Developing Eutrophication Standards for Lakes and Reservoirs

A Report Prepared by the Lake Standards Subcommittee, May 1992

NORTH AMERICAN LAKE MANAGEMENT SOCIETY

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TABLE OF CONTENTS

List of Tables

List of Figures

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Executive Summary

Water quality standards and criteria are used by federal, state, and provincial government as tools to manage, protect, and guide the improvement of North America's water resources. In most cases, these standards or criteria were intended to address the regulation of point source discharges to lotic waters (rivers). While many of these standards may be effectively applied to protect the quality of lakes and reservoirs, this is not always the case. In the case of eutrophication, the inherent differences between lotic water bodies and lentic water bodies (lakes and reservoirs) necessitate the development of separate standards for these two types of water systems. The basic difference is that lakes and reservoirs are more sensitive to nutrient loading than most rivers.

Purpose and Scope

The purpose of this document is to assemble and summarize information on eutrophication criteria and standards. The approaches of seven states (Vermont, Minnesota, Maine, Oregon, North Carolina, Virginia and Georgia), a regional water resource management agency and hydropower producer (Tennessee Valley Authority [TVA]), a Canadian province (British Columbia), and the International Joint Commission (IJC) serve as the primary basis for this document. The intent is to present a cross-section of approaches to the issue, identify similarities and differences among the approaches, and provide the reader with a summary of potential approaches for developing and implementing eutrophication criteria and standards.

Data Requirements

Most of the approaches required information on the trophic status variables—total phosphorus, chlorophyll *a*, and Secchi transparency—on either a statewide or lake-by-lake basis (see Table 1). Other prominent types of information included lake morphometry (area and mean depth), watershed (area and land use composition), lake uses, user perceptions, fisheries management, determination of point sources in the watershed, and literature review.

Role of Lake Monitoring

Lake monitoring data was required in all cases, although the intensity and extent varied considerably. The biological approach of TVA required intensive water quality and biological data collection prior to implementation. Minnesota's ecoregion approach required a comprehensive statewide water quality monitoring program, complemented by more detailed data acquisition at selected reference lakes in each ecoregion (Tables 1 and 2).

Table 1. Summary of Approaches for Standards Development and Implementation.

Approach (*)	
User Survey (VT)	Generally characterize trophic condition and user perceptions of lakes at state level and conduct detailed analysis for individual lakes.
Ecoregion (MN)	Generally characterize the trophic condition of lakes at a statewide level and detailed assessment for a set of reference lakes for each ecoregion. Criteria established by most sensitive use within each ecoregion.
Water Use (B.C.)	Detailed literature review, establish interrelationships between trophic characteristics and fishery requirements.
Nondegradation (ME)	Characterize TP (total phosphorus), chlorophyll, and Secchi; fishery classification; and watershed characteristics. Conduct simple P budget modeling, determine acceptable increase in P and categorize lake for protection.
Nuisance Phytoplankton (OR)	Characterize average chlorophyll *a* based on a minimum of 3 monthly samples and determine thermal stratification status. Nuisance chlorophyll *a* concentrations established based on above.
Nutrient Sensitive (NC)	Separate chlorophyll *a* criterion set for warm water and cold water fisheries. Criteria exceedance triggers watershed study to determine source of loading.
Nutrient Enriched (VA)	Designate nutrient enriched waters by considering chlorophyll *a*, dissolved oxygen fluctuation, and TP. Implement companion regulation to control point source P as necessary.
Biological (TVA)	Develop an Index of Biotic Integrity for reservoirs. The index will identify biotic communities that are significantly out of balance and will be used in assigning management priorities.
Lake Specific (IJC, GA)	Typically includes a detailed analysis of biota, water chemistry, and loading determinations. This results in in-lake goals or tributary loading goals, and typically a basin-wide plan for achieving the goal.

* state, province, or organization

Approaches which addressed nuisance conditions focused on chlorophyll *a* (e.g., nuisance phytoplankton [Oregon], nutrient sensitive [North Carolina] and nutrient enriched [Virginia]). Generally, they did not initially require an extensive collection of data. However, exceedance of the standard will generally trigger more extensive studies (e.g., Oregon).

Application of Eutrophication Criteria

Once established, eutrophication criteria have a variety of applications including:

1. enforcing and establishing permit limits (NPDES);
2. goal setting and prioritization;
3. managing cumulative impact and watershed planning; and
4. reporting on attainment of beneficial uses (e.g., 305(b) reports) and state performance audits.

As indicated in Table 3, the actual use of the criteria varied between states/provinces. Criteria are most effective for meeting water quality goals if they are codified in state or provincial statute (i.e., specifically noted in a water quality standard) and applied in enforcement or permit setting. However, the establishment and use of the criteria outside of state statute can still prove to be valuable for a majority of the applications in Table 3 (e.g., Minnesota). Using criteria without the force of statute demands that the criteria be derived from and supported by a statewide monitoring effort.

Table 2. Data Needs to Develop and Implement Eutrophication Standards.

Approach	Morphometry (area, depth)	Watershed (area, land use)	Trophic (TP,chl, SD)	Lake Uses	User Perception	Biological	History	Point Source	Literature
User Survey (VT)			I/S		I/S				
Ecoregion (MN)	E/S	E	E/S	S	S		E		X
Water Use (BC)	I		S	S/I				I	X
Nondegradation (ME)	I	I	I		S	I	I		
Nuisance Phyto. (OR)			I	I					
Nutrient Sensitive (NC)			I	I					
Nutrient Enriched (VA)			I						
Biological (TVA)			I/S			I/S	I		
Lake Specific (IJC,GA)	I	I	I	I		I		I	

I = individual lake or reservoir
E = ecoregion/reference lakes
S = statewide or province-wide assessment

TP = total phosphorus
Chl = Chlorophyll *a*
SD = Secchi disk
DO = dissolved oxygen

Table 3. Application and Uses of Eutrophication Criteria (Criteria Used to Complement or Implement Specified Activities[1]).

Approach	Enforcement	Prioritization	NPDES (permits)	Goal Setting	Manage Cumulative Impact	Watershed Plan	305(b) Report[2]	Statute[3]
User Survey (VT)	P		I	I	P	P	P	N[5]
Ecoregion (MN)	P	I	I	I	P	I	I	N
Water Use (BC)	P		I	I	P	I	I	Y
Nondegradation (ME)		I		I	I	I		Y
Nuisance Phyto. (OR)		I	I			I		Y
Nutrient Sensitive (NC)		I	I					Y
Nutrient Enriched (VA)	I	I	I					Y
Biological[4] (TVA)								N
Lake Specific (IJC, GA)	I		I		I	I		Y

1 I = implemented, P = potential
2 or other water quality assessments
3 indicates whether criteria are codified in state or provincial statutes (y = yes, n = no)
4 under development
5 adopted state rule

Conclusions

1. Because lakes and reservoirs generally are more sensitive to nutrient loading than rivers, eutrophication standards should be developed to protect them from the negative impacts of cultural eutrophication. While some rivers also may be sensitive to nutrient loading, (e.g., producing nuisance periphyton growth), different standards may be required for their protection.

2. Because federal criteria or guidance is lacking, state eutrophication control programs may continue to be discretionary in their approach.

3. To protect water quality, eutrophication standards should be developed by the states and provinces. The approach selected must be tailored to local/regional conditions and user expectations.

4. Lake monitoring is an essential part of eutrophication standards application and in most cases an extensive data base is a prerequisite for standards development.

5. Eutrophication criteria and standards can serve a variety of purposes depending on how they are applied. Their primary purpose, however, is to assist lake managers in the protection and improvement of lake water quality.

Recommendations

1. Provinces, states, and other entities which manage lakes or reservoirs should develop eutrophication criteria and standards to protect the condition and improve the management of these resources.

2. The U.S. EPA should provide leadership on eutrophication standards development. Necessary steps include:

    a. Eutrophication standards should be listed as a priority in the next revision of the Long Term Standards Framework.

    b. The U.S. EPA should provide financial and technical incentives for the states to develop eutrophication standards.

    c. Technical assistance should be provided for the states to assist them in the development of eutrophication standards. The U.S. EPA and the North American Lake Management Society should cooperate on the development of appropriate guidance.

3. The U.S. EPA should increase the amount of financial assistance to the states for lake monitoring because of the important role that monitoring plays in the development and application of eutrophication standards and the overall management of lakes and reservoirs.

I. Introduction

The need to establish water quality criteria and standards for eutrophication has been recognized at the state, provincial, and federal levels of government. Establishment of criteria is deemed essential to the protection of lake water quality. The State of Maine, for example, has implemented a standard requiring "stable or decreasing trophic status" for its lakes (Maine DEP, 1986). This standard, in effect, does not allow land use changes in a watershed which may adversely impact the trophic status of a lake. British Columbia has established phosphorus criteria to protect the most sensitive uses of lakes in that province, particularly drinking water, recreation, aesthetics, and cold water fishing (Nordin, 1985). In 1987, the North American Lake Management Society (NALMS) established a Task Force on Lake Water Quality Standards to determine the opinions of state water resource managers regarding the need for lake eutrophication standards, and to gather information on existing lake standards. The results from that effort are addressed in a report (NALMS, 1988) and are summarized herein.

Currently, the United States has no criterion for phosphate-phosphorus to control eutrophication (U.S. EPA, 1987). However, the need to address eutrophication standards in the U.S. EPA Water Quality Standards Framework was discussed in 1989 at a conference sponsored by the U.S. EPA Office of Water in Dallas. The draft document on the Water Quality Standards Framework (U.S. EPA, 1989a) which followed that conference suggests that the development of eutrophication standards may be addressed in future triennial reviews.

The purpose of this document is to summarize and review information on approaches that have been used in the development of lake eutrophication standards or criteria. This document focuses on approaches that have been taken to develop standards or criteria to protect and improve the quality of lakes and reservoirs. No single approach is advocated over another—instead, a diversity of approaches is presented. Specific criteria or standards are not recommended in this document.

This document focuses only on eutrophication-related standards or problems. Although toxics and sediment are very important concerns at both the state and federal levels (NALMS, 1988; U.S. EPA, 1989b), the NALMS Board of Directors decided in 1989 to approach each of these major issues separately. Therefore, this document examines water quality standards strictly from the standpoint of eutrophication concerns in lakes and reservoirs. Unless otherwise noted, the term "lake" as used in this document is intended to refer to both lakes and reservoirs.

The Lake Standards Subcommittee, which developed this document, is comprised of individuals with varied expertise in the area of lake management and standards development. The varied backgrounds, affiliations, and geographic locations of these individuals brought a wide variety of perspectives to this document. The members and their affiliations are as follows:

Chair: Mr. Steve Heiskary, Minnesota Pollution Control Agency

Co-chair: Ms. Nancy Bryant, ENSR Consulting and Engineering

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Mr. Eric Smeltzer, Vermont Department of Environmental Conservation

The intended audience for this document are individuals or governmental entities charged with developing or enforcing lake eutrophication standards. This may include state and provincial lake resource managers as well as those charged with managing a single lake or reservoir. This document also may be useful to U.S. EPA staff involved in Clean Lakes projects, enforcement and permitting issues related to lake eutrophication, and/or water quality standards development.

The Executive Summary provided a brief synopsis of this document. The remainder of the document provides background information and details of various approaches that have been reviewed. This review should help the readers draw their own conclusions on the necessity for eutrophication standards and determine the approach(es) best suited for their particular situation. Following is a summary of the document's organization.

II. **Limnology and Water Quality Standards** This section discusses basic differences between rivers, lakes, and reservoirs. These differences demonstrate the need for specific standards.

III. **Background on Water Quality Standards** This section: 1) defines the concepts of water quality standards, 2) differentiates between narrative and numeric criteria, 3) provides a brief overview of the United States' process to establish water quality standards, and 4) provides some background on existing United States criteria which may relate to lake eutrophication.

IV. **Legislative Background: Current Status of Eutrophication Standards** In this section, relevant sections of the U.S. Clean Water Act and comparable Canadian statutes are reviewed with respect to lake trophic standards. A brief summary of pertinent U.S. EPA standards documents (1980 and 1987), the Metropolitan Washington Council of Governments review of lake related standards (MWCG, 1982) and the Lake Standards Task Force report (NALMS, 1988) also is presented.

V. **Approaches for Developing Lake Eutrophication Standards** In this section, a series of approaches is provided. These approaches represent either past or ongoing efforts by state and provincial agencies to develop eutrophication standards. Included are examples from states that have primarily "natural" lakes (Maine, Vermont, and Minnesota) and those states/agencies that deal primarily with reservoirs (North Carolina, Virginia, Georgia, and Tennessee Valley Authority). Lake or reservoir-specific approaches also are included.

VI. **Data Needs and Acquisition of Data** Data and resource management considerations are addressed for lakes and reservoirs. A brief description of methods for acquiring information and examples of lake and reservoir sampling strategies are included.

VII. **Uses of Lake Standards** A short summary of the existing and potential uses of eutrophication standards is included here.

VIII. **References** Includes pertinent references for further information on the approaches presented.

II. Limnology and Water Quality Standards

A. Differences Between Rivers, Reservoirs, and Lakes

A number of papers have been written on the differences between rivers, reservoirs, and lakes (e.g., Soballe and Kimmel, 1987). In order to understand why separate eutrophication standards may be required for each of these water resources, the principal differences between these water systems need to be considered.

Natural lakes are frequently of catastrophic origin formed by glaciers, volcanoes or tectonic processes (Wetzel, 1975), whereas reservoirs are man-made surface impoundments of rivers. The majority of natural lakes in the United States tend to be located in the Midwest, Northwest, Northeast, and Florida, while the majority of reservoirs are located in the southeastern, central, southwestern and western United States. Rivers, on the other hand, are found all across the country.

The fundamental physical and biotic processes of rivers, reservoirs, and lakes are the same, but these processes may differ in magnitude and importance as a result of dissimilarities in horizontal water movements amongst these systems (Soballe and Kimmel, 1987). Water residence time is often deemed the most important distinction between these resources with rivers having the shortest residence time, lakes the longest, and reservoirs intermediate between the two.

For the purposes of this document, perhaps the most important distinction between rivers, reservoirs, and lakes is that of algal abundance per unit of phosphorus. Given the same concentration of phosphorus, suspended algal abundance tends to be greater in lakes and reservoirs than in rivers (Soballe and Kimmel, 1987). Abiotic factors such as higher turbidity levels, higher turbulence, and shorter residence time tend to reduce the likelihood that rapidly flushed rivers will exhibit nuisance levels of suspended algae. In rivers, excess nutrients may contribute to nuisance periphyton growth.

Within a run-of-the-river reservoir, distinct "zones" form. Kimmel and Groeger (1984) refer to these zones (upstream to downstream) as riverine, transitional, and lacustrine. Generally, suspended sediments and nutrients are greater and water clarity is lower in the riverine zone. Despite the availability of nutrients, algal production may be inhibited by light availability in this zone. These conditions typically shift as water flows downstream through the reservoir. Because very distinct water quality gradients are exhibited in reservoirs, a single trophic state characterization may be inappropriate (Kennedy, 1984).

In summary, rivers, reservoirs, and lakes lie on a continuum with respect to their physical and biotic characteristics. The nutrient/phytoplankton response is more similar in lakes and reservoirs than it is in rivers. Free flowing rivers do not usually exhibit nuisance levels of phytoplankton, though excess periphyton growth may cause problems. Thus, phytoplankton do not typically inhibit the use of river resources. Therefore, specific water quality standards to prevent phytoplankton blooms on rivers generally are not needed. In contrast, lakes and reservoirs, with an excess supply of nutrients, tend to exhibit nuisance phytoplankton blooms which consequently inhibit the desired uses of these water bodies. Generally, lakes tend to be more responsive to a given load of nutrients than reservoirs. However, within a single reservoir, the algal response to nutrients may vary greatly.

These facts suggest that lakes, reservoirs, and rivers need to be considered separately when assigning eutrophication-related standards. Because of the inherent differences between lakes, reservoirs, and rivers, a standard which is established to protect the uses of one resource may not be appropriate—or even necessary—for another.

B. The Need for Lake and Reservoir Eutrophication Standards

The need for lake and reservoir eutrophication standards has been identified in a number of surveys and reports (Duda et al. 1987; Johnson, 1989). These reports suggest that eutrophication standards could serve as a basis for improved management and a means for measuring progress and assuring accountability of new restoration or protection programs.

Duda et al. (1987) provided a comprehensive review of previous surveys and reports on nationwide trends in eutrophication. The report summarized the results from a succession of national surveys intended to evaluate trends in the quality of lakes and reservoirs in the United States. A NALMS survey of the states' water pollution control administrators estimated that 120 lakes were contaminated with toxic substances and 12,000 lakes had noxious growths of weeds and algae. About 4,200 lakes were identified by the responding states as having impaired uses. Two-thirds of the 38 responding administrators indicated that at least half of their lake and reservoir waters were seriously affected by nonpoint source pollution.

Two surveys conducted by the Association of State and Interstate Water Pollution Control Administrators (ASIWPCA, 1984 and 1985) underscore the pollution problems encountered by lakes and reservoirs in the United States. The 1984 survey assessed water pollution control progress from 1972 to 1982. Four times as many lakes (1,650,000 acres) had degraded compared to those which improved in quality (390,000 acres) during the decade (ASIWPCA, 1984). More alarming were the 1985 survey results: 4.4 million lake and reservoir surface acres were impaired by nonpoint pollution and another 3.7 million acres were threatened (ASIWPCA, 1985). These results indicated that in 1986—14 years after Congress passed the Clean Water Act—53 percent of assessed United States lakes and reservoirs were adversely affected by nonpoint source pollution.

More recently, in a review of the 1988 305(b) Report presented to Congress, U.S. EPA (1989b) noted that 50 percent of the lakes assessed by the states were considered either eutrophic or hypereutrophic. Although these data do not lend themselves to a statistical assessment of trends, U.S. EPA noted that, in comparison to the 1986 305(b) Report, the number of lakes considered eutrophic increased more than 10 percent, while the number of mesotrophic and oligotrophic lakes decreased 8 and 7 percent, respectively. The various reports and surveys cited in Duda et al. (1987) and the results in U.S. EPA (1989b) suggest that eutrophication continues to be a very significant problem in lakes and reservoirs.

There is no consensus among the states on the need for water quality standards as a means for stemming eutrophication. Many arguments have been raised for and against such standards. A survey of state agencies by NALMS in 1987-88 (NALMS, 1988), as summarized by Johnson (1989), provides some insight on the conflicting opinions regarding the need for eutrophication standards. The survey consisted of 46 questions covering four topics:

1. Are lake water quality standards needed?
2. How are such standards used now or how would they be used if adopted?
3. What are the data needs for eutrophication standards development and use?
4. Should there be lake standards for toxic substances?

The need for eutrophication standards drew a varied response from the 44 states which answered that question. Of those responding, 27 states recognized a need for developing eutrophication standards. Some "regional" differences were noted. All of the states in U.S. EPA Regions V and X believed a need exists for eutrophication standards. In contrast, all of the states in Region III did not see a need for developing specific eutrophication standards. The difference in responses between regions could be related to the number of lakes for which each state has management responsibility. Excluding Alaska's 3 million lakes, the vast majority (>50,000) of the United States' lakes are located in Regions V and X. In contrast, Region III has very few lakes (<1,000).

A second part to the first question, "Do you see the need for developing lake-specific policies?" revealed a more consistent response from the states. To this question, 34 states responded "yes," while 9 responded "no."

Another series of questions focused on the states' ability to monitor their lakes. Only 10 of the 47 states responding characterized their ability to monitor the trophic status of all lakes in their state as "good." In comparison, 24 characterized their ability to monitor all their lakes as "poor." The latter response was most typical for states in Regions IV, V, and X; while states in Regions I, III, and VI appear to be more confident in their ability to monitor all their lakes. The large number of lakes in Regions IV, V and X may explain their apparently "poor" capability of monitoring all lakes.

Numerous concerns and many common problems were expressed in this survey. These included overdevelopment around lake shorelines, excessive nonpoint source pollution (sediment, nutrients and bacteria), a lack of adequate water quality data to perform assessments on lake resources and to detect trends, and the need for more assistance from U.S. EPA (both financial/technical assistance and guidance to develop adequate lake management programs).

In March 1989, the U.S. EPA Office of Water sponsored a conference in Dallas, Texas to discuss U.S. EPA's proposed "Draft Framework for the Water Quality Standards Program" (U.S. EPA, 1989c). A panel session on lakes entitled "Lake Protection through Standards" was attended by representatives from federal and state governments and private industry. Some of the key points which arose from the session, as cited by U.S. EPA (1989c) included:

1. A recognized need for increased monitoring of lakes by the states.
2. Existing state standards should include lakes, to some degree.
3. A need for inter-agency coordination on potential conflicting water quality/quantity issues (this is particularly important for reservoirs).
4. A need for guidelines for establishing lake management (protection) programs.
5. The appropriateness of existing standards to protect lakes (e.g., Gold Book) should be evaluated.
6. A desire to add lakes to the U.S. EPA Water Quality Standards Framework.

Surveys, reports and conference proceedings referred to in this section agree that lake and reservoir resources in the United States are degrading and in need of attention. Overall perceptions on the need for lake standards seem to be mixed. While there is a need for improved tools (standards, criteria, or policy) to protect lakes and reservoirs, it is also evident that states do not want U.S. EPA to establish criteria for them or to require that each state have the same type of standards. States want additional financial and technical assistance from U.S. EPA, aimed at improving existing lake programs and helping the states to better monitor and protect their lake resources.

III. Background on Water Quality Standards

A. The United States' Concept of Water Quality Standards

The primary federal law in the United States to protect the quality of water resources is the Clean Water Act of 1987 (as amended; originally the Water Quality Act of 1965). The goal of the Clean Water Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters and where attainable, to achieve a level of water quality that provides for the protection and propagation of fish and shellfish, wildlife, and recreation in and on the water." The U.S. EPA implements this law, and is directed to design programs, such as the Water Quality Standards Program, to carry out this objective. Under 40 CFR Part 131, U.S. EPA has issued regulations governing the development, review, revision, and approval of water quality standards by the states. Thus, the states play the primary role in setting water quality standards which serve as the foundation for their water quality management programs.

The water quality standard defines the quality goals for a water body by designating desired uses, setting criteria to protect those uses, and protecting the existing water quality through an antidegradation policy. Water quality criteria are adopted as part of the water quality standards. In addition to setting goals for the water body, water quality standards also provide a legal basis for implementing a wastewater discharge permitting program and for controlling nonpoint sources of pollution.

The state designates uses for each water body and adopts water quality criteria to protect the designated uses. Criteria are definite limits on a particular pollutant or on a particular condition of a water body. The uses of a water body include "existing uses" that were attained on or after November 28, 1975 (the date U.S. EPA promulgated its first water quality standards regulation). "Existing uses" cannot be modified or changed. However, uses can be added that require more stringent criteria. At a minimum, a water body's uses must include recreation in and on the water, and propagation of fish and wildlife. Specific categories such as boating, trout propagation, or potable water supply also may be adopted. "Designated uses" are desired uses that may or may not already be attained.

After designating the uses of a water body, the state must adopt numeric or narrative criteria to protect and support the specified uses. Numeric criteria are values assigned to measurable components in the water body. In-lake phosphorus or chlorophyll *a* concentrations are examples of numeric criteria. Narrative criteria are verbal descriptions of desired water quality conditions. Phrases such as "no nutrient increases which would accelerate eutrophication" or "nutrients shall not be present in concentrations sufficient to cause objectionable algal densities" are examples of narrative criteria. When criteria are met, water quality is at a level to protect the designated use.

In addition to uses and criteria, state water quality standards must contain an antidegradation policy and a method for implementing the policy. The antidegradation policy is divided into three tiers. The first tier requires that, at a minimum, all existing uses must be maintained and protected. Water quality may not be degraded below the level necessary to support those uses. The second tier requires that water quality which is higher than necessary for the protection of existing uses must be maintained, unless lowering it would allow important social and economic development. States must conduct rigorous analyses and obtain public

comment before the lowering of high quality water can be allowed, and the quality must still protect existing uses. Finally, the third tier designates Outstanding National Resource Waters (ONRWs) that are of special ecological or recreational significance, such as those found in parks and wildlife refuges. The existing quality of ONRWs must be maintained, regardless of other social or economic considerations.

In summary, under 40 CFR Part 131, water quality standards provide the framework for a state to designate uses for a water body, to adopt numeric or narrative criteria to protect those uses, and to establish antidegradation policies to prevent the deterioration of existing uses.

B. Numeric vs. Narrative Criteria

Numeric water quality criteria have several advantages over narrative criteria in the application of state water quality standards to lakes. Numeric criteria provide a quantitative yardstick by which compliance with a water quality standard can be determined with relative ease and certainty. Although an adequate amount of monitoring is required to make a compliance determination, the contesting arguments and appeals, which often accompany the more subjective process of interpreting a narrative criterion, may be avoided.

Another important advantage of numeric criteria is that they set a limit on the cumulative effect of multiple pollution sources in a lake's watershed. Numeric criteria provide a reference point for determining the finite assimilative capacity of a lake for phosphorus or other pollutants. Cumulative impact sources can then be managed by allocating waste load distributions equitably among the various sources in a manner that attains the in-lake criterion. Narrative criteria, in contrast, are generally applied on a case-by-case basis, without the total perspective on all the pollution sources in the watershed.

The ability to manage cumulative phosphorus impacts is particularly important in large lake basins where no single source of phosphorus is a significant cause of lakewide eutrophication, but rather many point and nonpoint sources combine together to produce a problem. The Great Lakes, Lake Champlain, and many large reservoir systems are examples of water bodies where eutrophication is the result of many discrete sources. In basins such as these, cumulative impacts may be best dealt with through the establishment of numeric in-lake criteria followed by wasteload allocations among all point and nonpoint sources. The phosphorus management approach conducted in the Great Lakes Basin, as described later in this manual (Section V), is an example of the effective application of in-lake numeric criteria (phosphorus concentration objectives). Lake modeling studies determined the phosphorus assimilative capacity of the various lake segments with respect to the in-lake criteria. Target phosphorus loads were then established, followed by allocations of specific loading reductions among point and nonpoint sources basin-wide (DePinto et al. 1986).

A disadvantage of numeric criteria is that a single number applied nationwide or statewide is not flexible enough to accommodate individual lake characteristics or regional differences in user perceptions and expectations of lake resources. Narrative criteria applied on a case-specific basis provide this desirable flexibility. However, the ideal approach may be to develop numeric criteria that are as lake-specific or region-specific as necessary.

One concern regarding numeric criteria is that lakes where the existing water quality exceeds a minimum criterion may be allowed to deteriorate until that criterion is reached (Duda et al. 1987). While anti-degradation provisions of the Clean Water Act and state water quality standards are designed to prevent this situation, anti-degradation policies have sometimes

proven difficult to implement. Numeric criteria established on a lake-specific or region-specific basis can provide anti-degradation protection by imposing stricter criteria for more oligotrophic waters.

On the other hand, numeric criteria corresponding to a high level of aesthetic quality and water clarity may not be realistically attainable in lakes that are naturally eutrophic. Again, lake-specific or region-specific numeric criteria can deal with this problem by recognizing local differences in attainable trophic states. An ecoregion approach, discussed later in this manual (Section V), and evaluation tools, such as that of Vighi and Chiaudani (1985), can be used to help define a realistically-attainable lake condition.

Another concern regarding numeric criteria is whether the criteria should be expressed as seasonal mean values, or as instantaneous "not to exceed" values. There are a number of reasons why seasonal mean values are preferable (Walker, 1985a):

1. Mean values derived from a lake monitoring program can be more reliably and precisely estimated than other statistics, such as the maximum. Monitoring for compliance with an in-lake mean criterion is, therefore, more feasible.

2. Mean values are used in most lake models.

3. Mean values are typically used in lake assessment and classification and are predominantly documented in the existing scientific information on eutrophication impacts.

4. Detection of a violation of a maximum, "not to exceed" criterion depends largely on the number of samples taken.

C. Advantages and Disadvantages of Eutrophication Standards

The primary advantage of adopting eutrophication standards is that violations prompt management action and remedies are instituted when available. Eutrophication standards for lakes and reservoirs can protect water quality. Without standards, eutrophication problems may be met with a certain amount of indifference. If management actions to meet a specified criterion are not explicitly described, then it is possible that no corrective action will take place. A second advantage of adopting eutrophication standards is that such standards can serve as a benchmark for comparing effectiveness of pollution abatement programs on lakes and reservoirs and for monitoring water quality changes over time.

The adoption of eutrophication standards may also have several disadvantages. Standards may not address the spatial and temporal variability of water quality conditions. If seasonal or annual averages are used as standards, then short duration exceedances would not violate the standard. Thus, impacts to designated uses might occur frequently and never prompt management action. The spatial variability that is characteristic of reservoirs makes application of eutrophication standards difficult. There may be a violation of a standard at one or more monitoring points, but not at other locations. Conversely, conditions could exist in many unmonitored areas of the lake/reservoir that would be violations of standards, while conditions at monitoring sites met all eutrophication standards. Meaningful application of such standards to reservoirs will require both carefully designed standards and carefully designed monitoring programs. This problem can be avoided if average values are established so that

more extreme nuisance conditions occur with an acceptably low frequency (see Lake Champlain example, Section V, User Survey Approach). Also, criteria must be defined that are applicable to the water use that is being protected. Frequently, the designated uses of lakes do not coincide with the uses perceived by the lake users.

Selecting the appropriate level of a criterion can complicate the adoption of a meaningful standard. If too many lakes are in violation of a given criterion, a water resource agency may elect to use its limited resources based on political factors and not on the degree of degradation. Finally, standards can be misleading and not be flexible or broad enough to reflect the complexity of lentic systems. A certain amount of false positive and false negative interpretations of use impacts may occur based on a comparison of a measured standard to a specified criterion.

IV. Legislative Background: Current Status of Lake Eutrophication Standards

A. United States and Canadian Legislative Approaches

Standards for addressing lake eutrophication are not explicitly mandated by nation-wide legislation in either the United States or Canada. This may explain why institutional problems exist in regulating the effects of nutrient over-enrichment in lakes and reservoirs. Approaches to water quality management differ between the United States and Canada because of different historical divisions of responsibility between federal and state/provincial levels of government.

In the United States, the Water Quality Act of 1965 (Clean Water Act) relied on violations of water quality standards as a basis for pollution control. Because this approach was not fully successful in limiting water pollution, the 1972 Amendments to the Clean Water Act established a dual system that consisted of: 1) water quality standards for ambient waters, and 2) minimum requirements for the abatement of point sources and areawide management plans for the abatement of nonpoint sources.

The standards system was founded on the basis of a federal/state partnership. Under Section 304 of the Clean Water Act (as amended), U.S. EPA is required to develop and publish ambient water quality criteria appropriate for different use designations. States are required, under Section 303, to adopt ambient standards (consisting of a use designation and criteria to protect that use designation) and U.S. EPA is required to approve or disapprove the state standards. Every three years, states are required to review their standards, consider revisions, and submit them to U.S. EPA for approval. If any state standard is not consistent with the Clean Water Act, U.S. EPA may promulgate a federal standard under Section 303. This has occurred for a small number of water bodies.

The water quality criteria recommended by U.S. EPA are intended to accurately reflect the latest scientific knowledge on: 1) the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, aesthetics, and recreation, which may be expected to occur as a result of the presence of pollutants in any body of water including ground water; 2) the concentration and dispersal of pollutants, or their by-products, through biological, physical, and chemical processes; and 3) the effects of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and organic and inorganic sedimentation for varying types of receiving waters. These U.S. EPA criteria are not rules and do not have regulatory impact. Rather, they present scientific data and guidance on the environmental effects of pollutants. The criteria can be used to derive regulatory requirements based on these considerations of water quality impacts. The U.S. EPA periodically publishes a summary of all contaminants for which the Agency has developed criteria recommendations. The most recent publication is the Quality Criteria for Water Quality, (May 1987), commonly referred to as the "Gold Book."

U.S. EPA has chosen not to issue national criteria for phosphorus levels to serve as a basis for controlling eutrophication. The Gold Book summary on phosphorus acknowledges the following points: 1) high phosphorus concentrations are associated with accelerated

eutrophication of waters, when other growth-promoting factors are present; 2) aquatic plant problems develop in reservoirs and other standing waters at phosphorus values lower than those in critical flowing streams; 3) reservoirs and lakes collect phosphates from influent streams and store a portion of them in consolidated sediments, thus serving as a phosphate sink; and 4) phosphorus concentrations critical to noxious plant growth vary among different geographic areas.

The Gold Book also acknowledges factors which affect variability in the amount or percentage of inflowing nutrients that may be retained by a lake or reservoir before adverse effects are manifested. These factors include: 1) the nutrient loading to the lake or reservoir, 2) the volume of the euphotic zone, 3) the extent of biological activities, 4) the detention time within a lake basin or the time available for biological activities, and 5) the level of discharge from a lake or reservoir.

To prevent the development of biological nuisances and to control cultural eutrophication, the Gold Book suggests that total phosphate-phosphorus should not exceed 50 µg/L in any stream at the point where it enters a lake or reservoir, or 25 µg/L within the lake or reservoir. The Gold Book also summarizes work by Hutchinson (1957), noting that most relatively uncontaminated lake regions are known to have surface waters containing from 10 to 30 µg/L total phosphorus. A later case study of China Lake in Maine (Section V) would suggest that a level of 25 µg/L would be considered much too high in a lake with historically low concentrations.

A review of state water quality standards that are specific to the eutrophication of estuaries, streams, and lakes was conducted by the Metropolitan Washington Council of Governments (MWCG) in 1982. The purpose of this analysis was to present a comprehensive review (up to the early 1980s) of narrative and numeric state standards related to nutrient enrichment. The report focused on in-stream standards for phosphorus, nitrogen, and chlorophyll *a*. The MWCG document was intended to help identify appropriate water use criteria to be applied in the consideration of pollution management alternatives for the Potomac River estuary.

The information compiled by the MWCG study reveals the wide range of standards (e.g., 7-200 µg/L for phosphorus) used by different states. The study also noted that many states that had established narrative water quality statements anticipated that these narrative criteria would be replaced with numerical limits when further scientific information became available concerning the relationship of nutrient levels to the eutrophication of aquatic systems.

The lack of national direction in the United States regarding phosphorus criteria has resulted in a diversity of different state approaches (including virtually unenforceable narrative "criteria"). Repeated surveys by NALMS (e.g., [NALMS, 1988]) have documented minimal progress at the state level regarding eutrophication control. Due to a lack of federal criteria, state control programs may continue to be discretionary in their approach.

In Canada, the constitutional division of responsibility between the federal government and the provinces was established in the British North American Act of 1867. The provinces were specified to be the owners of natural resources and they guard this primacy with zeal. Exceptions to this concept exist for federally-owned land, issues of importance to Canada, interprovincial water issues, atomic energy matters, and international waters such as the Great Lakes. While issues of importance can take the form of national legislation, such as the Canadian Environmental Protection Act which regulates certain toxic substances, no national legislation exists for water pollution control, lake quality management, or ambient water quality standards adoption. Consequently, each province has its own approach with little federal responsibility or oversight.

The Province of Ontario provides a good example. Three pieces of general provincial legislation (the Environmental Protection Act, the Environmental Assessment Act, and the Ontario Water Resources Act) provide authorization for various water quality management programs. A series of policies were established for managing Ontario's waters and a set of Provincial Water Quality Objectives (analogous to state ambient standards) were adopted. Like the United States government's water quality criteria, Ontario's list of objectives does not contain an objective for phosphorus to control eutrophication. Instead, "general guidelines" were promulgated in Ontario "to avoid nuisance concentrations of algae in lakes, average total phosphorus during the ice-free period should not exceed 20 µg/L ... and for rivers and streams it should not exceed 30 µg/L." Although the Inland Lakes Program within the Ontario Ministry of the Environment provides a sampling network for inland lakes, water quality management of these lakes seems to be the local responsibility of the 38 Conservation Authorities (CAs) in Ontario. The CAs have prepared watershed plans that were submitted to the province. The CAs can play a lead role in addressing eutrophication when the provincial "general guidelines" are exceeded on a water body. The situation of a provincial/CA partnership addressing lake eutrophication is quite analogous to the federal/state partnership which exists in the United States. Just as Section 314 lake restoration projects or Section 319 nonpoint source management projects can address lake eutrophication with combined federal and state funding, provincial/CA projects can do the same in Ontario with a combination of provincial and local funding.

A review of British Columbia's approach to eutrophication criteria is included in Section V. British Columbia's approach to criteria development and application differs from that of Ontario. Thus, differences in approaches to criteria development exist among Canadian provinces as they do among states of the United States. But, the actual differences in approaches may not be so important so long as the approach provides a viable mechanism for protecting or improving the condition of lakes.

V. Approaches for Developing Lake Eutrophication Standards

A variety of approaches have been used to develop lake eutrophication standards or criteria. To some degree they reflect the differences in lake and reservoir resources (water quality, morphometry, etc.) and the statutory basis for achieving Clean Water Act and Provincial goals. These approaches include the application of technology-based point and nonpoint source controls, lake inflow criteria, in-lake water quality standards, use classifications, and innovative approaches such as point/nonpoint trading. The examples of lake standard/criteria development presented here embody many of these different techniques for managing the resource.

Based on the lake standards survey conducted by NALMS, the following approaches or data needs were cited by the states (as summarized in Johnson, 1989):

- For those states with lake standards, total phosphorus was most frequently noted; however, chlorophyll *a* and Secchi transparency are commonly cited as well.

- Professional judgment and literature values are most frequently used to derive these standards.

- A vast majority of the states feel that special use classifications are a valid means for developing categories for lake standards. Morphometric and ecoregion considerations also are frequently cited.

- Chemical constituents, in particular total phosphorus and total nitrogen, are most frequently cited as the basis for state standards in contrast to physical or biological parameters.

A. User Survey Approach (Vermont)

In 1986, the Vermont General Assembly provided statutory direction to develop numeric phosphorus "limits" for the state's waters. Following a formal state rulemaking process, the Vermont Water Resources Board adopted revisions to the state's water quality standards in 1991 that include, for the first time, numeric criteria for some waters. Specific numeric total phosphorus concentration criteria were adopted for twelve segments of Lake Champlain, a large, natural, interstate and international water body. The criteria range from 10 to 54 µg/L, and were derived from a user survey approach.

Lake user surveys conducted as part of statewide lake eutrophication monitoring programs provide a means for quantifying the link between water quality variables and lake user impacts. Lake user surveys have been used in Vermont and Minnesota to identify specific total phosphorus, chlorophyll *a*, or Secchi disk values at which algal nuisances and impairment of recreation are perceived by the public (Heiskary and Walker, 1988; Smeltzer and Heiskary, 1990). One of the most useful applications of user survey data is support for the development of numeric water quality criteria. Numeric lake criteria for variables such as total

phosphorus, chlorophyll *a*, and Secchi disk transparency are often aimed at protecting values and uses such as recreation and aesthetics. The user survey approach provides a quantitative, accountable, and region-specific basis for deriving numeric criteria to preserve these lakes uses.

The user survey form used in Vermont and Minnesota is shown in Table 4. This two-part questionnaire was completed each time a lake water sample was obtained by citizens participating in statewide volunteer water quality monitoring programs. The first question (A) asked the observers to describe the physical condition of the lake water at the time samples were taken. The second question (B) sought an opinion on the recreational suitability of the lake at the time of sampling. The survey responses were accompanied by simultaneous water quality measurements including total phosphorus and chlorophyll *a* concentrations, and Secchi disk transparency.

Analysis of these data (Smeltzer and Heiskary, 1990) indicated that low transparency and high phosphorus and chlorophyll *a* concentrations were associated with greater perceived algal problems and recreational impairment by the survey respondents. There were striking regional differences in these relationships. In lake regions such as Vermont and northern Minnesota with predominantly oligotrophic or mesotrophic lakes, nuisance conditions and use impairment were recorded at much higher water transparencies than for other regions such as southwestern Minnesota where eutrophic and hypereutrophic lakes are common. These regional differences in user perceptions of water quality indicate that if a user survey approach is to serve as a basis for developing lake water quality criteria, then the data should be as specific to the lake region of concern as possible.

These user surveys were conducted by environmentally concerned citizens and not randomly chosen samples of public opinion. However, this group may actually provide an ideal data base for the development of lake water quality standards (see Smeltzer and Heiskary, 1990). Another limitation of the user survey approach described here is that it addresses only aesthetic and recreational impacts from algae growth in open water areas of lakes. Other potential eutrophication impacts such as shoreline periphyton and aquatic plant growth, hypolimnetic dissolved oxygen depletion, fisheries impacts, and water supply impairment were not considered. Alternative approaches are needed where these impacts are critical.

Table 4. Lake user survey form *(from Smeltzer and Heiskary, 1990).*

A. Please circle the one number that best describes the physical condition of the lake water today.

1. Crystal clear water.
2. Not quite crystal clear, a little algae visible.
3. Definite algal greenness, yellowness, or brownness apparent.
4. High algal levels with limited clarity and/or mild odor apparent.
5. Severely high algae levels with one or more of the following: massive floating scums on lake or washed up on shore, strong foul order, or fish kill.

B. Please circle the one number that best describes your opinion on how suitable the lake water is for recreation and aesthetic enjoyment today.

1. Beautiful, could not be any nicer.
2. Very minor aesthetic problems; excellent for swimming, boating, enjoyment.
3. Swimming and aesthetic enjoyment slightly impaired because of algae levels.
4. Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels.
5. Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels.

In spite of these limitations, the user survey approach has made a very useful contribution to the process of developing rational, defendable numeric phosphorus criteria for Lake Champlain. A user survey such as the one described here could be easily implemented wherever a citizens water quality monitoring program exists.

B. Ecoregion and Attainable Trophic State Approach (Minnesota)

Because of regional diversity in lake and watershed characteristics, it was unlikely that a single total phosphorus value could be adopted as a statewide criterion for lake protection in Minnesota (Heiskary et al. 1987). Rather, a methodology was needed for developing lake water quality criteria on a regional or lake-specific basis.

The methodology for establishing lake water quality criteria in Minnesota considered the following (from Heiskary and Walker, 1988):

1. phosphorus impacts on lake condition (as measured by chlorophyll *a*, bloom frequency, transparency, and hypolimnetic oxygen depletion);

2. impacts on lake user (aesthetics, recreation, fisheries, water supply, etc.); and

3. attainability (as related to watershed characteristics, regional phosphorus export values, lake morphometry, etc.).

Previous papers (Heiskary et al. 1987) have described the range in the trophic status of lakes in Minnesota and the utility of the ecoregion framework in explaining some of this variability. Ecoregion maps, as developed by U.S. EPA ERL-Corvallis, are based on land use,

soils, land form, and potential natural vegetation (Omernik, 1987). Recognizing patterns in lake trophic status between these regions has permitted the development of some generalized lake management strategies (Heiskary and Wilson, 1988).

As shown in Figure 1, almost all of Minnesota's lakes are found in four of the state's seven ecoregions (Heiskary et al. 1987). Typical land use varies from the forests in the north to the primarily cultivated land and pastures to the south. A more detailed presentation of the information may be found in Heiskary and Wilson (1988).

The ecoregion framework provides a regional perspective on the uses of lakes in each part of the state and allows for the definition of "most sensitive uses" in each region. The MPCA has defined the "most sensitive use" of a lake as that use (or uses) which can be affected or even lost as a result of an increase in the trophic status of the lake. Two examples include drinking water supplies and cold water fisheries. In the case of drinking water supplies, eutrophication can increase water treatment costs (Walker, 1985b), contribute to taste and odor problems (Walker, 1985b), and increase production of trihalomethanes during the treatment process (Palmstrom et al. 1988). In a cold water fishery, increased nutrient loading will reduce oxygen in the hypolimnion (Walker, 1979) and cold water species may die off as these populations are driven into warmer surface waters (Colby and Brooke, 1969).

Table 5 presents some of the most sensitive lake uses for each ecoregion. Lakes corresponding to some of these categories have been specifically identified in Minnesota Rules Chapter 7050.0470, subp. 1-8 (1988), and include designations for the following:

1. Domestic consumption (as defined in Chapter 7050.0220, subp. 2.1); and

2. Fisheries and recreation (as defined in Chapter 7050.0220, subp. 3.2), whereby Class A specifically refers to waters designated for the propagation and maintenance of warm or cold water fish, with lake trout lakes specifically identified in Chapter 7050.0420.

Once uses have been defined for a lake, in a given region, appropriate management strategies may be developed. The management strategy for maintaining a given use (phosphorus goal) may vary between regions and should reflect user expectations and regional variations in attainable lake trophic state.

For example, drinking water supplies in the Northern Lakes and Forests ecoregion are typically characterized as oligotrophic to mesotrophic in nature. The cost of treating these waters to produce potable water is much less than water obtained from eutrophic lakes in central and southern Minnesota. These treatments have included extensive in-lake application of copper sulfate to reduce algal blooms and the use of potassium permanganate and activated carbon in the treatment plants to reduce taste and odor (Walker, 1985b; Hanson and Stefan, 1984). Even with these treatments, taste and odor complaints are common among users of these water supplies. Management strategies for water supplies should focus on decreasing the frequency and intensity of algal blooms.

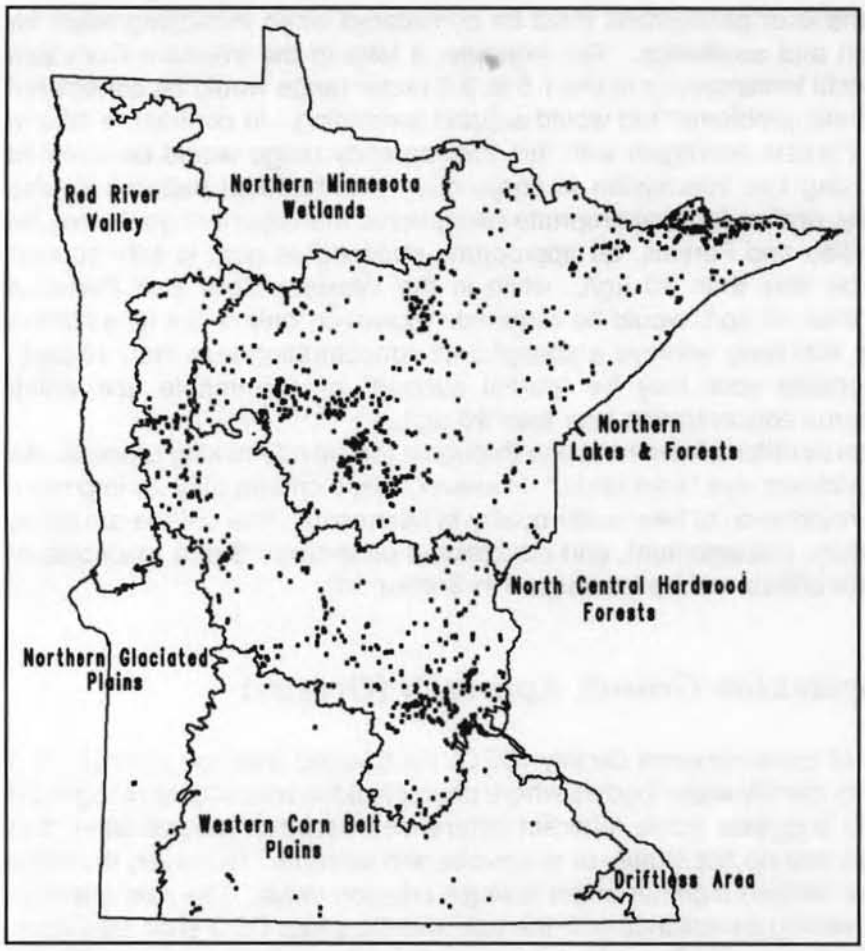


Figure 1. Minnesota Ecoregion Map (Symbols Indicate Lakes with Water Quality Data).

Table 5. Most Sensitive Lake Uses by Ecoregion and Corresponding Phosphorus Criteria.

Ecoregion	Most Sensitive Uses	P Criteria
Northern Lakes and Forests	- Drinking water supply	<15 µg/L
	- Cold water fishery	<15 µg/L
	- Primary contact recreation and aesthetics	<30 µg/L
North Central Hardwood Forests	- Drinking water supply	<30 µg/L
	- Primary contact recreation and aesthetics	<40 µg/L
Western Corn Belt Plains	- Drinking water supply	<40 µg/L
	- Primary contact recreation and aesthetics	
	(full support)	<40 µg/L
	(partial support)	<90 µg/L
Northern Glaciated Plains	- Recreation and aesthetics (partial support)	<90 µg/L

Regional patterns and user perceptions must be considered when managing lakes for primary contact recreation and aesthetics. For example, a lake in the Western Corn Belt Plains ecoregion with Secchi transparency in the 1.5 to 2.0 meter range would be considered to have only "minor aesthetic problems" but would support swimming. In contrast, a lake in the Northern Lakes and Forests ecoregion with this transparency range would be deemed "swimming impaired." Using this information in conjunction with regional patterns in lake trophic state, morphometry, and so forth, appropriate phosphorus management goals may be set. For the Northern Lakes and Forests, an appropriate phosphorus goal to fully support swimmable uses would be less than 30 µg/L, while in the Western Corn Belt Plains, a phosphorus goal of less than 40 µg/L would be required. However, only a few lakes in the Western Corn Belt Plains can likely achieve a phosphorus concentration less than 40 µg/L, and thus, a more reasonable goal may be "partial support" of swimmable use which corresponds to a phosphorus concentration less than 90 µg/L.

Minnesota's phosphorus criteria have not gone through a formal rulemaking process. As such, they cannot be considered true "standards." However, these criteria play an important role in the protection and restoration of lake water quality in Minnesota. The criteria are being used with existing regulatory, management, and educational programs. Some examples of uses and application of the criteria will be addressed in Section VII.

C. Nuisance Phytoplankton Growth Approach (Oregon)

The Oregon Department of Environmental Quality (DEQ) established average chlorophyll *a* values in their state rules to identify water bodies where phytoplankton may impair recognized beneficial uses. The rule suggests some inherent differences between natural lakes that stratify, in contrast to lakes that do not stratify or reservoirs and streams. However, the latter three water body types are lumped together under a single criterion value. The rule specifies the methodology for determining compliance with the rule and the steps DEQ shall take upon determination that the rule is exceed. The rule does allow the rule's values to be modified if natural conditions are responsible for exceedance of the values.

The actual rule, taken from Oregon Administrative Rules - Chapter 340 - Division 41-150 is included as follows:

> "The following values and implementation program shall be applied to lakes, reservoirs, estuaries and streams, except for ponds and reservoirs less than 10 acres in surface area, marshes and saline lakes:
>
> (1) The following average chlorophyll *a* values shall be used to identify water bodies where phytoplankton may impair the recognized beneficial uses:
>
> (a) Natural lakes which thermally stratify: 10 µg/L;
>
> (b) Natural lakes which do not thermally stratify, reservoirs, rivers and estuaries: 15 µg/L.
>
> Average chlorophyll *a* values shall be based on the following methodology (or other methods approved by the Department): a minimum of three (3) samples collected over any three consecutive months at a minimum of one representative location (e.g., above the deepest point of a lake or reservoir or at a point mid-flow of a river) from samples integrated from the surface to a depth equal to twice the Secchi depth or the bottom (the lesser of the two depths); analytical and quality assurance methods shall be in accordance with the most recent edition of Standard Methods for the Examination of Water and Wastewater.
>
> (2) Upon determination by the Department that the values in section (1) of this rule are exceeded, the Department shall:

(a) In accordance with a schedule approved by the Commission, conduct such studies as are necessary to describe present water quality; determine the impacts on beneficial uses; determine the probable causes of the exceedance and beneficial use impact; and develop a proposed control strategy for attaining compliance where technically and economically practicable. Proposed strategies could include standards for additional pollutant parameters, pollutant discharge load limitations, and other such provisions as may be appropriate.

Where natural conditions are responsible for exceedance of the values in section (1) of this rule or beneficial uses are not impaired, the values in section (1) of this rule may be modified to an appropriate values for that water body;

(b) Conduct necessary public hearings preliminary to adoption of a control strategy, standards or modified values after obtaining Commission authorization;

(c) Implement the strategy upon adoption by the Commission.

(3) In cases where waters exceed the values in section (1) of this rule and the necessary studies are not completed, the Department may approve new activities (which require Department approval), new or additional (above currently approved permit limits) discharge loadings from point sources provided that it is determined that beneficial uses would not be significantly impaired by the new activity or discharge."

D. Nutrient Enriched Waters (Virginia)

In 1985 the Virginia General Assembly established a joint subcommittee to examine nutrient enrichment problems in Virginia's surface waters (Anon., 1987; Gregory, 1989). The subcommittee recommended that the Virginia Water Control Board (VWCB) develop:

1) water quality standards to protect surface waters from nutrient enrichment; and
2) strategies to implement those standards.

The VWCB appointed a Technical Advisory Committee (TAC) of state, regional, and national experts to assist them. There were specific issues the Board wanted advice on prior to developing these standards including such issues as whether narrative or numerical standards were needed, appropriate parameters and numerical levels, and the appropriate monitoring, sampling, and evaluation methods.

Prior to the workshop, TAC members completed three rounds of a Delphi questionnaire process. The first questionnaire wanted responses on major reasons for developing a water quality standard for control of nutrient enrichment, where the standard should be applied, variables necessary to develop a standard, and other issues that needed to be addressed in future questionnaires.

The second questionnaire focused on definitions, negative impacts from which the Board should protect state waters, technical ease, reliability of measurement, cost of analysis, applicability to water type, monitoring frequency, and acceptable levels. The third questionnaire placed an emphasis on background levels, data bases, experiences, degree of variability acceptable, and where, when, and how to collect samples for various measurements.

Using results from these questionnaires, the preliminary views of the TAC were assembled and summarized for the workshop. The workshop was designed to build on the Delphi process and develop as much consensus as possible among TAC experts on issues

related to developing nutrient control standards. Workshop issues were summarized with consensus recommendations of the TAC, and were subsequently submitted to the VWCB.

The TAC recommended four parameters that could be used as indicators of nutrient enrichment: corrected chlorophyll *a*, dissolved oxygen fluctuations, total phosphorus, and total nitrogen. Taking into consideration the recommendations of the TAC, the VWCB decided to base its designations on the first three parameters. As a result, the VWCB developed two regulations. The first established a water quality standard that designated as "nutrient enriched waters" those waters that showed evidence of degradation attributable to the presence of excessive nutrients. A companion regulation was created to control certain point source discharges of nutrients affecting state waters designated as "nutrient-enriched waters" (Gregory, 1989). The policy and regulation went through Virginia's regulation and adoption process basically intact and became effective on May 25, 1988. The policy/regulation states that after the point source controls are implemented and the effects of the regulation and nonpoint source control program are evaluated, the VWCB recognizes that it may be necessary to impose further limitations on discharges of nutrients to control undesirable growth of aquatic plants. The policy and regulation are viewed as the first phase of a strategy to protect Virginia's waters from the effects of nutrient enrichment (Gregory, 1989).

E. Nondegradation Approach (Maine)

China Lake in Maine is an example of lake degradation occurring because lake water quality was not actively protected. China Lake, at one time a popular recreational lake and water supply with good water quality and a cold water fishery, began experiencing repeated and sustained algal blooms (Welch, 1989). In less than a decade, in-lake phosphorus concentrations had increased from about 8 µg/L to about 15 µg/L. Secchi transparency had declined from readings of 4.5 meters in the 1970s to 1.5-2.0 meters in the mid 1980s. The rapid degradation of the quality of the lake was attributed to slight increases in external phosphorus loading caused by incremental development in the watershed. The increases in nutrients and algal productivity led to a reduction in hypolimnetic oxygen levels and a subsequent increase in the internal recycling of phosphorus, which accelerated the eutrophication process. The situation at China Lake helped to inspire the development of Maine's "nondegradation standard."

Maine has adopted narrative lake standards aimed at maintaining trophic state in those lakes where it is currently "acceptable," and on improving trophic state in lakes with culturally induced, obnoxious algal blooms. Specifically, the statute states that lake "waters shall have a stable or decreasing trophic state, subject only to natural fluctuations and shall be free of culturally induced algal blooms which impair their use and enjoyment." The statute further states that there shall be no new (point) discharges to lakes, that new point discharges to lake tributaries are prohibited if they will increase the trophic state of the lake, and that existing point discharges must be eliminated as soon as a practical alternative is identified.

To understand how such conservative standards as these could be appropriate and feasible, one must first understand the context of Maine's lakes. Most of Maine's 5000+ lakes are natural. Since the majority of the larger towns developed on rivers and there are very few riverine reservoirs in the state that have sufficient residence time to respond to nutrient addition, situations where municipal or industrial sewers historically discharged to lakes are rare. Hence, a law prohibiting such discharges is more easily implemented in Maine than in other states. Most lake watersheds are predominately forested with less than 10% of their area (often much less) devoted to non-forest land uses such as agriculture or residential/urban use. As a result of this and the geological setting of these lakes, most have low trophic status, with only a relative few (less than 1%) which might be considered eutrophic. The public identifies strongly with clear oligotrophic lakes. They have seen the impact that lake

eutrophication can have on the economic and social well being of a community—dramatically demonstrated by the rapid decline of meso/oligotrophic China Lake to a eutrophic condition as result of internal recycling. Hence, there is strong public support for protecting lake water quality.

The narrative standard cited above prescribing that lakes should have a stable or decreasing trophic state provides a nondegradation goal for Maine lakes: an increase in trophic state is a violation of the standards. Taken absolutely, this goal would be difficult to achieve, since it might be agreed that any increase in phosphorus concentration theoretically infers an increase in trophic state; and any intensification of land use in a lake's watershed should, theoretically, result in an increase in the lake's phosphorus concentration, and hence its trophic state. By logical extension, this interpretation would declare a moratorium on all new activity in a lake's watershed unless: 1) it could be performed, constructed, or maintained so as not to export any additional phosphorus to the lake, or 2) it was accompanied by a concurrent reduction in some equivalent existing source of phosphorus within the watershed.

Such an absolute interpretation of this standard would, at best, be difficult to implement and it might be unnecessarily restrictive. Instead, the standard is interpreted as prohibiting any increase in trophic state perceivable to lake users. This allows some small, absolute increase in a lake's phosphorus concentration over time, provided the lake does not already support algal blooms, and hence some limited latitude for allowing new activity in the watershed. At the same time, however, it provides strong support for minimizing any new phosphorus export from that activity.

Criteria used to define "perceivable increase in trophic state" by the Maine Department of Environmental Protection (DEP) are given in Table 6. Simply stated, this method determines an acceptable increase in a lake's phosphorus concentration (Table 6) by using a simple phosphorus loading model, and estimates the maximum allowable increase in phosphorus load which would not exceed the acceptable increase in lake concentration. This allowable increment of phosphorus loading is allocated over the portion(s) of the watershed where future development is anticipated, and is then applied to developments on a per acre basis as they occur. The "acceptable increase in lake phosphorus concentration," which is the cornerstone to this method, is based on preventing a "perceivable" increase in trophic state.

Table 6. Acceptable Increase in Lake Phosphorus Concentrations (µg/L).

	Lake Protection Level		
Water Quality Category	High	Medium	Low
Outstanding	0.5	1.0	1.0
Good	1.0	1.5	2.0
Moderate/Stable	1.0	1.25	1.5
Moderate/Sensitive	0.75	1.0	1.25
Poor/Restorable	0.1	0.5	NA
Poor/Low Priority	2.0	4.0	6.0

The acceptable increase in lake phosphorus concentration, in µg/L or ppb, is determined by the level of protection applied to a lake and its water quality category. A high level of protection is recommended for public water supply lakes and for high value cold water fisheries. A medium level of protection is recommended for all other lakes. A low level of protection is not recommended but is provided as an option for special cases. The water quality categories are summarized in Table 7. If adequate data do not exist to assign a water quality category, a default category of moderate sensitive is assigned.

Table 7. Water Quality Categories for Lake Protection in Maine

Outstanding	Lakes in this category are very clear (average Secchi disk [S.D.] transparency >30 ft), have very low algae levels (chlorophyll *a* <2µg/L) and have very low phosphorus concentrations (2 to 5 ppb). These lakes are rare and unique resources which are particularly sensitive to small increases in phosphorus concentration.
Good	Lakes in this category are clear (average S.D. 20 to 30 ft) with relatively low algae levels (chlorophyll *a* 2 to 4 µg/L) and phosphorus concentrations 5 to 10 ppb. This water quality type is common, particularly among the larger lakes in the state.
Moderate/Stable	These lakes are less clear (average S.D. 10 to 20 ft) but do not have summer algae blooms (minimum S.D. >6 ft). Algae levels are moderate (chlorophyll *a* 4 to 7 µg/L) as are phosphorus concentrations (10 to 20 ppb). Despite their relatively high nutrient and algae levels, lakes in this category do not appear to be in high risk for developing algae blooms because of: 1) high water color (>30 Pt-Co Units), 2) consistently high summer oxygen levels in the metalimnion, and/or 3) very stable algae and nutrient levels with little seasonal variation.
Poor/Restorable	Lakes in this category support obnoxious summer algae blooms (minimum S.D. <6 ft) and are candidates for restoration. They are treated very conservatively because any additional phosphorus loading will reduce the feasibility of restoration. There are 20 to 30 lakes in the state which fall into this category.
Poor/Non-Restorable	These lakes have a long history of obnoxious summer blooms and little public interest in recreation. Restoration is not considered feasible because they are small lakes with very large, highly agricultural watersheds where the only possibility for restoration would require elimination of that land use throughout much of the watershed. Few of Maine's lakes fall into this category.

The criteria which have arisen from the narrative non-degradation standard are incremental numeric criteria. This combines the best of narrative and numeric standards because these criteria can provide good protection for any lake even if there is little or no trophic or nutrient budget data available for the lake. The criteria are responsive to the lake's current trophic state, no matter what it is.

Though Maine's standards and criteria may not be appropriate for the specific conditions present in many other states, one element may prove useful to states with large numbers of lakes for which they have little data and no obvious water quality problems. The incremental criteria, defining an acceptable increase in trophic state and suggesting an allowable increase in phosphorus loading, can provide specific, lake responsive protection without a large data base. While this approach may not be feasible statewide, it may have some value in a regional application.

F. Nutrient Sensitive Waters (North Carolina)

North Carolina's approach to the control of eutrophication could serve as a model for how to utilize specific criteria along with special use classifications to achieve restoration and protection of lakes and reservoirs under the Clean Water Act. In the late 1970s, North Carolina adopted a chlorophyll *a* criterion of 40 µg/L for warm waters and 10 µg/L for cold waters as part of its water quality standards in response to section 303 of the Clean Water Act. Exceedance of these criteria triggers an investigation of whether the water body and its entire watershed should be classified as nutrient sensitive. If algal populations impair or threaten water uses, scientific investigations are conducted to determine major sources of nutrient loadings and to identify cost-effective abatement action. Thus, in North Carolina, the establishment of a "nutrient sensitive waters" classification gives broad authority to the Environmental Management Commission to seek abatement of the point and nonpoint source releases of nutrients upstream from the priority water body.

Two major reservoir watersheds (Falls of the Neuse Lake and Jordan Lake) have been declared nutrient sensitive and resulted in new wastewater treatment plants as well as major existing ones having to meet a total phosphorus effluent limitation of 1.0 mg/L.

Nonpoint pollution sources also are addressed. The state legislature created a targeted agricultural water quality cost sharing program to provide an incentive for producers and growers to use nutrient abatement practices. The program provides a 75 percent cost share and has been enthusiastically received. To control urban nonpoint sources, the state issued developmental (land use) guidelines to counties and municipalities in the lake watersheds for controlling urban pollutants through local ordinances. With the NPDES stormwater permit program and a recently-enacted special water supply watershed use designation, North Carolina should be well positioned to control eutrophication in the two major reservoirs. Expansion of this approach to other lakes and reservoirs with eutrophication concerns in North Carolina seems appropriate.

G. Biological Approach (Tennessee Valley Authority)

The Tennessee Valley Authority (TVA) is currently developing an Index of Biological Integrity (IBI) for reservoirs. The index will identify biotic communities that are significantly out of balance compared to what a specific reservoir could be expected to support. The index will be used in the assignment of reservoir management priorities. An IBI based on measures of a fish community has been used by a number of state and federal agencies for the assessment of streams (Karr et al. 1986, Miller et al. 1988). Several states, notably Ohio, use the IBI in setting stream water quality standards that have stood the test of court challenge. TVA uses the IBI in its stream water quality monitoring program to help prioritize watersheds for nonpoint source evaluation.

IBI is particularly useful in identifying impacts from pollutants that are episodic in nature. IBI serves as an integrator of the temporal variability observed in many chemical pollutants. Many factors other than chemical pollution also affect the biotic integrity (e.g., habitat

degradation from flow regulation) and are identified by IBI. Biological criteria are increasingly being adopted in setting water quality standards and IBI has the potential to be an extremely useful component of these standards.

The physical and chemical water quality standards developed for flowing waters have not been protective of standing waters. Likewise, biomonitoring and biocriteria developed for streams cannot be used to evaluate and protect resources in lakes and reservoirs. A single biotic index utilizing a broad range of aquatic organisms would provide a more coherent picture of environmental health. TVA is particularly interested in a reservoir IBI to provide a picture of the overall health of its reservoir system as well as the health of individual reservoirs.

Modification of the IBI for use in reservoirs involves development of metrics and/or indices that incorporate information about taxa other than fish (e.g., benthic invertebrates, algae, macrophytes, etc.). The monitoring effort providing the data used in developing the reservoir IBI addresses the differences in biotic communities that exist in various reservoir habitats (e.g., embayments, overbanks, lacustrine, riverine, and transitional zones). Additionally, some physical and chemical attributes may be explicitly incorporated into a reservoir IBI. Although the reservoir IBI may not identify impacts as being specifically caused by cultural eutrophication, it will identify the degraded conditions associated with cultural eutrophication.

One example of a TVA reservoir that might benefit from the development of a reservoir IBI is Boone Reservoir. Boone Reservoir is the most eutrophic tributary reservoir in the TVA system. Chlorophyll *a* levels range from 12 to 16 µg/L and Secchi depths of 1.5 meters or less are common during the summer. A pronounced metalimnetic oxygen reduction has been observed in the reservoir and is believed to be primarily the result of algal decomposition and/or respiration. A water quality management plan prepared for Boone Reservoir concluded that although eutrophication was significant in the reservoir, it did not constitute a use impairment because no water quality criteria had been violated and no documented impact to designated uses had been identified (Anderson and Lewis, 1986). The water quality standards for the State of Tennessee do not directly address eutrophication or reservoir environments. For example, the state criterion for dissolved oxygen is applicable at a depth of five feet. Therefore, the severe metalimnetic oxygen depletion deeper in the reservoir did not violate the criterion.

In 1986, a Water Quality Task Force that included representatives from TVA, U.S. EPA, and the Tennessee Department of Health and Environment undertook a cooperative project to investigate pollution reduction strategies on Boone Reservoir. The project assessed pollutant loadings from point and nonpoint sources and applied a two-dimensional water quality model to the reservoir. The model was used to evaluate the effects of various pollution reduction alternatives and their associated costs. Numerous meetings of the Task Force were held to discuss alternative water quality objectives and their biological significance. The two criteria chosen to evaluate the response of the reservoir to various pollution reduction scenarios were: 1) the volume of the reservoir with dissolved oxygen less than 3 mg/L, and 2) the algal biomass. The modeling results showed that pollution abatement schemes targeting nonpoint sources would be considerably more cost effective than point source reductions in improving dissolved oxygen and reducing algal biomass (Bender et al. 1989). However, without a clearly definable and directly measurable water quality standard, pollution reduction strategies will be difficult to implement and monitor.

H. Water Use Based Approach (British Columbia)

British Columbia has elected to establish criteria according to different uses (Nordin, 1986). In three of the water uses they have defined—drinking water, protection of aquatic life, and recreation and aesthetics—nutrients are important. The sequence for determining criteria is shown in Figure 2. Literature review, input from other agencies (e.g., existing criteria), and

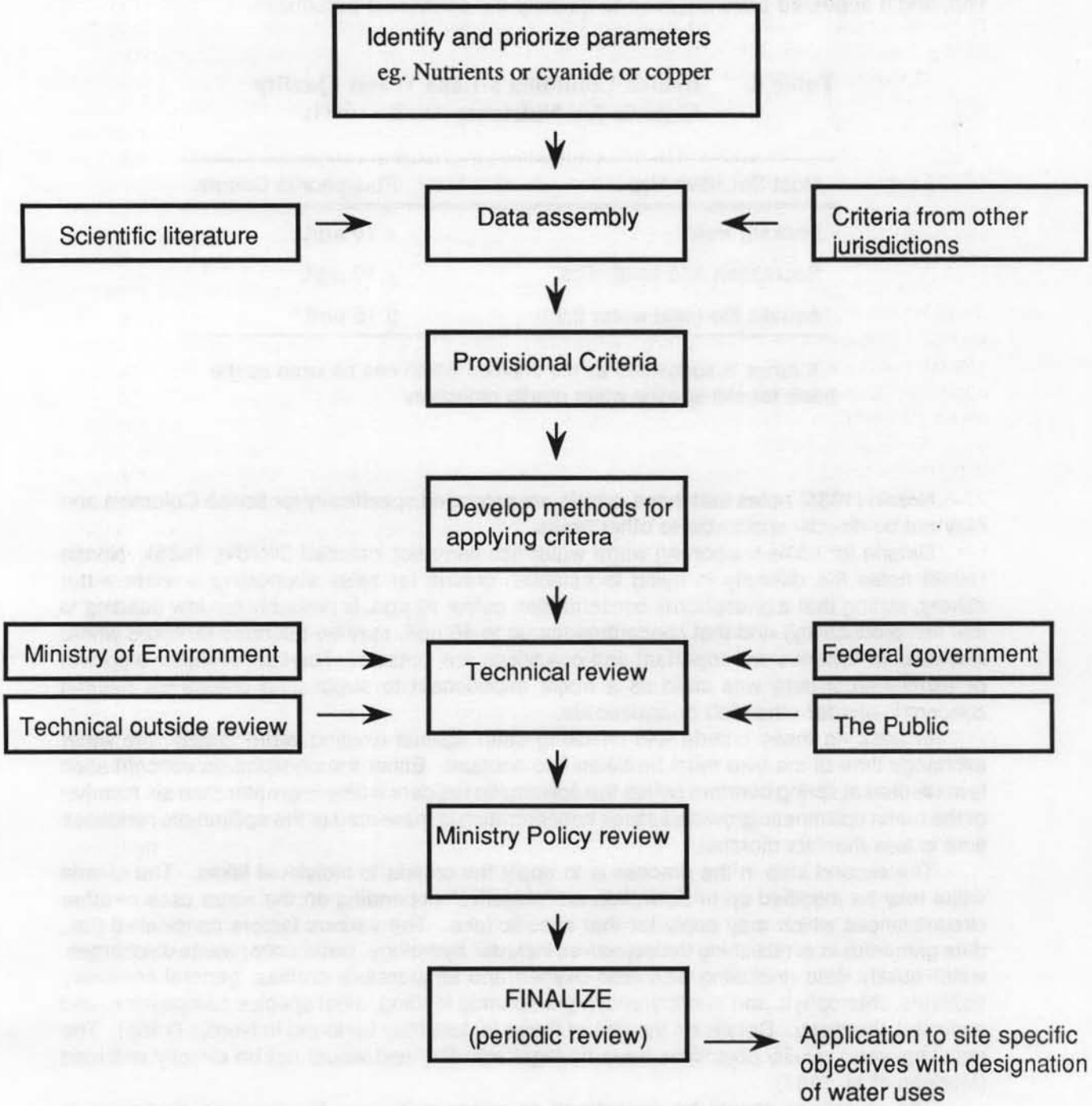


Figure 2. Water Quality Criteria Development Process for British Columbia.

evaluation of problems which exist or have existed in British Columbia were used to derive the criteria. Literature review focused on interrelationships between nutrients, primary productivity, and hypolimnetic oxygen depletion; cold water fishery requirements; and public perception of water quality. British Columbia's criteria are presented in Table 8. Phosphorus concentration was used because there is ample evidence in the literature that quantitative interrelationships exist between it and chlorophyll and transparency, its acceptance as an index of eutrophication, and it appeared advantageous to quantify the controlling parameter.

Table 8. British Columbia's Lake Water Quality Criteria for Nutrients *(Nordin, 1985).*

Most Sensitive Use	Phosphorus Criteria
Drinking water	< 10 µg/L
Recreation and aesthetics	< 10 µg/L
Aquatic life (cold water fish)	5-15 µg/L*

* A range is suggested as the criterion which can be used as the basis for site specific water quality objectives.

Nordin (1986) notes that these criteria are proposed specifically for British Columbia and may not be directly applicable to other areas.

Criteria for lakes supporting warm water fish were not included (Nordin, 1985). Nordin (1986) notes the difficulty in trying to establish criteria for lakes supporting a warm water fishery, stating that a phosphorus concentration below 10 µg/L is probably too low (leading to low fish productivity) and that concentrations up to 40 µg/L may be tolerable for lakes where recreational fisheries are important and conditions are suitable. The lack of either empirical or experimental data was cited as a major impediment to suggesting criteria for nutrient concentrations for other fish or aquatic life.

In applying these criteria and checking them against existing water quality, the water exchange time of the lake must be taken into account. Either the phosphorus concentration is measured at spring overturn (when the epilimnetic residence time is greater than six months) or the mean epilimnetic growing season concentration is measured (if the epilimnetic residence time is less than six months).

The second step in the process is to apply the criteria to individual lakes. The criteria value may be modified up or down into an "objective" depending on the water uses or other circumstances which may apply for that specific lake. The various factors considered (i.e., data gathered) in establishing the objectives include: hydrology, water uses, waste discharges, water quality data (including dissolved oxygen and temperature profiles, general chemistry nutrients, chlorophyll, and transparency), phosphorus loading, algal species composition, and sediment chemistry. Details on the use of these factors may be found in Nordin (1985). The resulting water quality objectives have no legal standing and would not be directly enforced (McKean et al. 1987).

The objectives should be considered as policy guidelines for resource managers to protect water uses in the specified water bodies. They will guide the evaluation of water quality; the issuing of permits, licenses, and orders; and the management of the fisheries and the province's land base. They will also provide a reference against which the water quality

in a particular water body can be checked, and aid decisions on whether to initiate basin-wide water quality studies.

Lake phosphorus concentrations up to 40 µg/L may be tolerable, depending on lake characteristics and the fish species considered. Except for salmonids and perhaps coastal lakes, the lack of either empirical or experimental data is a major impediment to suggesting criteria for nutrient concentrations for other fish or aquatic life.

I. Lake Specific Approach

1. Georgia Lake Standards Legislation

In May 1990, the Georgia General Assembly adopted a lake standards bill (Senate Bill 714). One feature of the legislation is that the standards setting approach is lake specific. Also, there is provision for variations in standards in different parts of each lake. This is especially important in long lakes and in lakes with large embayments. Another feature of the legislation is that standards will be based on comprehensive limnological studies. The legislation applies to all publicly owned lakes with a surface area of 1,000 acres or more. The standards setting approach is as follows:

1. The lake is selected from the list of 17 lakes that the Georgia Department of Natural Resources (DNR) has determined qualify under the legislation; i.e., publicly owned lakes more than 1,000 acres in size. Selection is based on a combination of need, local interest, and available funding.

2. A comprehensive study plan is developed for the lake in consultation with local officials and affected organizations.

3. A comprehensive limnological study of the lake and primary tributary streams is conducted. The studies are not to exceed two years in duration. Final reports are available to the public.

4. Total maximum daily loads (TMDLs) for nutrients will be established for each primary tributary to the lake including streams with permitted discharges. The TMDLs for tributaries will be established at the same time as the lake standards are established.

5. After water quality standards are established for each lake and its tributary streams and TMDL loadings are implemented, the DNR is to monitor each lake on a regular basis to ensure that the lake achieves and maintains such standards.

6. Subsequent to the limnological studies, the standards setting process is to be initiated immediately. The standards setting process approximates the federal procedures for adoption of regulations and includes: a scientific report on each study, draft recommendations for each numerical criteria proposed, public notice, and public hearing. Using the various reports and testimony, the Georgia DNR develops final recommended standards for submission to the Board of Natural Resources. The Board shall adopt the standards with any such modifications they determine necessary. The entire process is limited to one year.

The legislation requires that numerical criteria shall be adopted for each lake and include but not be limited to: 1) pH, 2) fecal coliform bacteria, 3) chlorophyll *a* for designated areas determined as necessary to protect a specific use, 4) total nitrogen, 5) total phosphorus loading for the lake in pounds per acre feet per year, and 6) dissolved oxygen in the epilimnion during periods of thermal stratification.

As of 1990, in accordance with the legislation, the Georgia DNR initiated studies in three lakes: Lake Lanier, Lake West Point, and Lake Walter F. George. The standards setting process is projected for 1992 for these lakes. Similar studies are scheduled for two additional lakes (Lake Allatoona and Lake Blackshear) in 1992.

2. Great Lakes

Perhaps one of the best success stories in water quality management has been the reversal of eutrophication trends in the Great Lakes. Both Canada and the United States made commitments in the Great Lakes Water Quality Agreement to take specific actions to restore the lakes. A combination of approaches was used consisting of lake-specific standards for phosphorus, lake-specific pollution loading reductions, and lake-specific ecological water quality standards. Combined with an oversight/evaluation function provided by the International Joint Commission, a great deal of progress has been made.

Based on extensive data analyses and water body sensitivity to eutrophication, an in-lake water quality standard for ambient levels of total phosphorus was specified for eight portions of the Great Lakes (ranging from 0.005-0.015 mg/L of total phosphorus). Simple simulation models were utilized in the 1970s to establish lake-specific loading reductions needed to achieve these water quality objectives or standards. Actions to achieve these reductions consisted of a combination of strategies: implementation of phosphate detergent bans, effluent limitations of 1 mg/L total phosphorus from municipal sewage treatment plants discharging more than 1 million gallons per day, and targeted nonpoint source (NPS) abatement efforts.

The NPS programs rely mainly on best management practices installed on agricultural land. Lake-specific target loads for total phosphorus were established and incorporated into the Great Lakes Water Quality Agreement. For example, tributary loading to the Saginaw Bay portion of Lake Huron was to be reduced to 440 metric tons per year (mty). Lake Ontario was to be reduced to 7000 mty and Lake Erie to 11,000 mty. The allocation of reductions to meet the Lake Erie target was 1700 mty for the United States and 300 mty for Canada to achieve needed reductions in loading. These were designed to achieve acceptable biological communities as well as water quality (reduction of taste/odor problems and hypolimnetic oxygen depletion).

In order to provide for the long term ecological health of the lakes and to serve as a measure of success for these complex Agreement programs, lake ecosystem objectives (ecological standards) are being established (e.g., for oligotrophic waters of Lake Superior, a top predator of lake trout and a key food chain organism *Pontoporeia hoyi*; for lake trout, productivity greater than 0.38 kg/ha with stable, self-producing stocks free from contaminants at concentrations affecting the trout or quality of harvested products in the standard; the crustacean *Pontoporeia hoyi* must be maintained at levels of 220-320/meter^2 at depths less than 100 meters and 30-160/meter^2 at depths greater than 100 meters). For mesotrophic waters that have been eutrophic such as Green Bay, Saginaw Bay, and Lake Erie, the predatory walleye fish and the mayfly (*Hexagenia limbata*) have been recommended as these ecosystems' objectives (ecological standards).

Terminal predators also are being included in the approach. The bald eagle has recovered in the interior of the Great Lakes basin but not along the lakes. The food web and presence of toxic substances have kept it from recovering. Because the eagle eats fish and water birds, it is a terminal predator and when it recovers we will know that man has restored adequate water quality for this terminal predator and hopefully other organisms in the food chain. The International Joint Commission's Science Advisory Board has recommended

interim numbers of pairs of reproducing eagles for each lake based on historical data. The proposed standard would be 20 for Lake Ontario, 40 for Lakes Michigan and Erie, and 100 for Lakes Huron and Superior. It is now up to the United States and Canada to adopt these recommended numbers as official ecological objectives under the Great Lakes Water Quality Agreement.

Two other aspects of this success story were instrumental in achieving progress on eutrophication control and ecosystem restoration. First, deadlines were included in the Agreement to force action. Without milestone dates, even the most well-intentioned effort would become delayed. Second, these approaches were worked out over a number of years under the Agreement. The United States and Canada asked the International Joint Commission to serve as a facilitator as the two countries and ten states/provinces (which have to address Great Lakes/St. Lawrence River matters) come to grips with problems and implement consensus solutions. With its effort at facilitating consensus building and with its role as evaluator of progress, the International Joint Commission serves as a model for an independent body being established to facilitate different jurisdictions in solving water quality management problems and then undertaking evaluations of progress so that the loop is closed on accountability.

With the tripartite strategy of lake-specific standards for phosphorus, lake specific pollutant loading reductions and lake-specific ecological ambient standards with milestone dates—together with an independent body to help facilitate and then evaluate the effectiveness of actions taken—the Great Lakes are on the road to recovery from a very serious case of eutrophication.

3. Lake Champlain

An application in Vermont involving Lake Champlain illustrates how user survey data can be applied to state lake water quality standard setting. Lake Champlain (Figure 3) is a large interstate and international body of water with a drainage basin that includes nearly half of Vermont and large areas within New York and Quebec. Major uses of Lake Champlain include recreation, public water supply, and wastewater disposal. Recent statutory and policy changes in Vermont have created the need for numeric phosphorus concentration criteria for Lake Champlain in Vermont's water quality criteria.

User survey data obtained for Lake Champlain included over 500 individual user survey responses paired with total phosphorus measurements recorded over two summers. Mean summer total phosphorus concentrations in Lake Champlain vary spatially among the various lake segments shown in Figure 3: from 10 µg/L in Malletts Bay to greater than 40 µg/L in South Lake. Tabulation of the survey results (Figure 4) shows how the frequencies of the various user responses were related to the total phosphorus concentration.

Figure 4 shows that user descriptions such as "a little algae" and "very minor problems" predominate when total phosphorus concentrations are below about 25 µg/L. Above the 25 to 30 µg/L phosphorus interval, responses such as "definite algal greenness" and "use slightly impaired" are most commonly noted. More severe nuisance perceptions involving "high algae levels" and "enjoyment substantially reduced" also begin to become frequent as phosphorus levels increase above 25 µg/L. These results suggested that a total phosphorus concentration of 25 µg/L would be an appropriate nuisance criterion for Lake Champlain.

For reasons discussed earlier in this document (Section III), it was considered preferable to express a numeric phosphorus criterion for Lake Champlain as a seasonal mean concentration, rather than as an instantaneous "not to exceed" value. The instantaneous nuisance criterion of 25 µg/L derived from Figure 4 was therefore translated into a summer mean value based on the approach described in Walker (1985a). In making this translation, it was assumed that the instantaneous phosphorus value was an appropriate surrogate variable for

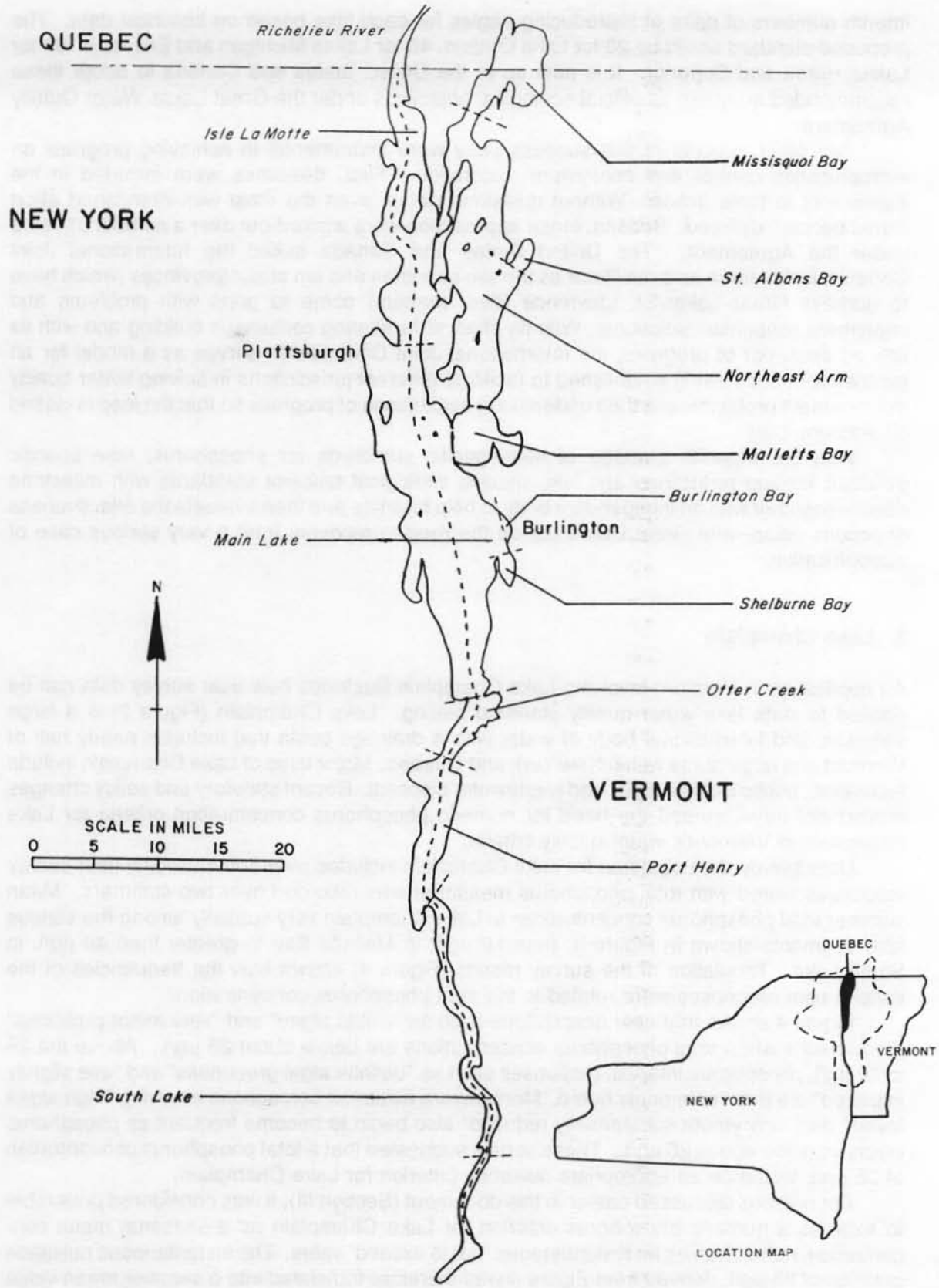
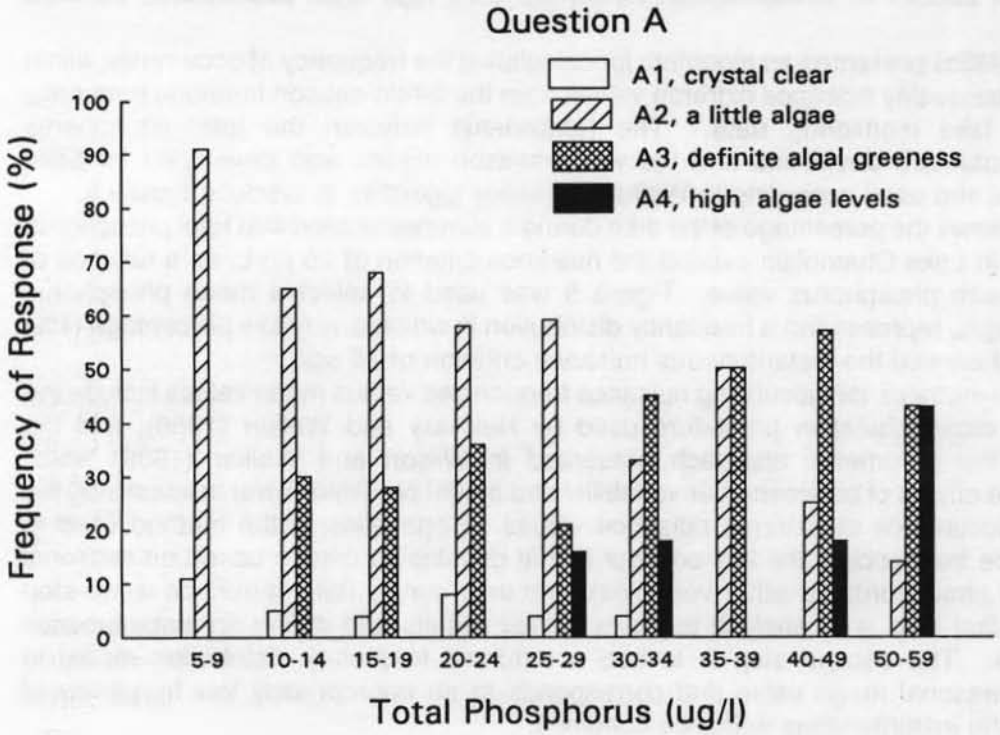


Figure 3. Map of Lake Champlain Segments.



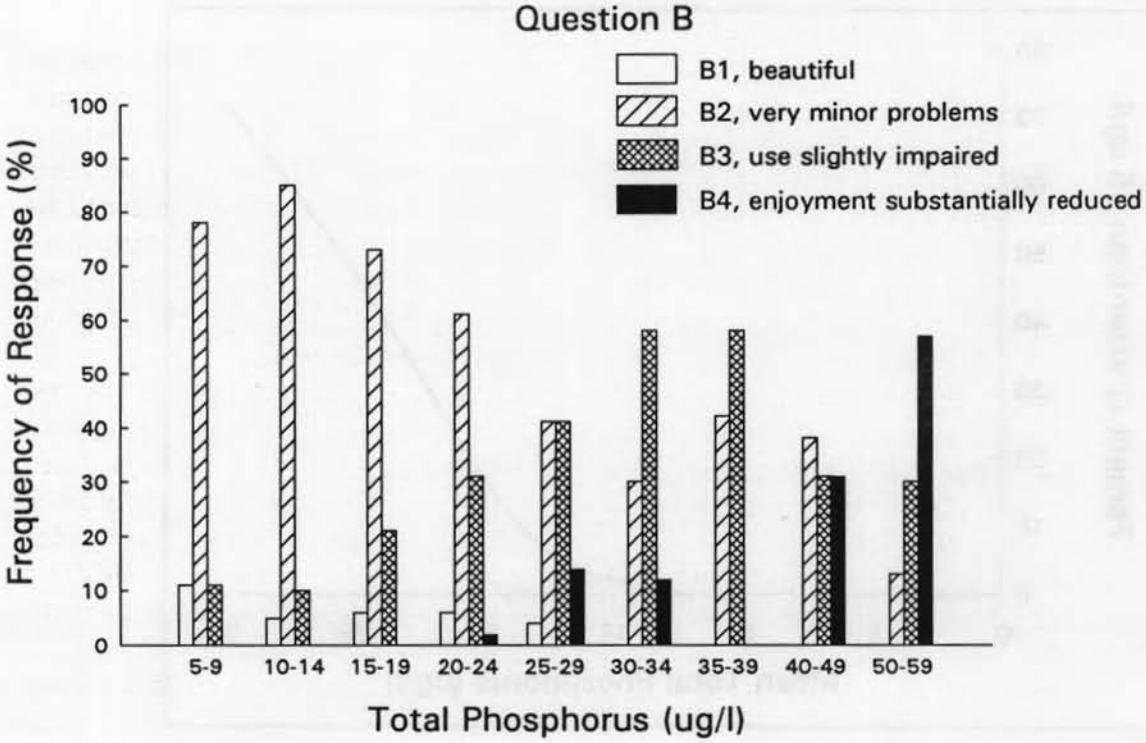


Figure 4. Relationship Between User Survey Response and Instantaneous Total Phosphorus Concentration in Lake Champlain.

the more direct causes of eutrophication nuisances (i.e., high algal populations, reduced transparency).

Walker (1985a) presented an algorithm for calculating the frequency of occurrence within a season of water quality nuisance extreme values from the within-season temporal frequency distribution of lake monitoring data. The relationship between the total phosphorus within-season standard deviations and the within-season means was developed for Lake Champlain data and used according to Walker's (1985a) algorithm to produce Figure 5.

Figure 5 shows the percentage of the time during a summer season that total phosphorus concentrations in Lake Champlain exceed the nuisance criterion of 25 µg/L, as a function of the summer mean phosphorus value. Figure 5 was used to select a mean phosphorus criterion of 14 µg/L, representing a frequency distribution in which a very low percentage (1%) of values would exceed the instantaneous nuisance criterion of 25 µg/L.

Alternative methods for calculating nuisance frequencies versus mean values include the nonparametric cross-tabulation procedure used by Heiskary and Walker (1988), and the refinement of the parametric approach presented in Wilson and Walker (1989) which incorporated the effects of between-year variability and model prediction error in assessing the probability of occurrence of extreme nuisance values. Regardless of the method used to assess nuisance frequencies, the key concept is that developing criteria based on seasonal means for total phosphorus (or other variables) from user survey data should be a two-step process. The first step is to analyze the user survey results and define an instantaneous nuisance value. The second step is to use a temporal frequency distribution model to calculate the seasonal mean value that corresponds to an appropriately low frequency of occurrence of the instantaneous nuisance condition.

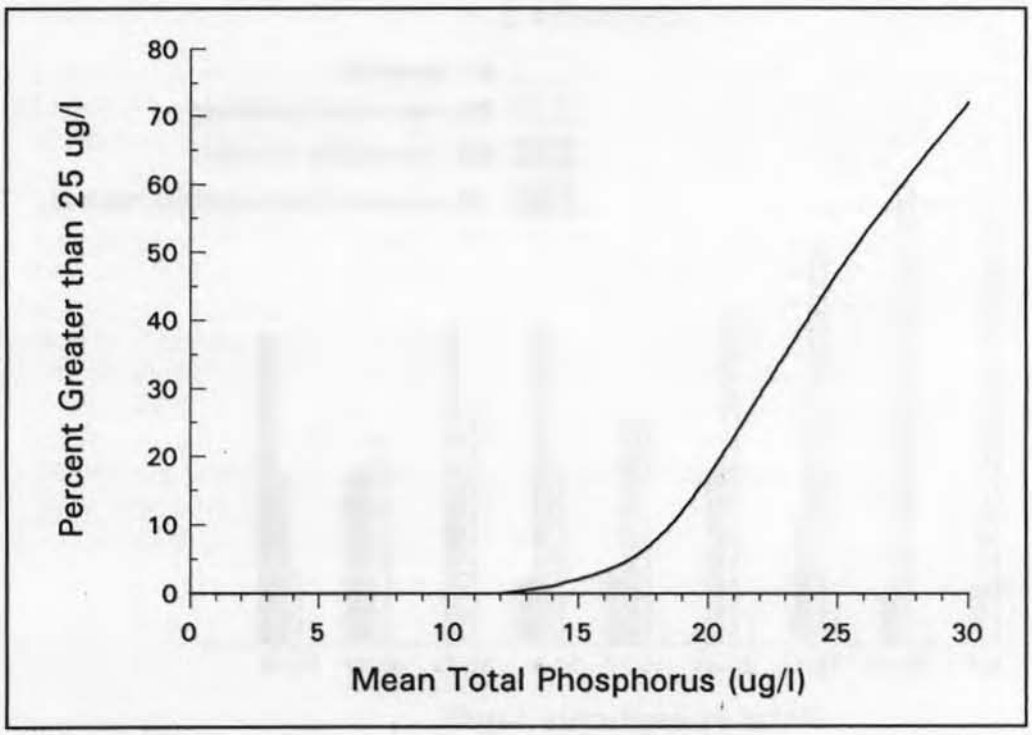


Figure 5. Percentage of the Time During the Summer During which Total Phosphorus Concentrations in Lake Champlain Exceed the 25 µg/L Instantaneous Nuisance Value Plotted versus the Summer Arithmetic Mean Total Phosphorus Value.

Based on the user survey results, a mean summer total phosphorus criterion of 14 µg/L was proposed by the Vermont Department of Environmental Conservation (1990) and by the Vermont Water Resources Board (the state's water quality standard-setting authority) as a numeric criterion for seven segments of Lake Champlain. This value was incorporated into Vermont's Water Quality Standards in 1991.

For certain other segments of Lake Champlain, it was necessary to modify the 14 µg/L criterion either upward or downward based on considerations discussed earlier in this document (Section V). The existing mean phosphorus concentrations in some areas of the lake are below 14 µg/L, and lower phosphorus criteria values were proposed for those segments to address anti-degradation concerns. Other segments of Lake Champlain are somewhat eutrophic naturally (based on segment and watershed characteristics) and there was doubt about whether the 14 µg/L value was realistically attainable. Higher criteria values were proposed for these areas.

4. Dillon Reservoir

Dillon Reservoir is a 25-year old reservoir located in Summit County, Colorado. Constructed as Denver's primary West Slope water supply, Dillon also quickly became a recreational center for fishing, camping, and boating. One of the reservoir's main attractions was its reputation for clear, deep blue water.

As this area became more popular and the watershed became increasingly more developed, water quality degradation became apparent with the onset of algal blooms. Studies of phosphorus loading to the reservoir revealed that approximately one-half of the phosphorus load came from natural sources, while the other half was from human activities including municipal wastewater effluent, parking lot runoff, construction site runoff, seepage from septic systems, and other nonpoint sources (Elmore et al. 1985).

The four municipal waste dischargers to the reservoir installed advanced treatment equipment to control phosphorus (less than 0.2 mg/L phosphorus discharged). However, since it was determined that existing nonpoint sources of phosphorus could still cause eutrophication, a phosphorus control strategy was developed.

Important elements of the strategy included point/nonpoint source education and the adoption of a total phosphorus standard specific to Dillon Reservoir. The standard was established after a two-year study of the reservoir. The historically good water quality and drinking water and recreational uses led to a fairly stringent in-lake phosphorus standard of 7.4 µg/L. This level was the same as the water quality measured in the reservoir back in 1982. The phosphorus standard served as a numerical basis for back-calculating the necessary load reductions to achieve the desired conditions or uses. The overall strategy required a "2-for-1 trading" between point and nonpoint sources of phosphorus, state-of-the-art controls (required by local governments) on new development in the watershed, and the use of National Pollutant Discharge Elimination System (NPDES) permits for enforcement when necessary.

VI. Data Needs and Acquisition of Data

A. Data Needs

In order to establish reasonable and defensible standards, measurements must be collected and analyzed on water quality, morphometry, and other water body characteristics. The amount and intensity of data collection may vary depending on the standard-setting approach taken. For example, Minnesota's ecoregion approach requires a greater amount of data gathering and synthesis than Virginia's nutrient enriched approach to initially establish a standard. However, data needs may increase substantially once a standard is in place and there is a need to determine if a waterbody is in compliance.

This section summarizes the types of data and information which may be needed to derive eutrophication standards for a particular geographic area or an individual lake or reservoir. Often, the data requirements will be the same for both lakes and reservoirs. This information is based on state agency opinions as surveyed by NALMS (1988), and the experience of state agencies who have or are currently developing eutrophication standards. A brief discussion on sampling strategies for obtaining this information also is included.

Crockett et al. (1989) provide a good discussion of the types of information needed to set criteria for water bodies. Although their work deals with Australian waters, many of the data needs also are applicable to North American lakes and reservoirs.

A wide variety of data was gathered prior to developing the phosphorus criteria for Minnesota's lakes (Heiskary and Wilson, 1988). The following list includes not only the types of information that went into developing the Minnesota phosphorus criteria but also the types of information which can be used for setting goals on individual lakes. The information needs outlined here may be applicable to lakes in other states and countries as well.

- Ecoregion: the area in which the lake and its watershed are located. If the lake is at or near an ecoregion boundary, assess which ecoregion is more appropriate for the lake based on information such as trophic status, morphometry, etc.
- Trophic characteristics: include mean summer epilimnetic (upper mixed layer) measures of total phosphorus (TP), chlorophyll *a*, and transparency. Other measures such as spring total phosphorus, total suspended solids, color, total nitrogen (TN), and TN:TP ratios also may be helpful.
- Morphometry: includes mean and maximum depth and surface area.
- Mixing status: characterizes whether the lake is dimictic (thermally stratified during summer), polymictic (does not stratify), or mixes intermittently (may stratify for short time periods during summer) on the basis of dissolved oxygen and temperature profiles or based upon morphometric characteristics.
- Watershed: includes total area and land use composition.
- Drainage type: characterize as drainage, seepage, inflow, reservoir, etc.
- Fishery or wildlife: identify the ecological and management classification(s).
- Macrophytes: includes general composition and species identification, and maximum depth and extent of coverage of lake basin.

- Most sensitive uses of the lake: identify whether the lake is a domestic water supply, supports a cold water fishery or is used for primary contact recreation. Document other uses as well.
- Lake user expectations for the lake: characterize through a survey or estimate based on regional uses and tendencies.
- Development in the shoreland area: identify the intensity of development and the Minnesota Department of Natural Resources classification (general, recreational, or natural).
- History of the lake and its watershed: historical information to answer questions such as: "Has the lake received wastewater effluent?," "Has extensive development occurred in the watershed?," or "Is the lake subject to severe water level fluctuations?," etc.

These are some basic data needs for developing eutrophication standards. All the approaches addressed in Section V were reviewed for their potential data needs for developing and implementing that approach. The results of that review are summarized in Table 2 in the Executive Summary.

B. Designing Monitoring Strategies

Collecting data is an important part of protecting water resources and developing standards. The amount of data assembled and intensity of sampling effort necessary for the development of eutrophication standards vary depending on the approach employed. For instance, the ecoregion/attainable trophic status approach used in Minnesota and the biological approach used by TVA both require more information on the states' resources than the nutrient-enriched approach used in Virginia or the nutrient-sensitive approach used in North Carolina prior to standards development.

Only 10 of 47 states currently characterize their ability to assess their lakes and reservoirs as "good," and 53 percent characterize their ability as "poor" (NALMS, 1988). The need for increased monitoring of lakes and reservoirs was noted by many state agencies at the U.S. EPA Water Quality Standards Conference in Dallas (U.S.EPA, 1989c). Clean Lakes Program Phase I grants may provide financial assistance when very detailed information is needed on a water body. When small amounts of data on many different lakes are required, Clean Lakes Program Lake Water Quality Assessment grants may provide financial support. In most cases, some type of sampling program will be needed before appropriate standards can be developed. Funding for this sampling may well be an issue or concern.

Numerous publications have addressed the issues involved in the design of sampling programs (e.g., Wedepohl et al. 1990). Some ideas and examples of programs designed for gathering data which can be used to develop standards are described below.

1. Lakes – "Ecoregion Approach"

Since 1985, the ecoregion framework has been used by the Minnesota Pollution Control Agency to design monitoring strategies and assess spatial trends in lake water quality. An important focus of the program has been the monitoring of "representative-minimally impacted" lakes in each ecoregion. Data from these minimally impacted lakes (or regional reference sites as they are referred to by Hughes et al. 1986) have proven extremely useful for examining intra-regional variability in trophic status and for characterizing the range in trophic status for different types of lakes in each region. The ecoregion approach also has been useful in

determining the effect of land use and lake morphometry on trophic status and in providing reference sites for trend assessment. Ultimately, this program serves as a basis for the development of realistic criteria for protecting water quality or for setting restoration goals. These applications are comparable to those proposed by Hughes and Larsen (1988) regarding the use of reference sites for estimating attainable conditions and setting biological and environmental criteria.

The characteristics that constitute a "representative-minimally impacted" lake will be different in different ecoregions. For example, in Minnesota's southern ecoregions, agricultural land use is predominant in the lake watersheds. In these southern ecoregions, "minimally impacted" simply suggests watersheds without major urban areas, known point sources, or major feedlots.

Whenever possible, representative-minimally impacted lakes are selected from the "most typical" portions of the ecoregions (Omernik, 1987). The following steps are followed to select "representative and minimally impacted" lakes:

- use existing data (e.g., 40 CFR 305(b) or Lake Water Quality Assessment reports) to assess range in morphometry, total phosphorus, and Secchi transparency readings for lakes in each ecoregion;
- select lakes believed to be "representative" of each region in terms of their morphometry and mixing status and that are relatively low in total phosphorus for that region (e.g., first or second quartile);
- use morphoedaphic index approach as reported by Vighi and Chiaudani (1985) to identify lakes that may be at or near their "background phosphorus concentration" (note that this approach may not be applicable in areas where "background" conditions are eutrophic);
- use range in drainage types (e.g., seepage, drainage, etc.);
- include representative fisheries (e.g., Northern Lakes and Forests ecoregion - lake trout, walleye, and bass-panfish fisheries are typical); and
- incorporate recommendations from Minnesota Department of Natural Resources area fishery offices as appropriate.

The water sampling program designed to collect the information necessary to implement the ecoregion approach focused on summer conditions. Sampling was generally conducted on at least two sites per lake on three or four dates between mid-June and mid-September. The following parameters were sampled and analyzed: phosphorus, nitrogen, chlorophyll *a*, Secchi transparency, general chemistry, and dissolved oxygen and temperature profiles. Additional data also were compiled on lake morphometry, watershed area, and land uses.

The above sampling plan may be applicable for many lakes and reservoirs. However, sample size and frequency and season(s) of sample collection adjustments may be necessary to adequately monitor the "growing season" or open water recreational season in a particular region.

2. Reservoirs - TVA Biological Approach

TVA has initiated an ambitious reservoir monitoring program in support of the development of a reservoir IBI (TVA, 1991). The monitoring program, referred to as "Vital Signs" Monitoring, collects data on the biological resources in several habitats in the 14 largest TVA reservoirs. Biological monitoring includes assessment of benthic macroinvertebrate communities, hydroacoustic estimates of fish abundance, fish community evaluation, and fish health

condition assessment. The program also includes sampling water and sediment for physical, chemical, and acute toxicity characteristics in the various zones of the reservoir; i.e., inflow, transition, and forebay (near the dam). Sediment samples are analyzed for metals, total and volatile suspended solids and particle size, and selected trace organics (organochlorine pesticides and PCBs). Water and sediment samples were screened for acute toxicity using response of light emitting bacteria and survival of the rotifer, *Brachionus calyciflorus*. In addition, historical data bases are being explored to provide insights into the ecological dynamics of reservoir and large rivers.

For more details on developing lake and reservoir monitoring strategies the reader is referred to the Lake and Reservoir Restoration Guidance Manual (Olem and Flock, 1990).

VII. Uses of Lake Standards

Eutrophication standards can be used to mitigate point source discharges, enforce anti-degradation, or establish goals for management or restoration and monitor water quality trends. The approach employed in development of standards depends on the water body and the intended use of the standards. In this section, the advantages and disadvantages of eutrophication standards are discussed. The various uses of standards are presented for the States of Minnesota, Virginia, Vermont, Maine, and the Province of British Columbia.

A. General Uses of Eutrophication Standards

Standards are employed differently in various states and provinces to protect or improve lake and reservoir resources. In NALMS' survey of the states, the question was asked: "For what purpose(s) are or might lake standards be used in your state?" The responses, as tabulated by Johnson (1989), are as follows:

PURPOSE(S)	NO. OF STATES RESPONDING	
	Existing Use	Potential Use
Enforcement	25	13
Permitting (NPDES)	27	15
Setting priorities	17	23
401 certifications	20	11
Establishing goals	14	22
Site new discharges	23	15
Managing cumulative impacts	12	28
Nonpoint regulatory controls	10	30
Watershed planning	14	28
Allocate lake restoration funds	7	31
Evaluate attainment of goals of	20	20

These survey results suggest that eutrophication standards are most frequently used for enforcement or permitting (NPDES, 401, etc.) activities. Many states also use standards to set priorities and goals, plan activities, and allocate lake restoration funds. The use of standards may even lead to more proactive lake and reservoir management.

B. Specific Examples

The following section describes how eutrophication standards are being used in Minnesota, Virginia, Vermont, Maine, and British Columbia.

Minnesota

Minnesota's phosphorus criteria have not proceeded through a formal rulemaking process. As such, they cannot be considered true "standards." However, these criteria play an important role in the protection and restoration of lake water quality in Minnesota. The criteria are being used with existing regulatory, management, and educational programs. Some examples of uses and applications of the criteria are itemized below.

1) Use in prioritizing and selecting projects to be funded through the Clean Water Partnership Program (Minn. Stat. section 115.091 to 115.103 (Supp. 1987)), and the federally funded Section 314 Clean Lakes and Section 319 Nonpoint Source Management Programs authorized by the Clean Water Act.

2) Use in developing water quality management plans. There are currently over 80 water management organizations in Minnesota preparing comprehensive local water management plans required or authorized under Minn. Stat. section 473.878 or Minn. Stat. chapter 110B.

3) Use as an educational tool for communicating what water quality expectations are reasonable for a given water body. In the case of degraded lakes, the criteria serve as reasonable targets or goals for restoration projects. The criteria also are frequently incorporated into the goal-setting portion of Lake Assessment Program studies (Heiskary, 1989).

4) Use in guiding enforcement decisions. These decisions are particularly important for protecting the quality of lakes and reservoirs currently at or below the criterion level.

5) Use in guiding the interpretations of nondegradation statutes.

Virginia

Upon review of historical water quality records, the Virginia Water Control Board (VWCB) designates "nutrient enriched waters" (Gregory, 1989). Once on this list, the VWCB implements their policy which requires certain municipal and industrial discharges to maintain monthly average total phosphorus concentrations of 2 mg/L or less. This limit is only applicable to dischargers that have a design flow greater than 1 MGD for permits issued before July 1, 1988. After July 1, 1988, this policy applies to any new discharges of 0.05 MGD or greater. Nonpoint sources of nutrients to the "nutrient enriched waters" are addressed through strategies developed by the Virginia Division of Soil and Waters.

The point source policy regulation states that after the point source controls are implemented and the effects of the policy and the nonpoint source control programs are evaluated, VWCB recognizes that it may be necessary to impose further limitations on discharges of nutrients. This policy is viewed as the first phase of a strategy to protect Virginia's waters from the effects of nutrient enrichment (Gregory, 1989).

Vermont

Vermont's phosphorus criteria are intended to guide a process of assimilative capability studies, modeling, and phosphorus load allocation; this is analogous to the approach used for phosphorus management in the Great Lakes (see Section V). Loading targets eventually will

be established among point and nonpoint phosphorus sources in a basin to attain the in-lake phosphorus criteria.

One of the greatest concerns that arose during the rulemaking process was the impact of numeric phosphorus criteria on the existing regulatory program. Proposed criteria were generally lower than existing phosphorus concentrations in Lake Champlain, and simple adoption of the criteria would create an immediate situation of noncompliance with state water quality standards. Discharge permits for the more than 50 wastewater treatment facilities in the Vermont portion of the Lake Champlain Basin would be in jeopardy if the criteria were directly enforceable against individual permit holders, including those with advanced phosphorus removal treatment in place.

To avoid this unreasonable situation, Vermont's new water quality standards for phosphorus in Lake Champlain include a provision for compliance with the criteria through compliance with an approved basin plan designed to achieve the in-lake criteria through an equitable and cost-effective allocation of loading reductions among all sources, both point and nonpoint. For example, the comprehensive basin plan might include a technology-based effluent limitation for all point source phosphorus discharges, with the remaining necessary loading reductions to be attained through specific nonpoint source control measures. Discharges in compliance with this plan would be considered in compliance with the state's water quality standards for permitting purposes, even if phosphorus levels in Lake Champlain continued to exceed the in-lake criteria as a result of as-yet-uncontrolled nonpoint or other sources.

In summary, the basin planning provision in Vermont's new phosphorus standards for Lake Champlain provided the necessary interface between the general goal of phosphorus reduction throughout the lake and the specific regulatory requirements of Vermont's discharge permitting program. The basin planning provision is intended to support a comprehensive process of loading allocation where the burden of phosphorus reduction is distributed fairly among all individual sources. Such a provision may be necessary to implement numeric phosphorus criteria in other large lake basins where eutrophication is the result of the cumulative impact of many diverse phosphorus sources, rather than a single, obvious, dominant source.

Maine

Maine's standard is useful as a watershed planning tool to guide future development of lightly developed watersheds. It is effective in a protection mode as long as the time baseline for addition of the allowable increment or phosphorus loading is firm and all new sources after this time are evaluated accordingly. In heavily developed watersheds where current trophic state is unacceptable and restoration is required, this standard provides little or no guidance. Since this situation is the exception rather than the rule in Maine, the standard's failure to guide restoration is of little consequence. Restoration is instead aimed at the goal of eliminating and preventing the recurrence of obnoxious blooms. Specific lake loading reduction goals are established on a lake-by-lake basis.

Maine's water quality standards also include a prohibition specifically addressing new nonpoint sources in lake watersheds. The statute states that "No change of land use in the watershed of a (lake) may, by itself or in combination with other activities, cause water quality degradation which would impair the characteristics or designated uses of downstream (lakes) or cause an increase in trophic state of those (lakes)." This provision by itself is not practically enforceable because: 1) the likely lag time in lake response to any incremental increase in phosphorus loading resulting from a single land use change, 2) the difficulty of identifying and characterizing such a trophic response, and 3) the difficulty of establishing a cause-and-effect relationship between one particular land use change amongst many, and the documented trophic response. Despite its limited value as an enforcement tool, it has substantial value in

guiding and supporting other efforts aimed at water quality protection. It establishes up front both the link between land use and water quality and a conservative goal for lake trophic change. This statute provides strong justification for local and state adoption of conservative performance standards and/or best management practices that specifically address phosphorus loading impacts in lake watersheds. It is used particularly in support of strict implementation of state mandated local shoreland zoning and subdivision review ordinances.

British Columbia

British Columbia's phosphorus criteria serve as a tool for protecting the most sensitive lake uses. These uses typically include drinking, cold water fishing, recreation, and aesthetics. The two primary applications of the criteria are:

1) to evaluate data on water, sediment, and biota for water quality assessments; and

2) to establish site-specific water quality objectives.

Water quality objectives serve as policy guidelines for resource managers in their mission to protect water uses in specified water bodies. Water quality objectives guide the resource manager in the evaluation of water quality; issuance of permits, licenses and orders; and management of fisheries and the watershed (McKean et al. 1987). They also provide a reference against which the water quality status in a particular water body can be monitored, and as a basis for making decisions on the initiation of basin-wide water quality studies. In many instances, the water quality objectives serve as the primary means of planning for the protection and evaluation of water quality (Ministry of Environment, 1985).

The Ministry of Environment (1985) promotes the criteria as a means of avoiding the need for costly and high precision loading studies. In contrast to accuracy needed to establish "critical" loadings in waste allocations, loading estimates in the context of water quality objectives are used only to determine relative contributions from various sources. The loading contribution estimates are then used to prioritize the importance of various inputs. In Okanagan Lake, where the water quality objective for the lake was the same as the 1985 phosphorus concentration (10 µg/L), the management strategy focused on maintaining present (1985) concentrations (Ministry of Environment, 1985). In this case, if increased "trading" from development and municipal effluent were to occur, then source reductions from the sources, e.g., agricultural sources or septic tanks, would need to be sought. This suggests that point/nonpoint source "trading" is among British Columbia's management tools to ensure that water quality objectives are met.

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