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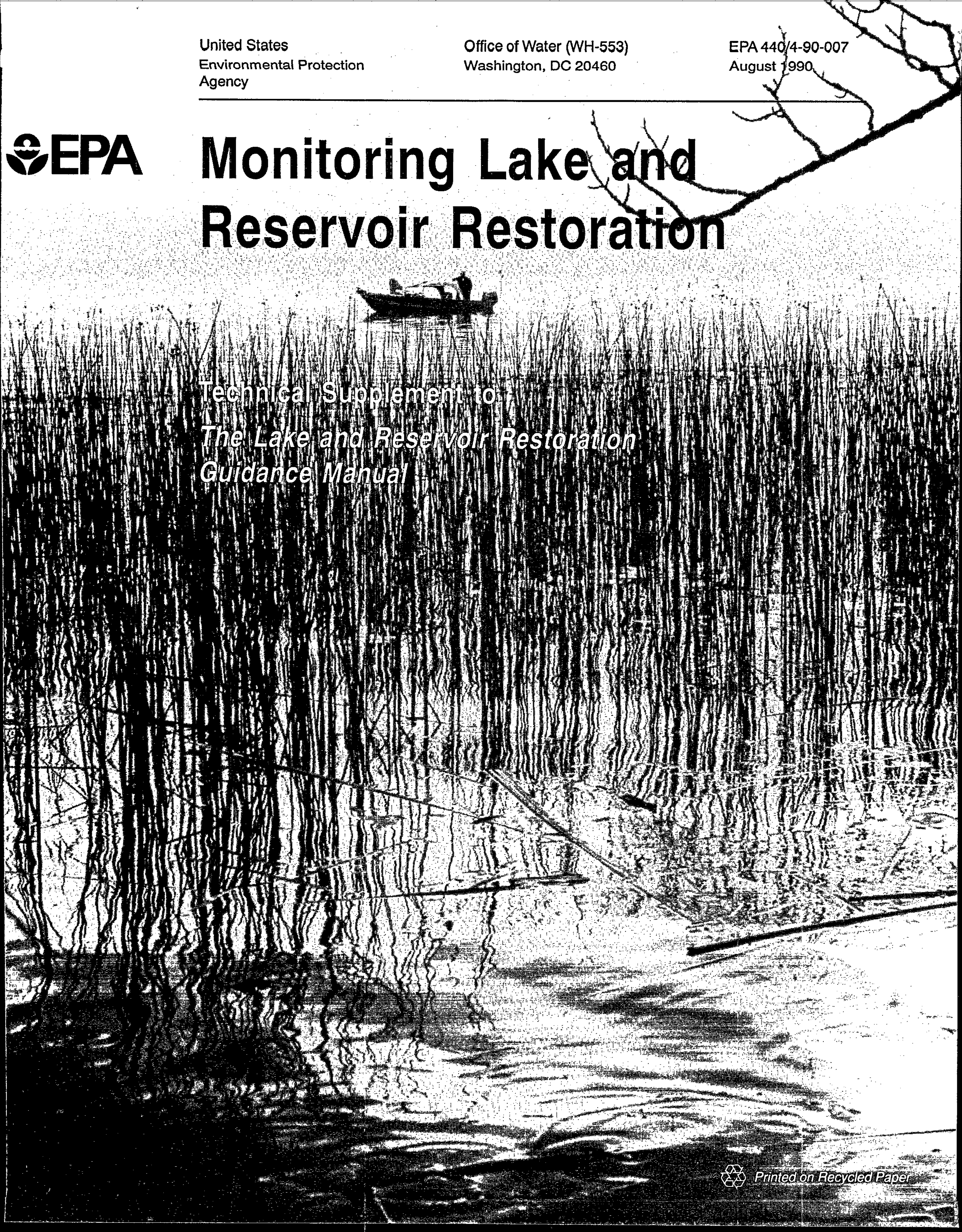
Monitoring Lake and Reservoir Restoration

Technical Supplement to:

The Lake and Reservoir Restoration Guidance Manual



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Monitoring Lake and Reservoir Restoration

Technical Supplement to

The Lake and Reservoir Restoration Guidance Manual

for

U.S. Environmental Protection Agency
Assessment and Watershed Protection Division
Washington, DC

1990

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Preface

Lake restoration doesn't work by itself. One cannot begin to restore a lake without understanding its background and the factors that comprise its present condition. And to determine whether restoration is working, one must certainly be able to credibly compare changes with prior conditions.

There's nothing mysterious about this process: it's a systematic, scientific collection and analysis of data known as monitoring. The practice of monitoring is not limited to scientists; many excellent monitoring programs use citizen volunteers, people without scientific backgrounds but with an interest in water quality.

Monitoring, then, is simply a tool, an essential tool in restoring a lake. *Monitoring Lake and Reservoir Restoration* defines and explains how to use this tool, including the importance of the often neglected long-term monitoring necessary to maintain a project's achievements.

In this manual the lake manager will find practical information on how to design and implement a lake monitoring program during and following a lake restoration project. In addition to describing monitoring methods for both the waterbody and the watershed, the manual deals with monitoring specific in-lake restoration techniques.

Although this manual specifically guides the lake manager who must meet the Clean Lakes Program Phase II monitoring requirements, readers will find it helpful as a starting point for more comprehensive studies of lake ecosystems and useful in designing any lake study. Researchers will welcome its recommendations for consistent methods and quality assurance procedures.

Monitoring Lake and Reservoir Restoration is the first technical supplement to *The Lake and Reservoir Restoration Guidance Manual*. As with the parent volume, this manual was prepared by the North American Lake Management Society for EPA's Clean Lakes Program, which welcomes comments and suggestions. These should be addressed to the Clean Lakes Program (WH-583), U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460.

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Chapter 1

Introduction

Overview of the Clean Lakes Program

The Clean Lakes Program, which was initiated in 1972 under section 314 of the Federal Water Pollution Control Act, was a direct response to widespread public demands for means to protect and support lakes. Since 1975, the program has provided more than $102 million to help fund State and local Clean Lakes projects.

The Clean Lakes Program was a direct response to widespread public demands for means to protect and support lakes.

A strong partnership has developed among Federal, State, and local governments that has greatly aided the planning and implementation of each Clean Lakes project. Although administration of the program is vested with the U.S. Environmental Protection Agency, each State is encouraged to organize and administer lake projects that meet its individual needs.

States apply for grants through the EPA regional office for lake projects that meet EPA and State criteria. After reviewing the grant application, the Agency may award cost-sharing financial assistance to a State, which may, in turn, fund work done by a community. Although the State may administer a Clean Lakes project for a community, local involvement in the monitoring program is necessary to ensure complete restoration of the lake and future protection from degradation.

Purpose of this Manual

Clean Lakes regulations require that projects be monitored both during and after implementation. This manual provides the guidance for both design and implementation of a monitoring program by outlining specific standards for specific types of lake restoration and protection projects.

This manual provides the guidance for both design and implementation of a monitoring program.

This manual uses technical and scientific information to supplement the less technical discussions on project monitoring found in *The Lake and Reservoir Restoration Guidance Manual* (U.S. Environ. Prot. Agency, 1988). It draws in part on an initial compilation of lake monitoring techniques (unpublished) completed in 1988 by Science Applications International Corporation of McLean, Virginia. This manual is intended to guide monitoring carried out in connection with the Phase II or implementation portion of a lake restoration project. While the information contained in this manual may prove useful during the development of diagnostic and feasibility studies for lake projects, diagnostic/feasibility (Phase I) monitoring is not treated directly. Generally, such activities are exploratory in nature and therefore more generic in terms of parameters measured. Throughout this manual it is

Primary users of this monitoring manual—regional EPA Clean Lakes project officers, State and local project managers, and project sponsors and consultants.

assumed that a scientifically based characterization of the lake's problem was developed in a Phase I diagnostic and feasibility study and that the proposed restoration or protection measures to be implemented in Phase II are logical and appropriate.

The plans presented in this manual are not intended as substitutes for the more rigorous, object-specific monitoring that is part of a Phase III or research project. However, data collected during the monitoring described in this manual may help to identify potential projects.

Intended Audience

The primary users of this monitoring manual are expected to be

- Regional EPA Clean Lakes project officers,
- State and local project managers, and
- Project sponsors and consultants.

Because Federal Clean Lakes regulations are intentionally flexible regarding the specifics of Phase II project monitoring, EPA Clean Lakes project officers can consider the needs of each individual project when approving a monitoring plan. Primary users should regard this manual as a foundation for the development of satisfactory and practical monitoring plans that can be federally approved.

Manual Organization

This manual is divided into six major parts, exclusive of this introduction, the references, and the appendix: five chapters treat monitoring planning and techniques for lakes and watersheds, and one chapter is devoted to a case study. Each chapter begins with a summary that highlights the salient points and concludes with a list of references for readers who wish to consult more in-depth materials on the individual topics.

Those readers responsible for designing the monitoring component of a lake restoration or protection project or for evaluating the monitoring plan will find Chapters 3, 4, and 5 to be the most valuable portions of this manual. Clean Lakes regulations relating to monitoring are included as an appendix.

The Environmental Protection Agency would appreciate any suggestions on how this manual could be made more practical and useful. Readers are encouraged to send comments and recommendations to:

Chief, Clean Lakes Section
Assessment and Watershed Protection Division (WH-553)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Chapter 2

Planning the Monitoring Program

Summary

1. A monitoring plan is required for all Clean Lakes projects.

2. The plan should include provisions for monitoring both during and after project implementation.

3. The scope of the monitoring program should be proportional to the cost of the project and should not unnecessarily drain resources needed for implementation. For projects without a research component, adequate data can usually be acquired for 10 percent or less of total project costs.

4. The Phase II monitoring program's structure should enable local sponsors to continue monitoring the lake over the long term without additional Clean Lakes funding.

5. Quality assurance must be a foremost consideration in a monitoring program. A quality assurance project plan is required for all Clean Lakes projects.

Background

Every Clean Lakes project requires a monitoring plan. The information gained from this program serves many purposes over the course of the project. Initially, monitoring data are used to determine the source of potential or actual lake impairment and to provide a basis for selecting appropriate restoration and protection techniques. During project implementation, monitoring data assist in assessing restoration work and help determine the need for adjusting project implementation measures. After the project, monitoring data provide the basis for evaluating project achievements and the impact of treatment.

Monitoring Plans

The foundation of a successful implementation monitoring program is a monitoring plan that is tailored to the specific problems and goals of each project. The plan should cover the periods of time both during and after the treatment phase and, typically, should call for measurement of both in-lake and watershed characteristics. It will identify the information to be obtained, how and when it will be obtained, and what methods will be used to ensure that the data are reliable.

The following elements should be included in every monitoring plan:

- Sampling frequency and stations
- Number of samples
- Types of samples (grab, composite, etc.)
- Number of field blanks and duplicates needed to meet data quality assurance requirements
- Field measurement and collection procedures and
- Analytical methods.

The goals, scope, and level of detail vary greatly among Clean Lakes project monitoring plans. The challenge, therefore, is to focus limited resources to obtain an appropriate level of information without burdening the project with an excess of monitoring requirements. It is easy to overdesign a monitoring plan, thereby taking resources away from project management, data evaluation, or the implementation of the project itself.

In most instances, the costs of a monitoring program will not exceed 10 percent and may often be closer to 5 percent of the total project expenditure. Much depends on the level of planned long-term monitoring and whether extensive watershed monitoring is required for project evaluation. A project designed and funded to include more intensive research may greatly exceed this 10 percent rule of thumb. Note also that section 314 regulations do not adequately reflect the scope of monitoring work—including long-term, post-restoration studies under Phase III grants—that is needed to support a research effort.

In most instances, the costs of a monitoring program will not exceed 10 percent and may often be closer to 5 percent of the total project expenditure.

Preproject (Phase I) Monitoring

Preproject monitoring is generally carried out as part of a lake diagnostic and feasibility study. In the case of an impaired lake, monitoring can reveal the source or cause of the impairment and provide information on possible restoration measures. In addition, preproject monitoring information, usually called "baseline data," is the foundation against which future monitoring results are compared. Such comparisons can be used to evaluate implemented projects, whether for restoration or protection.

This manual does not treat preproject monitoring directly. For this information, the reader is referred to Section 8 of the *Clean Lakes Program Guidance Manual* (U.S. Environ. Prot. Agency, 1981); regulations governing preproject monitoring are found in 40 CFR Part 35, Appendix A. These regulations broadly identify lake monitoring elements and provide generic guidance on how projects might be monitored. Monitoring results needed for a preproject diagnostic and feasibility study will, in most cases, produce a sufficiently detailed characterization of the lake for later comparison and evaluation of the project. The sections of this manual dealing with monitoring methods and with quality assurance are also applicable to preproject monitoring.

Monitoring During Phase II Implementation

Because implementation monitoring during treatment is a condition of all EPA Clean Lakes awards, a monitoring plan must be approved by the EPA project officer before Phase II work can begin. The regulations for implementation monitoring are found in 40 CFR Part 35, Appendix A. These regulations, while specific, are not inflexible; they allow the EPA project officer discretion to approve a monitoring program tailored for a particular lake or project. While the project officer must at least consider the protocol for developing a monitoring program, the stated objective of implementation monitoring is to "provide sufficient data that will allow the State and the EPA project officer to redirect the project, if necessary, to ensure desired objectives are achieved."

The regulations for implementation monitoring allow the EPA project officer discretion to approve a monitoring program tailored for a particular lake or project.

Chapter 5 of this manual presents monitoring considerations and specifications for the most frequently used in-lake restoration techniques. The plans are consistent with the protocol given in 40 CFR Part 35, Appendix A, of the regulations. Suggested criteria for interrupting a treatment based on monitoring results are summarized for each technique.

Phase II Monitoring Following Treatment

EPA regulations require monitoring of Phase II implementation projects for at least one year after restoration of the lake or installation of pollution control devices. Also, before other Phase II work can begin, the first year's post-treatment monitoring plan must be approved by the EPA project officer. The purposes of this post-treatment monitoring are to provide data needed to evaluate the effectiveness of restoration measures immediately after their implementation and to determine whether project objectives were achieved. It is important to note that the certainty of this determination is greatly increased in almost all cases by long-term (three to five years) monitoring. This is particularly important for watershed monitoring and certain specific lake restoration techniques (e.g., dredging to increase lake depth).

The discussion of project monitoring in Chapter 5 of this manual identifies in-lake techniques that require more than the minimum one year of post-treatment monitoring and outlines key monitoring considerations in addition to in-lake monitoring specifications for the first year (or years) of post-treatment monitoring.

Long-term and Phase III Monitoring

EPA regulations require only one year of monitoring following treatment, not because a longer program is unnecessary or undesirable but because the duration of cooperative agreements must be limited to a reasonably short time frame. For many types of projects, a year of post-project monitoring provides the necessary information while allowing the timely closing of a project grant. If additional monitoring is necessary, sponsors can be awarded costs beyond the first year as

Locally sponsored long-term monitoring is one of the most cost-effective activities in all lake management and it serves as an excellent foundation for a continuing lake management program.

part of the grant-eligible project budget. However, project periods beyond four years must receive special approval from the EPA regional administrator.

Locally sponsored long-term monitoring that follows project completion is one of the most cost-effective activities in all of lake management and should always be encouraged because it serves as an excellent foundation for a continuing lake management program. Eventually, however, most long-term monitoring requires a monetary commitment from the local sponsor in the absence of Federal financial support, although limited long-term monitoring may often be accomplished through volunteer efforts and State agency assistance.

To ensure locally financed continuation of the post-treatment monitoring program, the project manager must correctly ascertain the level of financial commitment that can be expected from the local sponsor. Key considerations when developing a long-term monitoring program should be minimization of costs, education of laypersons for volunteer monitoring, and periodic, professional interpretations of data for the project and local sponsors.

A long-term monitoring program can be as simple as Secchi disk readings that are collected twice a month during the growing season or as complex as a multifaceted program that compiles information on a variety of the lake's ecosystem components. In Chapter 6, various levels of long-term monitoring after project completion are outlined. The simplest level is appropriate where the local financial base is modest and the relative importance of (or threats to) the lake as a resource are limited. The more ambitious levels of monitoring are appropriate where there are greater local resources; where there is more likelihood of a lake being degraded by changing watershed conditions or in-lake biota; and where the lake is more valuable as a local or regional resource.

After the project is closed, the only monetary support currently available for long-term monitoring in the Clean Lakes Program is the Phase III post-restoration evaluation. Phase III funds are used on a limited number of previously completed and independently selected Clean Lakes implementation projects to verify the longevity and effectiveness of various restoration techniques. Because these projects are essentially research-oriented, monitoring requirements are highly case-specific and therefore not dealt with further in this manual.

Quality Control/Quality Assurance

Quality control, which ensures that monitoring data are accurate and precise, must be a foremost consideration in planning and conducting a monitoring program.

■ **Quality Control**, which ensures that monitoring data are accurate and precise, must be a foremost consideration in planning and conducting a monitoring program. Poor quality monitoring data are worse than none at all since this information represents a substantial investment of money and time and serves as the basis for even larger investments. (One midwestern State spent over $300,000 during the 1970s on poor quality data that jeopardized both the success of several projects and, ultimately, the State's lake management program as well.) A relatively small additional effort to ensure that reliable data are collected and properly maintained in a database is indispensable.

■ **Quality Assurance** requires that the project sponsor prove that the monitoring results are accurate and precise. For this reason, EPA specifies minimum requirements for quality assurance plans in Clean Lakes projects that it funds. Often, States and private consultants prepare an umbrella quality assurance program plan that encompasses EPA Clean Lakes project monitoring requirements. These requirements are found in *Interim Guidelines and Specifications for Implementing Quality Assurance Requirements for EPA Contracts* (U.S. Environ. Prot. Agency, 1980).

The following are the 16 elements of a quality assurance project plan:

- Title page with provisions for approval signatures
- Table of contents
- Project description
- Project organization and responsibility
- Quality assurance objectives for measuring data in terms of precision, accuracy, completeness, representativeness, and comparability
- Sampling procedures
- Sample custody
- Calibration procedures and frequency
- Analytical procedures
- Data reduction, validation, and reporting
- Internal quality control checks and frequency
- Performance and system audits and frequency
- Preventative maintenance procedures and schedules
- Specific routine procedures to assess data precision, accuracy, and completeness of specific measurement parameters involved
- Corrective actions, and
- Quality assurance reports to management.

Chapter 3 of this manual contains details on collecting quality control field samples.

Chapter 3

Monitoring Methods

Summary

1. The project officer and project manager must have a working knowledge of monitoring methods to ensure the quality of the data.

2. A confusing variety of analytical techniques and field collection procedures for lake studies has evolved that hinders data interpretation and limits comparability. Certain methods have become somewhat standardized through repeated use and should be relied upon unless a deviation can be clearly justified.

3. Ten percent of all water chemistry samples in addition to those used within laboratories for quality assurance purposes should be used for field quality control.

Background

Poor quality data that have been collected in a nonstandard fashion are a perpetual problem when interpreting and comparing lake water quality studies. Meaningful study-to-study comparisons become less precise—if they can be made at all.

Poor quality data that have been collected in a nonstandard fashion are a perpetual problem.

Many of the methods employed in lake and watershed evaluations have evolved from limnological procedures, others from the hydrological sciences, and

To minimize problems that arise when data from different projects cannot be compared, use of the procedures described in this chapter are recommended.

still others from engineering practices. Because of the multidisciplinary nature of lake studies, less experienced lake scientists often become perplexed or discouraged by the diversity of methods, and even the abilities of the most experienced are periodically questioned when these scientists deal with data outside their area of expertise.

Chapter 3 provides brief summaries of the methods and techniques used for obtaining lake data. The level of detail provided is intended to give project managers a working knowledge of the more common procedures.

The methods described here are not the only ones used and, in some cases, may not be the most appropriate for a particular application, such as a research project or a particular interference problem. However, because a set of standardized methods can help to minimize problems that arise when data from different projects cannot be compared, use of the procedures described in this chapter are recommended for Clean Lake monitoring programs.

Past problem areas are highlighted throughout Chapter 3, and suggestions are made on review techniques that a project manager can use to ensure quality data. The principal methods described here were generally derived from either Environmental Protection Agency recommended methods or from *Standard Methods for the Examination of Water and Wastewater* (1989). Other good references on this topic include publications by the U.S. Geological Survey (1977 a,b); Haveren (1986); Holtan et al. (1968); U.S. Bureau of Reclamation (1975); and Hillman et al. (1986).

In-lake Sampling Procedures

Water Chemistry Sampling

All water samples must be carefully collected, properly preserved, and appropriately analyzed.

All water samples are a subset of the whole lake. To be representative of the lake component being described, they must be carefully collected, properly preserved, and appropriately analyzed.

The following sections highlight the more important considerations a field technician must make when collecting samples to ensure they are representative of the waterbody and have not been contaminated during the process of collection. Where needed for a specific purpose, additional sampling requirements will be identified. When the purpose is not described, the following requirements can serve as general guidance:

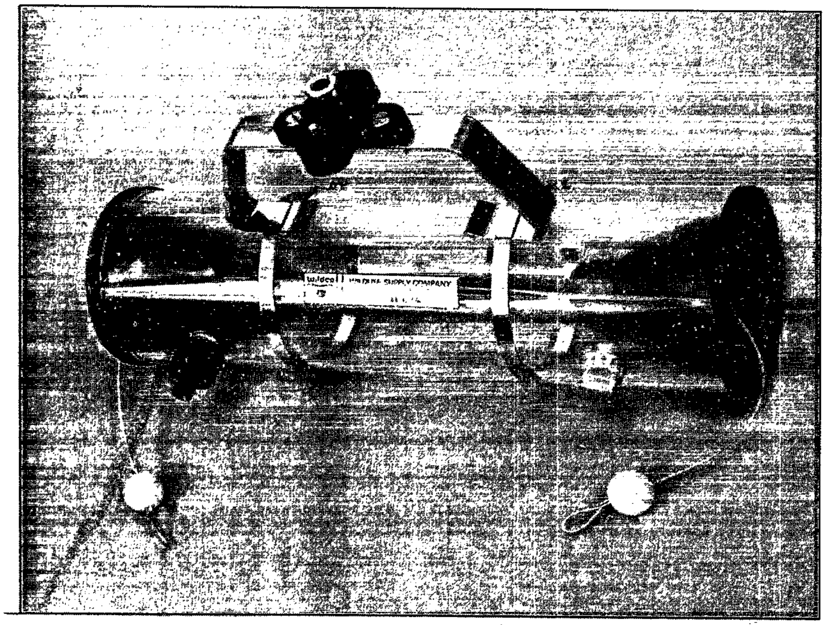
■ **Sample Locations for Shallow Lakes.** For the purposes of this manual, a shallow lake is defined as one that has fairly uniform oxygen concentrations in the surface-to-bottom profile and does not stratify. For general characterization, a sample from the one foot depth near the center of the lake will often describe conditions; shallow lakes tend to be well enough mixed so that a single sample is representative. Exceptions will be those lakes with complex configurations and the long, river-run impoundments that often show longitudinal differences.

■ **Sample Locations for Deep Lakes.** For the purposes of this document, deep lakes are defined as those lakes that stratify. Epilimnetic waters are sampled as shallow lakes, with the presumption that the upper waters are generally mixed. When sampling the hypolimnion, more careful techniques are required to avoid vertical chemical gradients that are often present because of the lack of wind mixing and constituents from lake sediments. The highest concentrations of dissolved material are usually observed nearest the lake sediments. The highest concentrations of phosphorus, which are often released under anoxic conditions, occur immediately above the sediments.

A precise characterization of hypolimnetic conditions would require a vertically integrated sample that is adjusted for volume. However, hypolimnetic conditions can almost always be sufficiently characterized for Clean Lake monitoring purposes by collection of two samples, one near the top of the hypolimnion and another just above the lake sediments (approximately three feet above the bottom). When collecting the bottom sample, care must be taken to ensure that the sample is free of bottom sediments.

■ **Water Samplers.** The most commonly used containers for collecting water from deep within a lake are the modified Kemmerer or Van Dorn (Alpha Bottle) samplers (Fig. 3.1). Water samples can also be collected using peristaltic pumps and weighted hose. When pumps are used, they are often combined with an in-line filter (0.45 μm membrane) when sampling for material that is dissolved because of anoxic conditions, such as dissolved phosphorus in an anoxic hypolimnion.

Samplers should be made of material compatible to the parameter being analyzed.



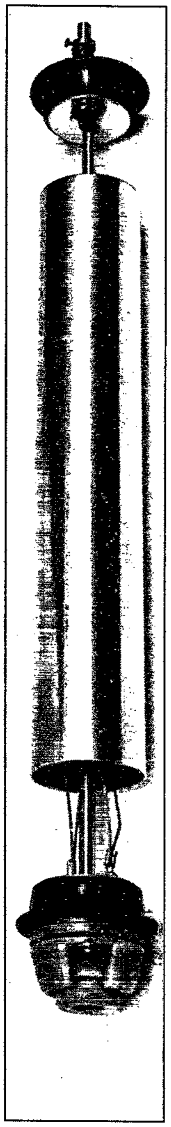


Figure 3.1.—Water samplers (courtesy of Wildlife Supply Co.)—(left) Alpha Bottle (Van Dorn sampler); (right) Modified Kemmerer sampler.

Samplers should be made of material compatible to the parameter being analyzed and should always be carefully cleaned prior to use. For nutrient analyses, the sampling equipment must be rinsed several times with the lake water to be sampled prior to obtaining the sample. Acid washing of equipment used to obtain chlorophyll samples is not recommended, as acid quickly destroys the chlorophyll. For most lakes, the sampler must be rinsed with lake water prior to sampling new stations. It is good technique to collect the lowest concentration samples first; e.g., top samples are collected before bottom samples. Stauffer (1981) is a useful reference on sampling equipment and methodologies.

To obtain chlorophyll samples, acid washing of equipment is not recommended.

Dissolved Oxygen Measurements

Dissolved oxygen samples for wet chemistry analyses are often collected with a Kemmerer- or Van Dorn-type sampler. The field sample is immediately fixed by adding manganous sulfate and alkaline iodide-azide prior to analysis (EPA Method 360.2).

When dissolved oxygen meters are used, they must be calibrated against Winkler analyses.

A dissolved oxygen electrode (EPA Method 360.1) is often used when numerous determinations are necessary. When dissolved oxygen meters are used, they must be calibrated against Winkler analyses both prior to and following each day's use. An additional check during midday is also advisable given the tendency for the calibration of some meters to drift. Many dissolved oxygen electrodes are susceptible to contamination by hydrogen sulfide or through loss of temperature compensation capability, with the error not always noticeable when manufacturer- recommended air calibration procedures are used alone.

Chlorophyll a Sampling

. . . chlorophyll a *samples should be collected on a depth-integrated basis, from the top 6 feet of the water column.*

Chlorophyll *a* is the most common biological parameter measured in lake monitoring programs. To help standardize the data, it is recommended that chlorophyll *a* samples be collected, on a depth-integrated basis, from the top 6 feet of the water column. Although other sampling depths have been suggested—two times the Secchi disk depth, the entire epilimnion, the photic zone—problems can arise with each of these approaches. Occasionally, chlorophyll data can be biased by high concentrations of metalimnetic algae, as can happen when the two times the Secchi disk-based sampling depth method is used. Similarly, high concentrations of blue-green algae are often found near a lake's surface during periods of calm weather, which will bias sample results if a surface-based sampling technique is used. The six foot integrated sample should be a good compromise in almost all cases.

Integrated chlorophyll samples can be collected with a Kemmerer water sampler, pump, or tube collector, as described by Kennedy (1985) and Stauffer (1981).

Chlorophyll a *samples should be filtered through a glass fiber filter immediately in the field.*

Chlorophyll *a* samples must be filtered through a glass fiber filter immediately in the field and then the filter should be cooled (frozen) and stored in a dark container until analyzed. Use stainless steel forceps when handling the filters. A good technique is to place the filter in a 15 mL centrifuge tube painted black or taped and containing a known volume (i.e., 10 mL) of 90 percent acetone. If raw water samples are simply cooled and stored for a period longer than a few hours prior to filtration, pigment can break down. Under no circumstances should raw water samples be held longer than 24 hours or frozen prior to analysis. Good references are *A Manual on Methods for Measuring Primary Production in Aquatic Environments* (Vollenweider, 1969) and *Standard Methods for the Examination of Water and Wastewater* (1989).

Secchi Disk Measurements

Secchi disk readings are obtained with a 20 cm diameter disk. Observations are made, during midday and without sunglasses, from the shady side of the boat. The observer, who should be wearing a life vest, makes the reading by looking as close to the water as possible to minimize glare. Ropes must be made of a nonstretchable material and periodically checked with a measuring tape. (Rope-making material will often shrink following several wet-dry cycles.)

Sediment Sampling

Chemical characterization of lake sediment is often an important component of Phase I diagnostic studies; rarely will there be a need to characterize lake sediments during the Phase II construction or post-monitoring periods. When sediment chemical characterization is desired, procedures will vary significantly, being decidedly site- and parameter-specific. Detailed methods for sampling will not be described here; for more information, an excellent reference on sediment and sampling techniques is *Sedimentation Engineering* (Vanoni, 1975).

Macrophyte Surveys

Macrophyte communities are best presented on a hydrographic map of the lake.

The level of effort required for completion of macrophyte surveys varies greatly. Generally, the surveys that might be associated with a Phase II project must be quantitative enough to allow comparisons between surveys and between lakes. Document species composition, distribution, abundance, and maximum depth of growth during the growing season by using visual observations as much as possible. Locate major community types (emergents, floating-leaved, and submergents) and then determine species composition and abundance of each community (abundant, common, sparse) using methods described by Phillips (1959). The information is best presented on a hydrographic lake map that illustrates distribution of the communities, with a species list and appropriate abundance symbol for each location. Boundaries of single species stands within the more general community type should also be noted.

Plants should be identified to the species level using a regional identification manual such as those written by Fassett (1969), Voss (1972), Godfrey and Wooten (1979), or Muencher (1964). Voucher specimens should be collected, dried, and pressed for future reference and verification.

Tributary Streams

The following section briefly describes some of the methods recommended for making discharge measurements in stream channels and for collecting stream water quality samples. The list of methods is not exhaustive; it only highlights the level of effort required to measure streamflow and provides guidance on obtaining representative water samples. Field engineers or technicians must be relied upon to select methods and equipment best suited for particular situations.

Streamflow Measurements

Given the importance of streamflow measurements, it is recommended that consultants unfamiliar with techniques consult with or enlist the services of the U.S. Geological Survey.

Discharge or streamflow is defined as the volume rate of flow of water, usually measured in cubic feet per second, past a specific point in the stream. As described in Chapter 4 of this manual, most lake responses to watershed loadings are a function of both water quantity and quality. Therefore, whenever water samples are collected in a stream, concurrent flow rate must also be known. The most common techniques for measuring streamflow are described here.

Given the importance of streamflow measurements, it is recommended that consultants unfamiliar with techniques consult with or enlist the services of a U.S. Geological Survey Water Resources Division office prior to initiating a streamflow measurement project. A good reference on flow measurement and computation of discharge is *Measurement and Computation of Streamflow*, the U.S. Geological Survey Water Supply Paper No. 2175, Volumes 1 and 2 (Rantz, 1982). Additional information may also be found in EPA's *Handbook for Sampling and Sample Preservation of Water and Wastewater* (U.S. Environ. Prot. Agency, 1982).

Instantaneous Flow Measurements

Instantaneous flow gagings measure the quantity of flow passing a monitoring site at one point in time. These measurements are commonly made directly in the stream channel where water quality samples are collected. Methods highlighted here are used for these open channel measurements. Measurement of flows in confined conduits, such as storm sewers, is not described but is discussed in the previously referenced U.S. Geological Survey or EPA publications.

The velocity-area method of measuring discharge is the principal method for calculating flow in open channels.

The velocity-area method of measuring discharge is the principal method for calculating flow in open channels. In the velocity-area method, streamflows are measured by determining the mean velocity of the water passing through the cross-sectional area of the channel. This is generally done by taking a series of velocity, width, and depth measurements across the stream and summing up the products of the areas and velocities. The formula is expressed as:

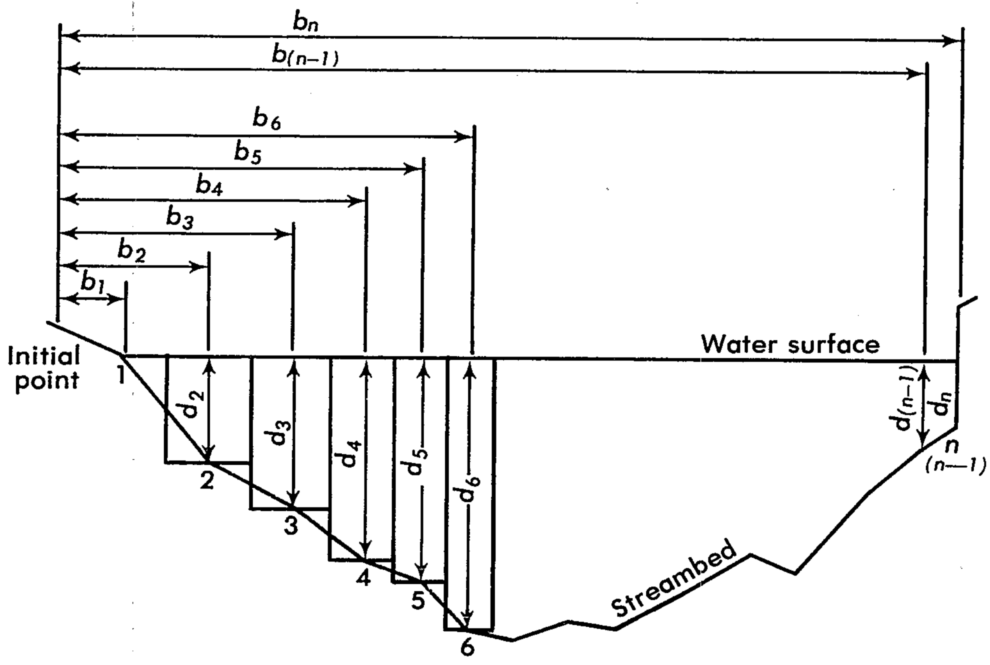
$$Q = \mathrm{Sum}(A_i V_i)$$

where

A_i is the cross-sectional area and

V_i is the mean velocity.

Stream cross-sectional area is determined using the midsection method where several depth measurements are obtained across the stream channel with sections of the stream assigned to each depth. Figure 3.2 shows a typical stream cross section and the measurement made to calculate cross-sectional area. Flow



EXPLANATION

1,2,3..............n	Observation points
b_1,b_2,b_3..........b_n	Distance, in feet, from the initial point to the observation point
d_1,d_2,d_3..........d_n	Depth of water, in feet, at the observation point

Figure 3.2.—Definition sketch of the midsection method of computing stream cross-sectional area. (Source: Buchanan and Somers, 1968.)

velocity measurements, usually expressed as feet per second, are also made within each of the partial sections as shown in Figure 3.2. When the water depth is less than 2.5 feet, these measurements are made at the 0.6 depth down from the water's surface to obtain an average velocity in the vertical. Where the stream is deeper than 2.5 feet, two measurements are made, one at the 0.2 depth and one at the 0.8 depth, with the measurements then being averaged to define velocity. A sufficient number of partial sections are needed so that no more than 10 percent of the total flow is described by any one partial section. Generally, this requires 20 or more partial section measurements. A typical streamflow measurement field sheet is shown in Figure 3.3.

A sufficient number of partial sections are needed so that no more than 10 percent of the total flow is described by any one partial section.

FLOW STREAM CROSS SECTION & DISCHARGE DATA

Location ____________ Date: ____________

	Start	Finish		
Time	______	______	Flow Meter # ____ Spin Test ____ Stream Width ____	Recorders Initials ______ # Measurements ______

Distance from Bank (ft)	Depth (ft)	Velocity (ft per sec)	Area (ft^2)	Discharge (cu. ft/sec)	Comment: (Vegetation- Sludge)

Figure 3.3.—A streamflow measurement field sheet.

Streamflow measurements are best made at sites that avoid complications caused by complex channels, abrupt changes in channel configuration, ponded conditions, and free-falling water. Careful field notes should be kept, and the project manager should occasionally review a copy of a streamflow gaging field data sheet.

■ **Velocity Measurement with Rotating Current Meters.** The rotating current meter, such as the Pygmy or Gurley meter, is the most commonly used device for measuring velocity. As in making any scientific measurement, care must be exercised to assure that the equipment is properly calibrated and maintained. For example, proper field sheets should show that a spin test was conducted on rotating current meters (if used). These tests are done to ensure that the meters are not binding, that they spin freely and accurately reflect the velocity of the water.

■ **Velocity Measurement with Floats.** Although this velocity measurement technique is not recommended for day-to-day use, situations occasionally exist where current meter readings are not possible, and ad hoc methods are needed. In these circumstances, flow velocities can be estimated simply by using a slightly buoyant surface float, such as an orange, grapefruit, or wad of tissue paper. To determine flow velocity, one or more floats are placed in the stream and the time needed to travel a measured distance is determined. A coefficient of 0.85 is commonly used to convert surface velocity to mean velocity. Flow is then determined as a product of the mean velocity and cross-sectional area of the stream.

Fixed control structures should be the method of choice when site conditions allow their use.

■ **Other Flow Measurement Techniques.** Flow rates are often measured by using a fixed control structure, such as a dam, sluice gate, weir, or flume. These control structures can provide excellent flow data and should be the method of choice when site conditions allow their use.

In some cases, periodic but accurate measurement of small streamflows is important. In these instances, i.e., where streamflow is less than 2 cubic feet per second, flow measurement using the velocity-area method can be very difficult. Small flows are best measured by catching the streamflow into a known volume (five gallon buckets are often used) and measuring the time taken to fill the known volume. Precise measurements are also possible by using dyes or other tracer dilution techniques. Occasionally, it is possible to install a portable weir plate in the stream channel. Standard tables are then used that relate water level to flow rate.

Continuous Flow Measurements

When at all possible, obtain a continuous record of flow. Water flows are related to stage (the height of the water in the stream channel): the higher the stage, the higher the flow. Normally, continuous water flow data are collected in natural stream channels following development of a stage-discharge relationship.

Since high flow events are very important... a special effort should be made to obtain a direct measurement.

A rating curve is developed by making several instantaneous streamflow measurements and then plotting them against the stage of the stream at the time of measurement. To develop a rating curve, a minimum of five direct stream gagings should be made, with the measurements describing the full range of streamflow conditions. Often, the higher flows are the most difficult to obtain. Since high flow events are very important to most lake studies, a special effort may be necessary to obtain a direct measurement of a high flow. Too often stage relationships are extrapolated beyond the capability of the data; the most important high flows are the ones having the greatest error.

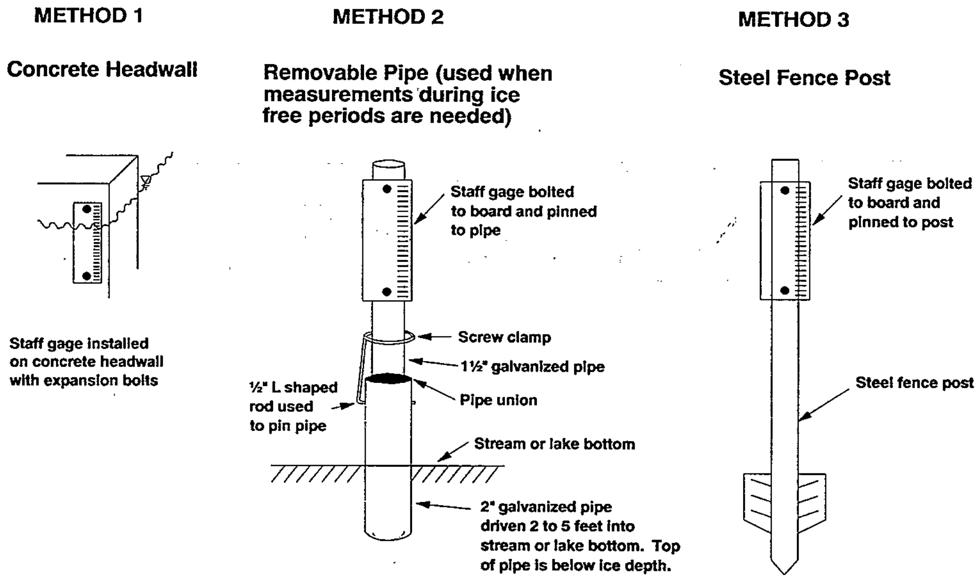
Once a stage-discharge relationship has been developed, flows can then be indirectly obtained from knowledge of water levels in the stream channel, alone. These water level measurements may be made either manually or automatically.

■ **Manual Water Level Measurement.** Once a stage-discharge relationship has been developed, flow rate estimates are simply made by measuring water levels at periodic intervals. These water levels are usually measured by reading a staff gage (Fig. 3.4) that has been installed directly in the stream channel. A periodic resurvey of staff gages is necessary to ensure they have not been disturbed by debris or ice movements.

Obtaining data from systems exhibiting significant flow variability is a major problem inherent to manual measurements. Important high flow events can be easily missed if measurements are done manually. The problem is exacerbated in the smaller, more flashy streams common to lake studies. Manual stage recording techniques should be used only in streams where flow is stable, and the probability of missing high flow events is small.

Manual stage readings commonly are made in lake studies where the dam or outlet structure serves as a control and a stage-discharge relationship can be established. In these cases, a staff gage is often attached to a concrete abutment near the outflow, but not so close as to be within the drawdown regime of the discharge.

■ **Automatic Water Level Recorders.** A variety of continuous water level recorders are currently used to obtain a record of streamflow. In the past, the most common method has been to use a stilling well in which there is a float attached to a rotating chart that records stage.



Note: All Staff gages must be referenced to a nearby datum and be resurveyed prior to and after use

Figure 3.4.—Various staff gage installation techniques.

More recently, bubbler tubes have been used, with stage being related to the pressure required to force gas from the tube placed on the stream bottom; data are then recorded automatically on tape. In these newer stations, a continuous record of flow can be easily calculated by computer once a rating curve has been developed. A U.S. Geological Survey Water Resources Division office should be contacted for guidance before a water level recording station is installed. Information on monitoring hardware can be obtained from the U.S. Geological Survey's Hydrologic Instrumentation Facility, a lab that has an excellent ongoing hardware testing program. Write to USGS's Facility at Bldg. 2101, Stennis Space Center, MS 39529.

Automatic stations, such as the one illustrated in Figure 3.5, require periodic, often weekly, maintenance. If water quality samples are also being collected, then additional servicing is necessary. The cost of a continuous record of streamflow ranges between $5,000 and $20,000 a year. These stations are more completely described in the U.S. Geological Survey Water Supply Paper No. 2175 (Rantz, 1982).

Streamwater Sample Collection

Stream sampling . . . can easily become the largest source of error in obtaining water quality information.

Streamwater sampling is a vital part of most lake studies and can easily become the largest source of error in obtaining water quality information. This fact is not well enough recognized and needs to be emphasized.

Small samples of water are collected from lake tributary streams to characterize the chemical and physical nature of the water entering a lake, with nutrients and sediment normally being the constituents of most concern. Concentrations of these parameters must be combined with streamflow to provide the loading information critical for most studies.

Homogeneity of a stream at a cross section is determined by physical factors such as proximity of inflows and turbulence in the channel. Characteristics are not necessarily homogeneous across the width and depth of a stream cross section. Poor lateral or vertical mixing is often observed. Immediately below the con-

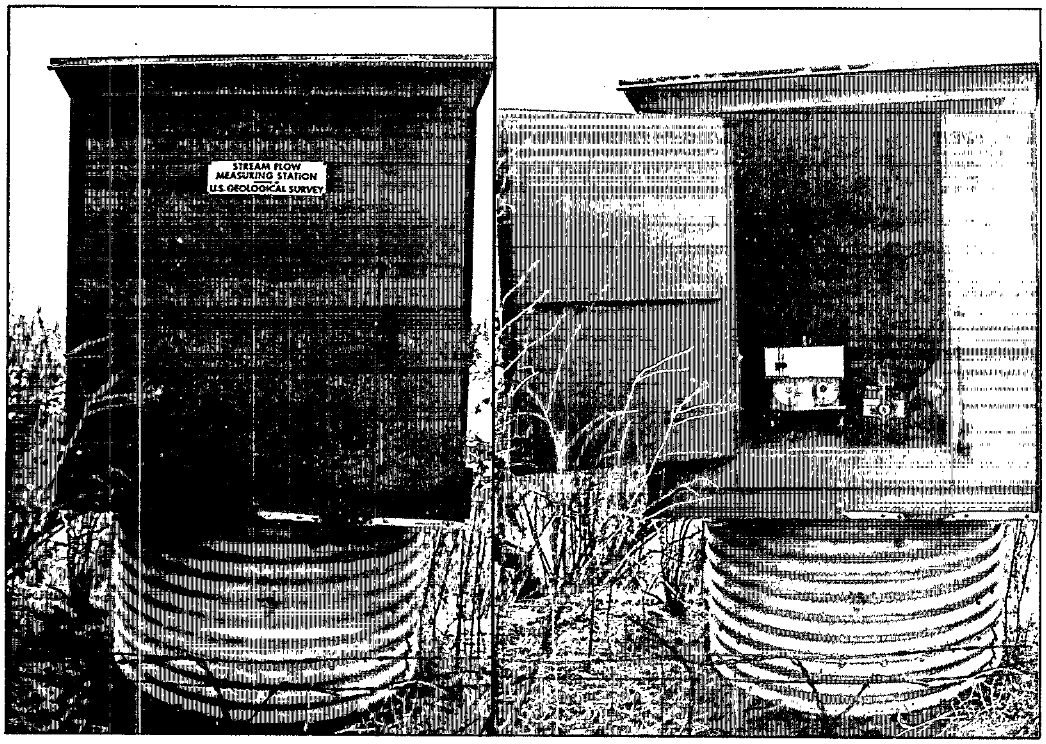


Figure 3.5.—An automated stream gaging and sampling station.

fluence of a stream and a tributary, distinct physical separations may exist between the water of the tributary and that of the main stream and, particularly in large rivers, this separation sometimes persists for many miles downstream. Sampling locations where mixing is incomplete should be avoided.

Vertical heterogeneity is also common in streams.

Vertical heterogeneity is also common in streams. Figure 3.6 shows an idealized description of the velocity, sediment concentration, and sediment discharge regime present in a stream channel. As can be seen, sediment concentrations are highest near the stream's bottom. Therefore, for phosphorus and the other constituents often associated with sediments, single grab samples taken from a stream system are often very poor representations of the whole. Use of careful techniques will ensure that samples taken from stream cross sections are representative.

■ **Manual Sample Collection.** Where the stream is well mixed (such as at a site immediately below an overflow structure), a single grab sample may adequately represent water quality at that instant. However, where there is some likelihood of stratification, a vertical composite sampling technique is preferable.

Portable integrating sampling devices that allow water to enter the sample container at a rate proportional to the water flow rate at the intake nozzle should be used. This sampling device, which is described in Porterfield (1972), is raised or lowered from a selected position in the stream to represent all the river flow at the particular point along the cross section. The process is repeated at other points along the cross section, and then the individual depth-integrated samples are combined to reflect average characteristics.

■ **Automatic Samplers.** Automatic samplers are commonly installed at streamflow gaging stations to obtain samples over a routine time period (e.g., every 30 minutes, 2 hours, 6 hours) or can be set to collect samples in response to changing water levels (flows). Automatic samplers are recommended whenever

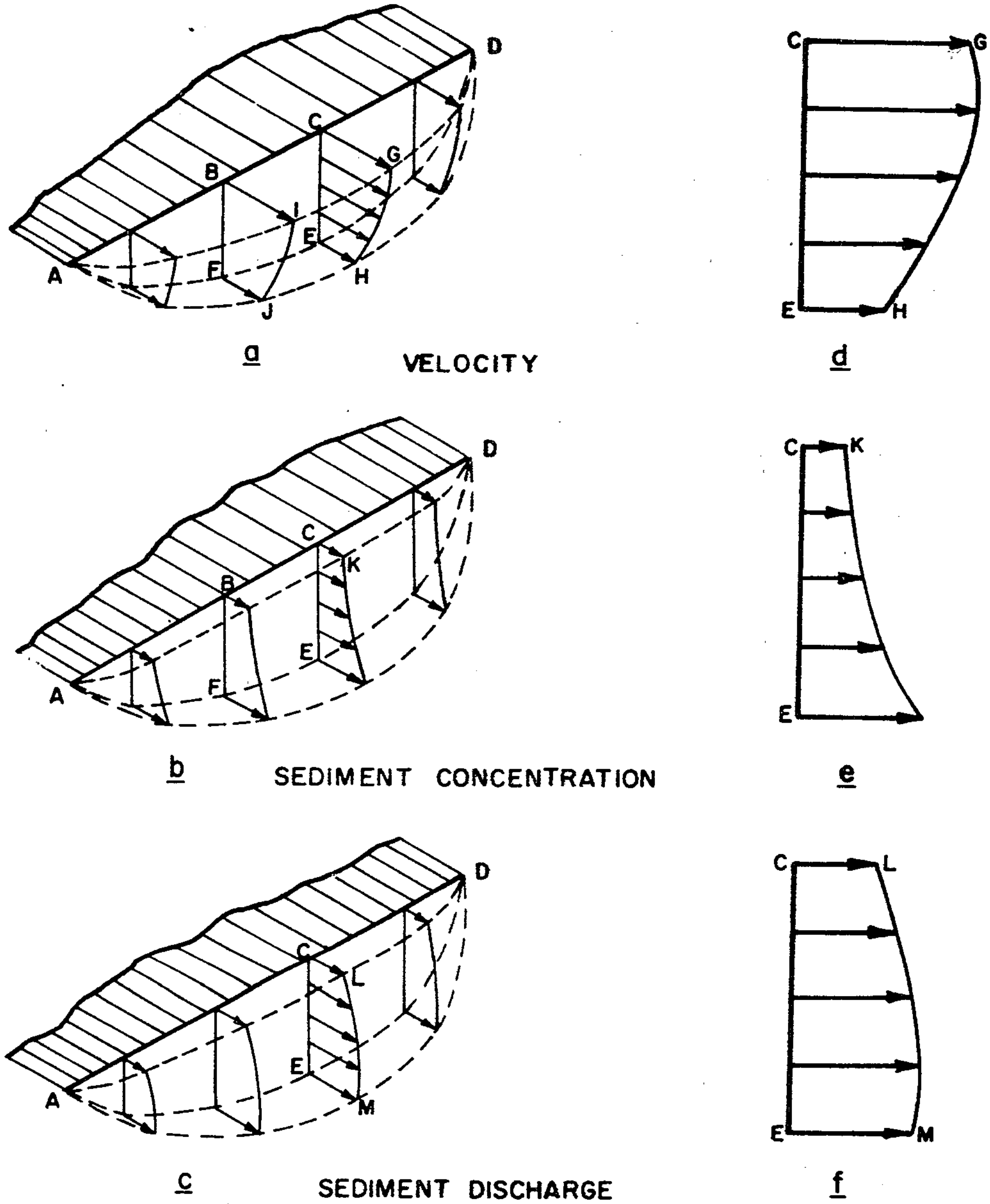


Figure 3.6.—Velocity, sediment concentration, and sediment discharge within a stream channel.

storm events must be characterized. Although water samples may be collected by hand during storm events, automatic stations generally provide the best information. Various types of automatic samplers are described in EPA's *Handbook for Sampling and Sample Preservation of Water and Wastewater* (1982). Note that care should be exercised with older samplers that lack prepurge capabilities; without a good prepurge, initial samples are often contaminated and do not represent actual conditions.

Care should be exercised with older samplers that lack prepurge capabilities.

Holding time constraints that cannot be met often affect collection of dissolved phosphorus data when automatic samplers are used. Automatic samplers must be equipped with a refrigeration unit to keep phosphorus and nitrogen samples chilled until they can be collected. Samples should be collected from the station regularly to ensure that holding times prior to analyses are not exceeded.

Automatic samplers require special maintenance.

A correction factor to adjust for the inability to vary sample intake location within the stream should be developed for all but the smallest tributaries. An individual correction factor must be obtained at each site by collecting a sample composite across and vertically within the stream channel as described in the manual collection techniques section. Then the manually collected sample is compared with the automatically collected sample to develop a correction factor.

Automatic samplers require special maintenance. For example, because the intake hose should be free of obstructions, it must be cleaned routinely to prevent plugging and growth of periphyton that can cause changes in sample concentrations. Therefore, to assure unbiased data, the following maintenance procedure is recommended:

- After the sampler has been set up and is ready to use, collect one bottle of distilled, deionized water as if it were a normal sample running through the entire hose and sampler.
- Cap the sample bottle and place it in the center of the sampler, where it will remain chilled.
- Following collection of the actual field samples, retrieve the quality control check sample and analyze for the same parameters as the actual samples.

Always provide documentation that automatic sampler quality assurance checks were made.

If the results of the analyses indicate concentrations above the detection limit, further study is needed to define the source of the problem. Always provide documentation that automatic sampler quality assurance checks were made.

Sample Handling and Preservation

This section highlights a few selected procedures of special concern for collecting and handling water quality samples. More complete information is available in the *Handbook for Sampling and Sample Preservation of Water and Wastewater* (U.S. Environ. Prot. Agency, 1982).

Water Chemistry Collection Containers

Prior to sample collection, bottles and collectors should always be double- or triple-rinsed with the lake or stream water to be sampled.

All samples must be collected in previously cleaned containers (do not use phosphorus detergents) that are appropriate for the parameter being analyzed. Prior to sample collection, bottles and collectors should always be double- or triple-rinsed with the lake or stream water to be sampled. For phosphorus and nitrogen collection, 250 mL acid-washed polyethylene or glass bottles should be used. Do not use acid-washed containers for chlorophyll *a* collection.

Sample Preservation

Dissolved phosphorus samples may not be acidified; they must be field-filtered, cooled, and analyzed within 24 hours.

Total phosphorus, ammonium nitrogen, nitrite-nitrate nitrogen, and total Kjeldahl nitrogen can be analyzed out of a single sample that has been preserved by adding H_2SO_4 to acidify to a pH of 2 or less. Samples must be analyzed within seven days following preservation, according to EPA methods.

Dissolved phosphorus samples may not be acidified; they must be field-filtered, cooled, and analyzed within 24 hours. Raw samples that have been cooled and filtered at the laboratory will often not reflect concentrations actually present in lake water. Filtration methods are discussed further in the following section.

Analytical Methods

Over the past several decades, a major work entitled *Standard Methods for Examination of Water and Wastewater* (1989) has evolved to standardize techniques for examining water samples. Both *Standard Methods* and EPA's equivalent, *Methods for Chemical Analyses of Water and Wastes* (U.S. Environ. Prot. Agency, 1983), are intended to ensure accuracy and reproducibility of laboratory results. Nevertheless, lake scientists who have examined data obtained from samples split between two or more laboratories sometimes wonder whether that objective has been attained. Although laboratory analytical techniques are better described than other elements of lake studies, care is still needed to ensure that proper techniques are followed so that good data are obtained.

The following sections highlight techniques recommended for a set of selected chemical parameters that are often most critical to lake studies. A complete description of the analytical methods for these and other parameters can be found in *Methods for Chemical Analysis of Water and Wastes.*

Phosphorus

It is strongly recommended that EPA Method 365.1 be used for all phosphorus analyses completed as part of a Clean Lake Phase II monitoring program. This automated procedure best fulfills the goals of attaining uniformity between studies, collecting more reproducible data, and, most importantly, obtaining lower limits of detection. An alternative method should be used only when well justified by special circumstances.

The most careful analytical methods are needed when phosphorus concentrations are in the range of 0.001 mg/L to 0.050 mg/L. Occasionally, less sensitive techniques can be used when phosphorus concentrations are known to be higher than 0.02 mg/L. Figure 3.7 identifies the various forms of phosphorus that can be differentiated from a single sample. The two forms that are highlighted, total phosphorus (STORET No.00665) and dissolved reactive phosphorus (STORET No.00671, called dissolved orthophosphate in the EPA methods handbook), should be reported in Phase II monitoring.

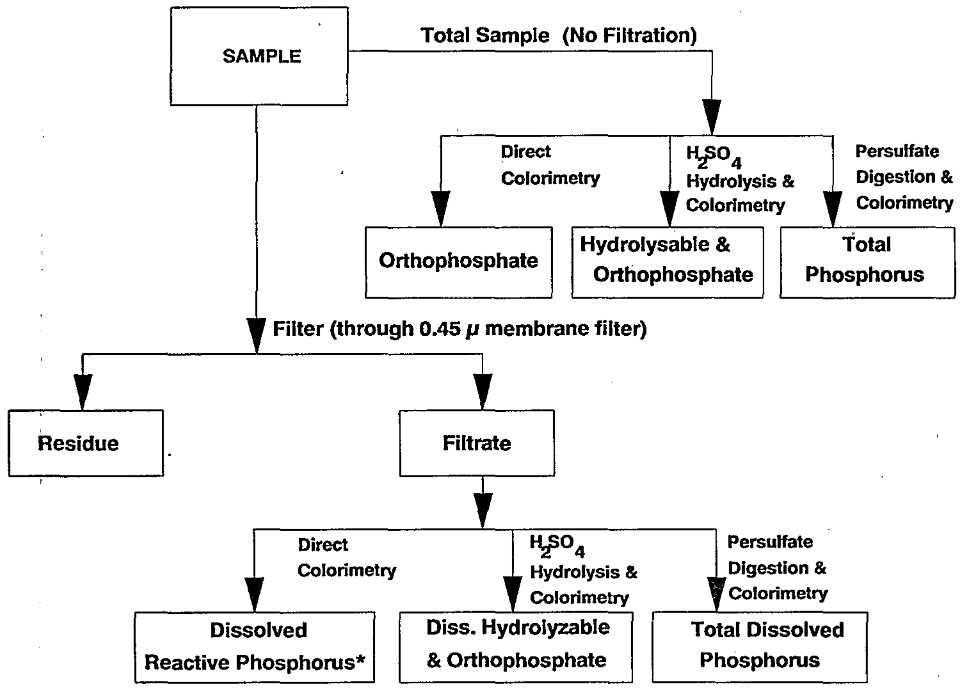
■ **Total phosphorus**, as the name implies, is a measure of all the constituent present in a water sample, including that which may be associated with suspended solids, colloids, or organic compounds. To allow analysis, the raw water sample is digested by boiling the sample with strong acids to dissolve all material. Digestion techniques occasionally vary, being dependent upon the amount of suspended sediment associated with the water sample.

■ **Dissolved reactive phosphorus** is a representation of that form of phosphorus that is most readily available for uptake by algae. By definition, dissolved phosphorus is that portion that passes through a millipore-type membrane filter with pore diameters of 0.45 µm. This size opening has come to be generally adopted as defining "dissolved" as opposed to "particulate" material. Obviously this definition is arbitrary and may not reflect the real amount of phosphorus available to algae, but it has evolved as the method of choice. Field filtration of raw water samples is required for dissolved reactive phosphorus analysis. Dissolved forms of phosphorus can change quickly following collection. If samples are not immediately filtered, changes can occur from co-precipitation with metals (this commonly happens when an anoxic water sample is exposed to air) and from biological uptake within the sample bottle even if the sample has been cooled.

It is strongly recommended that EPA Method 365.1 be used for all phosphorus analyses completed as part of a Clean Lake Phase II monitoring program.

. . . total phosphorus (STORET No.00665) and dissolved reactive phosphorus (STORET No.00671, called dissolved orthophosphate in the EPA methods handbook), should be reported in Phase II monitoring.

The method recommended for collecting dissolved phosphorus samples from an anoxic environment uses an in-line filter technique that eliminates any air contact .



* Also referred to as dissolved orthophosphate
or dissolved inorganic phophorus

Figure 3.7.—Analytical scheme for differentiation of phosphorus forms.

The method recommended for collecting dissolved phosphorus samples from an anoxic environment uses an in-line filter technique that eliminates any air contact (Stauffer, 1981).

■ **Particulate phosphorus** is, by definition, total phosphorus minus total dissolved phosphorus. As a quality assurance effort, the project manager should occasionally scan reported data to ensure that dissolved reactive phosphorus concentrations are not reported to be greater than total phosphorus concentrations for the same water sample.

To prevent confusion, total and dissolved reactive phosphorus should be reported as P and not PO_4.

To prevent confusion, both total and dissolved reactive phosphorus should be reported as elemental phosphorus, i.e., total phosphorus (P) and not as total phosphate (PO_4). Note that phosphorus reported as PO_4 will be 3.133 times higher than if reported as elemental P.

Nitrogen

Nitrogen, a plant nutrient that limits aquatic plant productivity in some lakes and river systems, can exist in several different forms. The most common forms of nitrogen evaluated in lake studies are total nitrogen, ammonium nitrogen, nitrite + nitrate nitrogen, and total Kjeldahl nitrogen.

■ **Total nitrogen** is, by definition, all nitrogen found in a water sample. It is a sum of total Kjeldahl nitrogen (organic and reduced nitrogen) plus nitrite + nitrate nitrogen. Total nitrogen to total phosphorus ratios are used to identify which nutrient is limiting to plant growth in lake waters. A lake is usually defined to be phosphorus limited if the total nitrogen/total phosphorus ratio is greater than 10:1.

■ **Ammonia nitrogen** (more accurately occurring as **ammonium** in lakes) is the form most readily used by lake plants. It is found in highest concentrations below wastewater discharges or in anoxic lake waters. The common analytical techniques are an automated phenate method (EPA Method 350.1) or an ion selective electrode method (EPA Method 350.3).

■ **Nitrite + nitrate nitrogen** are usually analyzed together. Although nitrite can be discriminated from nitrate nitrogen, this more expensive differentiation is usually not necessary for most lake studies. Rarely will nitrite concentrations be significant. The most common analytical method for nitrite-nitrate uses a cadmium reduction technique (EPA Method 353.3). Similar to phosphorus, all nitrogen species should be reported as elemental nitrogen (N), not as NO_3. For example, when reported as NO_3 instead of as NO_3-N, values will be 4.4 times higher.

Nitrite and nitrate nitrogen are usually analzyed together.

■ **Total Kjeldahl nitrogen** is analyzed by using a digestion technique that converts nitrogen components of biological origin to ammonia. The total Kjeldahl value will also include any ammonia present in the sample. Organic nitrogen is, by definition, total Kjeldahl nitrogen minus ammonia nitrogen.

As a quality assurance effort, the project manager should occasionally scan reported data to ensure that ammonia concentrations are not reported to exceed total Kjeldahl nitrogen concentrations for the same water sample.

Alkalinity/Acid Neutralizing Capacity

When alkalinities are less than 20 mg/L, the Gran analysis method should be used. The Gran method for alkalinity provides information that is usually referred to as acid neutralizing capacity because it includes alkalinity plus additional buffering capability of dissociated organic acids and other compounds.

Dissolved Oxygen Measurements

As discussed under the section on sampling procedures, dissolved oxygen is usually measured using a modified Winkler titration. Dissolved oxygen meters must be calibrated against Winkler titrations prior to and following a day's use.

Chlorophyll a

Field filtering is required prior to laboratory analyses for chlorophyll *a*. Chlorophyll *a* concentrations should also be corrected for pheophytin prior to being reported. The analytical techniques described in *Standard Methods* are appropriate for Clean Lake study needs.

Field QA/QC Samples

At least 1 in every 10 water samples should be a field quality control check sample.

At least 1 in every 10 water samples should be a field quality control check sample. The following are various types of field check samples that should be collected during the monitoring project. All QA/QC sample results should be reported.

■ **Field Duplicates.** A field duplicate is a sample taken to determine variability in the sampling procedure and the source sampled. It is useful when the concentration of the parameter being sampled is both close to the detection limit of the laboratory and to the level of concern for the parameter. Generally a field duplicate should be taken after every tenth sample.

■ **Field Blanks.** A field blank is a sample of reagent grade deionized water that is processed through the sampling equipment in the same manner as the actual sample. This is done to determine if field cleaning procedures are adequate. A field blank should be taken with every field duplicate. Ideally, no contaminants will be detected in the field blank. If contaminants are detected, the validity of the day's samples must be judged.

■ **Split Samples.** A split sample is taken to determine interlaboratory variability. The sample is collected, preserved, and split into two portions for analysis at two different laboratories. Split samples are designed to determine analytical variability between laboratories, not sampling variability.

■ **Spike Samples.** Spike samples are used to estimate the accuracy of an analysis. A known amount of substance is added to the sample, and the amount recovered is determined. Samples spiked in the field can be used to estimate sampling efficiency and handling loss.

Chapter 4

Watershed Monitoring

Summary

1. Long-term hydrological and chemical data that cover a variety of events are needed to quantify runoff-derived pollutant loadings. The difficulty of defining loadings increases with decreasing watershed size.

2. The high costs, long time frames, and high level of effort required to define long-term, average watershed loadings to lakes will normally preclude collection of this data during a Phase II implementation project.

3. At the time of project completion, a post-project watershed inventory must be conducted to document existing conditions.

4. A short-term, periodic grab sampling of tributary streams can provide qualitative information on loadings and quantitative information on pollutant source type.

5. The watershed monitoring protocol should be designed so that the local sponsor will be encouraged to continue the program on a long-term basis. Data relevance along with cost and ease of acquisition are important considerations.

6. There is a paucity of data on the effectiveness of land management practices that were installed to meet water quality objectives. Watershed evaluations should contain, where feasible, long-term measurements of the effectiveness of the project's watershed improvement practices.

Background

Lakes are products of their watersheds; therefore, a lake's water quality reflects the condition and management of the lake's watershed. Many lake restoration and protection projects include watershed components. In some projects, agricultural practices are modified; in others, urban runoff is treated; and in still others, groundwater contamination sources are corrected. All these projects are geared toward reducing pollutant loadings to lakes.

Like in-lake project components, watershed controls require monitoring to evaluate effectiveness. However, unlike in-lake techniques, watershed improvements are usually installed in an incremental fashion over long time periods and generally with less risk of acute damage to a lake during implementation. Therefore, a watershed monitoring program will rarely dictate discontinuation of watershed improvements during the project.

One of the most difficult and problematic decisions a lake manager must make is deciding how to measure nutrient, sediment, and other pollutant contributions to a lake. Defining monitoring needs for point source loadings is relatively straightforward. Measurement of groundwater-carried pollutants is extremely difficult, however; fortunately, loadings from this source are rarely as significant as those delivered to a lake from surface runoff. The EPA is also reviewing available methods for assessing nonpoint source-contaminated groundwater discharges to surface water. Since the majority of a lake's watershed-derived pollutants are generated from surface runoff, Chapter 4 will focus primarily on monitoring surface-derived sources.

Project managers must be careful not to over-design a monitoring program.

It is difficult to monitor nonpoint source-derived pollutants. Watershed climatic conditions are rarely steady state. Tributary loadings of water, nutrients, and sediments are normally extremely variable, exhibiting significant storm-to-storm, season-to-season, and year-to-year differences. Documenting long-term average loadings often requires installation of a comprehensive network of streamflow gaging and automated sample collection stations that are operated and maintained over a long period, often three or more years. In addition, data interpretation, which can be difficult, requires professional judgment from the analyst.

For these reasons, quantification of watershed-derived sediment and nutrient loadings to a lake are not normally conducted under a Clean Lakes Phase II study. The high costs of watershed monitoring and the limited time available for post-project monitoring usually preclude the long-term, comprehensive tributary monitoring activities needed to define nonpoint source pollutant loadings and document effects of improved management practices. Therefore, the project manager should not attempt to prescribe an intensive, short-term data collection program with expectations that lake loadings will be quantified. Project managers must be careful not to over-design a monitoring program by budgeting a disproportionate amount for water sample collection and laboratory analyses at the expense of project administration, quality assurance, data interpretation, and general watershed evaluations.

The bulk of Phase II watershed monitoring information will more often than not be comprised of data obtained from surveys and inventories.

In the context of Phase II studies, the meaning of the word "monitoring" will not be limited to the collection and analysis of chemical and hydrological data but will be expanded to include watershed inspections, inventories, and general condition surveys. These sorts of monitoring activities aid data interpretation and provide essential information that will help fulfill monitoring objectives at a reasonable cost. The bulk of Phase II watershed monitoring information will more often than not be comprised of data obtained from surveys and inventories.

Relationship of Phase II to Phase I and III Studies

Prior knowledge of system variability is an aid in designing an appropriate watershed monitoring component.

As explained in Chapter 1, the Phase I study identifies a lake's trophic status, the magnitude and sources of pollutants, and the lake's expected response to pollutant reductions. Ideally, a Phase II watershed monitoring component would be a scaled-back version of the Phase I study, designed to measure watershed loading reductions. Prior knowledge of system variability is an aid in designing an appropriate watershed monitoring component. The Phase III grant program is a mechanism to obtain the higher level of information usually necessary to quantify watershed pollutant loadings to lakes and the effectiveness of best management practices.

Watershed Monitoring: A Hierarchical Approach

Although the watershed monitoring component of a Phase II study is important, it is nonetheless only part of a lake restoration or protection project; its design must be consistent with the overall objectives of each project and will vary in intensity from one to another.

As a decisionmaking aid, watershed monitoring programs have been divided into three basic levels. Therefore, when designing a watershed monitoring program, the project manager should generally determine the appropriate monitoring intensity based on the following hierarchy:

Level I: Watershed Inventories

Watershed inventories can be extremely helpful when evaluating existing and potential nonpoint source loadings.

A post-project watershed inventory should always be compiled for any lake implementation project. In some cases, a simple update of the Phase I study information will suffice. During the construction phase, inspections are needed if best management practices are being installed. Watershed inventories can be extremely helpful when evaluating existing and potential nonpoint source loadings.

Level II: Limited Stream Monitoring

Tributary stream sample collection programs should be considered for watersheds or sub-watersheds where significant problems have been previously identified. A common tributary sampling strategy combines flow measurements (preferably continuous) with collection of water samples that are analyzed for phosphorus, nitrogen, and suspended sediments. A common sampling interval is 14 to 28 days, with the sample being collected near the point(s) where the most important tributary stream(s) enter the lake.

A drawback of this protocol is that such time series-based monitoring programs will almost always underestimate actual loadings if simply combined to estimate loads. However, this sampling strategy can be especially helpful in identifying significant differences between adjacent sub-watersheds.

Level III: Comprehensive Watershed Monitoring

The most accurate information on lake loadings comes from a comprehensive network that continuously records streamflow, and flow-activated sampling stations that can characterize storm events. Where the existing database merits, continuation of a comprehensive network that is already in place should be en-

Pollutant delivery to lakes varies from storm to storm and year to year.

. . . a description of the loadings received by a lake during any one-year or even two-year period might fail to reflect the actual long-term loadings. . . .

Some might even argue that, between changing land use and climatic variability, there may not, in fact, be a "long-term" condition that makes any sense.

couraged. Supplemental funding for acquisition of watershed loading information may be available and should be sought.

The Nature of Nonpoint Source Pollutant Loadings to Lakes

Pollutant delivery to lakes varies from storm to storm and year to year. Important reasons for this variability include climatic factors: storm intensity and duration, coverage of the storm over the basin, and timing of tributary flows. For the most important pollutants, the highest concentrations are usually observed during periods of highest flow and are often associated with short-term but intense storm events. Smaller watersheds are subject to the greatest variability.

As an example, Figure 4.1 shows data collected by Baker (1988) that illustrate the typical patterns of concentration changes that occurred during a runoff event from a 149 square mile watershed near Melmore, Ohio. Total phosphorus, suspended solids, and nitrate nitrogen were observed to increase with increasing discharge as is typical of nonpoint source-derived pollutants. During the falling portion of the hydrograph, total phosphorus concentrations declined but not as rapidly as suspended solids concentrations. Nitrate concentrations continued to increase.

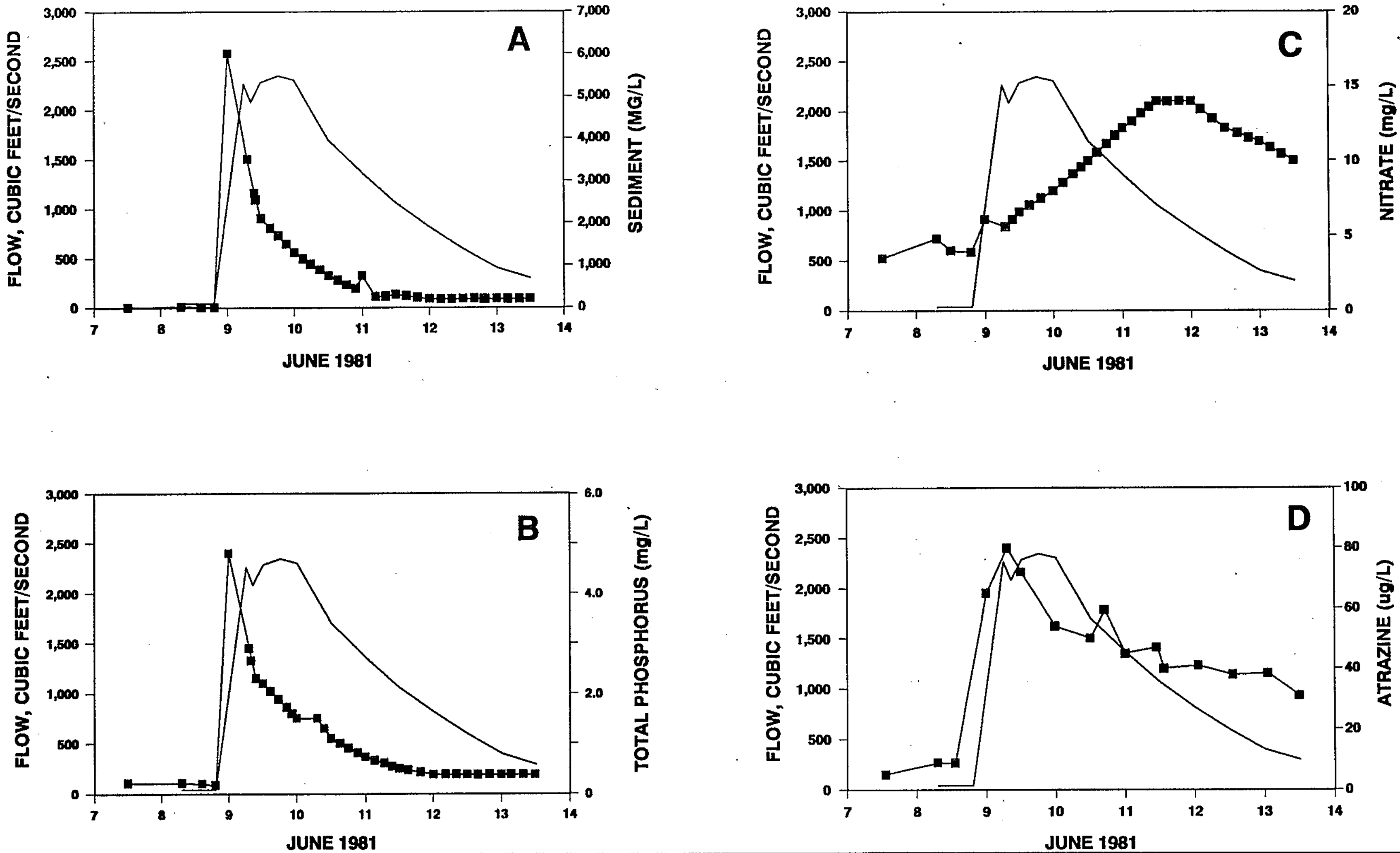
This particular storm event produced elevated flows for a relatively long time, three to four days. However, in urban or smaller rural watersheds, storm events often produce elevated flows for a time period measured in minutes or hours. Several samples must be collected before contaminant loadings from even a single runoff event can be reasonably described.

In addition to within-storm variability, nutrient and sediment loadings also exhibit a great deal of season-to-season and year-to-year variability. Figure 4.2 shows the seasonal and annual variability that was observed over a nine-year period from the same watershed near Melmore, Ohio. Clearly, a description of the loadings received by a lake during any one-year or even two-year period might fail to reflect the actual long-term loadings, no matter how intense the monitoring effort. Some might even argue that, between changing land use and climatic variability, there may not, in fact, be a "long-term" condition that makes any sense.

In other long-term studies, similar amounts of year-to-year variability have been observed. Figure 4.3 shows that yearly phosphorus loadings from a small, 1.27 square mile watershed at White Clay Lake, Wisconsin, ranged from a low of 112 pounds to a high of 646 pounds over the seven-year monitoring period. At Delavan Lake, Wisconsin (Fig. 4.4), phosphorus loss from a 21.8 square mile watershed varied from 1,400 pounds to 15,100 pounds over a five- year period. The large variability observed in these studies is similar to that found by Minns and Johnson (1979). They concluded from their study of rivers draining into the Bay of Quinte that year-to-year variation in runoff is the major source of variation in watershed export of phosphorus.

In summary, although it is certainly desirable to define nutrient and water loadings to a lake following installation of improved watershed management practices, the nature and characteristics of runoff events and complications caused by the incremental implementation of best management practices over the project time frame often preclude obtaining such information. There is a high level of risk associated with attempting to draw conclusions about the "average" loadings received by a lake if data are limited to what can be collected during a one- or two-year period. Also, where loadings are calculated using data collected only at regular intervals, true loadings are almost always underestimated because critical storm events are not well described.

Figure 4.1.—Typical pattern of concentration changes during a runoff event observed June 1981 at Honey Creek Station near Melmore, Ohio. Solid line represents flow. The connected squares represent: A. suspended solids; B. total phosphorus; C. nitrite plus nitrate nitrogen; D. atrazine (source: Baker, 1988).



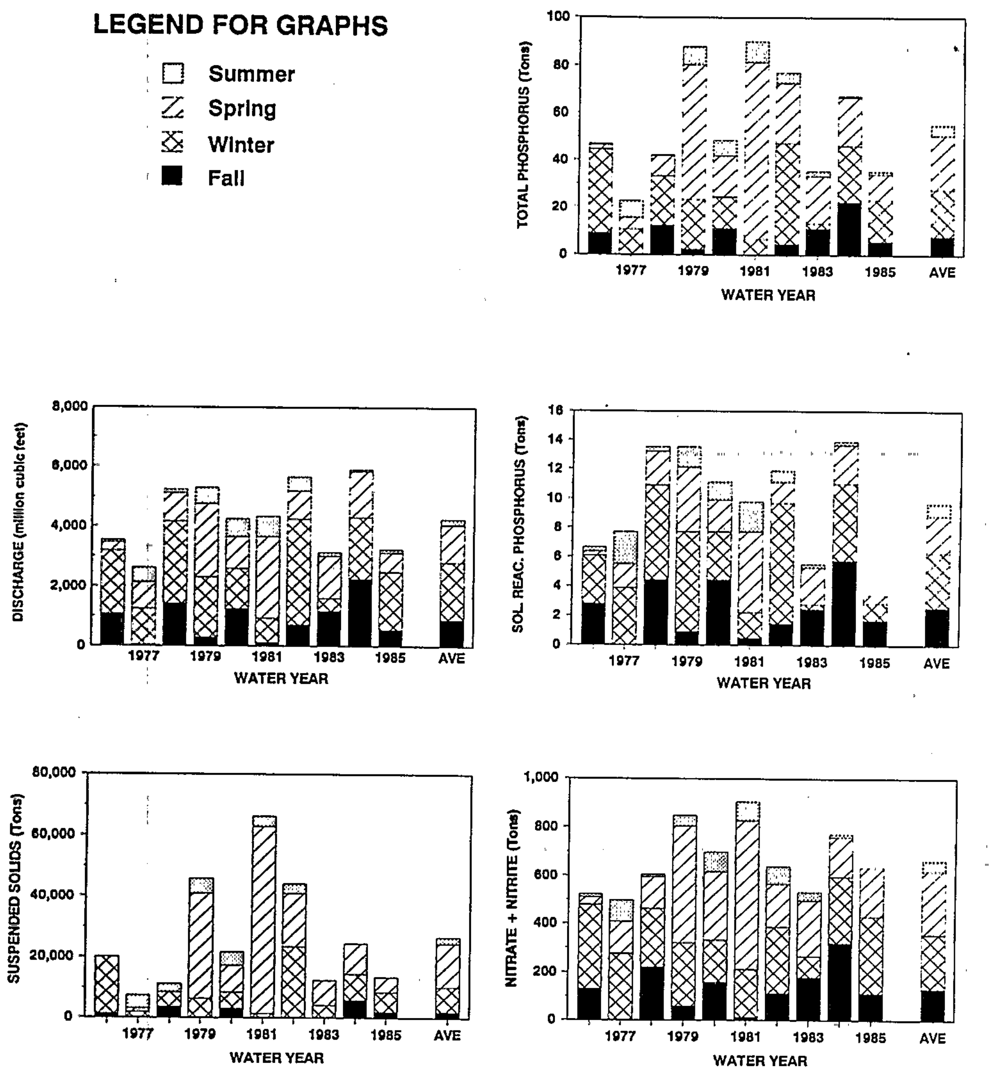


Figure 4.2.—Annual variability and seasonal distribution of discharge, loading of suspended solids, total phosphorus, dissolved reactive phosphorus, and nitrite plus nitrate nitrogen at Honey Creek, near Melmore, Ohio (source: Baker, 1988).

The Effect of Watershed Size on Runoff-derived Loadings

Peak pollutant concentrations are higher in the runoff from small watersheds than from large watersheds.

Baker (1988) studied watersheds in the Lake Erie basin ranging in size from 4.4 square mile to 6,330 square mile and identified significant patterns of stream delivery of agricultural pollutants. Knowledge of these patterns can help a manager who is designing a lake watershed monitoring program. Although Baker's conclusions were based on observations from agricultural watersheds, extrapolation to urban environments should also be possible. Baker observed that

- **Peak pollutant concentrations are higher** in the runoff from small watersheds than from large watersheds. This effect is most pronounced for sediments and sediment-associated pollutants, including particulate phosphorus.

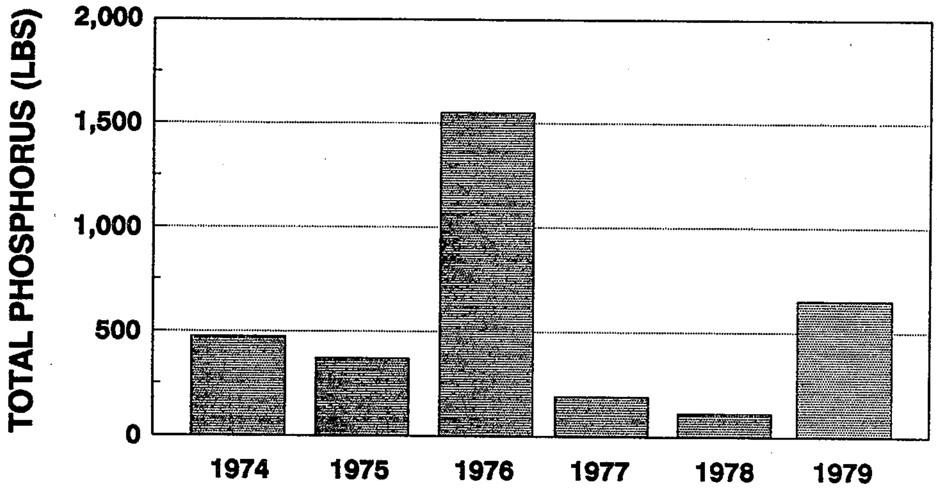


Figure 4.3.—Phosphorus loadings to White Clay Lake, Wisconsin, from a 1.27 square mile watershed (source: Persson, 1983).

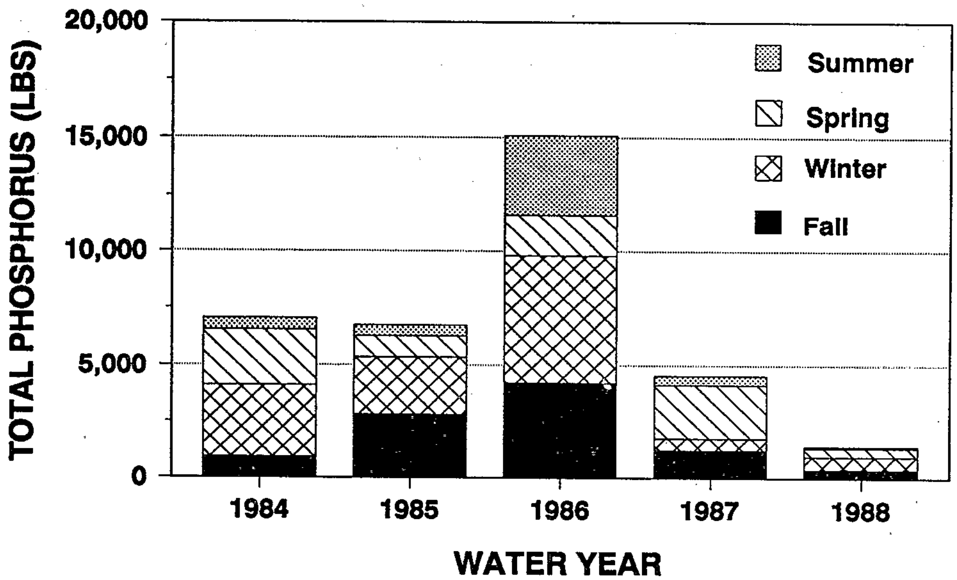


Figure 4.4.—Phosphorus loadings to Delavan Lake, Wisconsin, from a 21.8 square mile watershed (source: Holmstrom et al. 1988).

- **The duration of runoff events** and associated pollutant loadings increases with the size of the watershed.

- **The annual variability in pollutant yield** is greater in small watersheds than in large watersheds. This factor complicates the task of evaluating the effectiveness of watershed abatement practices for lakes that have small watersheds (i.e., where watershed area to lake area is 10:1 or less).

The annual variability in pollutant yield is greater in small watersheds than in large watersheds.

... it takes more sampling effort to accurately measure pollutant loadings from a small watershed ...

- **As watershed size becomes smaller,** increasing proportions of the total annual pollutant loading occur in shorter time windows. Consequently, it takes more sampling effort to accurately measure pollutant loadings from a small watershed than it does from a larger one, since it is easier for a sampling program to miss the high loading episodes in the smaller watersheds.

- **The time periods of peak sediment load** (and associated pollutants) differ between smaller and larger watersheds. In small systems, most sediment loads occur when there is a combination of bare soils and high intensity rainfall events, generally during spring and early summer. In larger watersheds, most export occurs earlier, generally during the times of peak discharge when sediment previously deposited in stream channels is resuspended and exported.

Lake Water Residence Times—Implications for Monitoring

Phase I lake studies are usually conducted over a single year. A one-year monitoring program will allow a somewhat qualitative description of the seasonality of watershed loadings; however, it will not allow description of year-to-year variability. Since most lakes have the capability to "average" the loadings they receive, consideration must be given to the implications this dampening-out effect has on the effects of individual event loadings.

... lakes require several flushings before effects of loading reductions are observed.

Lake water residence times vary greatly, ranging from a few days to tens or even hundreds of years. For lakes having longer residence times (a year or more), long-term average pollutant loadings become more important to overall lake water quality. These lakes, unlike many river-run lakes or large reservoirs, are often characterized as "completely mixed reactors" that have the potential to retain pollutants from previous years' loadings. Because of this capability, they require several flushing cycles before the effects of loading reductions might be observed. As an ideal example, a lake having a water residence time of one year will still retain 50 percent of its original water after a year of average inflow. Following the second year (after two flushings), 25 percent of the original water will still remain. In the third year, the lake will have 12.5 percent of the original water, and so on. This characteristic requires that the longer the water residence time, the longer the time frame needed for in-lake observations to detect any response to loading reduction.

As an example, if an estimated response to loading changes would be observable after 85 percent water replacement, then three years of monitoring would be necessary for a lake having a one year water residence time. Also, the longer the residence time, the more likely the lake will show response to average rather than event loadings. Lakes having very short water residence times (days or weeks) may show response to seasonal loadings. In those cases, a shorter-term monitoring program could identify a lake's response to loadings by focusing on critical time periods, such as the summer growing season. Even in these cases, year-to-year variability might obscure the lake's eventual response.

Moreover, because lakes are not always completely mixed reactors and because pollutants are not always conservative substances, evaluations may be even more tenuous. Vollenweider (1976) discusses the concept of phosphorus residence times and how they differ from water residence times. In a study of Shagawa Bay, Malueg (1975) observed that the lake responded to phosphorus reductions more slowly than predicted by water residence time. Similar findings were also observed in an Irish lake, Lough Ennell (Lennox, 1984), where an important factor in delaying recovery was the buffering capability of the lake sediments that acted as both a sink and a source of phosphorus. In other instances, where the mass of labile sediment-associated phosphorus is low, then a lake might improve more quickly than predicted by water residence times. Such a situation could be observed in a lake that received a brief, one-time loading, such as from a fertilizer spill.

Every completed Phase I study should include an estimate of long-term average water residence times. Where site-specific, long-term water inflow data are not available, a first approximation of a lake's water residence time can be obtained by using the following procedure:

By definition, a lake's average water residence time is calculated by dividing the lake's volume by the average annual water outflow (V/Q), with the volume of the lake expressed as cubic meters or acre-feet. Volumes are determined from lake depth surveys. Average annual inflow information can be approximated by using regional average annual runoff rates and adjusted for groundwater inflows and evaporation/precipitation if necessary. Surface water runoff will dominate most lakes' water budgets. The exceptions will be those lakes having very small watersheds. The map included in the pocket of this manual can be used to obtain this information. Bent (1971) also described a technique he used in Michigan to develop estimates of annual flow using multiple regression equations. This methodology, which relates streamflow to basin and climatic conditions, can provide an estimate of annual flow along with a standard error of estimate.

As an example, the average annual residence time for a lake located in northeast Pennsylvania can be calculated as follows: First, it is noted that average annual runoff rates are approximately 25 inches per year in this area (Gebert et al. 1987). It is then determined that, at this location, the difference between evaporation and precipitation is negligible (Natl. Oceanic Atmos. Admin. 1982). Groundwater inflows are also determined to be insignificant, as this lake has a relatively large watershed area of 20 square miles (12,400 acres). An estimate of the lake's watershed water loadings would then be 25,833 acre-feet per year (25 inches x 12,400 acres/12 inches per foot). If its volume were 50,000 acre-feet, the lake's water residence time would then be 1.9 years (50,000 acre-feet/25,833 acre-feet of runoff per year).

This particular Pennsylvania lake would be one that is expected to respond somewhat slowly to watershed changes. It is also an example of a lake that would require a period of six or more years before response to watershed reductions of conservative substances would be observed based on water residence times alone. Where more precise estimates of water loadings are necessary, Cooke et al. (1986) provide additional detail on defining water budgets.

Level I: Watershed Inventories

Applicability

Every Clean Lake project monitoring plan should have a component that describes watershed conditions after construction is completed.

Every Clean Lake project monitoring plan should have a component that describes watershed conditions after construction is completed. The level of detail that is needed will depend on the complexity of the watershed's land uses and the actions taken to improve watershed conditions.

As described earlier, the direct measurement of pollutant loadings to a lake is difficult to accomplish given financial and time constraints inherent to most lake projects. Fortunately, a relatively simple watershed inventory can provide the crucial information needed to minimize problems during the construction phase of a project and identify critical areas needing long-term protection.

Construction Phase

Many Clean Lakes projects require the installation of watershed management practices to minimize sediment and nutrient delivery to a lake. Practices commonly used include installation of grassed waterways, treatment ponds, water diversions, construction of animal waste control facilities, changes in cultivation practices, and septic system maintenance.

A periodic watershed inspection program is warranted if for no other reason than to document installation of practices as specified in the project design and to ensure that associated interim control measures, such as short-term erosion control practices, are being used.

. . . the watershed should undergo a periodic general inspection during critical time periods . . . .

In addition to these specific inspections, the watershed should undergo a periodic general inspection during critical time periods (e.g., late winter and late spring for small, agriculturally dominated watersheds) to check for new problems that might be developing, to serve as a verification of earlier surveys, and to identify possible previously unobserved problems. The inspections required in the monitoring plan would generally be documented by observer notes and referenced to a map of the watershed. The following is a typical checklist for these inspections:

- Are the watershed management practices being installed according to design?
- Are adequate controls in place to prevent unnecessary erosion or loss of nutrients at implementation sites?
- Are agricultural practices being improved according to design?
- Are there any new construction sites that were not anticipated and, if so, are adequate control measures in place?
- Have there been any new building permit applications or zoning changes that are potentially detrimental to project success?

Post-project Phase

An inventory of watershed conditions immediately following project completion is essential to establish a baseline for future evaluations and to serve as a model for the local project sponsor who presumably will be encouraged to conduct routine inspections in the future.

The level of detail required in documenting watershed conditions may vary, but the final report must always include a delineation of surface watershed boundaries and land uses on a map of appropriate scale. If important (as they might be for seepage lakes), groundwater contributing areas should also be delineated. In the majority of lake projects, a topographic map with a scale of 1:24,000 (7.5 minute quadrangle) is used.

In many cases, confined animal feeding operations contribute more than point sources.

Land uses should be broken into the basic categories identified in Table 4.1 and characterized as a percentage of the total watershed size. With the exception of lakes having very large watersheds, Level I information should always be provided. Level II or higher information should be required to document uses having high contamination potential such as point sources, confined agricultural feeding operations, land under development, and strip mines.

As an example, more detailed information is often desired for confined animal-feeding operations that commonly contribute large nonpoint source nutrient loadings to a lake. In many cases, these often difficult-to-quantify loadings exceed point sources as the most significant contributors of nutrients. Unlike municipal or industrial waste discharges, however, waste derived from confined animal lots is

Table 4.1.—Basic land use descriptions

LEVEL I	LEVEL II
1. Urban or built-up land	11. Low density residential 12. Medium density residential 13. High density residential 14. Commercial and Industrial 15. Land under development 16. Other urban or intensively used land
2. Agricultural land	21. Row crops 22. Nonrow crops 23. Pasture 24. Confined feeding areas 25. Mixed agriculture 26. Other agricultural land
3. Forestland	31. Deciduous forestland 32. Evergreen forestland 33. Mixed forestland
4. Water	41. Streams and canals 42. Lakes and reservoirs 43. Forested wetland 44. Nonforested wetland

not released at a relatively constant rate or normally discharged to a receiving water from a pipe, nor is the waste monitored under the National Pollution Discharge Elimination System (NPDES).

To evaluate feedlot contributions, variations of an Agricultural Research Service (ARS) technique (Young et al. 1981) are commonly used to quantify nutrients delivered to a receiving water from a confined animal operation. Figure 4.5 and Tables 4.2 and 4.3 are provided as an example of the type of inventory information needed to quantify this pollution source when this ARS-type evaluation is used. The potential magnitude of loadings is quantified from the information identified in Part A of Table 4.2. The hydrologic and pollutant reduction analyses require the SCS Group and Curve number information summarized in Table 4.3. Further guidance on appropriate types and level of information for more detailed evaluation of nonpoint sources can be found in *A Conceptual Framework for Assessing Agricultural Nonpoint Source Projects* (N.C. Agric. Ext. Serv. 1981).

In many cases, a fairly detailed description of watershed conditions should have been compiled as part of the Phase I study data; updates by office reviews (verified by field inspections) will often be all that is necessary for a Phase II summary, however. To be useful to the local lake project sponsor, the data compiled from this effort should not be overly complex and must be presented in an easy-to-understand format. Existing land use and management should be characterized as a percentage of the total watershed size and by potential contribution to the overall nutrient loading. Information on critical areas needing protection can be identified on a separate map to serve as an ongoing reference for the local organization.

. . . the data compiled from this effort should not be overly complex . . .

Level II: Limited Stream Monitoring

Applicability

Although the basic information obtained from the Level I watershed inventories and evaluations will provide significant insight into watershed conditions, it will not provide data on the actual nutrient or sediment characteristics of the lake's tributary streams.

Watershed data obtained from a short-term, time-series-based tributary stream sampling program have formed the basis from which many Clean Lakes Program

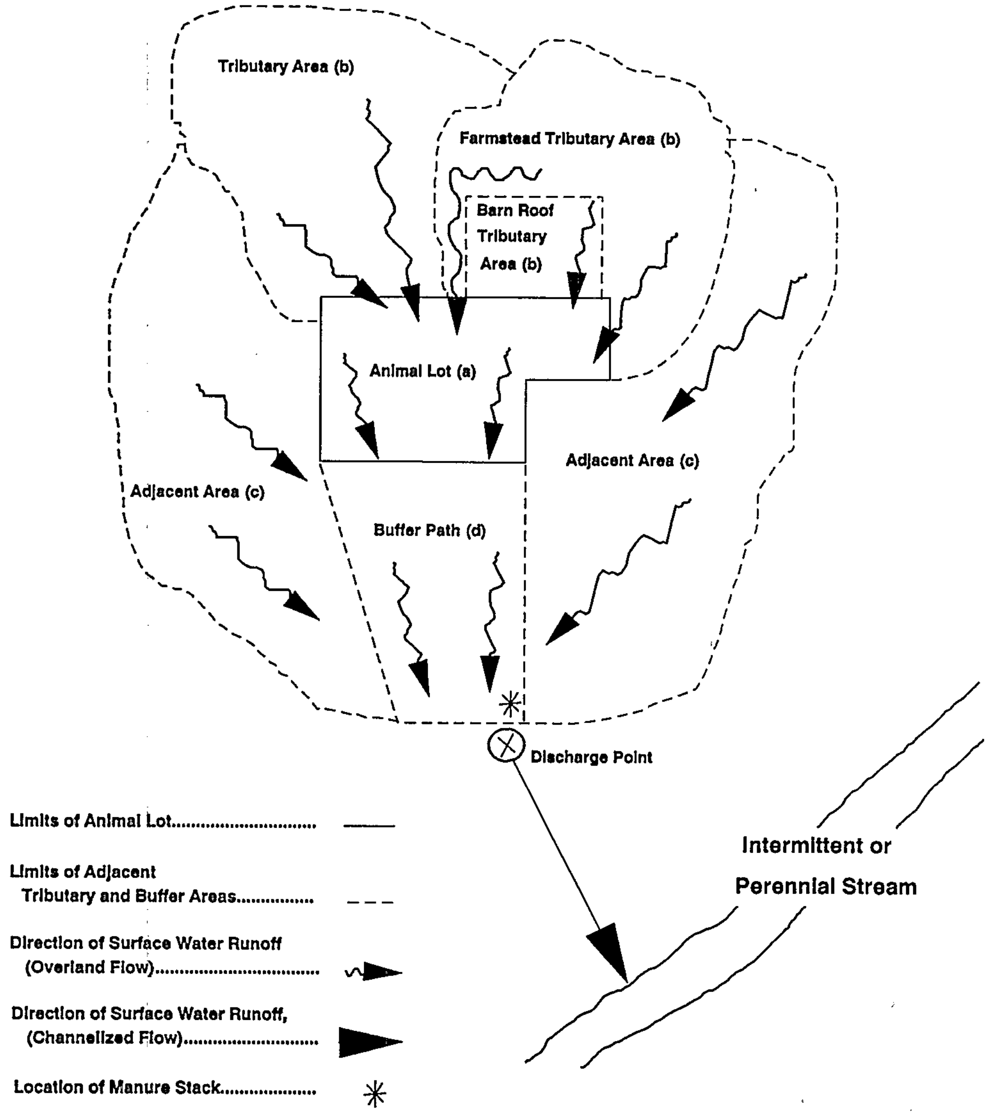


Figure 4.5.—Typical sketch of feedlot area showing general hydrologic information.

watershed projects have been implemented. In these studies, it has been common to determine pollutant concentrations from analysis of tributary stream grab samples collected on a fixed interval basis over one year. In some cases, loadings have been estimated by using simple averaging techniques applied to both concentration and instantaneous flow data. Unfortunately, not all of these monitoring efforts have provided valuable information.

The tendency to use shortcuts or inappropriate methods is not limited to Clean Lakes Program projects. Even when researchers have acquired data in attempts to examine nutrient loadings from various land use practices, the information has often been of less than desirable quality. Beaulac (1980) cited inappropriate or inconsistent methods as the primary reason he rejected information on nutrient export coefficients from many research studies.

However, a limited stream monitoring program can provide insight into watershed conditions—in some cases. A program of limited or Level II watershed monitoring is justifiable where the objectives are limited to verifying conditions found during the Phase I study and detecting order of magnitude differences be-

Table 4.2.—Typical feedlot inventory data sheet with information commonly needed for detailed evaluations

A. Animal Lot Information

1. Animal data

Animal types:[1]	____	____	____	____	____
Number of animals:	____	____	____	____	____
% Time animals in lot:	____	____	____	____	____

2. Lot configuration

Animal lot: Size (Acres): ____ Lot Surface: % Paved ____
% Sod ____ SCS CN ____
% Bare ____

Cleaning frequency of lot (days)? ____

B. Area that drains across the animal lot (Tributary Area b in Figure 4.5)

Landcover:	____	____	____	____	____
Size (Acres):	____	____	____	____	____
Soil Hydrol. Grp.:	____	____	____	____	____
SCS Curve Number:	____	____	____	____	____

C. Area that drains to the buffer path (Adjacent Area c in Figure 4.5)

Landcover:	____	____	____	____	____
Size (Acres):	____	____	____	____	____
Soil Hydrol. Grp.:[2]	____	____	____	____	____
SCS Curve Number:[2]	____	____	____	____	____

D. Buffer Path (d in Figure 4.5)

Landcover:	____	____	____	____	____
Size (Acres):	____	____	____	____	____
Soil Hydrol. Grp.:	____	____	____	____	____
SCS Curve Number:	____	____	____	____	____

[1]*Animal Types*

Slaughter steer	Sheep
Young beef	Turkey
Dairy cow	Chicken
Dairy young stock	Duck
Swine	Horse
Feeder pig	

[2]See Table 4.3 for SCS Group and Curve Numbers

tween watershed sub-basins. Defining average sediment and nutrient loadings is an unrealistic objective for most Level II monitoring programs.

A limited stream monitoring program can also be valuable if the local sponsor will continue the monitoring over a long time period. In these cases, identification of major changes in runoff quality/quantity and documentation of long-term average loadings are possible.

Construction Phase

In those lake projects where a limited stream monitoring program is being instituted, there will be little or no difference in protocol between the construction and post-monitoring phases. And in some cases where major watershed improvement practices are being installed and pollutant delivery conditions are extremely variable, stream monitoring data acquired during the construction phase, unless very site-specific, will be of little value to the project manager. By the time enough data can be obtained to define conditions, the conditions themselves will have changed.

If short-term, point source discharges are required during the construction phase, then periodic collection of water quality data from these sources should be considered. A case example might be where a lake is being hydraulically dredged and spoil site return carriage water is directed back to the lake or tributary stream. Monitoring the quality of return carriage water can help ensure that the site is

Table 4.3.—Surface condition constant and soil conservation service curve numbers for various cover conditions (Source: Hydrology Guide for Minnesota, USDA-SCS, St. Paul, MN)

		SCS CURVE NUMBER (CW)			
COVER	SURFACE CONSTANT	SOIL GROUP A	SOIL GROUP B	SOIL GROUP C	SOIL GROUP D
Fallow	0.22	77	86	91	94
Row crop:					
Straight row (up & dn)	0.05	67	78	85	89
Contoured	0.29	65	75	82	86
Small grain	0.29	63	74	82	85
Legumes or rotation meadow	0.29	58	72	81	85
Pasture:[1]					
Poor	0.01	68	79	86	89
Fair	0.15	49	69	79	84
Good	0.22	39	61	74	80
Permanent meadow	0.59	30	58	71	78
Woodland	0.29	36	60	73	79
Forest w/heavy litter	0.59	25	55	70	77
Farmsteads	0.01	59	74	82	86
Grass waterways	1.00	49	69	79	84
Animal lot:					
Unpaved		91			
Paved		94			
Roof area		100			

[1]Pasture should be considered "poor" if it is heavily grazed with no mulch. "Fair" pasture has between 50 percent and 75 percent plant cover, and "good" pasture is lightly grazed and has more than 75 percent plant cover.

being properly operated. Where discharge occurs, the effluent must comply with standards defined in section 401 of the Clean Water Act. State or local regulatory agencies will normally require discharge monitoring as a permit condition, which may preclude the need for developing a separate monitoring plan.

Where watershed conditions are not expected to vary greatly during project implementation, the construction phase monitoring plan can be identical to that of the post-project plan.

Post-project Phase

A limited stream monitoring program should be instituted if:

- Qualitative information on tributary streams will be of value; or
- Identification of previously unidentified sources of contamination is possible; or
- The design will serve as an example of a long-term monitoring program that will be continued by the local sponsor.

■ **Design Considerations for Limited Watershed Monitoring.** Much of the value of a limited monitoring program depends on its long-term continuation. Past studies have often had problems in attempting to normalize data that were gathered over a short time period, often over a limited range of runoff conditions. Most of the following discussion is therefore oriented toward the situation where the local project sponsor is expected to continue the monitoring program following completion of the formal Phase II project.

Equally important as the technical design criteria are those criteria necessary to ensure that the local sponsor will continue to collect data following project completion.

Equally important as the technical design criteria are those criteria necessary to ensure that the local sponsor will continue to collect data following project completion. These factors include:

- that the data be relevant to the lake problem;
- that costs be kept low and in perspective with the project as a whole;

- that data be easily obtained (this is especially important if an unpaid local volunteer is collecting the data); and
- that a mechanism is in place to provide a periodic, professional interpretation of the data.

■ **Critical Parameters.** The following parameters are those most often needed for lake projects and most likely to have been obtained during the Phase I study. These parameters will also be commonly obtained during the post-project phase under both a limited and a comprehensive monitoring effort. Specifically, they are:

- Suspended solids
- Total phosphorus
- Dissolved reactive phosphorus
- Total Kjeldahl nitrogen
- Ammonia nitrogen, and
- Nitrite + nitrate nitrogen.

Additional parameters obtained during earlier studies should also be monitored if necessary for specific project concerns. Examples include fecal coliforms, fluoride (an indicator of municipal wastewater discharges), potassium (an indicator of feedlot pollution), chloride, metals, pH, and pesticides. Again, careful consideration must be given to the cost of the monitoring program to encourage continued local sponsorship. For example, analytical costs will be significantly reduced if elimination of the nitrogen series can be justified.

■ **Sampling Frequency.** There have been many studies to determine the frequency of sampling necessary to characterize stream conditions. In a review of several intensive stream monitoring projects, Allum (1977) identified the value of preliminary data in helping to reduce sampling frequency and of making sampling decisions on a stream-by-stream basis. On the basis of Allum's work and a similar analysis by Walker (1977), Reckhow et al. (1980) suggested that a sampling interval of about 14 to 28 days could be used to characterize phosphorus concentrations as a general guideline for larger watersheds. They also proposed that sample collection not be systematic with respect to time (e.g., every two weeks), but that it be systematic with respect to flow—that more intensive sampling be done during high flow periods. In his review, Allum demonstrated that the standard error of the annual phosphorus flux generally varied between 10 and 20 percent of the true flux for the 14- to 28-day sampling period.

An analysis of Phase I study information will serve as the starting point for developing the technical design for a limited monitoring program. To minimize error, Phase I data should be examined to determine the importance of various flow events and flow periods so that the sampling strategy will be most intensive during those periods when highest loadings occur. For example, where there are important spring runoff events, specifications might state that samples should be collected once each week between March and May and monthly thereafter. However, Gaugush (1987) proposes that exact sampling dates should not be specified and that sampling should be done on a random basis within specified time frames.

Storm-generated loadings are usually extremely variable and often do not exhibit the ideal "first flush" phenomenon.

When storm events are important to loadings, identifying a sampling design becomes more difficult, especially if samples are to be manually collected by a local sponsor. Storm-generated loadings are usually extremely variable and often do not exhibit the ideal "first flush" phenomenon because of fluctuating rainfall intensities. Experience has also shown that the most significant events have the frustrating tendency to occur during the night or on holidays and weekends.

Although even collection of the minimum 13 to 28 samples per year per tributary may start stretching the resources of a local sponsor, a lesser sampling frequency should be avoided as errors may quickly result. Occasionally a careful analytical evaluation of historical data may show that acceptable information can be obtained from a lesser sampling frequency. The watershed case study in Chapter 7 illustrates an evaluation of the intensity of future sampling needed to estimate nutrient concentrations.

The representativeness of the information is also a consideration often as important as the numbers and timing of sampling. Care must be exercised when selecting a proper sampling site location, identifying appropriate field sampling techniques, and acquiring appropriate quality assurance samples. Chapter 3 provides more detail on sampling methods.

... obtaining continuous flow information is clearly the preferable approach.

■ **Streamflow Measurements.** Some method of streamflow estimation is necessary for all post-project monitoring where water quality samples are being obtained, if only to define the representativeness of a particular sample. Too often volunteers have taken collections from ponded areas, even when no flow is present, just to obtain a sample. Use of these samples to describe average conditions then introduces significant error to the data set.

Streamflow measurement can be accomplished continuously or instantaneously as described in Chapter 3. Often the Phase I study will have collected streamflow data on either a continuous or instantaneous basis. Maintaining the operation of a continuous record gaging station that is already in place is often justifiable. In many instances, a local sponsor who is interested in protecting significant investments made to improve land use practices will want to install a long-term station. Nevertheless, obtaining continuous flow information is clearly the preferable approach.

Often, however, only instantaneous streamflow measurements were made when samples were collected during the Phase I study. If a stage-discharge relationship was developed at these sites, flow rate determinations can be made by simple stage readings. Instantaneous measurements should be made periodically to verify the stability of the stage-discharge relationship. Also needed are special attempts to improve the rating curve at the station by taking direct stream gagings during the high flow runoff events.

Although continuous streamflow monitoring is desirable, it can add significantly to the cost of data acquisition. Even instituting a periodic, instantaneous streamflow measurement program can be a problem for the local sponsor because of increased costs (an additional $5,000 to $10,000) and the high level of expertise needed to obtain this data.

Level III: Comprehensive Watershed Monitoring

Applicability

Few long-term water quality records exist from which to judge effectiveness of nonpoint source watershed controls.

The purpose of monitoring a watershed where improved practices have been installed is to determine how much watershed practices have reduced pollutant loadings to the lake.

Unfortunately, this question has not often been adequately answered. Few long-term water quality records exist from which to judge effectiveness of nonpoint source watershed controls, with the problem being especially acute for smaller watersheds. Without more information that is obtained over a wide range of conditions at different sites, there will continue to be limited understanding of the effectiveness of various watershed practices and the evolution of nonpoint source

Typical Plan Element for Intermittent Sampling

The following is an example specification for the intermittent monitoring of a tributary stream.

1. Instantaneous flow measurements should be made at the tributary stream locations identified on an enclosed map.[1] The flow measurements should be made once a week from March through May and monthly, thereafter. The techniques used for making these measurements should conform to those recommended in *Discharge Measurements at Gaging Stations, Techniques of Water Resources Investigations*, Book 3, Chapter A8 (Buchanan and Somers, 1969).
2. Water samples should be collected at the tributary site(s) where streamflow measurements are required. Grab samples should be collected where sufficient turbulence exists in the tributary stream to ensure a representative sample. Where flow is less turbulent, special collection methods should be used.
3. Water samples should be analyzed for:
   - total phosphorus,
   - dissolved reactive phosphorus,
   - total Kjeldahl nitrogen,
   - nitrite + nitrate nitrogen, and
   - suspended solids.

Analytical methods used shall be those described in Chapter 3 of this manual.

control programs. Many attempts to document the reduction of nutrient and sediment loadings from implementation of watershed controls have been unsuccessful because monitoring programs were too limited and of too short a duration to provide accurate data.

By their nature, Clean Lakes Phase II post-project watershed monitoring strategies are rarely comprehensive enough to provide these data, nor should they be. The best use of funds available during project implementation is to assure proper completion of the project. Nonetheless, where good pre-project data exist, where a comprehensive monitoring network is in place, and where local interest is high, finding a way to continue data acquisition should be a high priority.

The following brief discussion describes some of the methods used by researchers to document the effectiveness of various watershed control measures and provides general background information on the level of effort required.

[1] Normally, the major tributary to the lake will be sampled. Where significant differences exist between subwatersheds (e.g., heavily urbanized versus agriculture-dominated) or for lakes having complex planimetric configurations, an additional site or sites can be of value. Selection of sampling sites will always be aided by evaluating Phase I information.

■ **Design Considerations for Comprehensive Watershed Monitoring.** Several researchers have described the watershed design criteria necessary to quantify watershed loading changes. Spooner et al. (1985) identified three basic experimental designs for watershed monitoring (before and after, above and below, and paired watersheds) and described the advantages and disadvantages of each.

Reckhow et al. (1980) identified considerations necessary for designing a sampling program and for analyzing data. They observed that, with the understanding that water quality varies in time and space as a function of many macroscopic and microscopic processes, water quality data series may be

- autocorrelated
- censored (due to observations below detection limits)
- non-normally distributed
- irregularly spaced in time (perhaps because of missing values) and
- subject to trends or seasonal patterns.

When considering selection of a statistical method for analysis of stream data, it is important to consider these characteristics along with the assumptions inherent to a particular statistical method. The Neuse River case study in Chapter 7 provides an example of how these factors can be considered during the development of a future monitoring strategy.

In some cases, such as where wasteload allocations are being made, the analytical tools selected to evaluate lake response to nutrient loadings will define data requirements. In these situations, more detailed guidance can be found in Chapter 2 of EPA's *Technical Guidance Manual for Performing Waste Load Allocations*, Book IV: *Lakes and Impoundments* (U.S. Environ. Prot. Agency, 1983).

Associated with most monitoring sites are continuous stage recorders and automatic water samplers programmed to collect samples on a time-series or flow-proportioned basis. Data summations that relate stage and rating curve information to provide a continuous record of flow are usually computer-generated. Loadings are developed with integration techniques after water quality data have been obtained over a wide range of flow events.

It is expensive to obtain this type of quality information. For example, the cost to monitor a single, easily accessible site can range from $10,000 to $30,000 per year. Since several years of record and more than one site are normally needed, the cost to monitor just one project often exceeds $100,000.

Streamflow Monitoring

Continuous monitoring of flow is almost always a necessity for a comprehensive watershed monitoring project. The method used to measure flow will depend on the characteristics of the site where flow is to be measured. Tributary stream flow measurement sites are most commonly located on open channels. Usually, the stations installed at these sites incorporate continuous float or pressure gage stage recorders. Where a natural control is used, a rating curve is developed by making several instantaneous flow measurements over a variety of flow rates and noting stage at the time of measurement. Occasionally, control structures with predetermined rating curves, such as broad-crested weirs or flumes, are installed in the streambed. An experienced hydrologist must identify the specific techniques to measure streamflow for each site. Chapter 3 describes the most important of these methodologies in more detail.

Sub-watershed conditions are often characterized by instantaneous measurements.

Additional detail on sub-watershed variability and conditions is often obtained by supplementing continuous flow record stations with instantaneous flow measurements on upstream tributary sites. To account for year-to-year variability, both watershed and subwatershed sites are normally monitored over a period of several years.

In most cases, the use of automatic sample collectors is necessary to ensure collection of storm event flow data.

Characterization of Constituent Concentrations in Streamflow

In most cases, the use of automatic sample collectors is necessary to ensure collection of storm event flow data; this is especially true for urban runoff sites. Only larger, more stable river systems can be adequately characterized by manual sample collection.

Methods for obtaining representative samples are site-specific. In streams exhibiting stratified conditions or longitudinal variability, special compositing techniques must be used. Similarly, when automatic sampling stations are installed, correction factors must be developed as most samplers will have a fixed sample intake location that may or may not be representative of overall stream conditions. Chapter 3 describes appropriate sampling techniques in more detail.

Watershed Inventories

. . . even the most complete monitoring station defines only an average of the conditions upstream of the monitoring site.

Without supplementary information on watershed conditions, even the best, most comprehensive tributary stream database will be of little value. Description of watershed conditions, such as that which might be obtained from a Level I watershed inventory, is always a component of a comprehensive watershed monitoring strategy. It must also be noted that even the most complete monitoring station defines only an average of the conditions upstream of the monitoring site.

Interpretation of Tributary Stream Data

The following sections describe methodologies often used in both limited and comprehensive watershed tributary stream data collection programs. Intermittently collected tributary stream concentration data can be interpreted in several ways. Tributary concentration data can be used to

- calculate loadings if combined with streamflow data,
- evaluate transport mechanisms, and
- analyze and assess nutrient and sediment sources.

In some instances, loading calculations will be warranted and insights into transport mechanisms may be possible, although results of such calculations must be used cautiously. Generally, a further understanding of pollutant sources will be the most valuable information obtained from a limited watershed sampling program and, in some cases, trends may be detected. Clearly, the best information will be obtained from sampling programs continued over several years.

Loading Calculations

Estimation of loadings to lakes is the most common use of streamflow concentration data. Unfortunately, inappropriate techniques are all too often used to calculated these loadings. Frequently, loadings are derived by using the product of the arithmetic average nutrient or sediment concentrations and the arithmetic average flow rate. This method should be avoided, as it will almost always underestimate loadings where storm-generated events are important.

Walker (1987) concluded that the flow-weighted concentration combined with average flow is the best estimator when concentration does not vary greatly with flow. Verhoff et al. (1980) found that a flow interval method relating phosphorus flux to streamflow provides the best fit to the tributary data they evaluated.

When continuous flow information is available, an integration technique has been favored by the U.S. Geological Survey for load calculations. Walker (1987) developed an excellent software package (called FLUX) that allows easy calculation of loadings by use of several different techniques.

An example of the mid-interval technique (Porterfield, 1972), which is a method commonly used where noncontinuous data have been obtained, is described below.

■ **Mid-Interval Technique.** A better method than using arithmetic averages, and one that can be simply explained to others, is to assign representative sample data to corresponding flow data. Although this method is still very limited in its ability to describe loads because of an inability to yield an estimate of precision, it can be used to provide insight into watershed conditions.

In the simplest calculations, the measurement of concentration is combined with the streamflow measurement made during sample collection to calculate an instantaneous loading which is then assumed to characterize the tributary transport over a certain time interval associated with that sample. Generally, the time interval used is equivalent to one-half the time interval between that sample and the preceding sample plus one-half the time interval between that sample and the following sample. Multiplying the instantaneous loading for each sample by the time interval for each gives a total load for the time period associated with that sample. Summing the total loads for all the individual samples yields the total load for the time period covered by the sampling program. Expressed as a formula this procedure is:

$$\text{Total Load} = \text{Sum } C_i Q_i T_i$$

where

C_i = concentration of the ith sample

Q_i = instantaneous discharge when sample was collected and

T_i = the time interval associated with the ith sample.

Again, as a caution, loading information calculated from an intermittent sampling program must be used carefully, as nonpoint source generated loadings are very dependent on storm events.

■ **Time-Weighted Mean Concentrations.** When samples are collected over a uniform, fixed interval, average concentrations can be determined by directly averaging concentrations since each sample characterizes the stream for the same length of time. When samples are not collected on a regular basis or are collected over storm events, individual samples do not characterize the stream for equal lengths of time. Therefore, to estimate the average concentration, each sample has to be weighted according to the length of time it is used to represent the stream system. Time weighted mean concentrations (TWMC) are calculated by:

$$\text{TWMC} = (\text{Sum } C_i T_i)/(\text{Sum } T_i)$$

where

C_i is the concentration of the ith sample and

T_i is the time period for which the ith sample is used to characterize the stream concentration. It is equal to one-half the time interval between the samples immediately preceding and following the ith sample.

Time-weighted mean concentrations are of most value to analysts interested in the exposure of biota to particular pollutants; for instance, where exposure to organisms living in a stream reach is important, and where the corresponding flow rate is unimportant. Analysts concerned with lake water quality usually do not use average concentration information, since this technique will not provide good loading estimates.

■ **Flow-Weighted Mean Concentrations.** Where total loadings are of concern (as they are in most lake studies), average concentrations are estimated by weighing the individual samples with their associated flows. The resulting average concentration is referred to as a flow-weighted mean concentration (FWMC) and is equivalent to the total load divided by the total discharge for the period of interest. The FWMC is calculated by

$$FWMC = (\text{Sum } C_i T_i Q_i)/(\text{Sum } T_i Q_i)$$

where

C_i is the concentration of the ith sample and

T_i is the time period for which the ith sample is used to characterize the stream concentration. It is equal to one-half the time interval between the samples immediately preceding and following the ith sample.

Q_i is the instantaneous discharge at the time of the ith sample.

Source Analyses

Where different tributaries or sub-basins are sampled, order of magnitude differences can sometimes be observed, leading to identification of unknown nutrient or sediment sources.

Where different tributaries or sub-basins are sampled, order of magnitude differences can sometimes be observed, leading to identification of unknown nutrient or sediment sources. This source identification should have occurred during the Phase I study phase. However, since watershed and hydrologic conditions constantly change, one can never be completely confident that all potential sources have been adequately identified and characterized.

The following interpretive procedure was described by Baker (1988) and can be used to define the relative significance of point source discharges versus nonpoint source contributions. In some cases, this procedure can also be used to define the significance of groundwater contributions.

■ **Comparisons of Flow-Weighted and Time-Weighted Mean Concentrations.** There are often considerable differences between the FWMCs and the TWMCs when nutrient and sediment information is being analyzed. FWMC to TWMC ratios greater than 1 indicate that the concentrations are increasing with increasing discharge—suggesting important nonpoint source pollutants.

Where significant point sources are present in the watershed, the concentrations of pollutants tend to decrease with increasing stream flow as dilution plays a greater role. FWMC to TWMC ratios less than 1 suggest important point source contributions.

FWMC and TWMC ratio analyses are an example of a simple comparative method used to evaluate differences between watersheds and to identify the relative importance of different pollutant sources.

■ **Regression Analysis.** Flow and concentration data can be plotted to determine if there is a deterministic relationship and, if one is found, a flow-concentration regression model can be fitted (Walker, 1987). This type of regression

Phosphorus concentrations in streams will decrease with increasing flows where point sources dominate.

analysis provides similar information on the relative importance of point- and non-point-derived pollutants. In general, phosphorus concentrations in streams will decrease with increasing flows where point source contributions are important; where nonpoint sources dominate, phosphorus concentrations will generally increase with increasing flows. Subsequent analyses, if desired, can then be made on regression model residuals.

■ **A General Approach to Water Quality Monitoring Design.** In developing a water quality monitoring design, the following tasks should usually be considered (Hirsch et al. 1982; Reckhow et al. 1989):

1. Examine the historical data for patterns that may be attributed to a previous time trend, a seasonal cycle, or a relationship between streamflow and concentration. These patterns are called "deterministic" because their cause is determined, or known.

2. In each case, use the data to describe the deterministic pattern mathematically, with a simple deterministic mathematical equation.

3. Subtract, or remove, the mathematical estimate of each deterministic pattern from the water quality data, leaving a "residual." The residual is the observed water quality concentration minus the water quality concentration predicted using the deterministic mathematical equation.

4. Examine the residuals to ascertain that they are stationary (e.g., that the average and the variability do not change over time) and that they lack persistence (i.e., that the residual at any one sampling date is not correlated with the residual a fixed number of time periods apart).

5. If necessary, transform (e.g., take the logarithm of) the residuals to achieve stationarity. If appropriate, characterize the persistence using autocorrelation analyses.

6. Use the residuals to estimate the background variance (noise), correcting for autocorrelation.

7. Finally, use the background variance to define the relationship between the number of samples and the magnitude of the linear trend, again accounting for autocorrelation.

The watershed case study in Chapter 7 describes how this approach was followed in an analysis of a data set obtained from the Neuse River near Smithfield, North Carolina.

Chapter 5

In-lake Restoration Techniques and Monitoring

Summary

1. Different lake restoration techniques require different monitoring considerations.
2. Criteria for interrupting a lake restoration project during the implementation phase are necessary to prevent environmental damage.
3. Each in-lake measurement should have a purpose that is directly related either to project evaluation or to protecting the lake environment from adverse impacts during the treatment phase.
4. This chapter recommends an in-lake monitoring plan for each lake restoration technique independently from the other techniques discussed within this manual, thereby allowing the user to proceed directly to a monitoring plan for a specific project.

Background

Chapter 5 presents appropriate in-lake monitoring designs as they pertain to the most frequently used lake eutrophication and acidification restoration techniques. These specific monitoring plans are designed to be consistent with U.S. Environmental Protection Agency protocol as specified in 40 CFR Part 35 and to offer a standard monitoring approach for evaluating each project's success.

In-lake measurements are needed to evaluate most lake treatments. The parameters that are measured should pertain directly either to evaluating results of the treatment or to protecting the lake environment from adverse effects of treatment. Evaluation should assess not only the effectiveness of the restoration or protection technique but also, more broadly, whether the project as a whole achieves its objectives; therefore, specifications for monitoring are given for each restoration/protection technique. However, only rarely do lake restoration projects consist of only one technique; more often, a combination of two or more techniques are required. Therefore, the suggested monitoring plans may vary according to the individual project needs.

Evaluation should assess not only the effectiveness of the restoration or protection technique but also, more broadly, whether the project as a whole achieves its objectives.

Chapter 5 concentrates on in-lake restoration techniques and monitoring requirements. More often than not, in-lake restoration measures are implemented in close conjunction with watershed protection measures. Watershed monitoring is treated separately in Chapter 4, and long-term monitoring needs, which are implied for most in-lake restoration projects, are discussed in Chapter 6.

Tables 5.1 and 5.2 summarize the lake restoration techniques discussed in this chapter and itemize the relative importance of the most common lake water quality parameters for in-lake measurement during and following treatment. The general role and importance of each parameter in a lake environment are discussed in detail in other documents, particularly *The Lake and Reservoir Restoration Guidance Manual* (U.S. Environ. Prot. Agency, 1988).

The eutrophication section is further divided into techniques designed primarily to control nuisance algae, maintain or increase water depth, or control nuisance plant growth. Discussion of the mode of operation and effects of each technique is limited to facts needed to understand the monitoring approach. More information on the operational aspects of each technique is available from numerous individual publications, but Cooke et al. (1986) have published the most comprehensive review to date.

Table 5.1.—In-lake monitoring during treatment phase*

RESTORATION TECHNIQUE	DO	TEMP	TP	DRP	NH_4-N	NO_{23}-N	TKN	CHL	MACRO	pH	ALK	SD	A	Z	TX
Control Algae															
Alum	e[1]	e	e	e	—	—	—	—	—	e	e	—	—	—	e
Dilution/flushing	—	—	e	e	e	e	e	—	—	—	—	—	—	—	—
Aeration/circulation	e	e	—	—	—	—	—	—	—	—	—	—	—	—	—
Hypolimnetic aeration	e	e	—	—	—	—	—	—	—	—	—	—	—	—	—
Hypolimnetic withdrawal	e	e	e	e	e	—	—	—	—	e	—	—	—	—	—
Sediment oxidation	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Food web manipulation	e	e	u[2]	u	u	u	u	e	u	—	—	e	—	e	e
Increase Depth															
Dredging	e	e	e	e	e	—	—	e	—	e	—	e	—	—	—
Control Nuisance Aquatic Plants															
Drawdown	e	e	—	—	—	—	—	—	—	—	—	—	—	—	e
Harvesting and sediment tilling	u	u	u	u	—	—	—	e	e	—	—	e	—	—	—
Chemicals	e	e	u	u	u	u	u	e	e	—	—	e	—	—	e
Grass carp	e	e	u	u	u	u	u	e	e	—	—	e	—	—	e
Mitigate Acidic Conditions															
In-lake liming	e	e	—	—	—	—	—	—	—	e	e	—	—	—	e
Watershed liming	u	e	—	—	—	—	—	—	—	e	e	—	—	—	e

*This monitoring is independent of the monitoring done during a Phase I diagnostic/feasibility study.
[1]"e" represents essential water quality parameters
[2]"u" represents useful but nonessential water quality parameters
Abbreviations: DO = dissolved oxygen; TEMP = temperature; TP = total phosphorus; DRP = dissolved reactive phosphorus; NH_4-N = ammonium nitrogen; NO_{23}-N = nitrite + nitrate nitrogen; TKN = total Kjeldahl nitrogen; CHL = chlorophyll a; MACRO = macrophytes; ALK = alkalinity; SD = Secchi disk; A = algae; Z = zooplankton; TX = see text for specific parameters

Table 5.2.—In-lake monitoring following treatment phase*

RESTORATION TECHNIQUE	DO	TEMP	TP	DRP	NH_4-N	NO_{23}-N	TKN	CHL	MACRO	pH	ALK	SD	A	Z	TX
Control Algae															
Alum	e[1]	e	e	e	—	—	—	e	u[2]	e	e	e	—	—	e
Dilution/flushing	e	e	e	e	e	e	e	e	u	—	—	e	—	—	—
Aeration/circulation	e	e	u	u	u	u	u	e	u	e	—	e	e	—	—
Hypolimnetic aeration	e	e	e	e	e	u	u	e	u	—	—	e	—	—	e
Hypolimnetic withdrawal	e	e	e	e	e	u	u	e	u	e	u	e	—	—	—
Sediment oxidation	e	e	e	e	e	e	—	e	u	e	e	e	—	—	e
Food web manipulation	e	e	u	u	u	u	u	e	u	—	—	e	—	e	e
Increase Depth															
Dredging	u	u	u	u	—	—	—	u	e	—	—	u	—	—	e
Control Nuisance Aquatic Plants															
Drawdown	u	u	u	u	—	—	—	e	e	—	—	e	—	—	—
Harvesting and sediment tilling	u	u	u	u	—	—	—	e	e	—	—	e	—	—	—
Chemicals	e	e	u	u	u	u	u	e	e	—	—	e	—	—	—
Grass carp	e	e	u	u	u	u	u	e	e	—	—	e	—	—	e
Mitigate Acidic Conditions															
In-lake liming	e	e	—	—	—	—	—	e	—	e	e	e	—	—	e
Watershed liming	e	e	—	—	—	—	—	e	—	e	e	e	—	—	e

*This monitoring presumes that, in many cases, comparable data were collected during a Phase I diagnostic/feasibility study.
[1]"u" represents useful but nonessential water quality parameters
[2]"e" represents essential water quality parameters
Abbreviations: DO = dissolved oxygen; TEMP = temperature; TP = total phosphorus; DRP = dissolved reactive phosphorus; NH_4-N = ammonium nitrogen; NO_{23}-N = nitrite + nitrate nitrogen; TKN = total Kjeldahl nitrogen; CHL = chlorophyll a; MACRO = macrophytes; ALK = alkalinity; SD = Secchi disk; A = algae; Z = zooplankton; TX = see text for specific parameters

OBJECTIVE:

Control Nuisance Algae

Summary

1. The following techniques for algal control and suggested monitoring plans are discussed: nutrient precipitation/inactivation, artificial circulation, hypolimnetic aeration, hypolimnetic withdrawal, dilution/flushing, food web manipulation, and sediment oxidation.

2. The common elements of a sampling design throughout most of the techniques are total phosphorus, dissolved reactive phosphorus, chlorophyll *a*, dissolved oxygen, temperature, and Secchi depth.

An overabundance of nuisance algae is one of the most common symptoms of accelerated eutrophication in lakes. Direct impairments from these infestations include elevated turbidity in the water, occasional release of toxins, and lastly, taste and odor problems, which are particularly troublesome for waterbodies that serve as water supply reservoirs. Indirect impairments include accumulation of decaying biomass that results in lowered dissolved oxygen in the water, muck accumulation, and adverse changes to the fish community.

Nuisance algal growths in lakes result in large part from excessive supplies of nutrients, although other factors may contribute to the problem. Techniques to counter these growths are usually directed toward reducing the supply of nutrients to the lake. In particular, these techniques target phosphorus, since it is the nutrient that can be practically controlled to limit the growth of nuisance algae.

The techniques enumerated in this section are those that have become "standard" through repeated testing and successful use. A small number of less-tested techniques developed since the start of the Clean Lakes Program are not included here.

CONTROL TECHNIQUE #1:

Phosphorus Precipitation/Inactivation with Alum

Technical Considerations

The addition of aluminum salts (aluminum sulfate or sodium aluminate) is a proven lake restoration technique for controlling algal growth by creating a nutrient-limiting environment. The technique is straightforward and relies upon the affinity of aluminum complexes for phosphorus.

Alum, as aluminum sulfate is called, is usually applied in liquid form. Once the alum mixes with lake water, it quickly becomes aluminum hydroxide. Dissolved phosphorus adsorbs to the aluminum hydroxide, which precipitates toward the lake sediments and sweeps the water clean of phosphorus. Upon reaching a den-

Aluminum sulfate is effective on hard water lakes to control sediment phosphorus release.

Sodium aluminate and aluminum sulfate are used together to treat softwater lakes

sity equilibrium in the lake's sediments, the aluminum hydroxide forms a barrier that sorbs phosphorus, thereby greatly reducing its transport from the sediments to the overlying waters.

Liquid aluminum sulfate exists as an acidic medium (sulfuric acid); when added to the water, it will consume a portion of the acid neutralizing capacity (alkalinity) of a lake. Therefore, the pH and alkalinity of the lake must be measured as the alum is being applied. Aluminum hydroxide forms best when the lake water has a pH of 6 to 8. If the pH falls below 6, dissolved elemental aluminum, which is toxic to lake biota, becomes the dominant form.

Alum application to hardwater lakes is, depending upon the amount applied, less likely to significantly lower pH. The application of aluminum salts to softwater lakes is of much greater concern. The usual technique is to mix aluminum sulfate with sodium aluminate to buffer the acidity. Sodium aluminate is the preferred buffer rather than a carbonate salt because it allows more aluminum hydroxide formation and, therefore, has more potential to remove phosphorus.

The use of alum should not be considered unless phosphorus loading from the watershed has been reduced to acceptable levels.

Monitoring During Treatment

The most important parameters to monitor during the addition of alum are pH, alkalinity, dissolved aluminum, dissolved oxygen, and temperature. The utility of measuring phosphorus depends upon how long treatment takes. For example, if the actual application takes from one day to two weeks, it is unlikely that the results of a phosphorus analysis will be available in time to serve any useful purpose during the treatment period. If the application time is longer than two weeks, then phosphorus should be included as a measured parameter.

The major variable associated with the sampling design is application technique. There are two basic application techniques for alum: surface and deepwater applications. Table 5.3 gives the recommended specifications for in-lake monitoring during an alum treatment.

Considerations for Interrupting Treatment

Considerations for interrupting an alum treatment should include the following criteria:

1. **Surface Application:**
   - If the pH of the treated surface water is 6.0 or less, or
   - If the pH of the surface water changes by more than 2 standard units.

2. **Deepwater Application:**
   - If the pH of the water at 6 feet above or below the application depth is 6.0 or less, or
   - If the pH of the water at 6 feet above or below the application depth changes by more than 2 standard units.

A variety of other factors can be considered in making a final judgment to stop or allow an alum treatment. For example, if deepwater alum application is the method of treatment, the volume of water above the application depth may be more than sufficient to neutralize any added acidity. The change in acidity and dissolved aluminum may exist only until the treated area mixes with the overlying waters.

Table 5.3.—In-lake sampling design during alum treatment

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location(s)*
   Water samples should be collected at the site(s) selected by the project manager, usually at the center of the lake.

2. *Depth Distribution*
   Samples should be collected at 6-foot intervals from just below the surface to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.

3. *Analytical Determinations and Sampling Procedures*
   (a) If the alum application takes less than two weeks, measure pH and alkalinity.
   (b) If the alum application takes longer than two weeks, measure pH, alkalinity, dissolved aluminum, total phosphorus, and dissolved reactive phosphorus.

4. *Frequency and Duration*
   (a) If the alum application takes less than two weeks, sample every day.
   (b) If the alum application takes longer than two weeks, samples should be collected as follows:
   - pH: sample daily
   - alkalinity: sample daily
   - dissolved aluminum: sample once per week and
   - total phosphorus and dissolved reactive phosphorus: once every two weeks.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at weekly intervals.

In general, dissolved aluminum should not exceed 50 μg/L.

The water residence time of the lake is another factor. If the lake volume is exchanged rapidly (one to two times a month), then the effect of lower pH and higher dissolved aluminum may be less on local fauna; the effect on downstream fauna should be considered, however.

The criteria for interrupting an alum treatment are based upon the toxic effects of dissolved aluminum. It is generally agreed that concentrations of dissolved aluminum greater than 50 μg/L can adversely affect trout (Freeman and Everhart, 1971). However, the laboratory turnaround time for aluminum analysis is frequently too long to allow a decision to be made before an alum application is completed. The pH of the lake water dictates the chemical form of aluminum, and a pH of less than 6 drives the formation of dissolved aluminum in the water. Therefore, the criteria for stopping an alum project are based upon the pH of the lake water. Nevertheless, dissolved aluminum concentrations should be recorded in the event that a change is later observed in the biota of the lake. Although this has never been reported in the literature for an alum-treated lake, lake acidification research suggests that dissolved aluminum is one of the elements associated with the demise of acidified lakes' game fisheries.

Example—Wisconsin's Long Lake

Long Lake, one of the first softwater lakes treated with a combination of aluminum sulfate and sodium aluminate, was given a surface application in May 1972. The project was useful in demonstrating the feasibility of using an aluminum sulfate/sodium aluminate mixture to treat softwater lakes without seriously affecting the pH and alkalinity. Table 5.4 (unpublished data from the Wisconsin Department of Natural Resources) presents the pH and alkalinity data before and after the treatment.

Table 5.4.—Alkalinity and pH during alum treatment of Long Lake

DEPTH (ft)	1 DAY BEFORE TREATMENT ALKALINITY (mg/L)	pH (SU)	1 HOUR AFTER TREATMENT ALK. (mg/L)	pH (SU)	3 HOURS AFTER TREATMENT ALK. (mg/L)	pH (SU)	1 DAY AFTER TREATMENT ALKALINITY (mg/L)	pH (SU)
0	7.0	6.5	7.5	6.7	7.5	6.7	5.0	7.0
3	7.0	6.1	12.0	7.1	8.5	6.9	6.0	7.2
6	7.0	6.0	12.0	7.2	7.5	6.8	6.0	7.1
9	7.0	5.9	10.0	7.1	7.0	6.8	6.0	7.0
12	7.0	5.9	9.0	7.0	6.5	6.8	6.0	7.0

When the criteria for interrupting treatment are applied to the data collected for Long Lake, it is evident that application of alum was environmentally acceptable. The pH of Long Lake surface water was 6.5 at the time of treatment. One hour after treating a particular segment of the lake, the pH rose to 6.7. The change of 0.2 of a pH unit was well within the limits of acceptability. The treatment was successful, and the project proceeded without any problems.

The purpose of an alum treatment is to achieve a reduction in algal abundance by lowering the phosphorus concentration in the lake.

Monitoring Following Treatment

The purpose of an alum treatment is to achieve a reduction in algal abundance by lowering the phosphorus concentration in the lake. Success is defined by decreased algal standing crop (commonly measured by chlorophyll *a*) and phosphorus concentration following the treatment.

The most important phosphorus species to measure is total phosphorus, but a variety of other forms of phosphorus are present in the lake: total dissolved phosphorus, dissolved reactive phosphorus, and particulate phosphorus. Chapter 3 contains a more detailed description of phosphorus forms and analytical techniques.

Total phosphorus must be measured to help demonstrate project success. Total phosphorus measurements include the sum of the total dissolved organic and inorganic forms and the total particulate organic and inorganic forms. An alum treatment should affect the dissolved inorganic form of phosphorus (dissolved reactive phosphorus) by direct sorption on the aluminum hydroxide gel.

Mirror Lake—a successful lake treatment with alum.

Figure 5.1 illustrates the impact of an alum treatment on both total and dissolved reactive phosphorus concentrations in Mirror Lake, Wisconsin, which was treated with alum in May 1978. The project was successful, in part because the external phosphorus loading to the lake was reduced to acceptable levels before treatment (Knauer and Garrison, 1980).

An immediate reduction in the particulate phosphorus below the depth of application is usually evident after alum addition because the phosphorus is physically entrapped by the aluminum hydroxide floc settling through the water column. For example, the phosphorus sedimentation rate in Mirror Lake went from 9 mg/m^2/day just prior to an alum treatment to 77 mg/m^2/day during the alum treatment as a result of the descending alum floc sweeping the water of both particulate phosphorus and the sorbed dissolved reactive phosphorus.

The use of alum will not affect the nitrogen compounds in the lake, however. Unless there is other interest in nitrogen, there is no need to measure the various forms present in a lake treated with alum.

Alkalinity and pH are necessary chemical measurements that should be continued following application of alum. These two measurements are taken to detect adverse environmental conditions that can occur with the addition of the strong acid associated with alum and can assist the lake manager in either ruling out or considering alum as the cause. If adverse environmental lake conditions such as low dissolved oxygen develop during the post-project monitoring and produce a

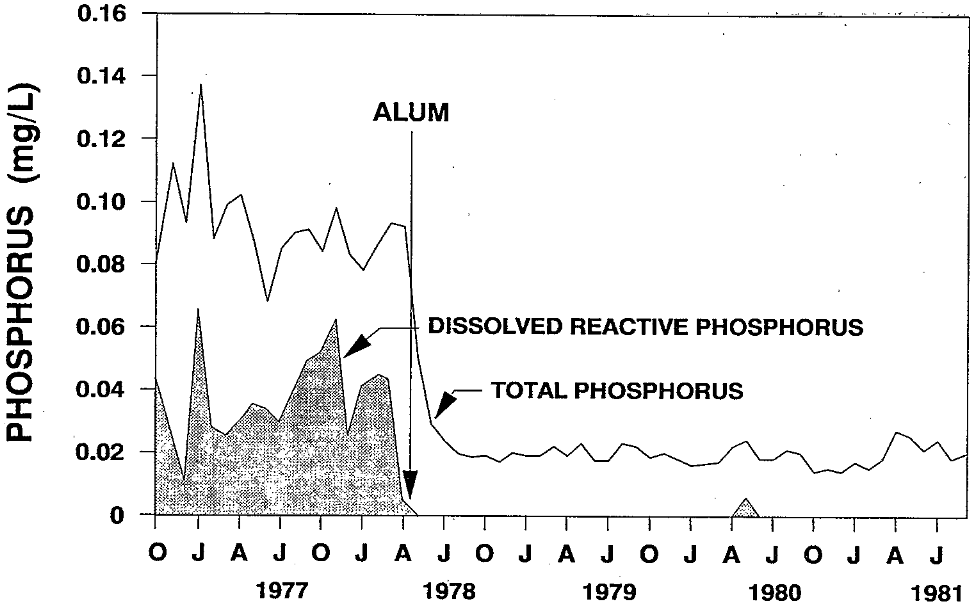


Figure 5.1—Total phosphorus and dissolved reactive phosphorus in Mirror Lake, 1977-81.

summer fish kill, these data will be necessary to determine the cause of the event. Otherwise, alum additions will automatically be blamed for any adverse lake problems that occur after treatment.

Dissolved oxygen and temperature profiles should also be measured. These calculations are needed to determine the occurrence of anoxia in the hypolimnion, the length of time the lake remains thermally stratified, and the timing of complete lake mixing.

Pickerel Lake—why alum treatment did not work.

The seasonal timing of lake mixing was an important consideration in determining why an alum treatment did not work at Pickerel Lake, a shallow waterbody in Wisconsin that was treated with alum in April 1973 during the spring overturn. The lake was thermally stratified by mid-May and remained stratified until late July through early August. Between late July and mid-September, Pickerel Lake alternatively mixed and stratified (Figure 5.2). During this time period, clumps of blue-green algae were resuspended from the bottom sediments and, because of favorable warm weather, a massive bloom occurred during August and September (Knauer and Garrison, 1980).

The addition of alum to Pickerel Lake was very effective in controlling phosphorus and algal biomass from the spring addition until the lake mixed in midsummer; at that time, however, the lake experienced algal blooms of a greater magnitude than the previous year. In the final analysis, the driving force behind Pickerel Lake productivity was the time of summer mixing; therefore, the alum treatment was of little value.

Documenting changes to macrophyte communities is useful in that the improved water clarity caused by an alum treatment can stimulate undesirable macrophyte growth in shallow areas of the lake. Table 5.5 outlines a detailed plan for in-lake monitoring following alum treatment.

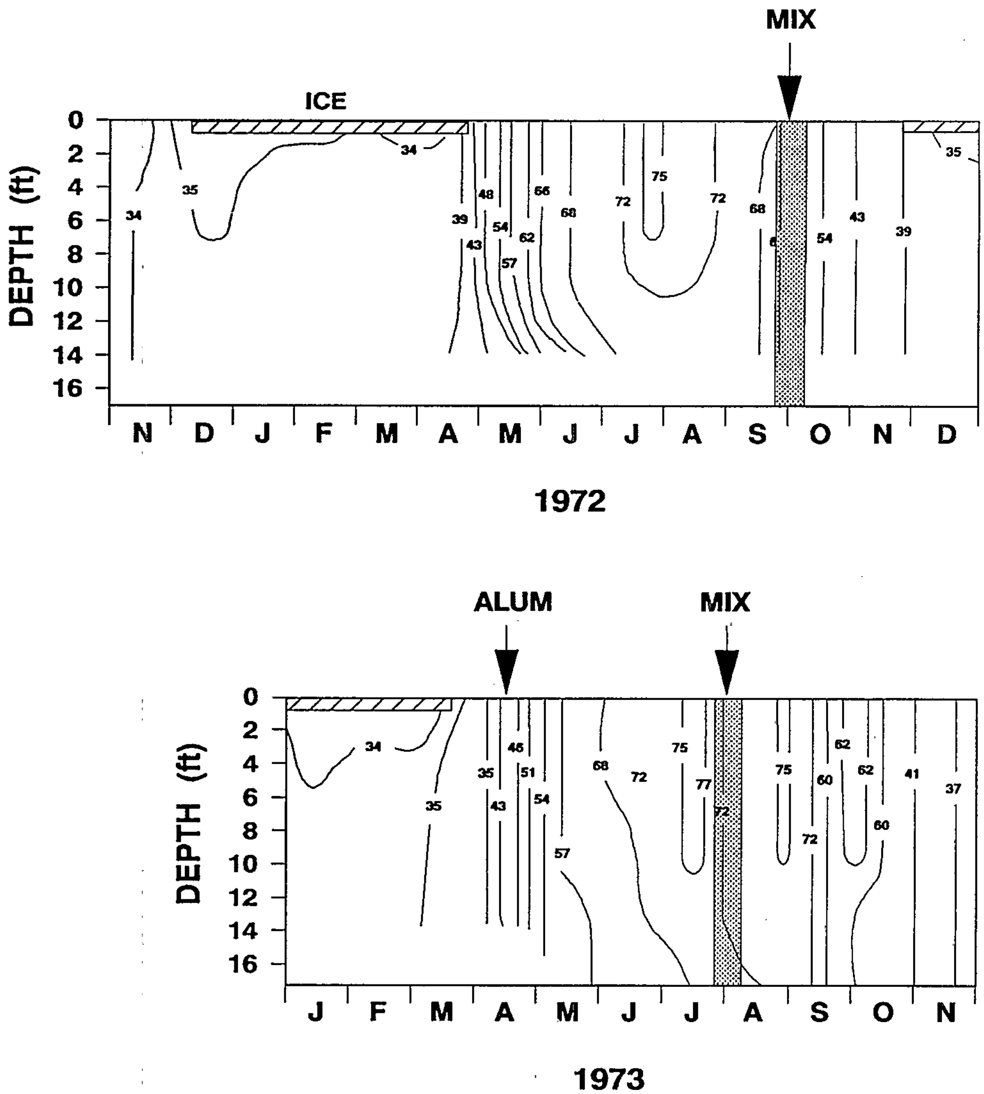


Figure 5-2.—Temperature measurements in Pickerel Lake, 1971-72.

CONTROL TECHNIQUE #2:

Dilution/Flushing

Technical Considerations

Dilution *needs a source of low nutrient water.*

This technique is actually two separate lake restoration practices that are often combined to achieve improved water quality. Dilution involves the addition of low nutrient waters to a lake or reservoir. To be effective, the low nutrient water additions should reduce in-lake nutrient concentrations, thereby reducing algal quantities.

Flushing *needs to be fast enough to wash algal cells from the lake before*

Flushing is a physical process related directly to an increase in the flushing rate of a lake or reservoir. If the increase in flushing rate is sufficient, an increase in algal cell washout can be expected, thereby decreasing algal biomass within the system.

Both systems work together to reduce algal densities. The technique was used effectively in Green Lake, Washington (Oglesby, 1969), where sufficient quantities

Table 5.5.—In-lake monitoring design following alum treatment

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location(s)*
   Water samples should be collected at the site(s) selected by the project manager, usually at the center of the lake.
2. *Depth Distribution*
   Samples should be collected at 6-foot intervals from just below the surface to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.
3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for alkalinity, pH, total phosphorus, dissolved reactive phosphorus, and dissolved aluminum. Note: dissolved aluminum may be discontinued if two consecutive samples are below 50 µg/L. See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Samples should be collected at monthly intervals for a minimum period of two years following treatment.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determination and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for water chemistry.

C. Secchi Disk Transparency

1. *Sampling Location*
   Same as for water chemistry.
2. *Frequency and Duration*
   Measurements should be made at monthly intervals during the growing season (May through October) for a minimum of two years following treatment.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determination and Sampling Procedure*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for Secchi disk.

of low nutrient water were available from Seattle's potable water supply. Reduced algal biomass in Green Lake was attributed to a reduction of in-lake phosphorus concentrations and increased cell washout.

In another Washington project, Moses Lake received dilution water from the Columbia River and showed a substantial improvement in water quality during the periods of water additions (Welch, 1979). Algal reduction was attributed to a lowering of inorganic nitrogen concentrations and cell washout.

While it is possible that other factors may have contributed to the lower biomass of blue-green algae in these lakes—e.g., iron limitation (Welch and Patmont, 1980)—it should be noted that in both cases when the dilution water was discontinued, the lake water quality reverted back to the original pretreatment conditions.

Monitoring During the First Two Weeks of Treatment

The success of a dilution/flushing project is dependent upon a source of low nutrient water in amounts that allow a substantial increase in the lake flushing rate. In most cases, the input of new water must continue throughout the growing season. The protocol described in Table 5.6 addresses monitoring only of the additional waters during the first two weeks of operation.

Table 5.6.—Monitoring design for the first two weeks of a dilution/flushing project

MONITORING THE ADDITION WATERS

PHYSICOCHEMICAL

A. Flow Measurement

Continuous flow measurements should be made throughout the two-week period at the outlet of the conduit that delivers the dilution/flushing waters to the lake. Flows should be estimated and reported on a daily basis. See Chapter 3 for appropriate flow measurement techniques.

B. Water Chemistry

A sample should be collected on a daily basis during the two-week period from the outlet of the conduit that delivers the dilution/flushing waters to the lake. The samples should be analyzed for

- Total phosphorus
- Dissolved reactive phosphorus
- Total Kjeldahl nitrogen
- Nitrite + nitrate nitrogen and
- Ammonium nitrogen.

IN-LAKE MONITORING

No inlake monitoring is necessary during the first two weeks of a dilution flushing project.

The most important parts of the treatment to measure are the inflow volume and nutrient concentrations within the dilution waters, two factors that will determine treatment effectiveness. The rationale for these measurements is based upon the impact of the dilution water on the receiving water. If the algal assemblage in the lake is phosphorus or nitrogen limited, the addition of a rate-limited nutrient may actually stimulate algal growth unless the washout rate is sufficiently increased.

In addition, the dilution process depends upon a low concentration of incoming nutrients to effectively dilute the higher concentration in the lake. The flow rate is needed to calculate the washout process and the mass of incoming nutrients. For example, using the equation

$$P = \frac{L}{Zp} \bullet \frac{1}{1 + 1/\sqrt{p}} \qquad \text{(Vollenweider, 1976)}$$

to calculate the steady state phosphorus concentration in a lake, where

P = phosphorus concentration in mg/L,

L = phosphorus load in g/m^2/yr,

Z = mean depth of lake in meters, and

p = the flushing rate in times per year,

and using a phosphorus loading rate, L, of 0.12 g/m^2/yr, a mean depth, Z, of 5 m, and a flushing rate of 0.25/yr, the calculated phosphorus concentration in the lake is 0.032 mg/L. If, in this example, the flushing rate is increased 4 times to accommodate a dilution/flushing experiment, but the phosphorus load is also increased 4 times, then the expected new concentration in the lake is approximately 0.048 mg/L.

This new concentration is unacceptable. The phosphorus concentrations associated with the dilution/flushing water in association with the volume of new water must not produce an expected higher phosphorus in-lake concentration. However, if the phosphorus loading is only doubled and the flushing rate is increased 4 times, the expected in-lake phosphorus concentration would be approximately 0.024 mg/L. Using this scenario, an improvement in the trophic condition of the lake is realized.

The rate of delivery of the source water will determine cell washout.

In the case of Moses Lake, the portion of the lake that was of concern, Parker Horn, received 10 percent of the lake volume per day during one summer. This flushing rate produced a lower algal biomass, probably as a result of cell washout. A simple description of cell washout is given by the following equation:

$$dx/dt = Kx - Dx$$

where

K = algal growth rate,

x = biomass, and

D = dilution rate.

Algal cell washout needs a rapid exchange of the lake water, e.g., every 3-10 days.

K, the algal growth rate, will vary between algal species and within species depending upon environmental conditions (e.g., herbivore population, sinking rates).

A reported doubling time for the blue-green alga, *Aphanizomenon flos-aqua*, during a growth phase was once every three days (Healey and Hendzel, 1976). For cell washout to limit biomass, the photic zone of the lake should be flushed at least once every three days. If consideration is given to a slower growth rate because of cooler dilution waters, algal sinking velocities, and predation, the 10-day flushing rate for Parker Horn certainly could include a cell washout process.

Considerations for Interrupting Treatment

The treatment should not increase the nutrient concentration of the target lake or reservoir once the project has begun. Other factors such as pH and heavy metal concentrations of the addition water should not create an unfavorable aquatic environment.

Dilution/flushing should be discontinued under the following conditions:

1. The phosphorus and/or nitrogen concentration of the addition waters are higher than the target lake average volumetric growing season concentrations in the photic zone.

2. The combination of inflow water volume and phosphorus concentrations produce an expected higher concentration in the lake based on phosphorus loading models.

It is assumed that potential hazardous materials (e.g., pesticides and heavy metals) in the addition waters were considered in the Phase I portion of the project.

Monitoring Following the First Two Weeks of Treatment

The monitoring plan described in Table 5.7 is designed to evaluate dilution/flushing water and lake water following the first two weeks of treatment. Documenting changes to macrophyte communities provides useful secondary information as they may respond to increased clarity following project implementation.

Table 5.7.—Monitoring design following the first two weeks of a dilution/flushing project

MONITORING THE ADDITION WATERS

PHYSICOCHEMICAL

A. Flow Measurement

Continuous flow measurements should be made at the outlet of the conduit that delivers the dilution/flushing waters to the lake. Flows should be estimated and reported on a daily basis. See Methods Chapter for appropriate flow measurement techniques.

B. Water Chemistry

A sample should be collected on a weekly basis from the outlet of the conduit that delivers the dilution/flushing waters to the lake. The samples should be analyzed for:

- Total phosphorus
- Dissolved reactive phosphorus
- Total Kjeldahl nitrogen
- Nitrite + nitrate nitrogen
- Ammonium nitrogen
- Temperature
- Dissolved Oxygen

IN-LAKE MONITORING

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location(s)*:
Samples should be collected at the site(s) selected by the project manager, usually at the center of the lake.

2. *Depth Distribution*:
Samples should be collected from just below the surface and at 6 foot intervals to the bottom. Care should be taken not to include suspended bottom sediments in the water sample.

3. *Analytical Determinations and Sampling Procedures*:
Total phosphorus, dissolved reactive phosphorus, total Kjeldahl nitrogen, ammonium nitrogen, and nitrite + nitrate nitrogen. See Methods Chapter for appropriate analytical and sampling techniques.

4. *Frequency and Duration*:
Samples should be collected at monthly intervals for the duration of the dilution/flushing project. Data should be obtained for at least a one year period.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location(s)*:
Same as water chemistry.

2. *Depth Distribution*:
Measurements should be made at 3 foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures:*
See Methods Chapter for appropriate analytical and sampling techniques.

4. *Frequency and Duration:*
Same as water chemistry.

C. Secchi Disk Transparency

1. *Sampling Location(s):*
Same as for water chemistry.

2. *Frequency and Duration:*
Secchi disk measurements should be made at monthly intervals for the duration of the dilution/flushing project during the growing season (May through October). Data should be obtained for at least a one-year period.

Table 5.7.—Monitoring design following the first two weeks of a dilution/flushing project (continued)

BIOLOGICAL

A. Chlorophyll *a* (Corrected for Pheophytin)

1. *Sampling Location*:
   Same as Secchi disk.
2. *Depth Distribution:*
   A sub-sample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determination and Sampling Procedure:*
   See Methods Chapter for appropriate analytical and sampling techniques.
4. *Frequency and Duration:*
   Same as Secchi disk.

CONTROL TECHNIQUE #3

Artificial Circulation

Technical Considerations

Artificial circulation of a lake has many uses.

Artificial aeration/circulation is a common method of alleviating the problem of dissolved oxygen depletion and has a long history of use in lakes and reservoirs. This method has been successfully used as a lake restoration technique to prevent fish kills, improve domestic water supplies, and reduce algal biomass, or cause a major shift from nuisance algae (blue-greens) to other algal types (greens). Artificial circulation, however, has had mixed reviews as a method to control algal problems in lakes (Pastorok et al. 1980).

The success of this treatment for algal control is based upon changes in the lake's physicochemical and biological elements. In most cases, artificially circulating a lake increases the concentration of dissolved oxygen in the bottom waters, which influences the redox reactions involving iron and manganese. These elements complex with phosphorus (Mortimer, 1942) and, in part, determine phosphorus inputs from the sediments, thereby reducing nutrient availability to promote algal growth.

Increases in the temperature of the bottom waters as a result of total lake mixing may counteract the redox reactions by stimulating decomposition rates and phosphorus release. Furthermore, an increased zone of oxic water over the sediments in the deep part of the lake may increase the area of habitat for burrowing macroinvertebrates and rough fish (carp) that contribute to phosphorus cycling within the lake system. The use of artificial circulation to control algal biomass by reducing phosphorus cycling from the sediments must consider the impacts of increased habitat for organisms that contribute to increased phosphorus cycling. As with most in-lake treatments, reduction of external phosphorus loads is also important.

Physical mixing can distribute algal cells throughout the entire lake.

The physical mixing of deep lakes may dilute the algal biomass throughout a greater volume of water, thereby increasing water transparency. This occurred during the first year of aeration at Kezar Lake, New Hampshire, where a compressed air system was installed to artificially mix the lake to alleviate a blue-green algal problem (N.H. Water Supply Pollut. Control Comm. 1971). In the first

Other factors that control algal biomass during artificial circulation are changes in pH . . . increases in herbivorous zooplankton . . . and increases in algal virus activity.

year of operation, the compressors were started in July. The concentration of algae at the surface of the lake went from 1×10^6 cells/mL before the compressors were started to 1×10^4 cells/mL within a month of the start of artificial mixing.

This apparent reduction of algal density was misleading, however. If the cell densities were represented as a sum of all cells distributed with depth under the surface of the lake, e.g., cm^2 of lake surface area, then total algal biomass apparently changed very little. Before the start of the compressors, the cell count under a cm^2 of lake surface was 1.5×10^8. After three weeks of circulation, the cell count was $1.0 \times 10^8/cm^2$.

In the second year of operation, the compressors were started in the spring, and the lake was mixed throughout the spring and summer. Under these conditions, nuisance algal problems never developed, and the areal cell densities were much less than the previous year.

Other factors that control algal biomass during artificial circulation are changes in pH (shift in algal species favoring greens), increases in herbivorous zooplankton (increased grazing on algae), and increases in algal virus activity that may reduce blue-greens.

Monitoring During the First Two Weeks of Treatment

The construction phase of an artificial aeration/circulation project begins with equipment installation in the lake and continues through the first two weeks of operation. During this phase, it is important to evaluate the effectiveness of the equipment as well as the lake's responses by carefully monitoring temperature and dissolved oxygen conditions.

Table 5.8 describes an in-lake monitoring design for the first two weeks after the aeration/circulation device is operational.

Table 5.8.—In-lake monitoring design for the first two weeks of an aeration/circulation project

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location(s)*
   Measurements should be made at a site near the aeration/circulation device and at sites 200 feet and at least 1,000 feet away from the air release point.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Measurements should be made at daily intervals for the first two weeks of operation.

Consideration for Interrupting Treatment

The project must account for initial oxygen demand of bottom waters.

The immediate effects of mixing on dissolved oxygen throughout the lake determine whether aeration/circulation should be interrupted. When a lake is artificially mixed, bottom waters high in oxygen demand can be distributed throughout the entire water column, which can result in a lowering of the dissolved oxygen in the entire lake. If the artificial circulation results in an initial dissolved oxygen depletion to a level that threatens the support of game fish (<5 mg/L), the project will have failed to meet its objective.

Figure 5.3 represents an example of an aeration/circulation project that did not take into account the high oxygen demand of the bottom waters. A compressed air

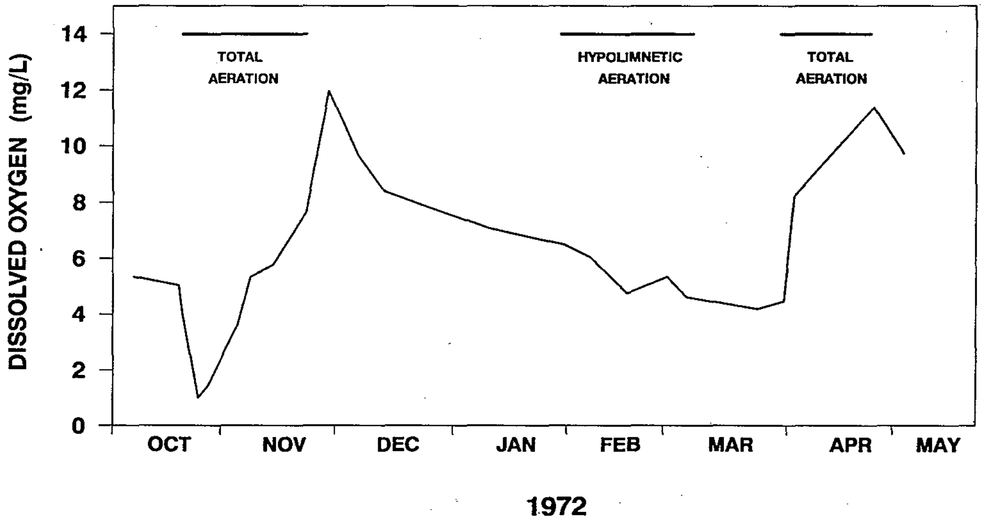


Figure 5-3.—Dissolved oxygen (volume weighted mean) for Mirror Lake, 1971-72. (Note the decrease to 0.9 mg/L when compressed air unit was first started.)

unit was operated from October 19 through November 21, 1972, in Mirror Lake, Wisconsin. The immediate result of destratification was a marked decline in dissolved oxygen to a minimum of 0.9 mg/L. The compressor was operated continuously for nearly two weeks before the dissolved oxygen concentration recovered to 5 mg/L (Smith et al. 1975). The very low dissolved oxygen concentrations had negative biological consequences for the lake.

Beware of undersized lake mixing systems.

Another potential problem associated with complete lake mixing is the possible increase in algal biomass. This possibility exists if the aeration/circulation device is underdesigned and so allows a slow intrusion of bottom waters high in nutrients into the epilimnion, thereby encouraging algal growth.

Consideration should be given to interrupting a whole lake aeration/circulation project if, within the first two weeks of operation, the dissolved oxygen in the top 6 feet is 5 mg/L or less.

Monitoring Following the First Two Weeks of Treatment

An aeration/circulation project is successful if the system design can maintain an acceptable oxic environment in the lake and either reduce algal densities or shift species composition to more desirable algal types, e.g., to greens. The task should be accomplished without adding to the overall problem by increasing algal biomass.

Both temperature and dissolved oxygen are measurable parameters that can be used to evaluate project success. Chlorophyll *a* can be used to determine algal biomass and Secchi disk measurements to determine water clarity. Algae must be identified and counted to determine if algal species change. Measurements of pH are used in combination with algal identification to assist in explaining any changes. Other useful measurements are those designed to evaluate specific project objectives such as nutrient control and creation of a zone of refuge for larger-bodied zooplankton.

A monitoring plan following start-up of the aeration/circulation system, described in Table 5.9, is designed to measure the success of the aeration/circulation project for one growing season during operation of the device. A growing season is defined as the period from May through October but may vary depending upon location within the United States.

Table 5.9.—In-lake monitoring following the first two weeks of an aeration/circulation project

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location(s)*
   Measurements should be made at a site near the air release point and at sites 200 feet and at least 1,000 feet away from the air release point.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at weekly intervals during the first month of operation. Thereafter, measurements should be made at two-week intervals until DO reaches 80 percent of saturation. After DO has reached 80 percent of saturation, measurements should be made at monthly intervals for six additional months while the aerator is being operated. Data should be obtained for at least a one-year period.

B. pH Measurements

1. *Sampling Location(s)*
   Samples should be collected at a site 200 feet from the air release points and at a site at least 1,000 feet from the air release points.

2. *Depth Distribution*
   Samples should be collected from the surface at the three foot depth and at the six foot depth.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Samples should be collected at weekly intervals for the first month of operation. Thereafter, they should be collected every two weeks for the duration of the growing season (May through October). Data should be obtained for at least a one-year period.

C. Secchi Disk Transparency

1. *Sampling Location*
   Secchi disk measurements should be made at the same sites selected for dissolved oxygen measurements and also near the center of the lake.

2. *Frequency and Duration*
   Same as for dissolved oxygen and temperature.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determination and Sampling Procedure*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Samples should be collected every two weeks for the duration of the growing season (May through October). Data should be obtained for at least a one-year period.

Table 5.9.—In-lake monitoring following the first two weeks of an aeration/circulation project (continued)

B. Algae

1. *Sampling Location*
   Samples should be collected at a site 200 feet away from the air release point.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determinations and Sampling Procedures*
   Algal samples should be obtained directly from a water sample; they should never be collected with a net. Samples should be preserved with Lugol's solution immediately following collection. Algae should be identified to species by using oil emersion and magnification of 900X or greater. Any algal species that comprise greater than 5 percent of the total should be enumerated at a magnification of 400X or greater. Use of an inverted microscope is recommended.
4. *Frequency and Duration*
   Same as for chlorophyll *a*.

CONTROL TECHNIQUE #4:

Hypolimnetic Aeration

Technical Considerations

Hypolimnetic aeration objectives are usually similar to those of total circulation with the added objective of providing oxygen in the lake hypolimnion without destroying the thermal barriers associated with summer stratification. Hypolimnetic aeration has been employed in European lakes since 1948. The original use of the technique was to remove dissolved metals from cold hypolimnetic water before it was used for industrial purposes (Mericer and Perrett, 1949).

The maintenance of an oxic environment overlying lake sediments with sufficient available iron can reduce phosphorus cycling.

In more recent times, hypolimnetic aeration has been used in drinking water reservoirs to prevent the dissolution of iron and manganese compounds from bottom sediments, thereby averting the need for expensive water treatment facilities (Ripl, 1980). Another demonstrated use of hypolimnetic aeration has been to control sediment phosphorus release. The maintenance of an oxic environment overlying lake sediments with sufficient available iron can reduce phosphorus cycling, which translates to a reduction in algal biomass.

Vadnais Lake, an example of a successful hypolimnetic aeration project.

In Vadnais Lake, Minnesota, two hypolimnetic aerators were used in conjunction with addition of iron to reduce the total phosphorus concentrations in the hypolimnion (Walker et al. 1989). The aerators maintained an average hypolimnetic oxygen concentration above 0.8 mg/L during the summers of 1987 and 1988. In previous summers, prior to hypolimnetic aeration and iron additions, the total phosphorus concentrations at fall overturn were 100 to 200 µg/L. In 1988, after hypolimnetic aeration and iron additions, the total phosphorus concentration at fall overturn was 35 µg/L.

In another example, liquid oxygen was injected into the hypolimnion of Amisk Lake, Alberta, to control internal phosphorus release and reduce algal biomass (Prepas et al. 1989). The total phosphorus rate of accumulation in the hypolimnion during the summer of oxygen injection was about 40 percent less than previous years. The chlorophyll *a* concentrations during the summer of hypolimnetic injection ranged from 4 to 16 μg/L. In previous years, the chlorophyll *a* concentrations ranged from 10 to 27 μg/L.

Creating a zone of refuge for large-bodied zooplankton....

An additional consideration is the creation of a zone of refuge for large-bodied zooplankton that allows them to escape predation during the day by remaining in poorly lit bottom waters and migrating to surface waters to feed on algae during the night. Increased grazing should further reduce algal biomass.

Monitoring During the First Two Weeks of Treatment

There have been a variety of hypolimnetic aeration designs, both workable and unworkable. The short-term test of a workable system is its ability to maintain the thermal layers that divide the lake into the epilimnion, metalimnion, and hypolimnion while increasing the dissolved oxygen concentration in the hypolimnion. Table 5.10 describes a monitoring design for the first two weeks of operation.

Table 5.10.—In-lake monitoring design for the first two weeks of hypolimnetic aeration

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Measurements should be made at a site 50 feet from the discharge of the hypolimnetic aerator and at a site at least 1,000 feet away from the discharge.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling procedures.
4. *Frequency and Duration*
   Measurements should be made at daily intervals for the first two weeks of operation.

Considerations for Interrupting Treatment

Stop the project if the hypolimnetic unit causes a breakdown of the lake's natural thermal barrier.

The rationale for stopping a hypolimnetic aeration project is based upon disruption of the thermal barriers within the lake. Once the thermal integrity between the hypolimnion and epilimnion has been eliminated, the original objective of maintaining oxic waters in the hypolimnion without increasing the water temperature cannot be achieved.

Hypolimnetic aeration should be stopped under the following conditions:

1. If, during the first two weeks, the operation of the hypolimnetic unit causes substantial erosion of the thermocline.

2. If, during the first two weeks, the operation of the hypolimnetic unit causes an increase in temperature of the hypolimnion of 0.5°C per day or greater.

Monitoring After the First Two Weeks of Treatment

A hypolimnetic aeration project's success is related to the system's ability to increase dissolved oxygen in the hypolimnion while maintaining the thermal integrity of lake stratification. The primary goals of an oxic hypolimnion are reduced phosphorus concentrations in the bottom waters and a reduced algal biomass in the epilimnion. To evaluate the success of the treatment, therefore, dissolved oxygen, temperature, algal biomass, phosphorus, and ammonium concentrations should be monitored. The duration of the monitoring program should be from start-up until fall overturn. Table 5.11 describes a recommended monitoring design for hypolimnetic aeration projects.

Table 5.11.—In-lake monitoring design for hypolimnetic aeration projects following the first two weeks of operation

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Samples should be collected at a site 50 feet from the discharge of the hypolimnetic aerator and at a site at least 1,000 feet from the discharge.

2. *Depth Distribution*
   Samples should be collected at 6-foot intervals from just below the surface to the bottom. Care should be taken not to include suspended bottom sediments in the water sample.

3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for total phosphorus, dissolved reactive phosphorus, total dissolved iron, and ammonium nitrogen. See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Samples should be collected every two weeks until the dissolved oxygen concentration reaches 1 mg/L. After it has reached 1 mg/L, samples should be collected at monthly intervals while the aerator is being operated. Data should be obtained for at least a one-year period.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at weekly intervals until the end of the first month of operation. Thereafter, measurements should be made every two weeks until the dissolved oxygen concentration reaches 1 mg/L. After it has reached 1 mg/L, measurements should be made at monthly intervals while the aerator is being operated.

C. Secchi Disk Transparency

1. *Sampling Location*
   Measurements should be made at the sites selected for water chemistry sample collection and at a site near the center of the lake.

2. *Frequency and Duration*
   Measurements should be made at two-week intervals for the duration of the growing season (May through October). Data should be obtained for at least a one-year period.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at two-week intervals for the duration of the growing season (May through October). Data should be obtained for at least a one-year period.

To be effective, hypolimnetic withdrawal must not cause the lake to destratify early.

CONTROL TECHNIQUE #5:

Hypolimnetic Withdrawal

Technical Considerations

Hypolimnetic withdrawal is a lake and reservoir management technique that has been used successfully in both Europe and the United States. Employed in lakes that maintain thermal stratification and develop anoxic hypolimnia with a significant hypolimnetic phosphorus mass, this technique maintains a bottom water withdrawal of high phosphorus waters, thereby allowing a consistent depletion of the sediment phosphorus pool. However, hypolimnetic withdrawal should not destabilize the thermal structure of stratification to the point of inducing total lake mixing. An early destratification may result in increased algal biomass in the upper waters as the result of mixing bottom waters high in phosphorus with the waterbody's surface layers.

In reviewing the results of 17 lakes where hypolimnetic withdrawal has been employed, Nurnberg (1987) reports that, in general, the epilimnetic and hypolimnetic phosphorus concentrations have decreased. The decline in epilimnetic concentrations of phosphorus correlated with the phosphorus exported via hypolimnetic withdrawal and the relationship improved as a function of years of operation.

Monitoring During the First Two Weeks of Treatment

The objective of hypolimnetic withdrawal is to reduce internal phosphorus cycling within a lake or reservoir. If thermal stratification is prematurely destroyed as a result of a downward displacement of the thermocline, serious algal problems may soon develop in the surface waters. It is important, therefore, to monitor both the thermal stability of the water column during the system's initial operation as well as the outflow from the hypolimnion, as most lakes where this technique will be used have anoxic conditions with elevated hydrogen sulfide and ammonium concentrations. Some States may also require that a permit with specific monitoring requirements be obtained for this discharge because of potential negative impacts on downstream water quality. A recommended monitoring design for the first two weeks of operation is shown in Table 5.12.

Consideration must be given to adverse impacts on the downstream environment.

Considerations for Interrupting Treatment

The following possibilities are two major concerns related to hypolimnetic withdrawal: the destratification of the lake during operation and a negative impact on the downstream environment from the discharge water. Both are considerations for interrupting a project.

In the absence of specific permit requirements, a hypolimnetic withdrawal project should be interrupted under the following conditions:

1. If the hypolimnetic discharge flows to a receiving stream, and the final amount of dissolved oxygen in the discharge water is less than 1 mg/L.

2. If the hypolimnetic discharge flows to a receiving stream, and the combination of temperature, pH, and NH_4-N produce unionized ammonium concentrations at levels considered toxic to biota.

3. If the temperature in the hypolimnion increases by more than 0.5°C/day.

Table 5.12.—Monitoring design for the first two weeks of a hypolimnetic withdrawal project

QUALITY OF HYPOLIMNETIC DISCHARGE WATER

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Samples should be collected from the hypolimnetic discharge.
2. *Frequency and Duration*
   Samples should be collected twice weekly during the first two weeks of operation.
3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for total phosphorus, dissolved reactive phosphorus, ammonium nitrogen, and pH. See Chapter 3 for appropriate analytical and sampling techniques.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.
2. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
3. *Frequency and Duration*
   Measurements should be made daily for the first two weeks of operation.

IN-LAKE MONITORING

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sample Location*
   Measurements should be made at site(s) selected by the project manager, usually at the deepest part of the lake.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling procedures.
4. *Frequency and Duration*
   Measurements should be made twice weekly.

Monitoring Following Treatment

To be effective, hypolimnetic withdrawal must be used continuously during periods of stratification for a number of years. The monitoring plan described in Table 5.13 is designed to measure the success of the project based upon in-lake algal and nutrient responses and to monitor the water quality of the hypolimnetic discharge to the receiving stream.

To be successful, this treatment may require several years of operation.

Table 5.13.—Monitoring design for a hypolimnetic withdrawal project following the first two weeks of operation

QUALITY OF HYPOLIMNETIC DISCHARGE WATER

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Water samples should be collected from the hypolimnetic discharge.

2. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for total phosphorus, dissolved reactive phosphorus, ammonium nitrogen, and pH. See Chapter 3 for appropriate analytical and sampling techniques.

3. *Frequency and Duration*
   Samples should be collected at monthly intervals while hypolimnetic waters are being discharged. Data should be collected for at least a one-year period.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.

2. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

3. *Frequency and Duration*
   Same as for water chemistry.

IN-LAKE MONITORING

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Samples should be collected at the site(s) selected by the project manager, usually at the deepest part of the lake.

2. *Depth Distribution*
   Samples should be collected at 6-foot intervals from just below the surface to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.

3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for total phosphorus, dissolved reactive phosphorus, ammonium nitrogen, and pH. See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Samples should be collected at monthly intervals during the growing season (May through October). Data should be obtained for at least a one-year period.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Anaytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Same as for water chemistry.

C. Secchi Disk Transparency

1. *Sampling Location*
   Same as for water chemistry.

2. *Frequency and Duration*
   Same as for water chemistry.

Table 5.13.—Monitoring design for a hypolimnetic withdrawal project following the first two weeks of operation (continued)

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determination and Sampling Procedure*
   See Chapter 3 for appropriate analytical and sampling procedures.
4. *Frequency and Duration*
   Same as for Secchi disk.

CONTROL TECHNIQUE #6:

Sediment Oxidation

Technical Considerations

Another method to immobilize phosphorus release from sediments.

Ripl (1976) developed a lake restoration method to oxidize the anaerobic surface sediments of lakes. The method is dependent upon the ability of iron in the sediments (either natural amounts or iron added as part of the treatment) to control phosphorus release. The method involves oxidizing the organic matter in the surficial sediments through increased denitrification, thereby increasing the binding capacity of ferric hydroxide complexes with sediment interstitial phosphorus. A solution of $Ca(NO_3)_2$ and, in some cases, $FeCl_3$ and $Ca(OH)_2$ is injected into the sediments. The technique has been demonstrated in Long Lake in Minnesota and in several European lakes.

Monitoring During Treatment

The objective of sediment oxidation is the same as for alum, artificial circulation, and hypolimnetic aeration: the reduction of phosphorus release from lake sediments. The anticipated reduction in sediment phosphorus release should lower the available phosphorus for algal growth in the photic zone. Because the treatment involves a one-time injection into the sediments, little monitoring can be done during the process.

Considerations for Interrupting Treatment

Once the injection of $Ca(NO_3)_2$ begins, there are no easily monitored lake parameters that will indicate that the process should be stopped. The addition of $Ca(NO_3)_2$ is not readily toxic; therefore, the risk of environmental problems is low.

Monitoring Following Treatment

The monitoring plan is designed to evaluate the effectiveness of the treatment. The important parameters to monitor are related to the chemical additions of the process: Ca, NO_3, possible changes in pH, and the target parameters of phosphorus and algal biomass. The recommended monitoring plan is shown in Table 5.14.

Table 5.14.—In-lake monitoring after sediment oxidation treatment

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Water samples should be collected at the site(s) selected by the project manager, usually at the deepest part of the lake.
2. *Depth Distribution*
   Samples should be collected at 6-foot intervals from just below the surface to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.
3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for total phosphorus, dissolved reactive phosphorus, ammonium nitrogen, nitrite + nitrate nitrogen, calcium, alkalinity, and pH. See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Measurements should be made at two-week intervals from May through October and monthly thereafter for a period of one year following treatment.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for water chemistry.

C. Secchi Disk Transparency

1. *Sampling Location*
   Same as for water chemistry.
2. *Frequency and Duration*
   Same as for water chemistry.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determination and Sampling Procedure*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for Secchi disk.

CONTROL TECHNIQUE #7:

Food Web Manipulation

Manipulating the food web requires time before a response may be noticed in algal biomass.

Technical Considerations

The purpose of food web manipulation is to reduce nuisance algal biomass. Overall, nutrient inputs and dynamics of a lake or reservoir comprise a key control on the level of production. Benndorf and Miersch (in press) suggest that food web manipulation in lakes having a phosphorus loading rate less than 0.6 gm $P/m^2 \cdot yr$ have a greater chance for success in reducing algal biomass than lakes with greater phosphorus loading rates.

The concept of food web manipulation is not new. The early work of Hrbacek et al. (1961) set the stage in Europe for use of this technique as a lake restoration tool. Shapiro (1978), Porter (1977), and Carpenter et al. (1985) have extended the biomanipulation philosophy to North American lakes. In principle, an increase in the piscivore biomass should bring about a decrease in the planktivore biomass (the larger predator fish prey upon the smaller fish that consume zooplankton). Decreases in the planktivore fisheries should increase the biomass of the large-bodied zooplankton that feed on algae. Because grazing rate increases geometrically with body length, the large-bodied zooplankters graze algae more efficiently. The ultimate goal of food web manipulation is to maintain sufficient populations of the large-bodied zooplankton over the summer season to consistently graze down the excessive amounts of algae.

The actual restoration technique can be applied in a number of different ways:

1. A complete fish kill accomplished with a fish toxicant (such as rotenone) will eliminate the fisheries and, therefore, predation pressure on the zooplankton. A dramatic increase in large-bodied zooplankton is frequently observed in these situations, along with a corresponding increase in water clarity.

2. A large increase in the stocking of piscivores could have the desired impact on the planktivores.

3. A zone of refuge that precludes predation can be created for herbivores by hypolimnetic aeration. The large-bodied zooplankton can avoid predation during the day by moving into the deep waters where light limits the efficiency of sight-feeding fish. During the night, zooplankton can migrate to the surface of the lake to feed upon the algae.

Monitoring During Treatment

The in-lake monitoring for a food web manipulation project will depend to some degree on which method is employed. The results from any of the biomanipulation methods will take some time, however, to be realized. Once the predation pressure is reduced on the zooplankton, they cannot respond in one day's time. The in-lake monitoring during treatment will be no different than the monitoring design following treatment.

Increasing the size and number of large-bodied zooplankton is the goal.

Considerations for Interrupting Treatment

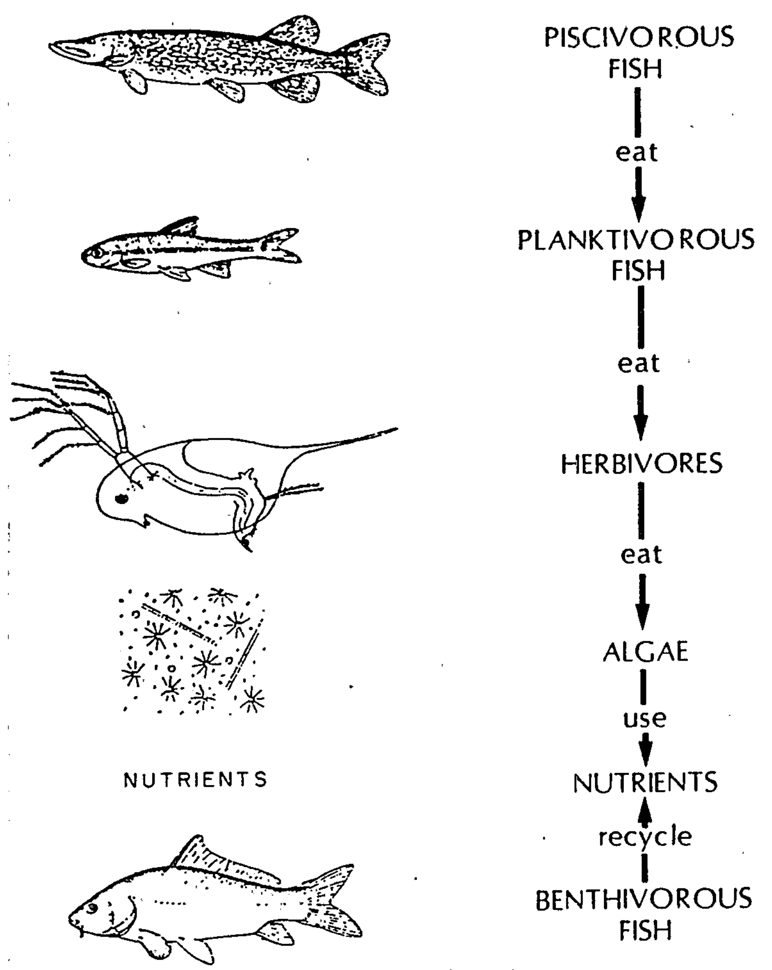
The basis for evaluating a food web manipulation project is its success in increasing the herbivore population and decreasing the algal densities or changing the species composition. Because evaluation of these projects is possible only after life cycles are completed, criteria for interrupting a project in the short term do not exist. It is worth restating, therefore, that serious consideration should be given to the probability of success before starting a food web manipulation project if the phosphorus loading rate to the lake exceeds 0.6 gm $P/m^2 \cdot yr$.

Monitoring Following Treatment

The basic goal of a food web manipulation project is to maintain a sufficient population of the large-bodied zooplankters and thereby decrease the algal biomass by grazing pressure. The length of the monitoring program depends upon the technique employed. If fish are stocked in large numbers over several years, monitoring should be delayed until they reach an effective size.

If a fish toxicant is used, the impact can be noticed within a month, but success depends upon the fish species selected for the stocking program. For example, it would be unwise to restock with rainbow trout as they would quickly consume the large-bodied zooplankters. Once biomanipulation has been implemented, monitoring should be conducted as outlined in Table 5.15.

The aquatic food chain (not to scale)



(source: Shapiro et al. 1982)

Table 5.15.—In-lake monitoring for a food web manipulation project

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sample Location*
   Measurements should be taken at the site(s) selected by the project manager, usually at the center of the lake.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at two-week intervals during the growing season (May through October), and monthly thereafter for at least a one-year period following completion of the project.

B. Secchi Disk Transparency

1. *Sampling Location*
   Same as for dissolved oxygen.

2. *Frequency and Duration*
   Same as for dissolved oxygen.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Same as for Secchi disk.

B. Zooplankton

1. *Sampling Location*
   Same as for chlorophyll *a*.

2. *Depth Distribution*
   With the exception of a zone of refuge treatment, a Number 10 (156 u mesh) plankton net should be pulled through a water column equal to the depth of oxygenated waters. The exact length of the plankton tow must be recorded to calculate the volume of water filtered.
   For a zone of refuge treatment, samples should be collected at 6-foot intervals from the surface to the bottom of the oxygenated water column. Samples should be obtained by use of a Schindler-Patalas trap, Clarke-Bumpus sampler, or similar apparatus.

3. *Analytical Determination*
   Species identification, representative body length, enumeration, and ratio of eggs to adult females should be made for the zooplankton in each sample. The individual species density should be reported as numbers of individuals per liter of lake water at each sample depth.

4. *Frequency and Duration*
   Same as for chlorophyll *a*.

C. Fish

Fish population should be surveyed one year following completion of the project using methods appropriate for the species present. To completely characterize both game and nongame species, most surveys will use gill netting for pelagic species and fyke nets/boom shocking for others.

OBJECTIVE:

Increase Depth

Summary

1. The rationale for increasing the depth of a lake or reservoir is to increase the storage capacity of the reservoir, to increase recreational potential for the waterbody, or to reduce macrophyte growth.

2. The essential monitoring requirements are to determine the macrophyte distribution and depth of growth and to re-map the deepened area of the lake.

Flood control reservoirs built in regions of the country where the uplands have a high erosion rate are usually designed to have a specific life span—a period before they are expected to fill in with sediments. Deepening can prolong the usefulness of these kinds of reservoirs by renewing their water-holding capacity.

Natural lakes as well as recreational reservoirs that have been built throughout the United States offer lakeshore property for home sites and opportunities for public recreation. It is not unusual for the inlet areas of such lakes and reservoirs to noticeably fill in within a decade after they are developed or reach designed pool capacity. As the managers of these recreational waterbodies will often attest, this becomes an unacceptable environmental development that adversely affects recreational opportunities.

Natural lakes may fill with sediment at a rate of 0.1 inch/year; reservoirs fill with sediment at a faster rate, e.g., 1.5 inches/year.

There are many causes for the rapid sedimentation of certain areas in lakes' and reservoirs' littoral zone. Those natural lakes that are within the glaciated part of the United States are over 10,000 years old, and many have as much as 35 feet of sediment within the original lake basin. These sediments normally are very organic; their origin is plant production and decay. The difference in sedimentation rates between manmade reservoirs and natural lakes reflects the origin of the sediments. Sedimentation rates measured by using either cesium-137 or lead-210 radioisotope methods for a series of lakes and reservoirs in Wisconsin ranged from less than 0.1 inch per year in the more remote natural lakes to greater than 1.5 inches per year in reservoirs (Wedepohl et al. 1983).

Agricultural activities upstream of lakes and reservoirs are a common cause of accelerated sedimentation. For limited periods during the year, agriculture disturbs the soil, thereby increasing its erodibility. Other causes for rapid infilling in the lakes' littoral zones include construction site erosion from houses and roads built near the lakeshore. Whatever the cause of rapid infilling to the lake or reservoir, reduction of watershed-derived sediment is often cost-effective.

CONTROL TECHNIQUE:

Dredging

Technical Considerations

Dredging is often done as a restoration practice to increase water depth and thereby reduce nuisance levels of rooted aquatic plants. In a few cases, dredging has been employed to remove a specific layer of sediments containing a high concentration of nutrients. In the majority of cases where dredging is the lake restoration technique of choice, however, it is done to restore water depth lost to sedimentation.

There are several hydraulic or mechanical techniques that can be used to dredge sediments from a lake or reservoir (Cooke et al. 1986). Hydraulic dredging with the use of a cutterhead is probably most often employed; however, small dredging operations have used front-end loaders, draglines, and backhoes to remove sediments from reservoirs where the water level was drawn down.

Various dredging techniques are hydraulic, dragline, and backhoes.

Typically, there is concern about contaminants that may be present in the sediments to be removed from reservoirs and lakes in agricultural or urban watersheds. These chemicals ultimately are transported, usually on the fine sediment particles, to the receiving waterbody. The chemical composition of the sediments to be removed dictates the necessary precautions that must be considered for land disposal. In this manual, it is assumed that the sediment characteristics were quantified during the Phase I study of the lake.

Knowledge of sediment chemistry is very important for disposal.

One symptom of rapid infilling of lakes or reservoirs—overabundant growth of attached aquatic plants—frequently causes the most use problems. If plant control is one of the objectives of a dredging project, the depth to be dredged must reflect the depth of plant colonization. Several equations for estimating the maximum depth of colonization (MDC) have been suggested by scientists (Canfield et al. 1985). These relationships between depth of plant growth and depth of light penetration (as measured by a Secchi disk) will vary for different areas of the United States. Equations developed from Secchi disk (SD) measurements in Florida and Wisconsin are as follows:

Dredge below the maximum depth of plant colonization.

Florida	$\log MDC = 0.42 \log SD + 0.41$
Wisconsin	$\log MDC = 0.79 \log SD + 0.25$

The reader is referred to Chapter 6 of *The Lake and Reservoir Restoration Guidance Manual* (U.S. Environ. Prot. Agency, 1988) for further discussion of this relationship.

Monitoring During Treatment

Dredging is a major disruption of the existing ecology. Habitat for benthic organisms is drastically altered, and changes in the water column are possible during treatment. In general, however, these perturbations are transient. The benthos will normally recolonize the dredged area, and the chemical conditions of the water column above the new sediments will reach an equilibrium with the chemistry of the newly exposed sediments.

Disposal of contaminated sediments is a serious problem.

A detailed monitoring plan for a dredging project depends upon the specific characteristics of the sediments to be removed. If, for example, the sediments contain materials such as mercury or PCBs, then special provisions must be made for their removal and disposal. An in-lake monitoring plan would also require that these parameters be measured in the water column. There is no way to anticipate and design a monitoring plan without prior knowledge, through a Phase I lake restoration study, of potentially dangerous materials in the sediments. A recommended monitoring plan is described in Table 5.16 for a dredging project without contaminated sediments.

Table 5.16.—In-lake monitoring design during dredging

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sample Location*
   Water samples should be collected at the site(s) selected by the project manager, usually at the center of the lake.
2. *Depth Distribution*
   Samples should be collected at 6-foot intervals from just below the surface to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.
3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for total phosphorus, dissolved reactive phosphorus, ammonium nitrogen, and pH. See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Samples should be collected at monthly intervals during the dredging operation.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for water chemistry.

C. Secchi Disk Transparency

1. *Sampling Location*
   Same as for water chemistry.
2. *Frequency and Duration*
   Same as for water chemistry.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Distribution*
   Same as for Secchi disk.

Considerations for Interrupting Treatment

The rationale for interrupting a dredging project is based upon an assessment of the nontargeted dredging area within the lake. Sediment displacement within the dredged area may create suspended solids problems in other areas, while increasing the nutrient load within the system. In addition to a long list of potential sediment contaminants, other measurements of concern are dissolved oxygen, nutrients, and unionized ammonium. A considerable increase in the oxygen demand to the lake as a result of the disturbed sediments could cause increased stress and mortality to the fishery, as could an increase in the unionized ammonium concentration, and increases in whole lake nutrient concentrations could promote algal blooms.

Consideration should be given to interrupting a dredging project under the following conditions:

1. If the dissolved oxygen concentrations in the non-target dredging area of the lake or reservoir fall below 5 mg/L in the surface waters.

2. If the combination of the NH_4-N concentration, pH, and temperature create concentrations of unionized ammonium within the lake that are lethal to fish.

Monitoring Following Treatment

A post-project monitoring plan following a dredging operation should be designed to evaluate the success of the treatment. If the purpose of the dredging was to deepen the lake and reduce rooted aquatic plants, then the evaluation should concentrate on mapping both the new, deeper portion of the lake and the macrophyte distribution and density within the project area. Table 5.17 presents a recommended monitoring plan to be followed after dredging is complete.

Table 5.17.—In-lake monitoring design after dredging

PHYSICOCHEMICAL

A. Mapping the Lake Bottom

Generally, lake bottom contours will be carefully resurveyed following completion of the dredging to determine quantities for payment to the dredging contractor. In the absence of this survey, there are several acceptable techniques available to determine the water depth above the sediments. The most common technique uses a recording sonar unit. Steps to follow during development of a lake depth map include

1. *Aerial Photographs*
   Obtain an aerial photograph of the lake. Mark a known straight line distance on the map for calibration. Mark off and measure transect lines across the portion of the lake that was dredged. The distance between the transect lines will vary depending upon the size of the lake dredging area. The closer the transects are to each other, the more accurate the map. A minimum of 50 feet and a maximum of 100 feet between transect lines is reasonable; however the configuration of the dredged area will affect distances selected.

2. *Benchmark*
   A benchmark must be established on the lakeshore for use as a reference to record lake level at the time sonar soundings are made.

3. *Sonar Transects*
   Transect markers should be established on the shoreline, based upon the aerial photograph. A boat with a sonar and a strip recorder should traverse between the two established markers at a given, slow, steady speed.

4. *Lake Map*
   Using the calibrated aerial photograph and the strip chart from the sonar measurements, plot the depth to sediment surface along each transect. When all the depths are recorded along the transects, join the identical depths (e.g., all 5-foot depths) to form a lake bathymetric map. The lake map can be used to determine the amount of sediment removed if it is compared to the before-dredging hydrographic map using the normalized lake level.

BIOLOGICAL

A. Macrophytes

The aquatic macrophytes should be surveyed during the second year following completion of the project. They should be surveyed twice during the growing season (usually in late June and again in August) to determine species composition and distribution, abundance, and maximum depth of growth and depth from water surface to tops of plants.

OBJECTIVE:

Control Nuisance Plants

Summary

1. Techniques used for controlling nuisance rooted plant growth include water level drawdown, mechanical or chemical controls, and biological controls.

2. Common monitoring parameters for all techniques include phosphorus, nitrogen, chlorophyll *a*, macrophytes, and Secchi depth.

3. The major long-term problems observed with plant control projects are damage to a lake's fishery and increased algal growth following macrophyte control.

A balanced aquatic plant community is essential to the ecological well-being of all lakes. Aquatic plants benefit lakes by harboring food organisms for fish and waterfowl, providing spawning areas and protective cover for fish, preventing shoreline erosion and stabilizing the lake bottom, producing oxygen and organic material for other life in the lake, and providing food and building materials for a variety of wildlife species.

Unfortunately, aquatic plants can grow to excess in lakes, particularly those lakes that have been disturbed by human activities or subjected to the introduction of non-native plant species. Excessive aquatic plant growth can seriously impair a lake's recreational use by limiting boating, swimming, and fishing. These nuisance weeds are one of the most common and frustrating problems faced by lake users and managers in all areas of the United States.

A number of techniques exist for managing excessive aquatic plant growth. In some cases, nuisance plants can be controlled by limiting excess nutrients and sediment from watershed point and nonpoint sources. In-lake controls for aquatic plants (mechanical controls such as harvesting, rototilling, and disturbance of shallow water sediments; sediment covers; lake drawdowns to expose and compact shallow sediments; and chemical controls) are more or less temporary management measures that limit the impact of excess plants on desired recreational uses.

EPA Clean Lakes regulations explicitly state that plant harvesting and herbicide treatments are palliative measures that are ineligible for project funding unless they are proven to be the most cost-effective measures available, and necessary watershed nutrient controls have been installed. Commercially available biological controls are currently limited to herbivorous fish such as grass carp that may provide some degree of longer-term control but also carry the risk of destroying beneficial, nontarget plant species as well as nuisance plant communities.

Potential risks associated with extensive macrophyte control projects include the possibility that removal of too much plant growth could damage critical fish habitat and spawning areas. Also, reductions in macrophyte growth can allow increased algae production if available nutrients (which algae will use) have not been reduced.

CONTROL TECHNIQUE #1:

Water Level Drawdown

Technical Considerations

Lowering the water level of the lake exposes littoral sediments, plants, and plant reproductive parts to drying stresses. The drying is accompanied by freezing stress in overwinter drawdowns in the northern United States and heat stress in summer drawdowns. Drawdown can also promote compaction and dessication of highly organic sediments. Where highly organic sediments are exposed to freezing and dessication, however, high nutrient release rates have been observed following refill.

In addition to aquatic macrophyte control, drawdowns are used to compact sediments to increase lake depth and, by fishery managers, to concentrate fish either for greater predation or to increase the cost-effectiveness of chemical eradication treatments. Drawdowns can have both acute and chronic impacts on a lake's fishery. If they are not conducted properly, dissolved oxygen stress can result in partial or complete fish kills. Elimination of critical plant habitat can damage future repopulation, causing long-term changes to a lake's fishery.

The timing of drawdown for aquatic plant control depends upon the regional climatic characteristics and the lake's recreational uses. Winter drawdowns are most effective in climates with harsh winter conditions when there would be less disruption of recreation on the lake; therefore, summer drawdowns are rarely recommended in such regions.

A drawdown's effectiveness is also highly species-specific. Some macrophyte species show dramatic decreases after drawdowns, but other species react variably or even increase in abundance. Drawdown experiences with a variety of species are summarized by Cooke et al. (1986). The benefits of a lake drawdown are limited to a few years; therefore, the technique will probably have to be repeated regularly to maintain the reduced plant population.

Some macrophyte species show dramatic decreases after drawdowns, but other species react variably or even increase in abundance.

Monitoring During Treatment

A distinction should be made between monitoring the first instance of drawdown on a lake and monitoring during subsequent maintenance drawdowns. If a lake has not been drawn down for several years, the monitoring needed will be somewhat more intensive than that needed thereafter.

A key parameter to monitor during all lake drawdowns is dissolved oxygen. Other parameters that may be monitored during lake drawdown are phosphorus and nitrogen species, chlorophyll *a*, and Secchi depth.

Table 5.18 describes a recommended plan for monitoring during a lake drawdown and refilling.

Considerations for Interrupting Treatment

The greatest risk when a lake is being drawn down is loss of dissolved oxygen in the remaining lake pool. This risk increases as a greater amount of organic matter enters the remaining pool relative to the volume of the pool. The risk can also be great if, during a summer drawdown, the level of a thermally stratified lake is reduced enough to cause mixing of low-oxygen, hypolimnetic waters with higher-oxygen surface waters. Dissolved oxygen readings become the criterion for determining if a lake drawdown must be interrupted, or if artificial aeration should be initiated.

Table 5.18.—In-lake monitoring design during complete lake water level drawdown and refilling

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Measurements should be made at the site(s) selected by the project manager, usually at the deepest part of the lake.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at 10 percent time intervals from the start of drawdown until the lake begins to refill, and thereafter at 20 percent increments until the lake has reached full stage.

B. Downstream Observations

Periodic observations (at least weekly) of downstream effects of increased discharges (flooding, erosion, sedimentation) should be made during the period of the drawdown.

A second criterion for interruption is the downstream effects of the drawdown. Sustained high flows downstream of the lake may result in flooding of lands and/or destruction of fish and wildlife habitat. These problems can usually be avoided through careful design and implementation of a drawdown.

The following guidelines should be followed in considering interruption of a lake drawdown:

1. **In-lake:**
   - If the epilimnetic dissolved oxygen concentration decreases to 5 mg/L or less.

2. **Downstream:**
   - If observations indicate excessive flooding or other damage as a result of increased discharge volumes.

The purpose of interrupting a drawdown because of in-lake dissolved oxygen depletion is to weigh the risk of an unanticipated loss of the lake's fish resources and to allow dissolved oxygen levels to recover. In cases where the present fishery is not a valuable resource, the decision may be made to continue the drawdown despite the loss of dissolved oxygen.

Monitoring Following Treatment

The measure of success of a lake drawdown for aquatic plant control is the degree to which plant growth decreases from pre-project levels. Success will be enhanced if the aquatic plants are not replaced by increased algae growth. Macrophyte surveys should be carried out annually for the first two years to determine change in species composition from pre-project conditions. Table 5.19 describes a recommended monitoring plan following refill of the lake.

Table 5.19.—In-lake monitoring design following lake water level drawdown and refilling

PHYSICOCHEMICAL

A. Secchi Disk Transparency

1. *Sampling Location*
   Measurements should be made at the site(s) selected by the project manager, usually at the center of the lake.

2. *Frequency and Duration*
   Samples should be collected at monthly intervals following refill of the lake. Data should be obtained for at least a one-year period.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Same as for Secchi disk.

B. Macrophytes

The aquatic macrophytes should be surveyed during the first and second years following completion of the project. They should be surveyed twice during the growing season (usually in late June and again in August) to determine species composition and distribution, abundance, and maximum depth of growth and depth from water surface to tops of plants.

Survey macrophytes to determine species composition, distribution, abundance, maximum depth of growth, and depth from water surface to tops of plants.

CONTROL TECHNIQUE #2:

Mechanical or Chemical Control of Nuisance Plants

Technical Considerations

There are a variety of aquatic plant control measures that attack unwanted plants directly. These techniques are essentially temporary or cosmetic in nature. The goal of each of these techniques is simply to achieve a short-term reduction in nuisance plant growth. Because of the similarities in monitoring strategies, they will be treated as a group for the purposes of this manual.

Mechanical or chemical control of nuisance plants includes those measures that either physically prevent unwanted plants from growing or remove unwanted plants from the lake. Specific techniques include:

. . . sediment covers are spread on an area of lakebed to retard plant growth.

- **Bottom screens** and other types of sediment covers, which are spread on an area of lakebed to retard plant growth. The most effective screen materials are gas-permeable so they will not be buoyed up off the lakebed by the gaseous products of plant decomposition. Some covers must be removed and cleaned annually. Bottom screens are typically used for relatively small areas, such as around piers, beaches, and in boating lanes.

Only rarely is it possible to use harvesting as a restoration technique by removing enough plant nutrients to achieve net nutrients to achieve net nutrient removal from the lake.

■ **Mechanical harvesting**, which relies on large machinery to cut vegetation and remove it from the lake. Only rarely is it possible to use harvesting as a restoration technique by removing enough plant nutrients to achieve net nutrient removal from the lake. Most often harvesting is used during the growing season to provide immediate short-term relief from conditions that impair boating and swimming.

■ **Tilling of lake sediments**, which disturbs and dislodges root masses in the lake sediment. This technique is usually performed in the spring or fall when there is less vegetative matter in the water. Like harvesting, it is best to remove as much dislodged vegetative matter as possible after a sediment tilling operation.

■ **Chemical controls** that involve application of various herbicidal agents to kill unwanted plants; the specific chemicals used vary depending on the plant species. Mode of operation, selectivity, and use restrictions that must be placed on the waterbody also vary from chemical to chemical.

Monitoring During Treatment

The monitoring required during mechanical and chemical treatments depends on the nature and magnitude of the techniques employed.

Installation of bottom screens, alone, requires no monitoring other than periodic visual observation of the screen to ensure that it remains firmly in place on the sediments and does not buckle because of disturbance or entrapment of gasses. No recommended monitoring specifications are given for bottom screen installation.

For mechanical harvesting and sediment tilling, the most important parameters to monitor are changes in macrophyte coverage and subsequent algal response. Less important parameters include total and dissolved reactive phosphorus, ammonium, nitrite + nitrate, and total Kjeldahl nitrogen, chlorophyll *a*, and dissolved oxygen and temperature profiles. A recommended monitoring plan is described in Table 5.20.

For large-scale herbicide treatments, changes in macrophyte coverage should be observed. Also, dissolved oxygen should be measured at regular intervals prior to and following a herbicide treatment. The length of these intervals will depend on the waiting period associated with the herbicidal action of each chemical. Over the longer term, nutrient levels (total and dissolved phosphorus, ammonium, nitrate, and total Kjeldahl nitrogen) and chlorophyll *a* should be measured. A recommended monitoring plan is described in Table 5.21.

Considerations for Interrupting Treatment

There are no known serious adverse environmental impacts from mechanical plant control projects that would warrant immediate interruption of treatment. The impacts on a lake's fishery or changes in algal densities that might occur from these techniques can be evaluated over one or more growing seasons and adjustments to the techniques can usually be made to reduce adverse impacts to an acceptable level.

The most serious potential impacts of a chemical herbicide treatment are direct toxicity of the herbicide to fish or wildlife and indirect toxicity to fish resulting from depletion of dissolved oxygen by decomposing plants. Careful adherence to label directions is essential if the risk of direct and indirect toxicity is to be minimized. This risk can be managed further by examining the treatment area for indications of fish and wildlife toxicity after the first 50 percent of treatment is complete and immediately following treatment.

Table 5.20.—In-lake monitoring design for plant harvesting and sediment tilling

PHYSICOCHEMICAL

A. Secchi Disk Transparency

1. *Sampling Location*
   Measurements should be made at site(s) selected by the project manager, usually at the center of the lake.

2. *Frequency and Duration*
   Measurements should be made at monthly intervals. During sediment tilling operations, additional measurements should be made at weekly intervals.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Samples should be collected at monthly intervals.

B. Macrophytes

Macrophyte regrowth should be observed and documented at monthly intervals during the harvesting operation and until the end of the growing season. Mass of plants harvested should be calculated. Generally, several representative loads should be calibrated by weighing with total mass determined by keeping records of the number of loads removed. Several representative plant samples should be obtained from the harvested plants and tissue total phosphorus and percent water determined.

For sediment tilling operations, the aquatic macrophytes should be surveyed during the first and second years following completion of the project. They should be surveyed twice during the growing season (usually in late June and again in August) to determine species composition and distribution, abundance, and maximum depth of growth and depth from water surface to tops of plants.

The mass of plants harvested should be recorded.

Dissolved oxygen depressions can usually be avoided by limiting treatment areas to a fraction of the lake area and treating only when oxygen levels are 5 mg/L or more. Dissolved oxygen measurements should normally be made as near to dawn as possible when dissolved oxygen levels will be the lowest because of nighttime plant respiration. Generally, decreases in dissolved oxygen occur gradually following the treatment as the herbicide kills the treated plants and they begin to decompose.

Except for direct herbicide toxicity, any negative effects of mechanical or chemical plant control techniques would not be observed until well after treatment. Therefore, no specific criteria for interrupting treatment are given for these techniques.

Monitoring Following Treatment

The measure of success for both mechanical and chemical plant control methods is the short-term improvement in recreational or other use of the lake resulting from the reduction in nuisance plant growth. These techniques must generally be repeated every year to maintain increased use of the lake, although the process repeated over many years can result in longer-term changes to the lake environment. Recommended specifications are given in Tables 5.20 and 5.21.

The measure of success for both mechanical and chemical plant control methods is the short-term improvement in recreational or other use of the lake due to the reduction in nuisance plant growth.

Because mechanical and chemical plant control have the potential to change the structure of a lake's fish community and can encourage increased algal production, long-term monitoring of these lake ecosystem components is recommended along with evaluation of longer-term changes in plant growth.

Table 5.21.—In-lake monitoring design for large-scale herbicide applications

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Measurements should be made at the site(s) selected by the project manager, usually within the area being treated and near the center of the lake.

2. *Depth Distribution*
   Measurements should be made at 3-foot increments from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   Samples should generally be obtained as close to dawn as possible. See Chapter 3 for other appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Measurements should be made at two-day intervals, for herbicides with waiting periods between application and kill of less than two weeks. For herbicides with longer waiting periods, measurements should be made at weekly intervals.

B. Secchi Disk Transparency

1. *Sampling Location*
   Measurements should be made at site(s) selected by the project manager, usually at the center of the lake.

2. *Frequency and Duration*
   Measurements should be made at two-week intervals until the end of the growing season.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Same as for Secchi disk.

B. Macrophytes

Changes in macrophyte coverage and regrowth in the treated areas should be observed and documented at monthly intervals until the end of the growing season.

C. Toxic Effects on Fish and Wildlife

The treatment area should be examined for indication of fish and wildlife toxicity after the first 50 percent of treatment is complete and after the entire treatment is complete.

CONTROL TECHNIQUE #3:

Biological Control of Nuisance Plants (Grass Carp)

Technical Considerations

The only biological controls currently accepted for use against aquatic plants are genetically sterile grass carp (also known as white amur) *Ctenopharyngodon idella*, although research is being conducted on numerous other biological agents, including different fish species, insects, and plant pathogens, as well as on the results of food chain manipulations.

Grass carp are more effective in warmer regions. Formulae used in some States yield a stocking rate based on climatic region, plant type, and amount of vegetation in a lake (Wiley et al. 1987). Use of these fish for plant control is restricted or prohibited in many States because of their potential for damaging natural fisheries, cycling nutrients, and destroying beneficial plant communities.

A number of factors combine to reduce grass carp feeding rates in a lake over the long term. These factors include reduced consumption as fish mature, as well as mortality and escape. Supplemental stocking of additional fish is often required to maintain initial vegetation consumption levels. However, where initial consumption levels are too high, this natural reduction in activity can benefit the lake. Stocking strategies for grass carp take into account this change in feeding rate over time: in serial stocking, additional fish are placed in the lake at intervals, while in batch stocking, enough fish are placed in the lake initially to compensate for decreases in efficiency. Serial stocking reduces the risk of long-term damage to the biotic systems of the lake and is usually the recommended strategy.

Monitoring for the First Year After Fish Stocking

The first-year monitoring program for grass carp projects should focus on macrophyte responses as well as in-lake nutrient and algae levels. Experience has shown that grass carp feed preferentially on certain species of aquatic plants such as naiads, *Chara* spp., and most pondweeds. Since it is important to ensure that stocked grass carp do not destroy all plant species beneficial to fish and wildlife, leaving large growths of nuisance species such as Eurasian watermilfoil, periodic macrophyte composition studies should be conducted after the first stocking.

In some grass carp projects, the water's nutrient levels have increased following elimination of large numbers of macrophytes, which suggests the importance of monitoring for phosphorus and nitrogen after the introduction of grass carp. In addition, chlorophyll *a* and Secchi depth measurements should be made regularly during the growing season.

Table 5.22 describes a recommended plan for monitoring a lake stocked with grass carp during the first year after stocking.

Considerations for Interrupting Treatment

Grass carp projects are difficult if not impossible to interrupt should serious adverse impacts arise; therefore, serial stocking is recommended. Selective removal of grass carp from any lake (but particularly from large lakes) is difficult no matter which method is used. In addition, any criteria for interrupting treatment will depend upon the initial plant communities that existed in the lake and the objectives of the project in terms of plant removal. Therefore, the guidelines for interrupting a grass carp treatment may prove difficult to follow unless a clear percentage plant removal target is determined at the beginning of the project. Interruption can take the form of eliminating the second stocking of grass carp in a serial stocking strategy if selective removal of stocked fish is found to be impossible.

Grass carp projects are difficult if not impossible to interrupt should serious adverse impacts arise; therefore, serial stocking is recommended.

Interruption of a grass carp stocking program should be considered under the following conditions:

1. Removal of significantly greater than target percentage of total plant cover.

2. Evidence of grass carp escape into an adjacent hydrologic system. (This may require a complete fishery eradication.)

3. Evidence of a significant increase (beyond natural variability) in nutrient or phytoplankton biomass that adversely affects use of the lake.

Mark-recapture techniques should be used to survey grass carp populations.

Table 5.22—In-lake monitoring designed for the first year after herbivorous fish stocking.

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Measurements should be made at the site(s) selected by the project manager, usually at the center of the lake.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Measurements should be made at monthly intervals during the growing season (May through October).

B. Secchi Disk Transparency

1. *Sampling Location*
   Same as for dissolved oxygen.
2. *Frequency and Duration*
   Same as for dissolved oxygen.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for Secchi disk.

B. Macrophytes

The aquatic macrophytes should be surveyed one month following the stocking. They should be surveyed to determine species composition and distribution, abundance, and maximum depth of growth and depth from water surface to tops of plants.

C. Fish

Fish populations should be sampled during the first year after initial stocking of herbivorous fish. Mark-recapture techniques such as those described by Youngs and Robson (1978) should be used to estimate numbers. Lengths and weights should be obtained from samples of each species to enable the evaluation of population and size structure.

Monitoring Following Treatment

A grass carp stocking project is a success when the reduction in nuisance plant growth is consistent with the avoidance of long-term adverse changes to the biotic integrity of the lake. The reduction in nuisance plant growth can be evaluated by ground observations or aerial photography, but in a grass carp project it is particularly important to evaluate changes in species composition by conducting a macrophyte survey, which should be completed during the first growing season after stocking is initiated. Similarly, to ensure that adequate comparative data are available on base year fish population structure, a fishery survey should be completed during the first spring and fall after stocking.

Over the longer term, macrophyte surveys should be completed once a year during the first three years to determine if consumption of vegetation is decreasing over time. Perhaps more importantly, a fisheries survey should be completed every two years after grass carp are stocked in any lake in which fish are a valued resource. Grass carp have the potential to exert strong adverse effects on native fish populations through consumption of vegetation needed for fish spawning, cover, and food organisms, and, unless the fish are inspected prior to stocking by a fish pathologist, through transmission of disease (Cooke et al. 1986). The fisheries survey should be completed before any decision is made to stock supplemental grass carp to maintain consumption levels.

Table 5.23 describes a recommended monitoring plan for use after the first year of a herbivorous fish stocking project.

Grass carp have the potential to exert strong adverse effects on native fish populations through consumption of vegetation needed for fish spawning, cover, and food organisms.

Table 5.23.—In-lake monitoring design after the first year of a herbivorous fish stocking project

PHYSICOCHEMICAL

A. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Measurements should be made at the site(s) selected by the project manager, usually at the center of the lake.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling procedures.
4. *Frequency and Duration*
   Measurements should be made at monthly intervals for at least two years after the initial stocking of the herbivorous fish.

B. Secchi Disk Transparency

1. *Sampling Location*
   Same as for dissolved oxygen.
2. *Frequency and Duration*
   Secchi disk measurements should be taken monthly during the growing season (May through October) for at least two years after the initial stocking of the herbivorous fish.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for Secchi disk.
2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.
3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Same as for Secchi disk.

B. Macrophytes

The aquatic macrophytes should be surveyed during the first and second years following stocking. They should be surveyed twice during the growing season (usually in late June and again in August) to determine species composition and distribution, abundance, and maximum depth of growth and depth from water surface to tops of plants.

C. Fish

Mark-recapture techniques such as those described by Youngs and Robson (1978) should be used to estimate numbers. Length and weight should be obtained from samples of each species to enable the evaluation of population and size structure.

OBJECTIVE:

Mitigate Acidic Conditions

Summary

1. Addition of limestone to an acidic lake or its watershed can allow successful stocking of game fish species and help return the lake to a productive sport fishery.

2. The treatment phase ordinarily lasts approximately one month, beginning with the initiation of liming and continuing during the time that the lake chemistry approaches a new equilibrium. Key monitoring parameters are pH, acid neutralizing capacity, and calcium.

3. The post-treatment phase involves monitoring most of the same parameters included in treatment monitoring plus certain parameters likely to change slowly following base addition, such as the biological parameters.

4. Addition of base materials to watersheds has similar but much longer lasting effects than surface water treatment. Monitoring considerations, therefore, may be different temporally but will include the same parameters.

"Liming" is a generic term used to connote the addition of any base materials to neutralize surface water or sediment or to increase alkalinity. The most common product used to treat acidic lakes is limestone, the same mineral used in agriculture (Olem, 1989). Limestone can be applied to the lake surface, injected into the sediment, continuously dosed to upland streams, or applied to the watershed.

Acidic lakes cannot support healthy fisheries.

Fisheries managers have known for years that adding lime to acidic, unproductive lakes can allow successful stocking of game fish species and help return the lake to a productive sport fishery. Acidic lakes occur in areas where the soils have no natural buffering capacity and acid rain and other processes cause acidification of waterbodies. Many of these lakes are unable to support a healthy reproducing fishery.

There are other sources of acids to lakes that are not related to pollutants in the air. Some waters are mildly acidic because of their passage through naturally acidic soils. Stained lakes, for instance, may have pH levels between 5 and 6. Acidic deposition to these lakes contributes additional mineral acidity to already slightly acidic waterbodies.

Acidic drainage from abandoned mines affects thousands of miles of streams and numerous lakes throughout Appalachia (Olem, 1989). Acid mine drainage also occurs in the midwestern coal fields of Illinois, Indiana, and Ohio and in coal and metal mining areas of the western United States, where affected streams and lakes can have pH levels below 4. In some cases, liming can restore these lakes to productive use.

All liming projects should include a rigorous monitoring program designed to characterize changes in key hydrological, physical, chemical, and biological parameters during and after treatment. The results of a monitoring program will help determine whether the project meets its water quality and biological objectives. Monitoring may also help determine when it is appropriate to stock a treated lake with selected fish species.

CONTROL TECHNIQUE #1:

In-lake Liming

The use of base materials to neutralize acidic lakes is a proven technique for restoring waterbodies that are acidic for a variety of possible reasons. Addition of base materials to the lake surface is currently the most common treatment to mitigate acidic conditions.

A good example of an in-lake liming project is the Lake Acidification Mitigation Program (LAMP) funded by the Electric Power Research Institute (Porcella, 1989). Two drainage lakes located in the Adirondack region of New York, Woods Lake and Cranberry Pond, were treated with limestone in 1985. Both lakes were characterized as small acidic headwater systems with short residence times and, although they differ in size and depth, both lakes have similar watershed characteristics.

Restore acidic lakes by adding limestone.

A fine limestone slurry was distributed in the lakes, which resulted in a high dissolution efficiency. Four weeks after liming, dissolution was 86 percent and 79 percent in Woods Lake and Cranberry Pond, respectively. Essentially all of the limestone was dissolved in both lakes within four months of application with only minimal accumulation in the bottom sediments.

The short-term changes in the water chemistry of Woods Lake included an immediate increase in pH from less than 5.0 to above 9.0; a stabilization in pH below 8.0 after equilibrium with atmospheric CO_2 was reached; increase in calcium, alkalinity, and dissolved inorganic carbon; and a shift in speciation of aluminum from a dominance of organic (non-labile) monomeric aluminum to the inorganic (labile) monomeric form (Fordham and Driscoll, 1989; Driscoll et al. 1989b). After about one month, marked decreases in aluminum, manganese, and zinc were observed in the water column. These minerals accumulated as mineral precipitates in lake bottom sediments.

Growth and condition of stocked trout were reported by Gloss et al. (1989) to be good after liming. Spring fingerling fish survival over the first four months after stocking in both lakes was nearly identical (66 and 64 percent) to average survival rates in circumneutral Adirondack lakes.

In two New York State lakes that were limed, trout grew well.

Overall, no deleterious effects of liming were observed. Maintenance of suitable water quality conditions allowed the reintroduction and restoration of the brook trout population (Schofield et al. 1989).

Technical Considerations

A monitoring program for lakes is implemented in three phases: pretreatment, treatment, and post-treatment. This section discusses monitoring during the transitional and post-treatment phases.

The treatment phase should normally last about one month. The actual addition of base will normally take one to five days, depending on the method of application. Helicopter application, for example, is usually the fastest method; the entire surface of the lake can be uniformly covered in several hours. On the other hand, treatments by other methods may take several days. For instance, application of slurried limestone to a large lake in New York State took five days when a small boat was used to apply the material (Brocksen and Emler, 1988).

Addition of limestone to a lake may take 1-5 days.

The actual length of the treatment phase depends on when the water chemistry has stabilized in terms of its immediate response to the base application. Limestone treatment often causes an immediate pH increase to very high levels until new equilibrium conditions are reached with respect to carbon dioxide and other carbonate species. The transition phase measurements will monitor these changes until water chemistry stabilizes.

Some of the elements described for monitoring lakes treated with base materials influence and are influenced by the treatment methodology. For example, sediment sampling and analyses are different when the treatment technique involves injection of base materials into sediments rather than the more common application directly to the water column (Ripl, 1980). Water quality parameters may also differ depending on the base material applied. Although limestone is the most commonly used base material for neutralization, other chemicals have been used, such as calcium hydroxide, calcium oxide, sodium carbonate, and sodium bicarbonate (Olem, 1989). Sodium, and not calcium, would be a monitored parameter when sodium-based neutralizing materials are used in place of the more common calcium-based chemicals.

Monitoring During Treatment

Certain key parameters are likely to change immediately after liming: pH, turbidity, acid neutralizing capacity, calcium, and aluminum.

The physical and chemical parameters to be monitored during treatment include those that can indicate the response of the system to the neutralization treatment and provide information on the base material's distribution throughout the water column. Certain key parameters are likely to change immediately after liming: pH, turbidity, acid neutralizing capacity, calcium (when calcium-based materials are used), and aluminum. Acid neutralizing capacity is a Gran titration method that includes alkalinity plus additional buffering from dissociated organic acids and other compounds. All parameters should be monitored during the treatment phase, preferably on a weekly basis.

Table 5.24 summarizes the recommended in-lake parameters to be monitored during the treatment phase. Physicochemical parameters should be evaluated during this period, while characterization of sediment chemistry and biological parameters should be reserved for the regular post-treatment phase.

Sampling during the treatment phase would be conducted immediately prior to addition of the base material, during the neutralization process, and weekly for about one month following treatment. This monitoring characterizes transitional changes in physical and chemical parameters as the system changes from acidic conditions to neutral or alkaline conditions. During this transitional period the

Table 5.24.—Monitoring during the treatment phase of an in-lake liming project

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Samples should be collected at the site(s) selected by the project manager, usually at the deepest part of the lake for whole-lake liming.
2. *Depth Distribution*
   Samples should be collected from just below the surface and at 6-foot intervals to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.
3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for acid neutralizing capacity (Gran plot), pH, turbidity, calcium, and dissolved aluminum. See Chapter 3 for appropriate analytical and sampling techniques.
4. *Frequency and Duration*
   Samples should be collected immediately prior to base addition, once during treatment, and weekly for one month following treatment.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.
2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.
3. *Frequency and Duration*
   Same as for water chemistry.

water may, until the base materials are mixed, be highly alkaline. There have been reports of pH values as high as 9.5 immediately after liming, even when slightly soluble limestone has been used as the neutralizing agent (Fordham and Driscoll, 1989). The treatment monitoring program, therefore, should be more intensive temporally and spatially and less intensive with respect to monitored parameters than the post-treatment phase.

The hydrologic parameters, lake level and discharge, should also be considered. These data will allow more accurate assessment of the water quality changes that occur. For example, a major storm event immediately following treatment may have effects on water quality that would not occur under normal hydrologic conditions.

Sampling should be conducted just before treatment begins, during the treatment process, and weekly thereafter until equilibrium conditions are reached. The minimum water column measurements should include samples collected from the surface and bottom (three feet from sediment surface). Samples should be collected at the deepest point in the lake and, if possible, in the major embayments. It is desirable to also collect other samples from the major inlet streams and the lake outlet.

pH values as high as 9.5 have been observed immediately after liming.

Considerations for Interrupting Treatment

Because liming the lake surface ordinarily is completed in a few days, no criteria are presented for interrupting treatment. Addition of excessive amounts of base material would not generally be noticed until after the planned dosage had been applied.

Monitoring Following Treatment

Post-treatment monitoring may be extended over several annual cycles or for one hydrologic retention time. Reacidification may occur sooner because of factors such as incorrect dosage calculation or unusually high storm flows. Monitoring would help determine when retreatment is needed.

Reacidification may occur sooner when there are unusually high storm flows.

All of the parameters monitored during the treatment period, with the exception of turbidity, should also be measured during the post-treatment period. Turbidity is monitored immediately following liming to evaluate how long undissolved limestone remains in the water column after treatment. Significant turbidity has been shown to last for days and sometimes even weeks following treatment.

Certain parameters (including sediment analyses and all biological parameters) are likely to change slowly following base addition. They do not need to be monitored during the transition period but must be checked during the post-treatment phase to evaluate changes in response to liming. Table 5.25 summarizes the recommended in-lake parameters to be monitored during the post-treatment phase and the locations for collection.

The success of lake liming depends on maintenance of adequate water quality to sustain the desired aquatic communities (Bukaveckas, 1989; DePinto et al. 1989; Driscoll et al. 1989a; Roberts and Boylen, 1989; Schaffner, 1989). Monitoring measurements, therefore, should include not only hydrological, physical, and chemical measurements, but also biological parameters. The exact type of biological measurements will depend on the management objectives of the resource. Monitoring measurements for a put-and-take fishery, for instance, will be different from a lake with a sustained, reproducing fish population.

Table 5.25.—Monitoring following the treatment phase of an in-lake liming project

PHYSICOCHEMICAL

A. Water Chemistry

1. *Sampling Location*
   Samples should be collected at the site(s) selected by the project manager, usually at the deepest part of the lake for whole-lake liming.

2. *Depth Distribution*
   Samples should be collected just below the surface and at 6-foot intervals to the bottom. Care should be taken not to include suspended bottom sediments in the water samples.

3. *Analytical Determinations and Sampling Procedures*
   Water samples should be analyzed for acid neutralizing capacity (Gran plot), pH, calcium, and dissolved aluminum. See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Samples should be collected at monthly intervals for at least a one-year period following treatment.

B. Dissolved Oxygen (DO) and Temperature

1. *Sampling Location*
   Same as for water chemistry.

2. *Depth Distribution*
   Measurements should be made at 3-foot intervals from the surface to the bottom.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Same as for water chemistry.

C. Secchi Disk Transparency

1. *Sampling Location*
   Same as for water chemistry.

2. *Frequency and Duration*
   Measurements should be made monthly during the growing season (May through October) for at least a one-year period following treatment.

BIOLOGICAL

A. Chlorophyll *a* (corrected for pheophytin)

1. *Sampling Location*
   Same as for water chemistry.

2. *Depth Distribution*
   A subsample should be obtained from an integrated sample representing a water column equal to 0–6 feet from the surface.

3. *Analytical Determinations and Sampling Procedures*
   See Chapter 3 for appropriate analytical and sampling techniques.

4. *Frequency and Duration*
   Same as for Secchi disk.

CONTROL TECHNIQUE #2:

Watershed Liming

Technical Considerations

Addition of base materials to the watershed of a lake is a relatively new technique for mitigating acidic conditions. The method has been conducted on several watersheds in Sweden, Norway, and Great Britain (Brown, 1988; Rosseland and Hindar, 1988; Olem, 1989). In the United States, watershed liming has been practiced only recently. In 1989, Woods Lake watershed in the Adirondack region of New York State was treated in the most comprehensive technical evaluation of watershed liming to date.

Watershed liming may be a long-term solution to lake acidification once the sources are controlled.

The watershed liming projects conducted so far have been designed so that neutral or alkaline lake water conditions remain for decades. Acidic conditions may never return in these situations if the source of the acidity is removed, such as through a reduction in atmospheric emissions of SO_2 and NO_x.

Suggested monitoring considerations are not dramatically different for watershed versus in-lake treatment methods for mitigation of acidic conditions. The major difference may be the temporal characteristics of the monitoring program. Watershed treatment often results in much more gradual increases in pH and changes in other water chemistry parameters compared to in-lake treatment (Olem, 1989).

The treatment phase should normally last about two to three months. The actual addition of base materials will normally take 1 to 10 days, depending on the method of application and area to be limed. Helicopter application, for example, is usually the fastest method and may allow base materials to be added over the selected subwatersheds over a period of hours. Some applications, such as application of limestone by tractor, may take several days if many acres are to be treated.

The actual length of the treatment phase depends on when the water chemistry has stabilized in terms of its immediate response to base treatment. The treatment phase measurements will monitor these changes until water chemistry stabilizes.

Monitoring During Treatment

Certain key parameters are likely to change during the first precipitation or snowmelt event following base addition. These include pH, turbidity, acid neutralizing capacity, calcium (when calcium-based materials are used), and aluminum. These parameters should be monitored at least twice during the treatment phase, preferably following a major precipitation or snowmelt event.

Water quality changes should become evident after the first rain or snowmelt.

Recommended in-lake parameters to be monitored during the treatment phase and the locations for collection are the same as for in-lake treatment (see Table 5.24).

Sampling during the treatment phase would be conducted immediately before addition of the base material and later during major precipitation events. This phase is intended to characterize transitional changes in physical and chemical parameters as the system changes from acidic to neutral or alkaline conditions.

The minimum water column measurements should include samples collected from the surface and bottom (three feet from sediment surface). Samples should be collected at the deepest point in the lake and, if possible, at the major embayments. It is highly desirable to collect samples from the inlet streams of the subwatersheds where base materials were applied.

Monitoring Following Treatment

All of the parameters monitored during the treatment period, with the exception of turbidity, should also be monitored during the post-treatment period. Turbidity is monitored immediately following liming to evaluate whether undissolved limestone is flushed into the lake water column from the watershed. This would normally occur only when limestone material is distributed at or near the lake shoreline or directly in the tributary streams. The other parameters should be monitored on a quarterly basis during the post-treatment period.

Recommended in-lake parameters to be monitored during the post-treatment phase are the same as for in-lake treatment (see Table 5.25).

The success of aquatic liming depends on maintenance of adequate water quality to sustain the desired aquatic communities. Monitoring measurements, therefore, should include not only physicochemical measurements but biological parameters. The exact type of biological measurements will depend on the management objectives of the resource. Monitoring measurements for a put-and-take fishery, for instance, will be different from a lake where a reproducing fish population will be sustained.

Chapter 6

A Long-term Monitoring Protocol

Summary

1. A continuing data acquisition program should be established to track changing water quality conditions and guide future lake management actions.

2. The Phase II monitoring protocol should serve as a model for the local sponsor, who should be encouraged to continue the program after the project's formal completion.

3. An ongoing monitoring program should be designed around common skeletal models to ensure collection of consistent and comparable information. Additional data can be obtained to meet specific lake requirements.

4. Long-term monitoring programs can range from Secchi disk observations that are made every two weeks, to a more complex program that develops basic water chemistry and biological information, to a comprehensive effort where all major lake ecosystem components are tracked.

Lake water quality trends often cannot be detected unless a multi-year monitoring record is available.

Background

Data on the condition of the major components of a lake ecosystem are a prerequisite to sound management of the resource. This information, along with an ongoing database on water quality conditions within a lake, provides the basis for sound decisions on managing lake water quality. If a decline in lake water quality is noted, then a response must be made to identify and correct the cause. Conversely, if a restored lake exhibits improvement over time, the manager will know the present management strategy has been effective.

A major difficulty in detecting trends is that lakes, unlike rivers, often respond slowly to changed external influences. Because of these inherent lags and a natural background variability, lake water quality trends often cannot be detected unless a multi-year monitoring record is available. Wolman (1971), commenting on the detection of water quality trends, suggested that formal statistical procedures often can be used. He noted that

- Water quality records are often short term;
- Techniques and sensitivities of analytical methods have changed over time;
- Sampling locations and frequencies have also often changed;
- Numerous interrelated physical, chemical, and biological variables determine water quality;
- Natural background variability often hides water quality trends; and
- Causal explanation of trends requires a knowledge of human activities, hydrologic processes, and land use in watersheds.

While these conditions may, in fact, make the use of statistical tools more difficult, they do not preclude their implementation. However, they do pose complications that must be considered during the statistical analysis.

Most of the above-noted complications can be addressed by establishing a consistent, generic monitoring protocol upon which to build individual lake monitoring programs. The Phase II monitoring effort offers an excellent opportunity to set up a lake-specific data acquisition program while building a consistent and comparable nationwide lake database.

A lake monitoring program must be structured so the local sponsor will continue monitoring to establish a multi-year period of record following completion of the lake restoration or protection project. Once established, trend detection methodologies such as those described by Montgomery and Reckhow (1984) can be used to great advantage.

An ongoing, long-term monitoring program can be as simple as obtaining water clarity information with a Secchi disk twice each month during the growing season from a single, centrally located site in the lake, or it can be as complex as an in-depth multi-faceted program that simultaneously obtains physical, chemical, biological, and sociological data on a variety of lake ecosystem components.

When designing a monitoring program for a particular lake, the project manager's major challenge is often not technical but sociological.

When designing a monitoring program for a particular lake, the project manager's major challenge is often not technical but sociological. The project manager's judgment on the intensity of monitoring needed for a particular lake must be accurate or the local sponsor may decide to discontinue the program because of costs, maintenance problems, or hard-to-understand protocol. Usually, the most important factors are keeping costs low relative to the size of the project and, most importantly, ensuring that a periodic, professional interpretation of the data is made and communicated to the local sponsors.

The following sections outline three levels of long-term monitoring that can serve as frameworks on which to structure individual, lake-specific programs. The more intensive efforts will generally be associated with those lakes where residents have recently completed a costly restoration project; simpler monitoring efforts will often be associated with those lakes that have had minimal management activity. Unfortunately, lakes that have good water quality and are most sensitive to management changes are usually not managed. With these waterbodies, local initiative is all too often stimulated in response to a crisis—when monitoring programs are finally established after the fact.

Unfortunately, lakes that have good water quality and are most sensitive to management changes are usually not managed.

Monitoring Water Clarity

Collection of Secchi disk information is nearly always a component of the monitoring program—often it is the only component. Water clarity is an indirect measure of water quality that is directly related to the public's perception of lake quality. It is also data that are easy to obtain.

Water clarity is an indirect measure of water quality that is directly related to the public's perception of lake quality.

To be of most value, Secchi disk data should be collected once every two weeks during the growing season. Although more frequent (weekly or daily) measurements can be of some value, Smeltzer et al. (1989) noted that, for estimating average lake water clarity conditions, weekly and biweekly sampling frequencies yield almost the same amount of information. In many lakes, a single site located near the center will provide the least biased information on average conditions (Stauffer, 1988). Multiple sites may be needed where the lake has a very complex configuration or when it is a long, river-run reservoir.

Ongoing support, analysis, and feedback to the person or group responsible for managing the lake is necessary for even these simple monitoring efforts. Many States have volunteer lake monitoring programs that could be used to provide this necessary professional assistance; where these programs do not exist, an alternate method of support should be established.

Ongoing support, analysis, and feedback to the person or group responsible for managing the lake is necessary for even these simple monitoring efforts.

A Basic Lake Water Quality Monitoring Plan

Although water clarity information provided by Secchi disk data provides a basic indication of lake quality, it offers no insights into causal factors affecting a lake's condition. An example of an expanded water quality trend-monitoring protocol is presented in Table 6.1. Although this protocol is very basic and oriented towards smaller impoundments and natural lake environments, it does begin to provide a database from which in-lake cause-effect inferences can be drawn and lake-to-lake comparisons completed. And, most importantly, these data are relatively inexpensive to obtain.

A similar protocol, presently being followed by the U.S. Geological Survey (USGS) in some midwestern States, costs approximately $3,500 per year, per station (1989 dollars). In addition, 50 percent cost-sharing is often available from the USGS, thereby further reducing expenses.

While this basic monitoring program will often be adequate to describe lake conditions, additional data are sometimes needed to address specific lake concerns. Although there will always be lake-to-lake or region-to-region exceptions, the scope of this already low-cost protocol will rarely be reduced. It is more likely that additional parameters will be sampled or that changes will be made to the timing of data collection.

Table 6.1.—A basic water quality trend-monitoring protocol

	APPROXIMATE TIMES OF COLLECTION					
PARAMETER	MIDWINTER	SPRING DURING MIXED CONDITIONS	JUNE	JULY	AUGUST	COMMENTS
Water chemistry		X				2 depths—1.5 feet from surface —3.0 feet above bottom Parameters: TP, DRP, NH_4-N, NO_2+NO_3-N, TKN, Ca, Cl, Mg, Na, K, pH, total alkalinity, color, turbidity, total dissolved solids, SO_4, SiO_2
Total phosphorus, NO_3-N, TKN	X	X	X	X	X	3 depths—1.5 feet from surface —3.0 feet above bottom —2.0 feet below the top of the hypolimnion (if present)
Dissolved oxygen, temperature, pH, specific conductance	X	X	X	X	X	Profile—1.5 feet from surface, proceeding to lake bottom using 3- to 6-foot intervals depending on conditions and lake depth
Secchi-disk depth	X	X	X	X	X	Every 2 weeks
Chlorophyll *a*		X	X	X	X	6-foot integrated sample
Lake level	X	X	X	X	X	Every 2 weeks

Note: The sampling site will normally be located at the deepest point of the lake. On large lakes, more than one site may be required to adequately define water quality.

Elements of the Basic Lake Water Quality Trend Monitoring Program

- **Comprehensive water chemistry data** are obtained once each year to describe the lake's water quality. To minimize within-lake variability and to keep costs low, this information is usually collected when the lake is well mixed, often at the time of spring overturn. Although a single sample might characterize lake conditions, both top and bottom samples should be collected and analyzed to ensure that vertical differences were not present at the time of sampling. Ideally, the lake should be sampled more than once during this well-mixed period. Smeltzer et al. (1989) noted significant increases in the precision of describing spring phosphorus concentrations when several samples were obtained on different dates during the spring mix sampling period.

  Information on nitrogen and phosphorus is collected because these nutrients often limit plant production; on silica because it is often limiting to diatoms; and on chloride and sodium because they are often good indicators of the degree of watershed urbanization in regions not affected by marine influences or by natural sodium weathering.

  Data are also obtained on potassium, an indicator of animal waste contamination that is found in high concentrations in cattle manure (Travis, 1988).

- **Color and turbidity** are other indicators of water clarity. Colored lakes, such as those stained by organic acids, often have naturally low water clarity. High turbidity in the absence of significant algal production is indicative of suspended sediment that is limiting clarity. Data on alkalinity, calcium, magnesium, sulfate, pH, and dissolved solids are useful in understanding in-lake phosphorus dynamics and sensitivity to acid deposition.

- **Supplemental total phosphorus**, NO_3-N, total Kjeldahl nitrogen, and chlorophyll *a* analyses should be made during the growing season. Along with clarity data, these are the most common parameters used to describe lake trophic status. When these data are compared to each other, insights can be drawn regarding the importance of phosphorus, nitrogen, and corresponding algal production when water clarity is limited. Documenting lake conditions during periods of strong stratification can help identify the magnitude and potential of internal loading processes. Where internal phosphorus loadings are important, it is necessary to obtain additional information on hypolimnetic iron, manganese, sulfate, and ammonium.

- **Dissolved oxygen data**, which provide the most basic description of water quality, often serve as an indicator of lake productivity. In stratified lakes, an anoxic hypolimnion suggests mesotrophic or eutrophic conditions. Anoxia also favors sediment phosphorus release.

- **Temperature profiles** provide information on stratification.

- **Specific conductance profiles** can be used as a quality assurance tool to evaluate the magnitude of dissolved constituents. If specific conductance increases, corresponding increases of dissolved substances can be expected.

Both top and bottom samples should be collected and analyzed to ensure that vertical differences were not present at the time of sampling.

Documenting lake conditions during periods of strong stratification can help identify the magnitude and potential of internal loading processes.

Dissolved oxygen data, which provide the most basic description of water quality, often serve as an indicator of lake productivity.

One centrally located station near the deepest part of the lake will normally provide the least biased characterization of conditions.

Adequate support, analysis, and feedback are essential to a local sponsor who will continue to acquire long-term data.

- **Water level information** is necessary to make mass balance calculations and to determine lake volume.

- **One centrally located station** near the deepest part of the lake will normally provide the least biased characterization of conditions. As described by Gaugush (1987) and illustrated in Figure 6.1, exceptions are large reservoirs that often exhibit longitudinal differences. Gaugush also describes sampling designs appropriate for reservoirs such as the one shown.

Data that supplement Secchi disk information will provide a significantly better documentation of lake condition and may also, in some cases, supply information from which cause-effect relationships can be identified.

Again, it is necessary to emphasize that adequate support, analysis, and feedback are essential to a local sponsor who will continue to acquire long-term data. Although it is very difficult to develop conclusions based upon one or sometimes even several years of data, most local sponsors will expect some type of interpretive report.

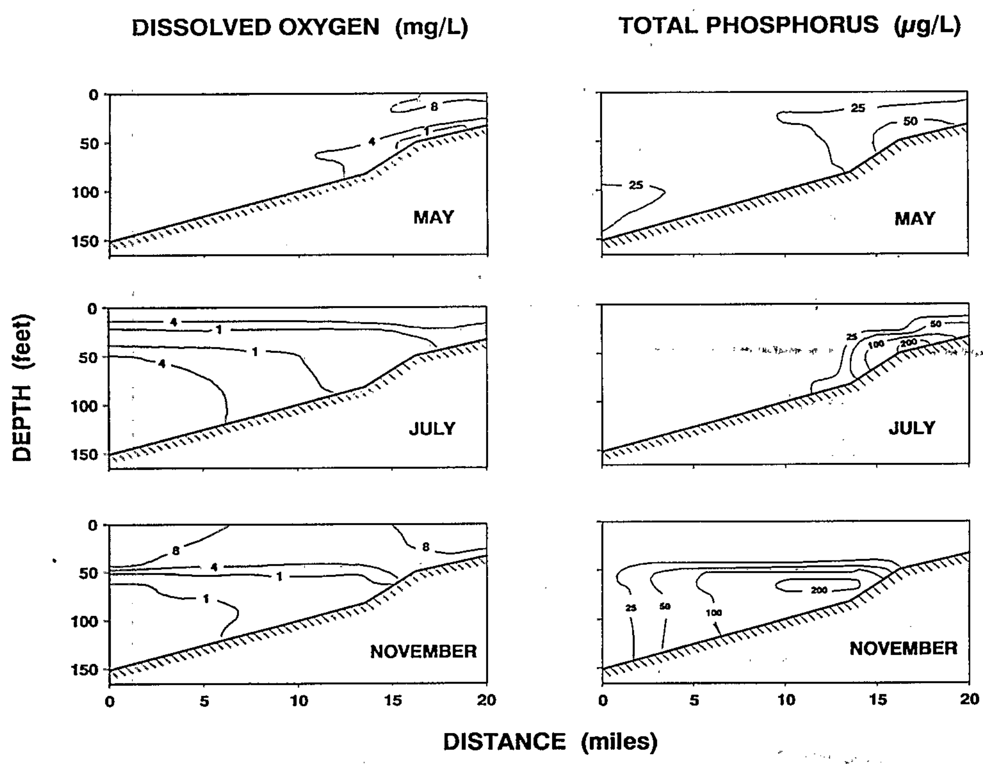


Figure 6.1—Longitudinal and vertical distributions of dissolved oxygen and total phosphorus in DeGray Lake, Arkansas (source: Gaugush, 1987).

A Comprehensive Long-term Lake Monitoring Protocol

Identifying causal factors of lake water quality changes often requires information on lake chemistry, macrophytes, phytoplankton, zooplankton, and fish communities, as well as watershed conditions. A sample long-term lake monitoring protocol designed to describe these elements of the lake ecosystem is presented in Table 6.2.

Identifying causal factors of lake water quality changes often requires information on lake chemistry, macrophytes, phytoplankton, zooplankton, and fish communities, as well as watershed conditions.

Table 6.2.—Typical elements of a comprehensive, long-term monitoring program

Parameter	Comments
Water Chemistry	Protocol at least as intensive as that in Table 6.1.
Macrophytes	Survey once or twice during the growing season. Define species present, distribution, abundance, frequency of occurrence, percent of lake colonized, maximum depth of growth, and distance of plant tops from the water's surface. Repeat survey every 3 years.
Zooplankton	Do bottom to top vertical tow with 80 u conical plankton net. Collect 3 times or more per year during the growing season. Identify dominant species and size range. Minimum diameter of net opening should be 0.2 meters.
Phytoplankton	Do six-foot-deep surface composite. Collect 3 or more times per year during the growing season. Use Lugol's solution for sample preservation. Identify dominant species.
Fish Community	Do boom shocker transects and gill netting once every 2 years, and fyke netting every 6 years for lakes with pike or walleye. Identify species, size, length, and catch per unit of effort.
Watershed	Identify major land uses once every 5 years. Track major development and agricultural changes continually. Establish a continually recording flow gaging station with automatic samplers at the major inlets (see Chapter 4).

Rationale for Comprehensive Monitoring

Lakes are often inappropriately characterized when there are no data on their major ecosystem components. For example, a scientist might conclude that general lake conditions had improved because Secchi disk readings increased as a result of improved watershed conditions. At the same time, local citizens and lake users might perceive that conditions had worsened because dense growths of rooted plants, which replaced the algae, were severely limiting lake recreation. Unfortunately, macrophyte-algae trade-offs are common in many shallow lakes where improvement in water clarity, for whatever reason, has resulted in dense stands of rooted plants.

Macrophyte-algae trade-offs are common in many shallow lakes where improvement in water clarity, for whatever reason, has resulted in dense stands of rooted plants.

Knowledge of a lake's macrophyte community can also help prevent errors when defining reasons for lake water quality changes. For example, water clarity can be degraded by any of several in-lake "improvement" techniques. If macrophytes are controlled by harvesting, chemical treatment, use of grass carp, or dredging, nutrients formerly used by rooted plants can become available for algae growth. Without knowledge of changes in the lake's rooted plant community, users might be led to conclude, wrongly, that the resultant decrease in lake clarity was caused by increased watershed nutrient loadings.

Similarly inaccurate conclusions can be drawn about the causes of an apparent water quality improvement that occurred because of changes in a lake's fish community. For example, a lake's improved water clarity could be attributed to the fact that a sewer had recently been installed around the lake, when in actuality the im-

Because of the lack of zooplankton grazing on the algae . . . water clarity is often much poorer than would be predicted based upon nutrient loadings.

provement occurred because the fish population had been restructured following treatment to eradicate undesirable planktivores. Water clarity improvements are also observed in lakes that have recently experienced massive winter or summer fish kills. These improvements, which are often temporary in nature, can occur even though no changes were made in nutrient loading to the lake.

Massive fish kills are not the only events that affect water clarity. Activities such as recreational fishing, which create more subtle differences in fish community structures (Shapiro, 1975), can also play important roles in defining a lake's water clarity. Knowledge of the zooplankton community will often provide insight into the type of fishery a lake supports. For example, in lakes where the zooplankton populations are low and size distribution small, often may be a fishery dominated by small planktivorous fish. Because of the lack of zooplankton grazing on the algae in such waterbodies, water clarity is often much poorer than would be predicted based upon nutrient loadings. If the monitoring program shows an increasing dominance of small zooplankton in a lake, then a management strategy might focus on increasing the number of higher level predator fish by increased stocking or by reducing recreational fishing.

A lake's fish community can also have a direct effect on its macrophyte community. In lakes where the fish population is dominated by bottom-feeding common carp or plant-eating grass carp, rooted plant communities are usually limited and water clarity is often poor. Poor water clarity is not always a direct result of fish activities, however, as high nutrient or sediment loadings to a lake may be providing desirable habitat for these particular species. Only a long-term monitoring program that has tracked these ecosystem components can identify the root cause.

The contributions lakes receive from watersheds will largely define long-term, average conditions.

Finally, knowledge of a lake's ever-changing watershed conditions is essential. Ultimately, lakes will respond to the conditions of their watersheds. Algal, macrophyte, and fish populations reach an equilibrium that is dependent in part upon the nutrient and sediment loads received by the lake. Although lake water quality will always vary from year-to-year or even decade-to-decade, the contributions lakes receive from watersheds will largely define long-term, average conditions.

A general description of watershed conditions can often be extrapolated from the watershed inventory that is part of a monitoring program. As described in Chapter 4, watershed inventories are often the most cost-effective method of obtaining data on the watershed's importance to the lake. However, where extensive watershed improvements are being implemented and evaluated or where documentation of problems is necessary before control measures can be implemented, more comprehensive data are necessary. The larger, more important lake tributary streams are often gaged and sampled to quantify sediment, nutrient, and pesticide loadings to a lake. In lakes where year-to-year watershed land use changes are not significant, inventory updates every 5 or 10 years are usually adequate.

Only if information is collected on most of the lake's major ecosystem components can definitive judgments be made on long-term trends and their causes. In addition to community-supported monitoring, State agencies responsible for making overall judgments on lake water quality should consider instituting a long-term, comprehensive monitoring program for selected lakes.

Chapter 7

CASE STUDY: Detection of Trends and Sampling Strategy Evaluations

Case Study of the Statistical Evaluation of the Neuse River, North Carolina, Total Phosphorus Data Set

The basis for this case study was a monitoring design completed for the Triangle Area Water Supply Monitoring Project, Research Triangle Park, North Carolina. The study, which was conducted by Ken Reckhow, Craig Stow, James Mitchell, and Nicolai Denisov, was completed, in part, to statistically evaluate the effectiveness of alternative monitoring strategies for detecting trends in water quality.

Introduction

The Neuse River near Smithfield, North Carolina (Fig. 7.1), drains a 6,192-square-mile area that includes runoff from the city of Raleigh, two upstream water supply reservoirs, and an extensive forested area. Starting in 1981, monthly phosphorus data were collected from this site by the U.S. Geological Survey. As shown in Table 7.1 and Figure 7.2, total phosphorus concentrations ranged from a low of 0.13 mg/L to a high of 1.8 mg/L over the seven-year period.

A statistical evaluation of these data was completed to provide information on water quality trends and guidance on the intensity of future sampling efforts needed to detect phosphorus trends. The project sponsor wanted an evaluation of the ongoing sampling program—should the monitoring program be continued in the future and, if so, what level of effort was needed—as well as data on improvement or deterioration of water quality.

Although this case study focuses on evaluating tributary stream data, its approach and techniques can also be used with data obtained directly from a lake.

Autocorrelation indicates that each observation in a time series is not independent of other observations. This means that some of the information that is conveyed in the current observation has already been conveyed in the previous observation. The result is that the amount of information actually available is not reflective of the number of samples collected: that is, completely "new" information has not been obtained. Autocorrelation causes problems with statistical analysis because, if it is present, conclusions regarding the strength of the analysis can be incorrect. Autocorrelation is often present in lake water quality data sets where sampling frequencies are high. This problem most commonly occurs when conservative substances (such as chloride) are sampled in lakes that have long water residence times. In essence, the same water is being sampled again and again.

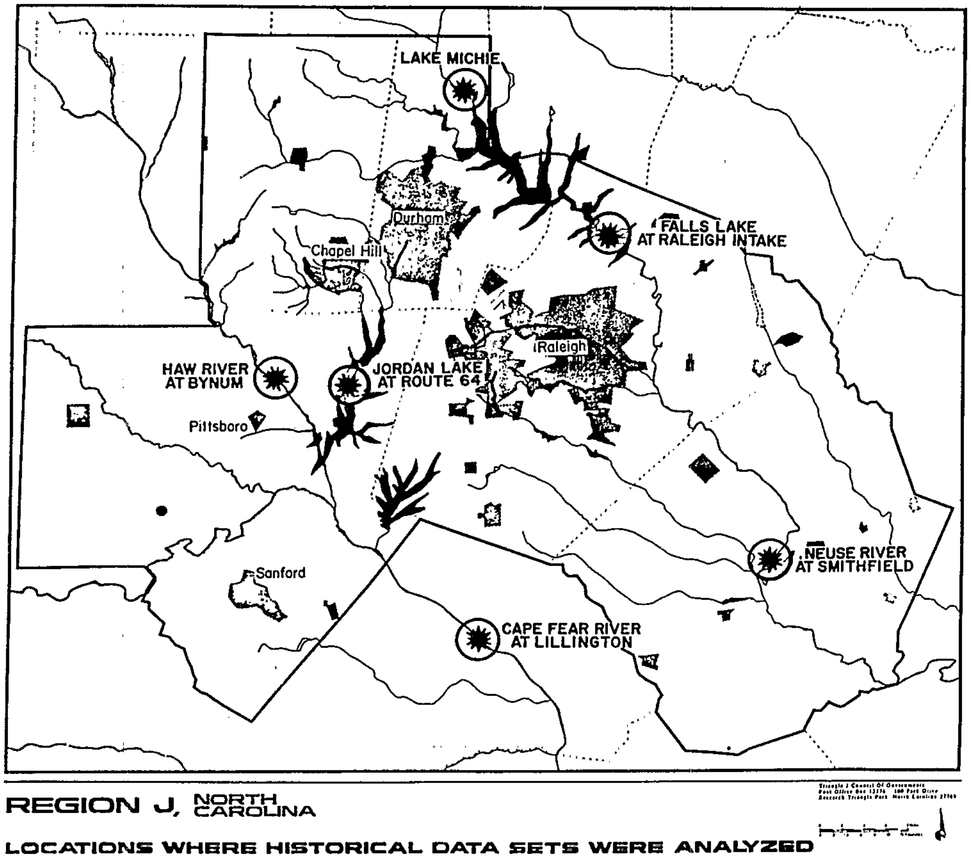


Figure 7.1—Neuse River study area.

Statistical Model Selection

As described in Chapters 4 and 6, major complicating factors in the analysis of water quality data are the natural background variations that often obscure culturally induced changes.

Seasonal differences are often noted on a yearly basis because of changes in solar radiation, temperature, and precipitation. Wind irregularities, rainfall events, and temperature variations also cause seemingly random water quality variations, but on a smaller scale.

If some of the components causing natural variability can be distinguished and eliminated from the data set, time trends can be more easily identified. One of the first steps in analyzing the Neuse River data was identification and separation of natural variability in the data set from that induced by cultural impacts. If natural variability can be mathematically described and removed from the water quality data set, only background variability, or noise, remains to complicate further trends analysis.

Two different statistical models were considered. Both parametric methods and nonparametric methods were evaluated for use with the Neuse River data set. The former methods are ones in which a change can be related to particular physical parameters, e.g., flow, depth, detention time; the latter, more commonly called distribution-free methods, do not require the assumption that the data be normally distributed.

Table 7.1.—Total phosphorus concentrations (mg/L) observed in the Neuse River, near Smithfield, North Carolina

YEAR	MONTH (DAY COLLECTED SHOWN IN PARENTHESES)											
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1981	1.80 (19)	0.62 (10)	0.39 (13)	0.45 (8)	1.10 (11)	1.20 (17)	0.68 (29)	1.10 (4)	0.50 (15)	1.50 (14)	0.53 (4)	0.82 (9)
1982	0.15 (27)	0.23 (15)	0.23 (11)	0.32 (14)	0.51 (11)	0.22 (8)	0.37 (8)	0.76 (12)	0.79 (7)	0.92 (7)	0.52 (15)	0.25 (15)
1983	0.26 (13)	0.21 (10)	0.18 (9)	0.18 (19)	0.27 (12)	0.46 (17)	0.90 (19)	1.10 (22)	1.10 (22)	1.40 (6)	1.20 (9)	0.71 (2)
1984	0.24 (6)	0.29 (15)	0.13 (23)	0.16 (20)	0.18 (11)	0.47 (22)	0.32 (18)	0.68 (28)	0.52 (17)	0.79 (18)	0.76 (27)	0.45 (11)
1985	0.22 (10)	0.21 (13)	0.49 (21)	0.68 (22)	0.76 (23)	0.74 (24)	0.53 (22)	0.35 (27)	0.85 (11)	0.57 (30)	0.66 (18)	0.14 (11)
1986	0.65 (17)	0.39 (18)	0.28 (26)	0.68 (10)	0.91 (15)	1.00 (18)		0.64 (28)		1.10 (22)	1.30 (6)	0.99 (2)
1987	0.17 (27)	0.20 (24)	0.14 (10)	0.31 (9)	0.58 (27)		0.91 (8)		0.74 (30)	0.88 (23)	0.44 (12)	0.89 (9)
1988	0.29 (21)	0.21 (18)	0.36 (17)	0.28 (26)	0.35 (27)							

A problem inherent to parametric models arises from uncertainty in the applicability of a given model.

Parametric models must be always cautiously applied since there is evidence that many water quality constituents (including flow) are log-normally distributed.

Parametric Methods

Parametric approaches in trend detection involve use of two separate models, one for detecting the trend itself and another to estimate potential errors. Where a trend is believed to be continuous rather than abrupt, then ordinary least squares regression techniques are commonly used. A t-statistic is often used for analysis of trend where a step trend is expected, e.g., a river system from which a wastewater discharge has been reduced or eliminated.

If seasonal patterns exist in the data set or if autocorrelation is present, then more sophisticated techniques such as ARIMA or Box-Jenkins models may be appropriate (Pankratz, 1983). In addition to seasonal trends, other water quality changes that can be related to identifiable factors, such as a predictable relationship between flow and concentration, should be removed from the data set. This removal will further reduce background variability from the trend.

A problem inherent to parametric models arises from uncertainty in the applicability of a given model to a given data set. In the Neuse River evaluation it was felt that one of the basic assumptions needed for parametric models—that the data be normally distributed—did not hold for this data set. This uncertainty prevented the use of a parametric model for this case study. Parametric models must be always cautiously applied since there is evidence that many water quality constituents (including flow) are log-normally distributed.

Distribution-free Methods (Nonparametric Methods)

Although distribution-free methods may not be as powerful as parametric methods, they do not require the assumption that the data be normally distributed. However, even with these methods there is still a need for independent (unautocorrelated) data.

For the Neuse River Analysis, the seasonal Kendall's Tau Test (Hirsch et al. 1982; Hirsch and Slack, 1984) was the method of choice because the data do not show a normal distribution: they are skewed significantly, and they display a seasonal cycle. In addition, the seasonal Kendall's Tau Test is not overly sensitive to extreme values, a situation commonly observed with water quality data. A more detailed discussion of the use of this test can be found in Gilbert (1987).

Evaluation of the Historical Database

To facilitate evaluation of the Neuse River data, basic statistical analyses were performed using the software package WQStat II. To simplify this case study, the actual equations used in the analysis will not be presented here. However, a copy of WQStat II can be obtained for a nominal fee from Jim Loftis, Agricultural and Chemical Engineering Department, Colorado State University, Fort Collins, Co 80523; (303) 491-6172.

Data Entry and Preparation

The data collected on the Neuse River were initially imported from an ASCII file into WQStat II, and a seasonal interval length was specified. In this case, a monthly interval was selected for preliminary evaluation because the data had generally been obtained on a monthly basis; sampling intervals typically ranged between 25 and 35 days. Had the data been collected much outside of this fairly regular time frame or on a more frequent basis, consideration would have to have been given to using a quarterly data input format.

Summary Statistics

Once entered and prepared, the following summary statistics were obtained from the data by using WQStat II:

- General statistics
- Skew and kurtosis statistics
- Time series plot
- Seasonal box and whiskers plot, and
- Correlogram.

General summary statistics are shown in Table 7.2.

The statistics for skew (a measure of the degree of the distribution's asymmetry) and kurtosis (a measure of the degree of the distribution's flatness), which are shown in Table 7.3, provide information on the normality of the data. If either the skew or kurtosis tests are significant, the data distribution is probably not normal. In this case, the skew value of 0.876 (calculated by WQStat II) is significant at the 0.20, 0.10, and 0.02 (80, 90, and 98 percent confidence) levels. This shows that the data are non-normally distributed.

The statistics for skew and kurtosis provide information on the normality of the data.

Table 7.2.—General summary information on the Neuse River data set

CHARACTERISTIC	VALUE
Mean	0.586 mg/L
Median	0.500 mg/L
Standard deviation	0.363
Number of data points	85

Table 7.3.—Skew and Kurtosis normality tests for the Neuse River data set

SKEW TEST (SKEW VALUE = 0.876)		
CONFIDENCE LEVEL	TEST	SIGNIFICANCE
98%	0.876 > 0.613	Significant
90%	0.876 > 0.420	Significant
80%	0.876 > 0.324	Significant
KURTOSIS TEST (KURTOSIS VALUE = 3.40)		
CONFIDENCE LEVEL	TEST	SIGNIFICANCE
98%	2.12 < 3.40 < 4.51	Not Significant
90%	2.30 < 3.40 < 3.83	Not Significant
80%	2.39 < 3.40 < 3.55	Not Significant

The total phosphorus concentration time series plot (Fig. 7.2) indicates that some seasonal patterns exist.

The seasonal box whiskers plot (Figure 7.3) shows, more specifically, the data's seasonality. Seasonality is considered significant if any of the boxes shown in the figure do not overlap. Since many of the boxes fail to overlap, and seasonality is present, consideration should be given to its removal from the data set prior to trend analysis.

The correlogram (Fig. 7.4) was produced because it can indicate the presence of seasonal patterns, trends, and/or autocorrelation. In Figure 7.4, the values along the horizontal axis represent lag values, which are observations N time periods earlier. In this case, a lag value of 1 represents values obtained one month previously, and a lag of six represents observations 6 months apart. The

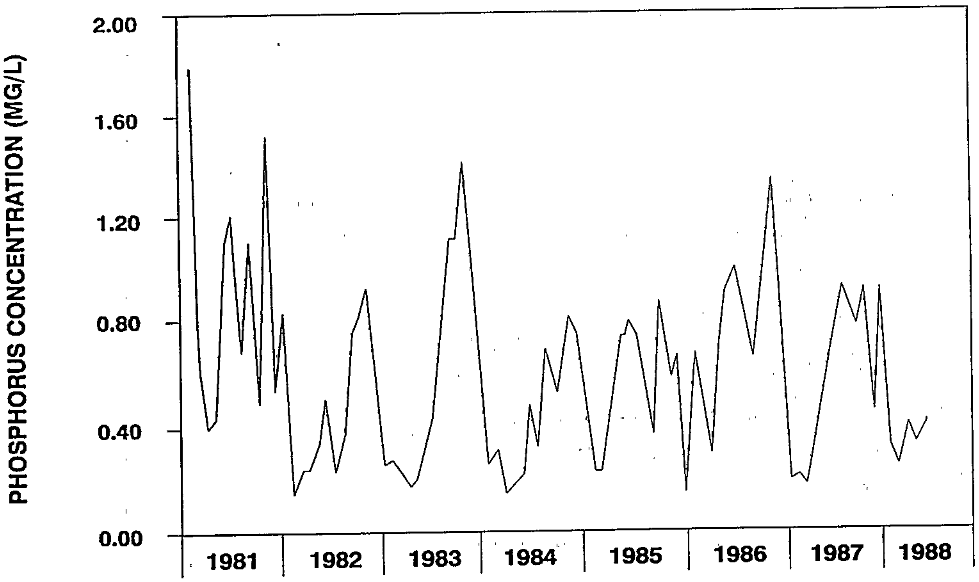


Figure 7.2—Neuse River total phosphorus concentration time series plot.

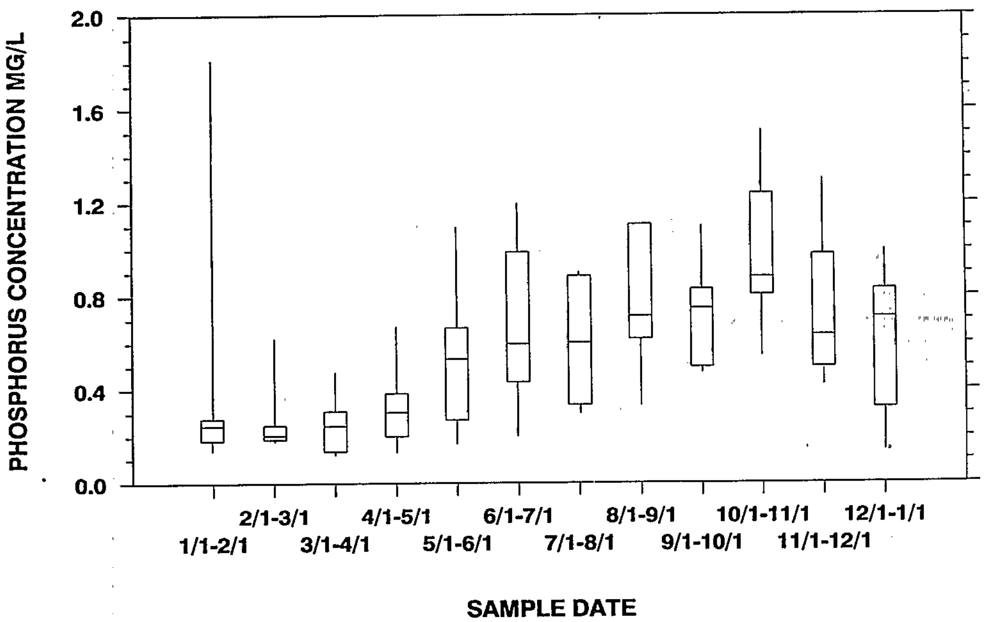


Figure 7.3—Seasonal box and whisker plot of the Neuse River data set.

lines extending outward from the center of the correlogram represent the autocorrelation between values at a particular time and those taken N observation periods (lags) earlier. The parallel horizontal lines represent the values beyond which correlation is significant at the .05 level (95 percent confidence level). For example, in Figure 7.4, the line at N=1 shows autocorrelation to be significant for observations made one month apart.

Seasonality in the data is shown in Figure 7.4 by the high positive autocorrelation values at lags 12 and 24 and large negative values for lags 6 and 18. Trend and autocorrelation both show up as initially significant correlation values that

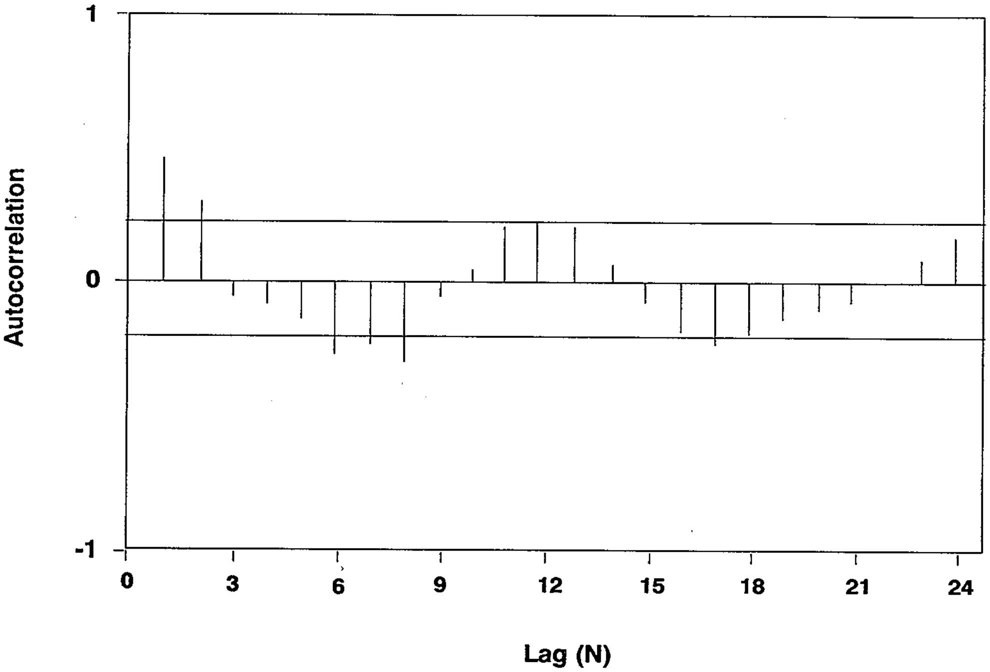


Figure 7.4—Unadjusted Neuse River data set correlogram.

gradually decay to zero. Although it is difficult to distinguish between trends and autocorrelation, trends generally cause a slower decay in the correlation values.

The correlogram shown in Figure 7.5 was produced following a detrending and deseasonalization of the data. It indicates that autocorrelation is no longer significant beyond the first lag. In this case, the autocorrelation still present at the first lag was due to a relationship between concentration and flow that could have been eliminated by using procedures described by Hirsch et al. (1982).

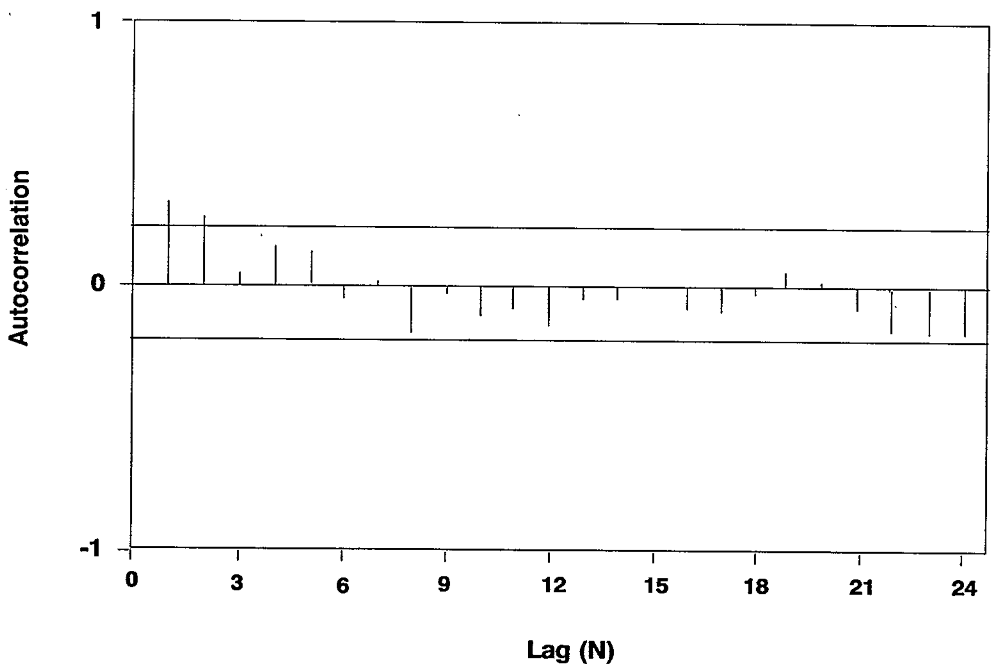


Figure 7.5—Deseasonalized/detrended Neuse River data set correlogram.

Had the correlogram shown the data to be autocorrelated, the assumption of independent data required for use of the statistical models would have been violated. Other techniques such as reentering the data in a quarterly format (averaged or centered) would have been used and the correlogram recomputed. Hirsch and Slack (1984) describe a statistical method for removal of autocorrelation within the seasonal Kendall's Tau Test in more detail. This correction must precede final analysis with WQStat II since their procedure has not yet been incorporated into the software.

Trend Analysis

Following data preparation and autocorrelation testing, WQStat II was used to run the Kendall's Tau trend detection tests. In this case it was not necessary to deseasonalize the data prior to trend detection, since it was handled within the seasonal Kendall's Tau Test.

As shown in Table 7.4, the seasonal Kendall's Taut statistic used to test for total phosphorus trend was –1.050. This value was found not to be significant at the 80, 90, or 95 percent confidence levels, which indicated no significant trend. More specifically, this test shows that one cannot reject the hypothesis that the phosphorus concentration trend was zero over the seven-year monitoring period.

Table 7.4.—Kendall Tau Test for trend detection on the Neuse River data set

SEASONAL KENDALL TEST (TEST STATISTIC = −0.619)

CONFIDENCE LEVEL	TEST	SIGNIFICANCE
95%	$-1.960 < -1.050 < 1.960$	Not Significant
90%	$-1.645 < -1.050 < 1.645$	Not Significant
80%	$-1.282 < -1.050 < 1.282$	Not Significant

The Kendall Sen slope estimate of -0.0100 units/year indicates little change in phosphorus.

The WQStat II program also calculated the seasonal Kendall Sen slope estimate. This value is the seasonal equivalent to Sen's nonparametric estimate of slope. It is the median of all possible slopes generated between the data points. The value for slope in the Neuse River data set was -0.0100 units/year, indicating little change in phosphorus over time. Figure 7.6 is a graph of the data over time, with the calculated phosphorus trend line.

Determination of Future Sampling Effort

. . . the database available precluded detection of any trends . . . where reductions were less than 30 percent.

The Neuse River analysis found no significant trend in the data. However, the database available precluded detection of any trends that might have been caused by phosphorus reduction in the watershed where reductions were less than 30 percent. Figures 7.7 and 7.8 were prepared using WQStat II to help determine the number of samples necessary for detecting future trends. For example, as shown in Figure 7.7, over 120 monthly samples (a 10-year monitoring program) would be necessary to detect a 23 percent linear decrease in total phosphorus, such as might be expected with implementation of an extensive nonpoint source control program, if an error rate of 10 percent is required. If larger error rates are acceptable, a less intensive sampling effort would be adequate.

If a step decrease in phosphorus is expected, such as that which could occur from the upgrading of a sewage treatment plant, then, as can be seen from Figure 7.8, only 64 monthly samples (a seven- to eight-year monitoring program) would be needed to detect the same 23 percent change in trend.

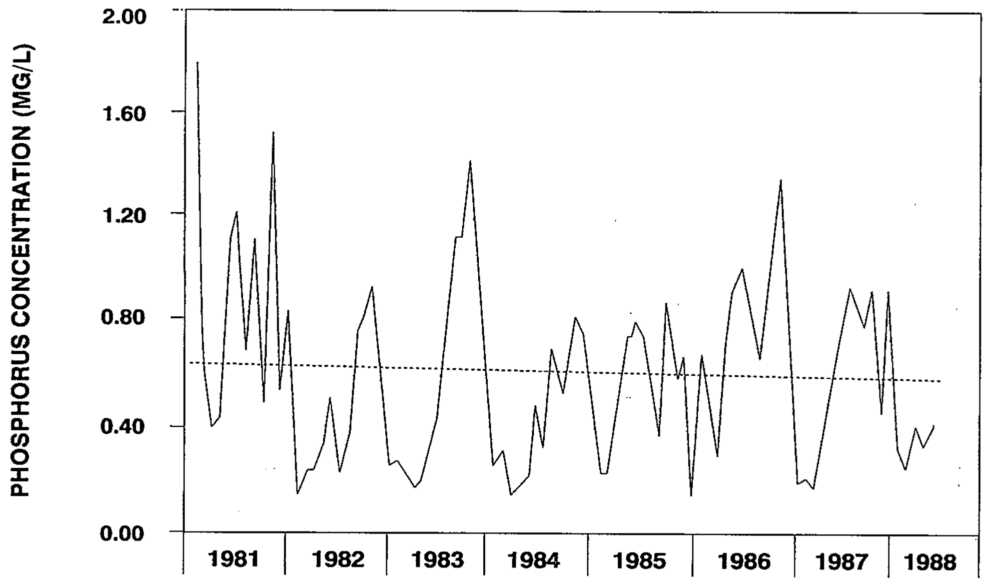


Figure 7.6—Neuse River total phosphorus concentration time series plot with calculated trend line.

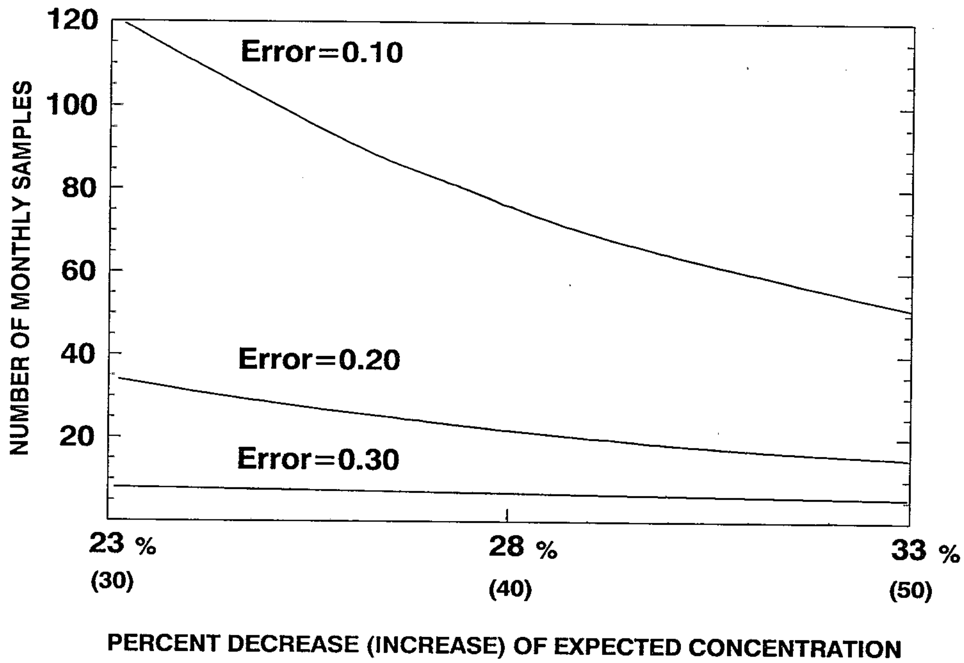


Figure 7.7—Sample size versus the magnitude of a linear trend for total phosphorus concentration for the Neuse River.

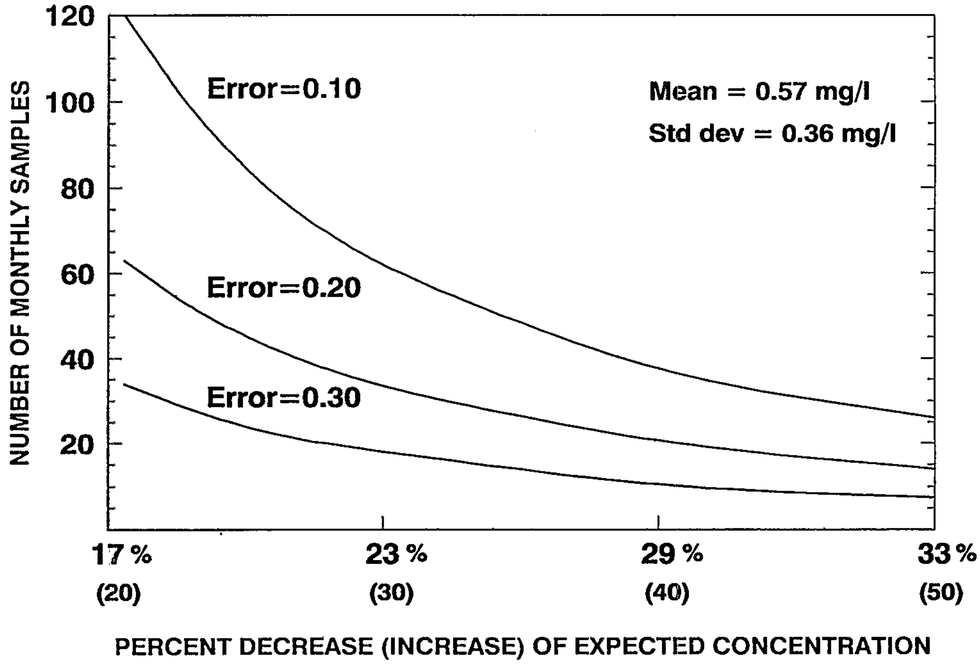


Figure 7.8—Sample size versus the magnitude of a step trend for total phosphorus concentration of the Neuse River.

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Appendix

Cooperative Agreements for Protecting and Restoring Publicly Owned Freshwater Lakes

U.S. Environmental Protection Agency

Subparts F–G—[Reserved]

Subpart H—Cooperative Agreements for Protecting and Restoring Publicly Owned Freshwater Lakes

AUTHORITY: Secs. 314 and 501, Clean Water Act (86 Stat. 816; 33 U.S.C. 1251 *et seq.*).

SOURCE: 45 FR 7792, Feb. 5, 1980, unless otherwise noted.

§ 35.1600 Purpose.

This subpart supplements the EPA general grant regulations and procedures (Part 30 of this chapter) and establishes policies and procedures for cooperative agreements to assist States in carrying out approved methods and procedures for restoration (including protection against degradation) of publicly owned freshwater lakes.

§ 35.1603 Summary of clean lakes assistance program.

(a) Under section 314 of the Clean Water Act, EPA may provide financial assistance to States to implement methods and procedures to protect and restore publicly owned freshwater lakes. Although cooperative agreements may be awarded only to States, these regulations allow States, through substate agreements, to delegate some or all of the required work to substate agencies.

(b) Only projects that deal with publicly owned freshwater lakes are eligible for assistance. The State must have assigned a priority to restore the lake, and the State must certify that the lake project is consistent with the State Water Quality Management Plan (§ 35.1521) developed under the State/EPA Agreement. The State/EPA Agreement is a mechanism for EPA Regional Administrators and States to coordinate a variety of programs under the Clean Water Act, the Resource Conservation and Recovery Act, the Safe Drinking Water Act and other laws administered by EPA.

(c) These regulations provide for Phase 1 and 2 cooperative agreements. The purpose of a Phase 1 cooperative agreement is to allow a State to conduct a diagnostic-feasibility study to determine a lake's quality, evaluate possible solutions to existing pollution problems, and recommend a feasible program to restore or preserve the quality of the lake. A Phase 2 cooperative agreement is to be used for implementing recommended methods and procedures for controlling pollution entering the lake and restoring the lake. EPA award of Phase 1 assistance does not obligate EPA to award Phase 2 assistance for that project. Additionally, a Phase 1 award is not a prerequisite for receiving a Phase 2 award. However, a Phase 2 application for a proposed project that was not evaluated under a Phase 1 project shall contain the information required by Appendix A.

(d) EPA will evaluate all applications in accordance with the application review criteria of § 35.1640–1. The review criteria include technical feasibility, public benefit, reasonableness of proposed costs, environmental impact, and the State's priority ranking of the lake project.

(e) Before awarding funding assistance, the Regional Administrator shall determine that pollution control measures in the lake watershed authorized by section 201, included in an approved 208 plan, or required by section 402 of the Act are completed or are being implemented according to a schedule that is included in an approved plan or discharge permit. Clean lakes funds may not be used to control the discharge of pollutants from a point source where the cause of pollution can be alleviated through a municipal or industrial permit under section 402 of the Act or through the planning and construction of wastewater treatment facilities under section 201 of the Act.

§ 35.1605 Definitions.

The terms used in this subpart have the meanings defined in section 502 of the Act. In addition, the following terms shall have the meaning set forth below.

§ 35.1605-1 The Act.

The Clean Water Act, as amended (33 U.S.C. 1251 *et seq.*).

§ 35.1605-2 Freshwater lake.

Any inland pond, reservoir, impoundment, or other similar body of water that has recreational value, that exhibits no oceanic and tidal influences, and that has a total dissolved solids concentration of less than 1 percent.

§ 35.1605-3 Publicly owned freshwater lake.

A freshwater lake that offers public access to the lake through publicly owned contiguous land so that any person has the same opportunity to enjoy nonconsumptive privileges and benefits of the lake as any other person. If user fees are charged for public use and access through State or substate operated facilities, the fees must be used for maintaining the public access and recreational facilities of this lake or other publicly owned freshwater lakes in the State, or for improving the quality of these lakes.

§ 35.1605-4 Nonpoint source.

Pollution sources which generally are not controlled by establishing effluent limitations under sections 301, 302, and 402 of the Act. Nonpoint source pollutants are not traceable to a discrete identifiable origin, but generally result from land runoff, precipitation, drainage, or seepage.

§ 35.1605-5 Eutrophic lake.

A lake that exhibits any of the following characteristics: (a) Excessive biomass accumulations of primary producers; (b) rapid organic and/or inorganic sedimentation and shallowing; or (c) seasonal and/or diurnal dissolved oxygen deficiencies that may cause obnoxious odors, fish kills, or a shift in the composition of aquatic fauna to less desirable forms.

§ 35.1605-6 Trophic condition.

A relative description of a lake's biological productivity based on the availability of plant nutrients. The range of trophic conditions is characterized by the terms of oligotrophic for the least biologically productive, to eutrophic for the most biologically productive.

§ 35.1605-7 Desalinization.

Any mechanical procedure or process where some or all of the salt is removed from lake water and the freshwater portion is returned to the lake.

§ 35.1605-8 Diagnostic-feasibility study.

A two-part study to determine a lake's current condition and to develop possible methods for lake restoration and protection.

(a) The diagnostic portion of the study includes gathering information and data to determine the limnological, morphological, demographic, socio-economic, and other pertinent characteristics of the lake and its watershed. This information will provide recipients an understanding of the quality of the lake, specifying the location and loading characteristics of significant sources polluting the lake.

(b) The feasibility portion of the study includes: (1) Analyzing the diagnostic information to define methods and procedures for controlling the sources of pollution; (2) determining the most energy and cost efficient procedures to improve the quality of the lake for maximum public benefit; (3) developing a technical plan and milestone schedule for implementing pollution control measures and in-lake restoration procedures; and (4) if necessary, conducting pilot scale evaluations.

§ 35.1610 Eligibility.

EPA shall award cooperative agreements for restoring publicly owned freshwater lakes only to the State agency designated by the State's Chief Executive. The award will be for projects which meet the requirements of this subchapter.

§ 35.1613 Distribution of funds.

(a) For each fiscal year EPA will notify each Regional Administrator of the amount of funds targeted for each Region through annual clean lakes program guidance. To assure an equitable distribution of funds the targeted amounts will be based on the clean lakes program which States identify in their State WQM work programs.

(b) EPA may set aside up to twenty percent of the annual appropriations for Phase 1 projects.

§ 35.1615 Substate agreements.

States may make financial assistance available to substate agencies by means of a written interagency agreement transferring project funds from the State to those agencies. The agreement shall be developed, administered and approved in accordance with the provisions of 40 CFR 33.240 (Intergovernmental agreements). A State may enter into an agreement with a substate agency to perform all or a portion of the work under a clean lakes cooperative agreement. Recipients shall submit copies of all interagency agreements to the Regional Administrator. If the sum involved exceeds $100,000, the agreement shall be approved by the Regional Administrator before funds are released by the State to the substate agency. The agreement shall incorporate by reference the provisions of this subchapter. The agreement shall specify outputs, milestone schedule, and the budget required to perform the associated work in the same manner as the cooperative agreement between the State and EPA.

§ 35.1620 Application requirements.

(a) EPA will process applications in accordance with Subpart B of Part 30 of this subchapter. Applicants for assistance under the clean lakes program shall submit EPA form 5700-33 (original with signature and two copies) to the appropriate EPA Regional Office (see 40 CFR 30.130).

(b) Before applying for assistance, applicants should contact the appropriate Regional Administrator to determine EPA's current funding capability.

§ 35.1620-1 Types of assistance.

EPA will provide assistance in two phases in the clean lakes program.

(a) *Phase 1—Diagnostic-feasibility studies.* Phase 1 awards of up to $100,000 per award (requiring a 30 percent non-Federal share) are available to support diagnostic-feasibility studies (see Appendix A).

(b) *Phase 2—Implementation.* Phase 2 awards (requiring a 50 percent non-Federal share) are available to support the implementation of pollution control and/or in-lake restoration methods and procedures including final engineering design.

§ 35.1620-2 Contents of applications.

(a) All applications shall contain a written State certification that the project is consistent with State Water Quality Management work program (see § 35.1513 of this subchapter) and the State Comprehensive Outdoor Recreation Plan (if completed). Additionally, the State shall indicate the priority ranking for the particular project (see § 35.1620-5).

(b) Phase 1 applications shall contain: (1) A narrative statement describing the specific procedures that will be used by the recipient to conduct the diagnostic-feasibility study including a description of the public participation to be involved (see § 25.11 of this chapter);

(2) A milestone schedule;

(3) An itemized cost estimate including a justification for these costs;

(4) A written certification from the appropriate areawide or State 208 planning agency that the proposed work will not duplicate work completed under any 208 planning grant, and that the applicant is proposing to use any applicable approved 208 planning in the clean lakes project design; and

(5) For each lake being investigated, the information under paragraph (5)(i) of this paragraph (b) and, when

available, the information under paragraph (5)(ii) of this paragraph (b).

(i) Mandatory information.

(A) The legal name of the lake, reservoir, or pond.

(B) The location of the lake within the State, including the latitude and longitude, in degrees, minutes, and seconds of the approximate center of the lake.

(C) A description of the physical characteristics of the lake, including its maximum depth (in meters); its mean depth (in meters); its surface area (in hectares); its volume (in cubic meters); the presence or absence of stratified conditions; and major hydrologic inflows and outflows.

(D) A summary of available chemical and biological data demonstrating the past trends and current water quality of the lake.

(E) A description of the type and amount of public access to the lake, and the public benefits that would be derived by implementing pollution control and lake restoration procedures.

(F) A description of any recreational uses of the lake that are impaired due to degraded water quality. Indicate the cause of the impairment, such as algae, vascular aquatic plants, sediments, or other pollutants.

(G) A description of the local interests and fiscal resources committed to restoring the lake.

(H) A description of the proposed monitoring program to provide the information required in Appendix A paragraph (a)(10) of this section.

(ii) Discretionary information. States should submit this information when available to assist EPA in reviewing the application.

(A) A description of the lake watershed in terms of size, land use (list each major land use classification as a percentage of the whole), and the general topography, including major soil types.

(B) An identification of the major point source pollution discharges in the watershed. If the sources are currently controlled under the National Pollutant Discharge Elimination System (NPDES), include the permit numbers.

(C) An estimate of the percent contribution of total nutrient and sediment loading to the lake by the identified point sources.

(D) An indication of the major nonpoint sources in the watershed. If the sources are being controlled describe the control practice(s), including best land management practices.

(E) An indication of the lake restoration measures anticipated, including watershed management, and a projection of the net improvement in water quality.

(F) A statement of known or anticipated adverse environmental impacts resulting from lake restoration.

(c) Phase 2 applications shall include: (1) The information specified in Appendix A in a diagnostic/feasibility study or its equivalent; (2) certification by the appropriate areawide or State 208 planning agencies that the proposed Phase 2 lake restoration proposal is consistent with any approved 208 planning; and (3) copies of all issued permits or permit applications (including a summary of the status of applications) that are required for the discharge of dredged or fill material under section 404 of the Act.

§ 35.1620-3 Environmental evaluation.

Phase 2 applicants shall submit an evaluation of the environmental impacts of the proposed project in accordance with the requirements in Appendix A of this regulation.

§ 35.1620-4 Public participation.

(a) *General.* (1) In accordance with this part and Part 25 of this chapter, the applicant shall provide for, encourage, and assist public participation in developing a proposed lake restoration project.

(2) Public consultation may be coordinated with related activities to enhance the economy, the effectiveness, and the timeliness of the effort, or to enhance the clarity of the issue. This procedure shall not discourage the widest possible participation by the public.

(b) *Phase 1.* (1) Phase 1 recipients shall solicit public comment in developing, evaluating, and selecting alternatives; in assessing potential adverse environmental impacts; and in identifying measures to mitigate any adverse impacts that were identified. The recipient shall provide information relevant to these decisions, in fact sheet or summary form, and distribute them to the public at least 30 days before selecting a proposed method of lake restoration. Recipients shall hold a formal or informal meeting with the public after all pertinent information is distributed, but before a lake restoration method is selected. If there is significant public interest in the cooperative agreement activity, an advisory group to study the process shall be formed in accordance with the requirements of § 25.3(d)(4) of this chapter.

(2) A formal public hearing shall be held if the Phase 1 recipient selects a lake restoration method that involves major construction, dredging, or significant modifications to the environment, or if the recipient or the Regional Administrator determines that a hearing would be beneficial.

(c) *Phase 2.* (1) A summary of the recipient's response to all public comments, along with copies of any written comments, shall be prepared and submitted to EPA with a Phase 2 application.

(2) Where a proposed project has not been studied under a Phase 1 cooperative agreement, the applicant for Phase 2 assistance shall provide an opportunity for public consultation with adequate and timely notices before submitting an application to EPA. The public shall be given the opportunity to discuss the proposed project, the alternatives, and any potentially adverse environmental impacts. A public hearing shall be held where the proposed project involves major construction, dredging or other significant modification of the environment. The applicant shall provide a summary of his responses to all public comments and submit the summary, along with copies of any written comments, with the application.

§ 35.1620-5 State work programs and lake priority lists.

(a)(1) A State shall submit to the Regional Administrator as part of its annual work program (§ 35.1513 of this subchapter) a description of the activities it will conduct during the Federal fiscal year to classify its lakes according to trophic condition (§ 35.1630) and to set priorities for implementing clean lakes projects within the State. The work plan must list in priority order the cooperative agreement applications that will be submitted by the State for Phase 1 and Phase 2 projects during the upcoming fiscal year, along with the rationale used to establish project priorities. Each State must also list the cooperative agreement applications, with necessary funding, which it expects to submit in the following fiscal year. This information will assist EPA in targeting resources under § 35.1613.

(2) A State may petition the Regional Administrator by letter to modify the EPA approved priority list established under paragraph (a)(1) of this section. This may be done at any time if the State believes there is sufficient justification to alter the priority list contained in its annual work program, e.g., if a community with a lower priority project has sufficient resources available to provide the required matching funding while a higher priority project does not, or if new data indicates that a lower priority lake will have greater public benefit than a higher priority lake.

(b) Clean lakes restoration priorities should be consistent with the Statewide water quality management strategy (see § 35.1511-2 of this subchapter). In establishing priorities on particular lake restoration projects, States should use as criteria the application review criteria (§ 35.1640-1) that EPA will use in preparing funding recommendations for specific projects. If a State chooses to use different criteria, the State should indicate this to the Regional Administrator as part of the annual work program.

§ 35.1620-6 Intergovernmental review.

EPA will not award funds under this subpart without review and consultation in accordance with the requirements of Executive Order 12372, as implemented in 40 CFR Part 29 of this chapter.

[48 FR 29302, June 24, 1983]

§ 35.1630 State lake classification surveys.

States that wish to participate in the clean lakes program shall establish and submit to EPA by January 1, 1982, a classification, according to trophic condition, of their publicly owned freshwater lakes that are in need of restoration or protection. After December 31, 1981, States that have not complied with this requirement will not be eligible for Federal financial assistance under this subpart until they complete their survey.

§ 35.1640 Application review and evaluation.

EPA will review applications as they are received. EPA may request outside review by appropriate experts to assist with technical evaluation. Funding decisions will be based on the merit of each application in accordance with the application review criteria under § 35.1640-1. EPA will consider Phase 1 applications separately from Phase 2 applications.

§ 35.1640-1 Application review criteria.

(a) When evaluating applications, EPA will consider information supplied by the applicant which address the following criteria:

(1) The technical feasibility of the project, and where appropriate, the estimated improvement in lake water quality.

(2) The anticipated positive changes that the project would produce in the overall lake ecosystem, including the watershed, such as the net reduction in sediment, nutrient, and other pollutant loadings.

(3) The estimated improvement in fish and wildlife habitat and associated beneficial effects on specific fish populations of sport and commercial species.

(4) The extent of anticipated benefits to the public. EPA will consider such factors as

(i) The degree, nature and sufficiency of public access to the lake;

(ii) The size and economic structure of the population residing near the lake which would use the improved lake for recreational and other purposes;

(iii) The amount and kind of public transportation available for transport of the public to and from the public access points;

(iv) Whether other relatively clean publicly owned freshwater lakes within 80 kilometer radius already adequately serve the population; and

(v) Whether the restoration would benefit primarily the owners of private land adjacent to the lake.

(5) The degree to which the project considers the "open space" policies contained in sections 201(f), 201(g), and 208(b)(2)(A) of the Act.

(6) The reasonableness of the proposed costs relative to the proposed work, the likelihood that the project will succeed, and the potential public benefits.

(7) The means for controlling adverse environmental impacts which would result from the proposed restoration of the lake. EPA will give specific attention to the environmental concerns listed in section (c) of Appendix A.

(8) The State priority ranking for a particular project.

(9) The State's operation and maintenance program to ensure that the pollution control measures and/or in-lake restorative techniques supported under the project will be continued after the project is completed.

(b) For Phase 1 applications, the review criteria presented in paragraph (a) of this section will be modified in relation to the smaller amount of technical information and analysis that is available in the application. Specifically, under criterion (a)(1), EPA will consider a technical assessment of the proposed project approach to meet the requirements stated in Appendix A to this regulation. Under criterion (a)(4), EPA will consider the degree of public access to the lake and the public benefit. Under criterion (a)(7), EPA will consider known or anticipated adverse environmental impacts identified in the application or that EPA can presume will occur. Criterion (a)(9) will not be considered.

§ 35.1650 Award.

(a) Under 40 CFR 30.345, generally 90 days after EPA has received a complete application, the application will either be: (1) Approved for funding in an amount determined to be appropriate for the project; (2) returned to the applicant due to lack of funding; or (3) disapproved. The applicant shall be promptly notified in writing by the EPA Regional Administrator of any funding decisions.

(b) Applications that are disapproved can be submitted as new applications to EPA if the State resolves the issues identified during EPA review.

§ 35.1650-1 Project period.

(a) The project period for Phase 1 projects shall not exceed three years.

(b) The project period for Phase 2 projects shall not exceed four years. Implementation of complex projects and projects incorporating major construction may have longer project periods if approved by the Regional Administrator.

§ 35.1650-2 Limitations on awards.

(a) Before awarding assistance, the Regional Administrator shall determine that:

(1) The applicant has met all of the applicable requirements of § 35.1620 and § 35.1630; and

(2) State programs under section 314 of the Act are part of a State/EPA Agreement which shall be completed before the project is awarded.

(b) Before awarding Phase 2 projects, the Regional Administrator shall further determine that:

(1) When a Phase 1 project was awarded, the final report prepared under Phase 1 is used by the applicant to apply for Phase 2 assistance. The lake restoration plan selected under the Phase 1 project must be implemented under a Phase 2 cooperative agreement.

(2) Pollution control measures in the lake watershed authorized by section 201, included in an approved 208 plan, or required by section 402 of the Act have been completed or are being implemented according to a schedule that is included in an approved plan or discharge permit.

(3) The project does not include costs for controlling point source discharges of pollutants where those sources can be alleviated by permits issued under section 402 of the Act, or by the planning and construction of wastewater treatment facilities under section 201 of the Act.

(4) The State has appropriately considered the "open space" policy presented in sections 201(f), 201(g)(6), and 208(b)(2)(A) of the Act in any wastewater management activities being implemented by them in the lake watershed.

(5)(i) The project does not include costs for harvesting aquatic vegetation, or for chemical treatment to alleviate temporarily the symptoms of eutrophication, or for operating and maintaining lake aeration devices, or for providing similar palliative methods and procedures, unless these procedures are the most energy efficient or cost effective lake restorative method.

(ii) Palliative approaches can be supported only where pollution in the lake watershed has been controlled to the greatest practicable extent, and where such methods and procedures are a necessary part of a project during the project period. EPA will determine the eligibility of such a project, based on the applicant's justification for the proposed restoration, the estimated time period for improved lake water quality, and public benefits associated with the restoration.

(6) The project does not include costs for desalinization procedures for naturally saline lakes.

(7) The project does not include costs for purchasing or long term leasing of land used solely to provide public access to a lake.

(8) The project does not include costs resulting from litigation against the recipient by EPA.

(9) The project does not include costs for measures to mitigate adverse environmental impacts that are not identified in the approved project scope of work. (EPA may allow additional costs for mitigation after it has reevaluated the cost-effectiveness of the selected alternative and has approved a request for an increase from the recipient.)

§ 35.1650-3 Conditions on award.

(a) *All awards.* (1) All assistance awarded under the Clean Lakes program is subject to the EPA General Grant conditions (Subpart C and Appendix A of Part 30 of this chapter).

(2) For each clean lakes project the State agrees to pay or arrange the payment of the non-Federal share of the project costs.

(b) *Phase 1.* Phase 1 projects are subject to the following conditions:

(1) The recipient must receive EPA project officer approval on any changes to satisfy the requirements of paragraph (a)(10) of Appendix A before undertaking any other work under the grant.

(2)(i) Before selecting the best alternative for controlling pollution and improving the lake, as required in paragraph (b)(1) of Appendix A of this regulation, and before undertaking any other work stated under paragraph (b) of Appendix A, the recipient shall submit an interim report to the project officer. The interim report must include a discussion of the various available alternatives and a technical justification for the alternative that the recipient will probably choose. The report must include a summary of the public involvement and the comments that occurred during the development of the alternatives.

(ii) The recipient must obtain EPA project officer approval of the selected alternative before conducting additional work under the project.

(c) *Phase 2.* Phase 2 projects are subject to the following conditions:

(1)(i) The State shall monitor the project to provide data necessary to evaluate the efficiency of the project as jointly agreed to and approved by the EPA project officer. The monitoring program described in paragraph (b)(3) of Appendix A of this regulation as well as any specific measurements that would be necessary to assess specific aspects of the project, must be considered during the development of a monitoring program and schedule. The project recipient shall receive the approval of the EPA project officer for a monitoring program and schedule to satisfy the requirements of Appendix A paragraph (b)(3) before undertaking any other work under the project.

(ii) Phase 2 projects shall be monitored for at least one year after construction or pollution control practices are completed.

(2) The State shall manage and maintain the project so that all pollution control measures supported under the project will be continued during the project period at the same level of efficiency as when they were implemented. The State will provide reports regarding project maintenance as required in the cooperative agreement.

(3) The State shall upgrade its water quality standards to reflect a higher water quality use classification if the higher water quality use was achieved as a result of the project (see 40 CFR 35.1550(c)(2)).

(4) If an approved project allows purchases of equipment for lake maintenance, such as weed harvesters, aeration equipment, and laboratory equipment, the State shall maintain and operate the equipment according to an approved lake maintenance plan for a period specified in the cooperative agreement. In no case shall that period be for less than the time it takes to completely amortize the equipment.

(5) If primary adverse environmental impacts result from implementing approved lake restoration or protection procedures, the State shall include measures to mitigate these adverse impacts at part of the work under the project.

(6) If adverse impacts could result to unrecorded archeological sites, the State shall stop work or modify work plans to protect these sites in accordance with the National Historic Preservation Act. (EPA may allow additional costs for ensuring proper protection of unrecorded archeological sites in the project area after reevaluating the cost effectiveness of the procedures and approving a request for a cost increase from the recipient.)

(7) If a project involves construction or dredging that requires a section 404 permit for the discharge of dredged or fill material, the recipient shall obtain the necessary section 404 permits before performing any dredge or fill work.

§ 35.1650-4 Payment.

(a) Under § 30.615 of this chapter, EPA generally will make payments through letter of credit. However, the Regional Administrator may place any recipient on advance payment or on cost reimbursement, as necessary.

(b) Phase 2 projects involving construction of facilities or dredging and filling activities shall be paid by reimbursement.

§ 35.1650-5 Allowable costs.

(a) The State will be paid under § 35.1650-4 for the Federal share of all necessary costs within the scope of the approved project and determined to be allowable under 40 CFR 30.705, the provisions of this subpart, and the cooperative agreement.

(b) Costs for restoring lakes used solely for drinking water supplies are not allowable under the Clean Lakes Program.

§ 35.1650-6 Reports.

(a) States with Phase 1 projects shall submit semi-annual progress reports (original and one copy) to the EPA project officer within 30 days after the end of every other standard quarter. Standard quarters end on March 31, June 30, September 30, and December 31. These reports shall include the following:

(1) Work progress relative to the milestone schedule, and difficulties encountered during the previous six months.

(2) A brief discussion of the project findings appropriate to the work conducted during the previous six months.

(3) A report of expenditures in the past six months and those anticipated in the next six months.

(b) *Phase 2.* States with Phase 2 projects shall submit progress reports (original and one copy) according to the schedule established in the cooperative agreement. The frequency of Phase 2 project progress reports shall be determined by the size and complexity of the project, and shall be required no more frequently than quarterly. The Phase 2 progress report shall contain all of the information required for Phase 1 progress reports indicated in paragraph (a) of this section. This report also must include water quality monitoring data and a discussion of the changes in water quality which appear to have resulted from the lake restoration activities implemented during the reporting period.

(c) *Final Report.* States shall prepare a final report for all grants in accordance with § 30.635-2 of this subchapter. Phase 1 reports shall be organized according to the outline of information requirements stated in Appendix A. All water quality data obtained under the grant shall be submitted in the final report. Phase 2 reports shall conform to the format presented in the EPA manual on "Scientific and Technical Publications," May 14, 1974, as revised or updated. The States shall submit the report within 90 days after the project is completed.

(d) *Financial Status Report.* Within 90 days after the end of each budget period, the grantee shall submit to the Regional Administrator an annual report of all expenditures (Federal and non-Federal) which accrued during the budget period. Beginning in the second quarter of any succeeding budget period, payments may be withheld under § 30.615-3 of this chapter until this report is received.

Appendix A—Requirements for Diagnostic-Feasibility Studies and Environmental Evaluations

Phase 1 clean lakes projects shall include in their scope of work at least the following requirements, preferably in the order presented and under appropriate subheadings. The information required by paragraph (a)(10) and the monitoring procedures stated in paragraph (b)(3) of this Appendix may be modified to conform to specific project requirements to reduce project costs without jeopardizing adequacy of technical information or the integrity of the project. All modifications must be approved by the EPA project officer as specified in §§ 35.1650-3(b)(1) and 35.1650-3(c)(1).

(a) A diagnostic study consisting of:

(1) An identification of the lake to be restored or studied, including the name, the State in which it is located, the location within the State, the general hydrologic relationship to associated upstream and downstream waters and the approved State water quality standards for the lake.

(2) A geological description of the drainage basin including soil types and soil loss to stream courses that are tributary to the lake.

(3) A description of the public access to the lake including the amount and type of public transportation to the access points.

(4) A description of the size and economic structure of the population residing near the lake which would use the improved lake for recreation and other purposes.

(5) A summary of historical lake uses, including recreational uses up to the present time, and how these uses may have changed because of water quality degradation.

(6) An explanation, if a particular segment of the lake user population is or will be more adversely impacted by lake degradation.

(7) A statement regarding the water use of the lake compared to other lakes within a 80 kilometer radius.

(8) An itemized inventory of known point source pollution discharges affecting or which have affected lake water quality over the past 5 years, and the abatement actions for these discharges that have been taken, or are in progress. If corrective action for the pollution sources is contemplated in the future, the time period should be specified.

(9) A description of the land uses in the lake watershed, listing each land use classification as a percentage of the whole and discussing the amount of nonpoint pollutant loading produced by each category.

(10) A discussion and analysis of historical baseline limnological data and one year of current limnological data. The monitoring schedule presented in paragraph (b)(3) of Appendix A must be followed in obtaining the one year of current limnological data. This presentation shall include the present trophic condition of the lake as well as its surface area (hectares), maximum depth (meters), average depth (meters), hydraulic residence time, the area of the watershed draining to the lake (hectares), and the physical, chemical, and biological quality of the lake and important lake tributary waters. Bathymetric maps should be provided. If dredging is expected to be included in the restoration activities, representative bottom sediment core samples shall be collected and analyzed using methods approved by the EPA project officer for phosphorus, nitrogen, heavy metals, other chemicals appropriate to State water quality standards, and persistent synthetic organic chemicals where appropriate. Further, the elutriate must be subjected to test procedures developed by the U.S. Army Corps of Engineers and analyzed for the same constituents. An assessment of the phosphorus (and nitrogen when it is the limiting lake nutrient) inflows and outflows associated with the lake and a hydraulic budget including ground water flow must be included. Vertical temperature and dissolved oxygen data must be included for the lake to determine if the hypolimnion becomes anaerobic and, if so, for how long and over what extent of the bottom. Total and soluble reactive phosphorus (P); and nitrite, nitrate, ammonia and organic nitrogen (N) concentratons must be determined for the lake. Chlorophyll *a* values should be measured for the upper mixing zone. Representative alkalinities should be determined. Algal assay bottle test data or total N to total P ratios should be used to define the growth limiting nutrient. The extent of algal blooms, and the predominant algal genera must be discussed. Algal biomass should be determined through algal genera identification, cell density counts (numbers of cells per milliliter) and converted to cell volume based on factors derived from direct measurements; and reported in biomass of each major genus identified. Secchi disk depth and suspended solids should be measured and reported. The portion of the shoreline and bottom that is impacted by vascular plants (submersed, floating, or emersed higher aquatic vegetation) must be estimated, specifically the lake surface area between 0 and the 10 meter depth contour or twice the Secchi disk transparency depth, whichever is less, and that estimate should include an identification of the predominant species. Where a lake is subject to significant public contact use or is fished for consumptive purposes, monitoring for public health reasons should be part of the monitoring program. Standard bacteriological analyses and fish flesh analyses for organic and heavy metal contamination should be included.

(11) An identification and discussion of the biological resources in the lake, such as fish population, and a discussion of the major known ecological relationships.

(b) A feasibility study consisting of:

(1) An identification and discussion of the alternatives considered for pollution control or lake restoration and an identification and justification of the selected alternative. This should include a discussion of expected water quality improvement, technical feasibility, and estimated costs of each alternative. The discussion of each feasible alternative and the selected lake restoration procedure must include detailed descriptions specifying exactly what activities would be undertaken under each, showing how and where these procedures would be implemented, illustrating the engineering specifications that would be followed including preliminary engineering drawings to show in detail the construction aspects of the project, and presenting a quantitative analysis of the pollution control effectiveness and the lake water quality improvement that is anticipated.

(2) A discussion of the particular benefits expected to result from implementing the project, including new public water uses that may result from the enhanced water quality.

(3) A Phase 2 monitoring program indicating the water quality sampling schedule. A limited monitoring program must be maintained during project implementation, particularly during construction phases or in-lake treatment, to provide sufficient data that will allow the State and the EPA project officer to redirect the project if necessary, to ensure desired objectives are achieved. During pre-project, implementation, and post-project monitoring activities, a single in-lake site should be sampled monthly during the months of September through April and biweekly during May through August. This site must be located in an area that best represents the limnological properties of the lake, preferably the deepest point in the lake. Additional sampling sites may be warranted in cases where lake basin morphometry creates distinctly different hydrologic and limnologic subbasins; or where major lake tributaries adversely affect lake water quality. The sampling schedule may be shifted according to seasonal differences at various latitudes. The biweekly samples must be scheduled to coincide with the period of elevated biological activity. If possible, a set of samples should be collected immediately following spring turnover of the lake. Samples must be collected between 0800 and 1600 hours of each sampling day unless diel studies are part of the monitoring program. Samples must be collected between one-half meter below the surface and one-half meter off the bottom, and must be collected at intervals of every one and one-half meters, or at six equal depth intervals, whichever number of samples is less. Collection and analyses of all samples must be conducted according to EPA approved methods. All of the samples collected must be analyzed for total and soluble reactive phosphorus; nitrite, nitrate, ammonia, and organic nitrogen; pH; temperature; and dissolved oxygen. Representative alkalinities should be determined. Samples collected in the upper mixing zone must be analyzed for chlorophyll *a*. Algal biomass in the upper mixing zone should be determined through algal genera identification, cell density counts (number of cells per milliliter) and converted to cell volume based on factors derived from direct measurements; and reported in terms of biomass of each major genera identified. Secchi disk depth and suspended solids must be measured at each sampling period. The surface area of the lake covered by macrophytes between 0 and the 10 meter depth contour or twice the Secchi disk transparency depth, whichever is less, must be reported. The monitoring program for each clean lakes project must include all the required information mentioned above, in addition to any specific measurements that are found to be necessary to assess certain aspects of the project. Based on the information supplied by the Phase 2 project applicant and the technical evaluation of the proposal, a detailed monitoring program for Phase 2 will be established for each approved project and will be a condition of the cooperative agreement. Phase 2 projects will be monitored for at least one year after construction or pollution control practices are completed to evaluate project effectiveness.

(4) A proposed milestone work schedule for completing the project with a proposed budget and a payment schedule that is related to the milestone.

(5) A detailed description of how non-Federal funds will be obtained for the proposed project.

(6) A description of the relationship of the proposed project to pollution control programs such as the section 201 construction grants program, the section 208 areawide wastewater management program, the Department of Agriculture Soil Conservation Service and Agriculture Stabilization and Conservation Service programs, the Department of Housing and Urban Development block grant program, the Department of Interior Heritage Conservation and Recreation Service programs and any other local, State, regional and Federal programs that may be related to the proposed project. Copies of any pertinent correspondence, contracts, grant applications and permits associated with these programs should be provided to the EPA project officer.

(7) A summary of public participation in developing and assessing the proposed project which is in compliance with Part 25 of this chapter. The summary shall describe the matters brought before the public, the measures taken by the reporting agency to meet its responsibilities under Part 25 and related provisions elsewhere in this chapter, the public response, and the agency's response to significant comments. Section 25.8 responsiveness summaries may be used to meet appropriate portions of these requirements to avoid duplication.

(8) A description of the operation and maintenance plan that the State will follow, including the time frame over which this plan will be operated, to ensure that the pollution controls implemented during the project are continued after the project is completed.

(9) Copies of all permits or pending permit applications (including the status of such applications) necessary to satisfy the requirements of section 404 of the Act. If the approved project includes dredging activities or other activities requiring permits, the State must obtain from the U.S. Army

Corps of Engineers or other agencies the permits required for the discharge of dredged or fill material under section 404 of the Act or other Federal, State or local requirements. Should additional information be required to obtain these permits, the State shall provide it. Copies of section 404 permit applications and any associated correspondence must be provide to the EPA project officer at the time they are submitted to the U.S. Army Corps of Engineers. After reviewing the 404 permit application, the project officer may provide recommendations for appropriate controls and treatment of supernatant derived from dredged material disposal sites to ensure the maximum effectiveness of lake restoration procedures.

(c) States shall complete and submit an environmental evaluation which considers the questions listed below. In many cases the questions cannot be satisfactorily answered with a mere "Yes" or "No". States are encouraged to address other considerations which they believe apply to their project.

(1) Will the proposed project displace any people?

(2) Will the proposed project deface existing residences or residential areas? What mitigative actions such as landscaping, screening, or buffer zones have been considered? Are they included?

(3) Will the proposed project be likely to lead to a change in established land use patterns, such as increased development pressure near the lake? To what extent and how will this change be controlled through land use planning, zoning, or through other methods?

(4) Will the proposed project adversly affect a significant amount of prime agricultural land or agricultural operations on such land?

(5) Will the proposed project result in a significant adverse effect on parkland, other public land, or lands of recognized scenic value?

(6) Has the State Historical Society or State Historical Preservation Officer been contacted? Has he responded, and if so, what was the nature of that response? Will the proposed project result in a significant adversely effect on lands or structures of historic, architectural, archaeological or cultural value?

(7) Will the proposed project lead to a significant long-range increase in energy demands?

(8) Will the proposed project result in significant and long range adverse changes in ambient air quality or noise levels? Short term?

(9) If the proposed project involves the use of in-lake chemical treatment, what long and short term adverse effects can be expected from that treatment? How will the project recipient mitigate these effects?

(10) Does the proposal contain all the information that EPA requires in order to determine whether the project complies with Executive Order 11988 on floodplains? Is the proposed project located in a floodplain? If so, will the project involve construction of structures in the floodplain? What steps will be taken to reduce the possible effects of flood damage to the project?

(11) If the project involves physically modifying the lake shore or its bed or its watershed, by dredging, for example, what steps will be taken to minimize any immediate and long term adverse effects of such activities? When dredging is employed, where will the dredged material be deposited, what can be expected and what measures will the recipient employ to minimize any significant adverse impacts from its deposition?

(12) Does the project proposal contain all information that EPA requires in order to determine whether the project complies with Executive Order 11990 on wetlands? Will the proposed project have a significant adverse effect on fish and wildlife, or on wetlands or any other wildife habitat, especially those of endangered species? How significant is this impact in relation to the local or regional critical habitat needs? Have actions to mitigate habitat destruction been incorporated into the project? Has the recipient properly consulted with appropriate State and Federal fish, game and wildlife agencies and with the U.S. Fish and Wildlife Service? What were their replies?

(13) Describe any feasible alternatives to the proposed project in terms of environmental impacts, commitment of resources, public interest and costs and why they were not proposed.

(14) Describe other measures not discussed previously that are necessary to mitigate adverse environmental impacts resulting from the implementation of the proposed project.

[illegible]

United States
Environmental Protection
Agency
(WH-553)
Washington, DC 20460

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