many government programs and personnel that work on lakes.

Emphasis

The program guides local lake management organizations across the State in planning and carrying out a variety of lake protection measures including soil and water conservation, lake user education, and advocacy for local protective regulations.

Program Elements

1. **Outreach and technical assistance:** Day-to-day guidance to lake property owners on how to identify needs, find and interpret lake/watershed information, and evaluate management alternatives. Each year local actions are promoted on "key lakes" that need special protection.

2. **Self-help monitoring:** Volunteers are trained to measure water clarity and lake levels. Each year the volunteers receive an interpretation of their lake data and a statewide summary report. Their data provide the DNR with long-term data on a larger number of lakes than it could survey.

3. **Education activities:** In conjunction with the University of Wisconsin-Extension the DNR provides water quality information to help lake property owners. Assistance is available through conventions, workshops, field days, and publications (such as: "The Lake in Your Community"; "Lake Tides," a newsletter; and "A Guide to Lake Management Law").

4. **Trend monitoring:** Fifty representative lakes across the State are monitored for physical, chemical, biological, and watershed changes. Analyses of these data are used as an evaluation tool to compare lakes statewide and to provide policy directions.

5. **Research and demonstration projects:** The intent of this element is to develop, test, and demonstrate lake protection and management techniques that can be used by local organizations.

Assistance/ Services

Technical guidance for public requests on lake problems. Training in water quality monitoring for the self-help program. Educational materials.

Funding Sources

State.

Staff

10 (six lake management coordinators in six DNR district offices; four staff members in the Central Office with expertise in organization/planning, engineering, limnology, and hydrogeology).

Other Lake-Related Programs

None listed.

WYOMING

Department of Environmental Quality
Water Quality Division
Herschler Building/4th Floor W.
122 West 25th Street
Cheyenne, WY 82002
307/777-7098

Purpose	Maintain or improve lake water quality in the State.
Emphasis	Problem correction at the local level.
Assistance/ Services	Technical assistance and guidance (staff-limited).
Funding Sources	Section 205(j) and 319 monies with required match. Will assist in obtaining Clean Lakes monies if requested.
Staff	Provided on case-by-case basis as available.

ALBERTA

Alberta Forestry, Lands and Wildlife
Fish & Wildlife Division
North Tower, Petroleum Plaza
9945-108 Street
Edmonton, AB T5K 2G6
403/427-6180

Purpose

The program is oriented toward the management and production of fish populations in individual lakes.

Program Elements

1. **Lake habitat inventories:** Surveys provide data on basic morphometry, water chemistry, and existing fish populations to determine fish populations using regulations and fish stocking programs.
2. **Management of fish populations** using regulations and fish stocking programs.

Assistance/ Services

Providing information on lake characteristics, critical fish habitats, fish populations, fish production and fisheries use to anglers, consultants, and government agencies.

Funding Sources

Funds are mainly from the provincial government. Part of angler license fees go to a habitat development program.

Staff

26 people (mainly fisheries background; some with wildlife management experience).

Other Lake-Related Programs

Alberta Environment: Water resources management, water quality control, environmental impact assessment; Alberta Forestry, Lands and Wildlife-Land Division: Shorelands and access; Forestry: Public access and recreation facilities (public land); Wildlife: Fisheries and wildlife matters; Alberta Municipal Affairs: Shoreland and access (non-public lands).

MANITOBA

Department of Natural Resources
Fisheries Branch
1495 St. James Street, P.O. Box 40
Winnipeg, MB R3H 0W9
204/945-7777

Emphasis

The program is primarily management (regulation/rehabilitation) oriented; dealing with both point (industrial pollutants and feedlot runoff) and nonpoint source (agriculture and forest activities) pollution. Some small grants are provided for aeration assistance and experimental design of aeration techniques.

Program Elements

1. Summer and winter oxygen monitoring and aeration.
2. Riparian land use control.
3. Consultative role on environmental assessments of developments causing point and nonpoint pollution.
4. Chemical rehabilitation of fish populations.
5. Recommendations on in-stream flows and lake/reservoir level strategies.
6. Controlling in-stream alteration (channelization) affecting sediment loading.
7. Recommendations on reservoir shoreline stabilization.
8. Fish screening at outlet spillways.
9. Rough fish removal.

Assistance/ Services

Consultative services; grants and technical assistance for aeration installations.

Funding Sources

Provincial.

Staff

Nine fisheries biologists spend a portion (5-40%) of their time on lake management issues.

Other Lake-Related Programs

Manitoba Environment, Workplace Safety and Health (139 Tuxedo Blvd., Winnipeg, MB R3N 0H6).

NEW BRUNSWICK

New Brunswick Department of Natural Resources & Energy
Fish and Wildlife Branch
P.O. Box 6000
Fredericton, NB E3B5H1
506/453-3755

Purpose To assess, monitor, and manage fish populations and habitat of publicly accessible lakes, impoundments, ponds and associated streams for sustained quality sport fisheries use.

Emphasis The ongoing program acquires data from initial and followup surveys as the basis for planned fisheries regulatory, biological, or habitat changes.

Program Elements

Inventory: Physical, chemical, biological, and angler or other user characteristics are assessed.

Planning: Appropriate strategies are prescribed.

Management: Tailored plans to fit the situation are implemented after appropriate public communications and review.

Public Information: Plans are made public at meetings and by direct contact. Lake depth maps are made available on a limited basis.

Special Uses These data also are used in the habitat protection program of which this department is one of the review agencies and the major enforcement arm in terms of number of field officers available.

Interactions Extensive factual responses to public queries, concerns, and complaints are made possible from this data bank. Other government fisheries and environmental agencies also use these data.

Staff One headquarters biologist and five regional biologists are directly concerned with this program. All biological staff use the data.

Funding Sources Provincial government sport fish management funding.

Other Lake-Related Programs

New Brunswick Department of Environmental collects time series of water quality data from certain lakes or impoundments.

The Canada Department of Fisheries and Oceans has pH monitoring programs established on 10 Southern New Brunswick lakes considered sensitive to acid precipitation.

NEWFOUNDLAND

Department of Environment
Water Resources Management
St. Johns, NF
709/772-4475

The department has expertise and policies dealing with problems regarding issues such as water quality and water pollution. No other information available at this time. Contact: Wasi Ullah, Director

Other Lake-Related Programs	Department of Fisheries & Oceans; Department of Environment Canada

Department of Fisheries Division
P.O. Box 700
Pictou, NS B0K 1H0
902/485-5056

Purpose

As a result of the 1982 Federal-Provincial Agreement on Trout, the Division has been provided with the responsibility for augmentation and restoration of the recreational trout fishery.

Emphasis

The Management Plan focuses on management and enhancement of the recreational trout fishery so as to provide maximum benefit to trout anglers, present and future.

Program Elements

1. **Habitat:** In cooperation with the Nova Scotia Department of Environment and the Federal Department of Fisheries and Oceans fish habitats are assessed, monitored, and protected through (a) close cooperation and review of internal activities and programs with potential impacts on habitat, (b) active survey and assessment programs for better delineation of usable habitat, (c) implementation of long-term habitat improvement programs (stream clearing, stream stabilization devices, erosion/sediment control, flowage stabilization devices, etc.).

2. **Production:** Hatchery production of trout fall fingerlings and yearlings has been greatly accelerated at three departmental hatcheries.

3. **Research:** To maximize the effectiveness of both artificial and natural productions, research will be conducted in the following areas.

   a. Improved broodstock genetics (long-term survivorship, disease resistance, fish quality, etc.).

   b. Post-distribution impact assessments of hatchery stocked fish on natural populations (disease susceptibility, genetic pollution, behavior, long-term wild population dynamics, etc.).

   c. Effect of predator fish species on natural and stocked fish populations and how to ameliorate predator imbalances (chemical poisoning, habitat manipulation, stock manipulation, angling, physical removal, etc.).

   d. Identifying environmental limitations for natural recruitment and stock introductions.

   e. Developing criteria for the creation of specific angler opportunities.

   f. Developing mechanisms and criteria for the enhancement of sea-run fisheries to create better Province-wide fisheries opportunities, specifically inland waters with identified natural limitations.

4. **Management:** Development of a long-term Management Plan to include (a) zonation of the Province based on environmental, stock, and user group consideration, (b) regulatory management through joint initiatives of user groups and the Department, (c) identification and conservation of unique sustainable wild trout populations, and (d) establishment of zone committees whose responsibilities would include recommendation and assessment of special management initiatives.

5. **Enforcement:** Work closely with enforcement agencies (DFO and Dept. of Lands & Forests) to ensure that management initiatives are monitored and enforced in each zone.

6. **Education:** To ensure that the public is fully informed and involved in the wise stewardship of its inland fisheries, the Department will (a) prepare brochures, films, videos, technical/scientific reports, etc., on fishery-related topics, (b) ensure attendance at meetings to provide exchange of information, and (c) involve public groups in enhancement projects (construction of artificial reeds and streamside incubators).

Ministry of Natural Resources
Fisheries Branch
Whitney Block, Queen's Park
Toronto, ON M7A 1W3
416/965-7885

Emphasis

Most programs and projects are geared toward management, although there are some research and assessment projects. Some grant aid is available for public involvement programs. Individual problem lakes are addressed as well as large numbers of lakes where broader problems are perceived.

Program Elements

1. **Fisheries management:** Methods include habitat inventory, habitat rehabilitation, habitat enhancement, and fisheries research and assessment.
2. **Water quality monitoring:** Extensive water chemistry surveys have been done on thousands of lakes and integrated into databases. Numerous programs for lake research and monitoring have developed from the acid rain problem.
3. **Self-help programs:** The public can receive information and assistance through local Ministry of Natural Resources (MNR) and Ministry of Environment (MOE) offices. Typical services include drinking water potability testing, septic tank inspections, and fish management information.
4. **Public participation:** Programs developed toward public participation include (a) the Community Fisheries Involvement Program (CFIP) which stresses habitat improvement and conservation of fish stocks and (b) the MOE self-help program whereby cottagers measure Secchi depth and chlorophyll *a* on a volunteer basis.

Assistance/ Services

Self-help and public participation programs; technical assistance; educational information; grant aid for CFIP.

Funding Sources

Regular Provincial budget funds.

Other Lake-Related Programs

Ministry of Environment, Acid Rain Program: Walter Chan (416/323-5051); Ministry of Environment, Acid Precipitation Office, 7th Floor, 40 St. Clair Avenue W., Toronto, Ontario M4V1M2); Federation of Ontario Cottagers Association (FOCA) Jean Anthon (416/284-2305; FOCA, 215 Morrish Road #105, Scarborough, Ontario M1C 1E9); MOE Public Information Centre, 135 St. Clair W., 1st Floor, 416/323-4321.

Ministere du Losir, de la Chasse et la Peche
Direction generale de la faune
150 est, boul. Saint-Cyrille
Quebec, QC G1R 4V1
418/643-5405

Purpose

The objectives of the Ministry of Leisure, Hunting, and Fishing are resource conservation and optimization of social and economic benefits of fish exploitation (native, sport, and commercial).

Emphasis

The program is oriented toward management of fisheries. Individual lake problems are dealt with at the regional offices and the central office (Quebec City) works on broader issues. A small portion of the program deals with short-term (one to three years) research on "applied" problems.

Program Elements

1. **Exploitation control zone (ZEC):** Sport fishing control and management are delegated to public associations in special areas (ZECs). Assistance (expertise and money) is provided through the regional offices to sport fishing associations (in the ZECs of non-organized territories).

2. **Stocking program:** Fish are stocked in areas of demand (mostly brook trout).

3. **Habitat conversation:** This occurs through analysis of impact assessment study reports and cooperation with the Ministry of Environment.

4. **Broad scope problem studies are done on areas such as:** acidification effects on walleye, lake trout exploitation, and interspecific competition between brook trout and other species.

Assistance/ Services

Technical assistance; grants for developing sport fishing or managing fish habitat.

Funding Sources

Provincial.

Staff

About 30 biologists and 70 natural resources technicians are spread among 10 regional offices. Ten biologists and five technicians work at the central office (Quebec City).

Other Lake-Related Programs

Ministry of Environment: Pollution control, environmental impact studies, acid precipitation, etc; Ministry of Energy & Resources: Forest exploitation, recreational development of public lands around lakes; Ministry of Agriculture, Fisheries, and Alimentation: Inland commercial fisheries; Hydro Quebec–Development and operation of hydroelectric projects and development of fisheries resources in reservoirs.

Saskatchewan Parks and Renewable Resources
Fisheries Branch
Box 3003
Prince Albert, SK S6V 6G1
306/953-2888

Purpose

To maintain and enhance fish supplies, ensure an adequate supply and variety of fish that will meet the needs of the major user groups and maximize the contribution of the fisheries sector to the provincial economy.

Emphasis

The program focuses on fisheries management using a broad issue approach (e.g., there are three management zones for sport fish conservation measures). Regulations and activities can be lake-specific.

Program Elements

1. **Sport fish stocking:** Stocking is used to maintain, enhance, and diversify sport fisheries in the southern half of the Province. In the north, conservation measures are relied upon to maintain fish populations.
2. **Fisheries enhancement:** Conservation and enhancement measures are used to maintain and rebuild fisheries. Fish enhancement projects include rearing ponds, lake aeration, fishways, and habitat improvement. Funds are available to help conservation groups in these activities.

Assistance/ Services

Funds for fish enhancement; stocking.

Funding Sources

Primarily government funded except the Fish Enhancement Fund, which is from angling license fees.

Staff

42 permanent (mostly with background in fisheries biology); 18 casual/part-time.

Other Lake-Related Programs

Department of Environment: Environmental impact studies, pollution control, etc; Saskatchewan Water Corporation: Oversees all aspects of water management; Resource Lands Branch (Saskatchewan Parks and Renewable Resources): Oversees man's development around water (e.g., recreational subdivisions) and on Crown land.

Appendix F

DOCUMENTS AND FORMS

Editor's Note: These forms and documents are to be considered as examples **ONLY!** Any person or organization who is considering contracting for services should have an attorney draft the proper contracts within a given jurisdiction.

Safety

Safety and protection of workers, lake property owners and observers is paramount. The following example of contract document is included to give the reader some background on what should be specified in contracts as well as citations to work hours and safety standards. Individual contracts will have to be developed locally by the sponsoring agency, local government offices and property owners with exact work specifications written out to insure compliance and orderly progression of the implementation of the lake restoration project. The following example was taken from a lake restoration project in the State of Washington.

■ **PROTECTION OF WORK, PROPERTY, AND PERSONS.** The CONTRACTOR will be responsible for initiating, maintaining and supervising all safety precautions and programs in connection with the WORK and all materials or equipment to be incorporated therein, whether in storage on or off the site, and other property at the site or adjacent thereto, including trees, shrubs, lawns, walks, pavements, roadways, structures and utilities not designated for removal, relocation or replacement in the course of construction.

The CONTRACTOR will comply with all applicable laws, ordinances, rules, regulations, and orders of any public body having jurisdiction. He will erect and maintain, required by the conditions and progress of the WORK, all necessary safeguards for safety and protection. He will notify owners of adjacent utilities when prosecution of the WORK may affect them. The CONTRACTOR will remedy all damage, injury or loss to any property caused, directly or indirectly, in whole or in part, by the CONTRACTOR, any SUBCONTRACTOR or anyone directly or indirectly employed by any of them or anyone for whose acts any of them be liable, except damage or loss attributable to the fault of the CONTRACT DOCUMENTS or to the acts or omissions of the OWNER or the ENGINEER or anyone employed by either of them or anyone for whose acts either of them may be liable, and not attributable, directly or indirectly, in whole or in part, to the fault or negligence of the CONTRACTOR.

In emergencies affecting the safety of persons or the WORK or property at the site or djacent thereto, the CONTRACTOR, without special instruction or authorization from the ENGINEER or OWNER, shall act to prevent threatened damage, injury or loss. He will give the ENGINEER prompt WRITTEN NOTICE of any significant changes in the WORK or deviations from the CONTRACT DOCUMENTS caused thereby, and a CHANGE ORDER shall thereupon be issued covering the changes and deviations involved.

■ **SUPERVISION BY CONTRACTOR.** The CONTRACTOR will supervise and direct the WORK. He will be solely responsible for the means, methods, techniques, sequences and procedures of construction. The CONTRACTOR will employ and maintain on the WORK a qualified supervisor or superintendent who shall have been designated in writing by the CONTRACTOR as the CONTRACTOR'S representative at the site. The supervisor shall have full authority to act on behalf of the CONTRACTOR and all communications given to the supervisor shall be as binding as if given to the CONTRACTOR. The supervisor shall be present on the site at all times as required to perform adequate supervision and coordination of the WORK.

■ **CHANGES IN THE WORK.** The OWNER may at any time, as the need arises, order changes within the scope of the WORK without invalidating the Agreement. If such changes increase or decrease the amount due under the CONTRACT DOCUMENTS or the time required for performance of the WORK, an equitable adjustment shall be authorized by CHANGE ORDER.

The ENGINEER, also, may at any time, by issuing a FIELD ORDER, make changes in the details of the WORK. The CONTRACTOR shall proceed with the performance of any changes in the WORK so ordered by the ENGINEER unless the CONTRACTOR believes that such FIELD ORDER entitles him to change in CONTRACT PRICE or TIME, or both, in which event he shall give the ENGINEER WRITTEN NOTICE thereof within seven (7) days after the receipts of the ordered change. Thereafter the CONTRACTOR shall document the basis for the change in CONTRACT PRICE or TIME within thirty (30) days. The CONTRACTOR shall not execute such changes pending the receipt of an executed CHANGE ORDER or further instruction from the OWNER.

■ **CHANGE IN CONTRACT PRICE.** The CONTRACT PRICE may be changed only by a CHANGE ORDER. The value of any WORK covered by a CHANGE ORDER or of any claim for increase or decrease in the CONTRACT PRICE shall be determined by one or more of the following methods in the order of precedence listed below:

(a) Unit prices previously approved.

(b) An agreed lump sum.

(c) The actual cost for labor, direct overhead, materials supplied, equipment, and other services necessary to complete the work. In addition, there shall be added an amount to be agreed upon but not to exceed fifteen (15) percent of the actual cost of the WORK to cover the cost of general overhead and profit.

■ **TIME FOR COMPLETION AND LIQUIDATED DAMAGES.** The date of beginning and the time for completion of the WORK are essential conditions for the CONTRACT DOCUMENTS and the WORK embraced shall be commenced on a date specified in the NOTICE TO PROCEED.

The CONTRACTOR will proceed with the WORK at such rate of progress to insure full completion within the CONTRACT TIME. It is expressly understood and agreed, by and between the CONTRACTOR and the OWNER, that the CONTRACT TIME for the completion of the WORK described herein is a reasonable time, taking into consideration the average climatic and economic conditions and other factors prevailing in the locality of the WORK.

If the CONTRACTOR shall fail to complete the WORK within the CONTRACT TIME, or extension of time granted by the OWNER, then the CONTRACTOR will pay to the OWNER the amount for liquidated damages as specified in the BID for each calendar day that the CONTRACTOR shall be in default after the time stipulated in the CONTRACT DOCUMENTS.

The CONTRACTOR shall not be charged with the liquidated damages or any excess costs when the delay in completion of the WORK is due to the following and the CONTRACTOR has promptly given WRITTEN NOTICE of such delay to the OWNER or ENGINEER.

■ **CONTRACT WORK HOURS AND SAFETY STANDARDS ACT — SAFETY AND HEALTH.** The CONTRACTOR shall not require any laborer or mechanic employed in the performance of the contract to work in surroundings or under working conditions which are unsanitary, hazardous or dangerous to his health or safety, as determined under construction safety and health standards promulgated by regulations of the Secretary of Labor.

The CONTRACTOR shall comply with the Department of Labor, Safety and Health Regulations for Construction promulgated under section 107 of the Contract Work Hours Safety Standards Act (40 U.S.C. 327 et seq.).

BID BOND

KNOW ALL MEN BY THESE PRESENTS, that we, the undersigned, ______ ____ as Principals, and ________________________________ as Surety, are hereby held and firmly bound unto ________________________________ as OWNER in the penal sum of ________________________________ for the payment of which, well and truly to be made, we hereby jointly and severally bind ourselves successors and assigns.

Signed, this ________________ day of ______________, 19____.

The Condition of the above obligation is such that whereas the Principal has submitted to ________________________________ a certain BID, attached hereto and hereby made a part hereof to enter into a contract in writing, for the ____

____

____

NOW, THEREFORE,

(a) If said BID shall be rejected, or

(b) If said BID shall be accepted and the Principal shall execute and deliver a contract in the Form of Contract attached hereto (properly completed in accordance with said BID) and shall furnish a BOND for his faithful performance of said contract, and for the payment of all persons performing labor or furnishing materials in connection therewith, and shall in all other respects perform the agreement created by the acceptance of said BID,

then this obligation shall be void, otherwise the same shall remain in force and effect; it being expressly understood and agreed that the liability of the Surety for any and all claims hereunder shall, in no event, exceed the penal amount of this obligation as herein stated.

The Surety, for value received, hereby stipulates and agrees that the obligations of said Surety and its BOND shall be in no way impaired or affected by an extension of the time within which the OWNER may accept such BID; and said Surety does hereby waive notice of any such extension.

IN WITNESS WHEREOF, the Principal and the Surety have hereunto set their hands and seals, and such of them as are corporations have caused their corporate seals to be hereto affixed and these presents to be signed by their proper officers, the day and year first set forth above.

______________________________ (L.S.)
Principal

____
Surety

By: ______________________________

PROVIDED, FURTHER, that the said Surety for value received hereby stipulates and agrees that no change, extension of time, alteration or addition to the terms of the contract or to the WORK to be performed thereunder of the SPECIFICATIONS accompanying the same shall in any wise affect its obligation on this BOND, and it does hereby waive notice of any such change, extension of time, alteration or addition to the terms of the contract or to the WORK or to the SPECIFICATIONS.

PROVIDED, FURTHER, that no final settlement between the OWNER and the CONTRACTOR shall abridge the right of any beneficiary hereunder, whose claim may be unsatisfied.

IN WITNESS WHEREOF, this instrument is executed in __________ counterparts, each one of which shall be deemed an original, this the ____________________ day of ______________, 19 ____.

ATTEST:

____
Principal

____
(Principal) Secretary
(SEAL)

By ______________________________ (s)

____
(Address)

____

____
Witness as to Principal

____
(Address)

____

____
Surety

ATTEST

by ______________________________ (s)

____
Witness as to Surety

____
(Address)

____
(Address)

____

____

NOTE: Date of BOND must not be prior to date of Contract. If CONTRACTOR is Partnership, all partners should execute BOND.

IMPORTANT: Surety companies executing BONDS must appear on the Treasury Department's most current list (Circular 570 as amended) and be authorized to transact business in the State where the PROJECT is located.

PAYMENT BOND

KNOW ALL MEN BY THESE PRESENT: that

____
(Name of Contractor)

____
(Address of Contractor)

a __________________________, hereinafter called Principal, and
(Corporation, partnership or individual)

____
(Name of Surety)

____
(Address of Surety)

____

hereinafter called Surety, are held and firmly bound unto __________________

____
(Name of Owner)

____
(Address of Owner)

hereinafter called OWNER, in the penal sum of ____________________ Dollars, $( ) in lawful money of the United States, for the payment of which sum well and truly to be made, we bind ourselves, successors, and assigned, jointly and severally, firmly by these present.

THE CONDITION OF THIS OBLIGATION is such that whereas, the Principal entered into a certain contract with the OWNER, dated the ________________________ day of ____________________ 19____, a copy of which is hereto attached and made a part hereof for the construction of:

____

____

____

____

NOW, THEREFORE, if the Principal shall promptly make payment to all persons, firms, SUBCONTRACTORS, and corporations furnishing materials for or performing labor in the prosecution of the WORK provided for in such contract, and any authorized extension or modification thereof, including all amounts due for materials, lubricants, oil, gasoline, coal and coke, repairs on machinery, equipment and tools, consumed or used in connection with the construction of such WORK, and all insurance premiums on said WORK, and for all labor performed in such WORK whether by SUBCONTRACTOR or otherwise, then this obligation shall be void; otherwise to remain in full force and effect.

PROVIDED, FURTHER, that the said Surety for value received hereby stipulates and agrees that no change, extension of time, alteration or addition to the terms of the contract or to the WORK to be performed thereunder of the SPECIFICATIONS accompanying the same shall in any wise affect its obligation on this BOND, and it does hereby waive notice of any such change, extension of time, alteration or addition to the terms of the contract or to the WORK or to the SPECIFICATIONS.

PROVIDED, FURTHER, that no final settlement between the OWNER and the CONTRACTOR shall abridge the right of any beneficiary hereunder, whose claim may be unsatisfied.

IN WITNESS WHEREOF, this instrument is executed in _________ counterparts, each one of which shall be deemed an original, this the ____________________ day of ____________________, 19 ____.

ATTEST:

____________________ Principal

____________________ By____________________ (s)

(Principal) Secretary
(SEAL)

____________________ ____________________

(Witness as to Principal) (Address)

____________________ ____________________

(Address)

____________________ ____________________

ATTEST:

____

(Surety) Secretary
(SEAL)

____________________ ____________________

Witness as to Surety Attorney-in-Fact

____________________ ____________________

(Address) (Address)

NOTE: Date of BOND must not be prior to date of Contract. If CONTRACTOR is Partnership, all partners should execute BOND.

IMPORTANT: Surety companies executing BONDS must appear on the Treasury Department's most current list (Circular 570 as amended) and be authorized to transact business in the State where the PROJECT is located.

PERFORMANCE BOND

KNOW ALL MEN BY THESE PRESENT: that

____
(Name of Contractor)

____
(Address of Contractor)

a ______________________, hereinafter called Principal, and
(Corporation, Partnership, or Individual)

____
(Name of Surety)

____
(Address of Surety)

hereinafter called Surety, are held and firmly bound unto ________________

____
(Name of Owner)

____
(Address of Owner)

hereinafter called OWNER, in the penal sum of ________________ Dollars, $(   ) in lawful money of the United States, for the payment of which sum well and truly to be made, we bind ourselves, successors, and assigned, jointly and severally, firmly by these present.

THE CONDITION OF THIS OBLIGATION is such that whereas, the Principal entered into a certain contract with the OWNER, dated the ______________________ day of ________________ 19____, a copy of which is hereto attached and made a part hereof for the construction of:

____

____

____

____

NOW, THEREFORE, if the Principal shall promptly make payment to all persons, firms, SUBCONTRACTORS, and corporations furnishing materials for or performing labor in the prosecution of the WORK provided for in such contract, and any authorized extension or modification thereof, including all amounts due for materials, lubricants, oil, gasoline, coal and coke, repairs on machinery, equipment and tools, consumed or used in connection with the construction of such WORK, and all insurance premiums on said WORK, and for all labor performed in such WORK whether by SUBCONTRACTOR or otherwise, then this obligation shall be void; otherwise to remain in full force and effect.

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