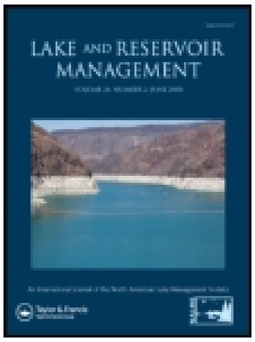

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NUTRIENT WATER QUALITY CRITERIA FOR LAKES IN BRITISH COLUMBIA

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ABSTRACT

A methodology has been developed to help protect lake water quality from degradation by nutrients. Criteria have been established which are keyed to protect the most sensitive water use of the lake. The categories of water use include aquatic life (including fisheries), recreation and aesthetics, drinking water, agricultural use, and industrial use. These criteria are the basis for more specific water quality objectives that are tailored to individual sites—either lakes or portions of lakes. Phosphorus concentration was chosen as the primary means of quantifying water quality, although nitrogen also can be used where it is the limiting nutrient. For phosphorus-limited lakes, the criteria used to protect drinking water and recreation are 10 μg/L total phosphorus. Criteria for fisheries and aquatic life differ according to important species. For example, for lakes with important salmonid fish resources, the criterion is a phosphorus concentration between 5 and 15 μg/L. For stratified lakes with important warmwater fisheries, a phosphorus concentration of 10–40 μg/L has been proposed. These criteria have been proposed specifically for British Columbia and may not be directly applicable to other areas.

INTRODUCTION

The problem of lake eutrophication has concerned limnologists, lake managers, and private citizens for many years. One tool that is available to assist with management of nutrients is the use of water quality criteria. Few systematic attempts at setting nutrient criteria have been made, despite the widespread use of criteria for dealing with other water quality problems, such as those caused by toxicants. Criteria can provide a point of comparison for evaluating different lakes for different uses or a comparison between lakes from different areas. Criteria can also provide the basis for site-specific water quality objectives to protect lakes from deterioration. It may be useful at this point to define criterion and objective as used in British Columbia (Pommen, 1984).

A criterion is defined as "a maximum and/or a minimum value for a physical, chemical, or biological characteristic of water, sediment or biota, which must not be exceeded to prevent specified detrimental effects from occurring to a water use under specified environmental conditions."

The criteria discussed here were conceived to be wide in scope and are based on three general areas: literature information, criteria which may exist from other jurisdictions, and evaluation of problems which exist or have existed in British Columbia (including a reading of public expectations for water quality). The term objective here refers to the application of a criterion to a site-specific location. The emphasis in this paper is on the criteria, with only some reference to objectives.

METHODS

The approach in British Columbia has been to establish criteria according to different water uses. Other jurisdictions have established single criteria for all uses (Robertson, 1982). The water uses British Columbia has defined are drinking water, protection of aquatic life, recreation and aesthetics, agriculture (livestock watering and irrigation), industrial use, and wildlife. In the first three uses nutrients are important, whereas the agricultural, industrial, and wildlife uses generally are not affected by use of water from eutrophied lakes unless the problem is severe or the needs special. The sequence for determining criteria is shown in Figure 1.

One *a priori* consideration for specific derivation of the criteria was to confirm the most suitable water quality characteristic for dealing with eutrophication. The obvious choice was total phosphorus concentration, but there were also reasons for considering water clarity, or algal biomass (chlorophyll *a*). Phosphorus concentration was used because there is now ample evidence in the literature that quantitative interrelationships exist between these measurements (Rast and Lee, 1978; Janus and Vollenweider, 1981). Other reasons include the use of phosphorus concentration in other criteria and the generally widespread acceptance of phosphorus as an index of eutrophication. It also appears advantageous to quantify the controlling parameter (nutrients) rather than the manifestations (algae or water clarity) (Lambou et al. 1983). Phosphorus loading has also been used to set criteria (U.S. Environ. Prot. Agency, 1976; Dep. Environ., 1972). Nitrogen limitation is a very rare occurrence in British Columbia's lakes, so no criteria were specified, although a method for deriving criterion concentrations for nitrogen has been described (Nordin, 1985).

Criterion for Drinking Water Supply

What was required was to determine a concentration of phosphorus below which no negative effects would be encountered when using a lake as a bulk supply of drinking water. Most utilities in British Columbia using lakes as sources have only minimal treatment (usually only chlorination) because of their generally good quality. A number of utilities, however, have been required to install additional treatment because of water quality deterioration. The difficulties are usually either excessive algae (if the intakes are shallow) or (if intakes are at depth) taste and odor caused by low dissolved oxygen, reduced iron, sulfur or manganese compounds, or increased amounts of taste- or odor-causing organic compounds. The criterion chosen was 10 μg/L, since it is the concentration at which problems with noticeable algae in surface water and hypolimnetic oxygen depletion begin to occur. Two other agencies, the International Joint Commission (1980) for Lake Ontario and part of Lake Erie and the Province of Ontario (1979), use 10 μg/L phosphorus as a criterion based on the assumption that 10 μg/L is a general threshold value for problems with hypolimnetic oxygen depletion. Bernhardt (1983) suggested that the desired trophic state for drinking water supply was oligotrophy (i.e., <10 μg/L). Mackenthun (1965) believed concentrations of inorganic phosphorus of 10 μg/L should be used as a goal to prevent algal blooms.

Criterion for Protection of Aquatic Life

Because of the range of organisms that might be considered, trying to protect the biological community as a whole is beyond our present understanding. Usually, the attention to lake biota has been directed toward protecting fish. The focus for fisheries in British Columbia is almost entirely on salmonid species, and the criterion was formulated primarily to protect salmonids.

One major change that has been found to cause a significant change in lake biota, particularly fish, is a reduction of hypolimnetic oxygen caused by increased nutrients. Generally, a change in the benthos community can be observed with the onset of even short-term anaerobiosis. Zooplankton vertical migration (and consequent growth, reproduction, and survival) are affected by low hypolimnetic oxygen. Fish can be affected by the change in food organisms (benthos, zooplankton), as well as be directly affected by loss of a summer cool water refuge from low oxygen concentrations. Hypolimnetic oxygen depletion has been noted as a cause of fish community change in the Grosser Ploner See (Morawa, 1958), and a combination of oxygen depletion and a related change in benthic food organisms caused substantial changes in fish communities in Lake Erie (Price, 1961; Britt, 1961). Bregazzi and Kennedy (1982) noted a steep decline in perch in response to eutrophication. Many examples of the effects of eutrophication on fish have been reviewed by Larkin and Northcote (1969) and Beeton (1969). The effects of the changing water quality of the Okanagan Lakes of British Columbia on fish are documented in Northcote et al. (1972).

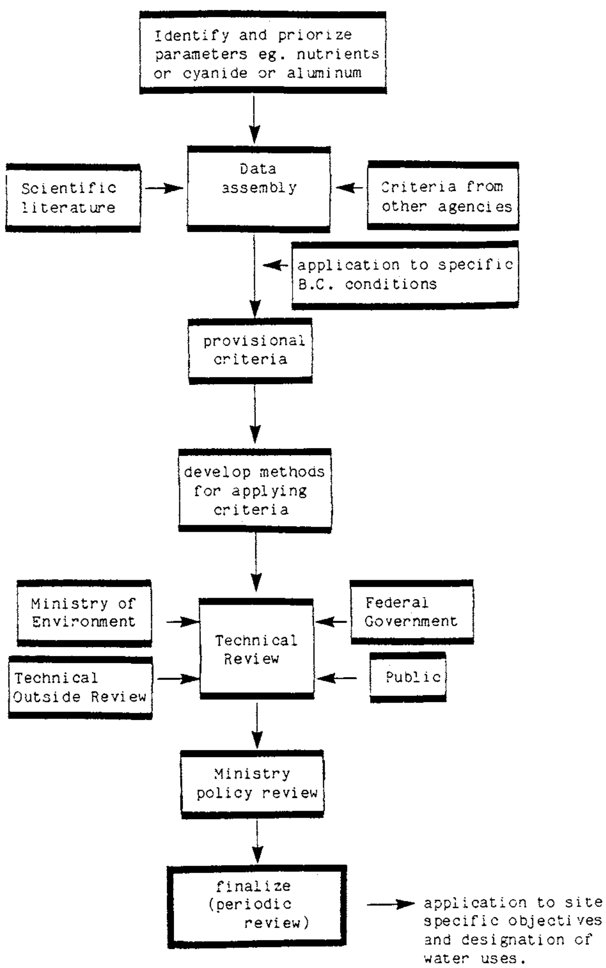

Figure 1.—Process for developing water quality criteria in British Columbia.

The concentration at which a change in oxygen depletion rate takes place is the significant transition from oligotrophy to mesotrophy—occurring at 10 μg/L. Some effort has been made to relate phosphorus to hypolimnetic oxygen depletion (Welch and Perkins, 1979; Rast and Lee, 1978; Rast et al. 1983). Because of the range of lake morphometry, however, hypolimnetic oxygen problems may be manifested at concentrations around this 10 μg/L. Lakes with large epilimnion to hypolimnion ratios, which are poorly flushed, are likely to be at considerably more risk than a large lake with a large, rapidly flushed hypolimnion. These lakes are likely to have different critical phosphorus limits that are related to the onset of hypolimnetic depletion. To take the range of morphology into account, the criterion is specified as a range. Even as a range, setting upper and lower limits is somewhat difficult. Many coastal British Columbia lakes are deficient in nutrients (3 μg/L), and enhancing fish production is accomplished by intentional fertilization with phosphorus and nitrogen (Stockner, 1981). Phosphorus application rates are generally a 50–80 percent increase over natural loading. Because of the low natural spring phosphorus concentrations (1–3 μg/L in many coastal lakes), a 50–80 percent increase does not raise the lake volume-weighted concentration more than 1 or 2 μg/L. However, this increase in phosphorus loading has significantly improved salmon production. Thus, it would appear that a minimum of 5 μg/L of total phosphorus would generally benefit salmon production. A concentration of 5–10 μg/L would be unlikely to stimulate any level of algal biomass which would detract from aesthetic or recreational values and would not interfere with any water supply system which used the lake as a source. The large hypolimnion as a percentage of total lake volume in the deeper of these lakes is a moderating factor reducing the tendency toward hypolimnetic oxygen depletion. The level of fisheries production in many ultra-oligotrophic British Columbia lakes is probably far below their potential because they lack nutrients. For an upper limit, 15 μg/L phosphorus was used since higher concentrations would present a significant risk for oxygen depletion even in large lakes.

British Columbia has an unusual range of nutrient problems. In some areas of the province, for example, the Okanagan Valley, the government is spending large amounts to remove nutrients from discharges to prevent deterioration of water quality. In other areas, it is making large expenditures to add nutrients to lakes and rivers to increase the algal production to benefit fish production.

Warmwater fisheries (e.g., bass) must be considered separately from salmonids. With species such as bass, hypolimnetic oxygen is of minor concern, since temperature preferences are higher and habitat requirements are different. For warmwater fish, a phosphorus concentration below 10 μg/L is likely to be undesirable, since the level of fish production would be quite low. Lake phosphorus concentrations up to 40 μg/L may be tolerable, depending on lake characteristics and the 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.

Criterion for Recreation and Aesthetics

For protection of water used for recreation and aesthetics, a number of previous criteria have been proposed. Ontario (1979) used 10 and 20 μg/L of total phosphorus during the ice-free period as criteria for lakes. It was felt that 10 μg/L provided a high level of protection against aesthetic deterioration. The 10 μg/L criterion would apply to lakes with natural concentrations of less than 10 μg/L. The 20 μg/L criterion was a more general one, intended to avoid nuisance concentrations of algae in lakes.

The International Joint Commission (1980) proposed total phosphorus objectives ranging from 5–15 μg/L, depending on the nature of the lake (e.g., 5 μg/L for Lake Superior and the main basin of Lake Huron, and 15 μg/L for western Lake Erie).

In considering a criterion for recreation and aesthetics, the trophic classification concept can also be used. A principal value of the trophic system is that it provides a basis for communicating the basic chemical and biological conditions of a lake. For instance, mesotrophic conveys a variety of lake characteristics, including water clarity, oxygen depletion, algal biomass, phosphorus concentration, etc. A transition from, for instance, oligotrophy to mesotrophy is generally associated with a number of significant changes (algal biomass, water clarity, oxygen depletion).

It should also be noted that the limnological terminology of oligotrophy, mesotrophy, and eutrophy carry with them synonyms of value judgement that are also used in a qualitative way: good, fair, and poor (Chapra and Dobson, 1981). Similar value judgements were used by Vollenweider (1968) in describing phosphorus loadings. He designated the oligotrophic and eutrophic loading rates "permissible" and "dangerous," respectively.

In gauging public perception in an informal way (no systematic surveys were done), a decided preference among those who use the lakes for swimming, sunbathing, or for general aesthetic enjoyment, seems to be high water clarity, which corresponds to the technical term "oligotrophy." Despite difficulties in gauging public perception, clarity is generally a major component of perceived water quality (Nicolson and Mace, 1975; Helfrich et al. 1982). Technical and public evaluation have been found to be very similar in one case (Bouwes and Schneider, 1979) and difficult to interpret in another case (Klessig and Bouwes, 1983).

On the basis of these data, the criterion that was recommended for lakes where the principal use was recreation and aesthetics is 10 μg/L.

Application of Criteria

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).

DISCUSSION

Problems arise in defining criteria in terms of water use because most lakes are multiple use and different water uses may have different criteria. The major difficulty is resolving the conflict between uses such as drinking water and recreation, which generally require low nutrient levels, and fisheries, which can benefit from a higher concentration (Wagner and Oglesby, 1984). This difficulty is addressed by designating a "most sensitive use" based on the judgment of resource managers and the value of the resources involved. If the lake has an important recreational use (criterion 10 μg/L) but also has an important warmwater fishery (criteria 10–40 μg/L), it might be managed for the more sensitive use (recreation) even though the warmwater fishery may be limited in its potential by lack of nutrients.

The criteria for nutrients which are proposed here are considered in the context of British Columbia only. They would not be appropriate or even acceptable in many other areas of the world. They reflect relatively stringent levels that are representative of the present water quality of the Province (Fig. 2). British Columbians appear to expect much "cleaner" water than might be expected in other areas of the world where degradation of water has been going on for a very long time, or where concentrations of nutrients are naturally very high because of geology, topography, or land use. Available literature contains many examples of higher acceptable concentrations in many areas of North America or Europe. For instance, the state of North Carolina has a chlorophyll *a* standard of 40 μg/L (Duda and Johnson, 1983). A point of contrast to the general intent of maintaining low nutrients and algal growth in surface water is shown by the situation in China. In China, most of the streams, rivers, ponds, and lakes are biologically extremely productive, since nutrient loading to Chinese surface waters is generally encouraged. The difference between British Columbia and China lies in the uses of fresh water. In British Columbia, water is used for drinking, agriculture, industry, fish production, and aesthetic and recreational purposes. For these multiple uses, it is advantageous to have the surface waters relatively pure, with low nutrient content. In China, fresh water is used primarily to produce food (i.e., fish), so high aquatic productivity is a priority (Francko and Wetzel, 1983).

Although the criteria concentrations may not be directly transferable, the approach to the subject can be adopted by other jurisdictions, and the numerical criteria can serve as points of discussion for other geographical areas.

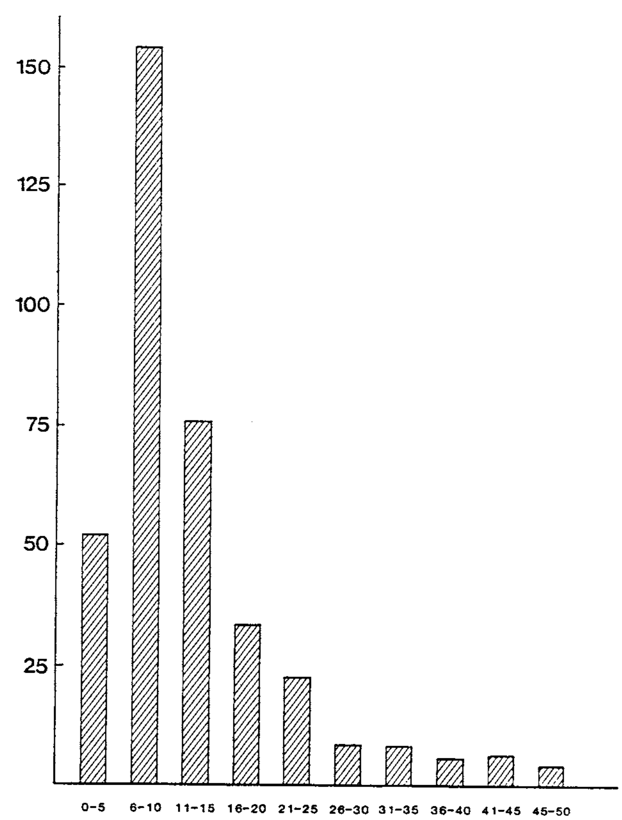

Figure 2.—Phosphorus concentrations in British Columbia. n = 400; X-axis is total phosphorus concentration; Y-axis is numbers of lakes.

REFERENCES

Beeton, A.M. 1969. Changes in the environment and biota of the Great Lakes. Pages 150-87 *in* Eutrophication: Causes, Consequences, Correctives. Nat. Acad. Sci., Washington, DC.

Bernhardt, H. 1983. Input control of nutrients by chemical and biological methods. Water Supply 1:187-206.

Bouwes, N.W., and R. Schneider. 1979. Procedures in estimating benefits of water quality change. Am. J. Agric. Econ. 61:535-9.

Bregazzi, P.R., and C.R. Kennedy. 1982. The responses of a perch *Perca fluviatilis* L. population to eutrophication and associated changes in fish fauna in a small lake. J. Fish. Biol. 20:21-31.

Britt, N.W. 1961. Extended limnological studies in Western Lake Erie sponsored by the Natural Resources Institute of the Ohio State University. Publ. 7. Great Lakes Res. Div., Univ. Michigan.

Chapra, S.C., and H.F.H. Dobson. 1981. Quantification of the lake trophic typologies of Naumann (surface water) and Thienemann (oxygen) with special reference to the Great Lakes. J. Great Lakes Res. 7:182-93.

Department of Environment. 1972. Guidelines for water quality; objectives and standards. Tech. Bull. No. 67. Inland Waters Branch, Ottawa.

Duda, A.M., and R.J. Johnson. 1983. Keys to water quality: Lake quality standards and point/nonpoint source abatement tradeoffs. Pages 62-8 *in* Lake Restoration, Protection and Management. Proc. 3rd annu. conf. N. Am. Lake Manage. Soc., Knoxville, TN. EPA 440/5-83-001. U.S. Environ. Prot. Agency, Washington DC.

Francko, D.A., and R.G. Wetzel. 1983. To Quench Our Thirst: The Present and Future Status of Freshwater Resources of the United States. Univ. Michigan Press, Ann Arbor.

Helfrich, L.A., M.B. Bain, D.L. Weigmann, and P.T. Bromley. 1982. Environmental perceptions and management preferences of lake property owners in Virginia. Va. J. Sci. 33: 26-35.

International Joint Commission. 1980. Report of the aquatic ecosystems objective committee. Great Lakes Sci. Adv. Board.

Janus, L.L., and R.A. Vollenweider. 1981. The OECD cooperative program on eutrophication. Canadian contrib. Natl. Water Res. Inst., Environ. Can., Burlington, Ontario.

Klessig, L.L., and N.W. Bouwes. 1983. Lake restoration criteria: the limnologists' view versus public perception. Pages 267-70 *in* Lake Restoration, Protection and Management. Proc. 3rd annu. conf. N. Am. Lake Manage. Soc., Knoxville, TN. EPA 440/5-83-001. U.S. Environ. Prot. Agency, Washington, DC.

Lambou, V.W., W.D. Taylor, S.C. Hern, and L.R. Williams. 1983. Comparisons of trophic state measurements. Water Res. 17: 1619-26.

Larkin, P.A., and T.G. Northcote. 1969. Fish as indicators of eutrophication. Pages 256-73 *in* Eutrophication: Causes Consequences, Correctives. Natl. Acad. Sci., Washington, DC.

Mackenthun, K.M. 1965. Nitrogen and phosphorus in water. U.S. Pub. Health Serv. Dep. Health Educ. Welfare.

Morawa, F.W.F. 1958. Einege Beobachtungen uber die Schwankungen des Fett und Wasserqehaltes von Fishen aus verschiedenen Umweltverhaltnissen. Verh. Int. Ver. Limnol. 13:770-5.

Nicolson, J.A., and A.C. Mace. 1975. Water quality perception by users; can it supplement objective water quality measures? Water Resour. Bull. 11: 1197-1207.

Nordin, R.N. 1985. Water quality criteria for nutrients and algae. Water Manage. Branch, Ministry Environ., Br. Columbia.

Northcote, T.G., T.G. Halsey, and S.J. MacDonald. 1972. Fish as indicators of water quality in the Okanagan Basin Lakes, British Columbia. Prelim. rep. no. 22. Okanagan Basin Study Comm.

Ontario. 1979. Rationale for the establishment of Ontario's Provincial water quality objectives. Ministry Environ.

Pommen, L.W. 1984. Principles for preparing water quality in British Columbia. Water Manage. Branch, Ministry Environ., Br. Columbia.

Price, J.W. 1961. Food habits of some Lake Erie fish. Publ. #7, Great Lakes Res. Div., Univ. Michigan.

Rast, W., and G.F. Lee. 1978. Summary analysis of the North American (U.S. portion) OECD eutrophication project. EPA-600/3-78-008. U.S. Environ. Prot. Agency, Corvallis, OR.

Rast, W., R.A. Jones, and G.F. Lee. 1983. Predictive capability of U.S. OECD phosphorus loading—eutrophication models. J. Water Pollut. Control Fed. 55: 990-1003.

Robertson, A. 1982. Water quality objectives for the Great Lakes. Pages 1177-81 *in* Oceans 1982 Conference, Washington, DC.

Stockner, J.G. 1981. White Lake fertilization for the enhancement of sockeye salmon (*Oncorhynchus nerka*) in British Columbia. Verh. Int. Verein. Limnol. 221: 293-9.

U.S. Environmental Protection Agency. 1976. Quality Criteria for Water. Washington, DC.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. DAS/CSI/68.27. Rep. Organ. Econ. Coop. Develop. Paris.

Wagner, K.J., and R.T. Oglesby. 1984. Incompatability of common lake management objectives. Pages 97-100 *in* Lake and Reservoir Management. Proc 3rd annu. conf. N. Am. Lake Manage. Soc. EPA-440/5-84-001. U.S. Environ. Prot. Agency, Washington, DC.

Welch, E.B., and M.A. Perkins. 1979. Oxygen deficit—phosphorus loading relation in lakes. J. Water Pollut. Control 51:2823-8.