CHAPTER 7

Nutrient Criteria Development

A. Introduction: Elements of Nutrient Criteria
B. Development of Ecoregional Nutrient Criteria
C. Development of State Nutrient Criteria
D. Using Criteria to Assess Water Resource Attainment

A. Elements of Nutrient Criteria

As presented in Chapter 1, five principal elements should be used to develop nutrient criteria. These five elements are summarized below.

1. Investigation of the Historical Record

Investigation of the historical record entails collecting and evaluating both anecdotal information and data sets relative to the lake and watershed of concern. This information may be gathered from long-standing residents of the area, local fishermen, and county, State, and Federal natural resource management and land use planning agencies. Academic institutions also are an excellent source of information; often, faculty will have extensive water quality or fishery information collected over several years as research or teaching projects. Occasionally, water supply authorities will have collected long-term historical data records such as phytoplankton composition or Secchi depth. In other instances, high-quality data sets may exist that are several decades old, such as the information collected by Birge and Juday on Wisconsin lakes. But most historical data are likely to consist of isolated observations on a small subset of lakes.

More recently, monitoring data may be available from volunteer monitoring organizations. Because these reports are not always common to routine literature reviews of published material, direct contact with the organizations may be necessary to obtain this information. The same applies to the many "gray literature" reports prepared by county, State, and Federal agencies.

Historical information, both quantitative and anecdotal, can be valuable, but it is often the most difficult to interpret. Nonetheless, it provides the investigator with a perspective on the relative quality of the resource over time. The principal difficulty is compatibility of methods used to collect historical data with current data collection methods and quality control. Although methodologies for water quality and basic limnology have not changed greatly in the past 25 years, all data must be carefully evaluated to determine if methodological biases would be introduced by combining historical and recent data to determine trends and historical reference conditions. Typically, the most compatible data are those that require the least sophisticated equipment to collect: Secchi transparency, total suspended solids, and algal species composition (phytoplankton, periphyton). Nutrient concentrations and chlorophyll concentration are sensitive to methodological changes, and biases are magnified if the measured concentrations are near or below the method detection limit.

EPA data sets on the STORET system are also available. In addition, the National Nutrient Criteria Program has information selected from STORET and augmented with additional State and academic information. In many instances, these data are of recent origin (e.g., since 1990), and a true historical perspective is not possible without the additional, older information. An illustration of the significance of this historical information is the lake database available in Wisconsin. The famous Birge and Juday studies extend back to the turn of the century, and in many cases, these monitoring data have been maintained by State or universities through the present. Such background information is invaluable in understanding the inherent nature of a particular system, and it lends the proper and accurate perspective necessary to distinguish natural from cultural enrichment. A good historical database is important for setting proper nutrient criteria and standards because it provides knowledge of what has happened before, what the normal natural trends are, what disruption humans have or have not caused, and what remediation efforts are possible.

2. Establishment of the Reference Condition

Present optimal lake conditions for an area must be reliably established (see Chapter 1). This is the other half of the lake assessment necessary for a responsible evaluation. The historical record described above tells the historical conditions for the lake or lakes of concern. The reference condition tells the best present status of those lakes. In some instances, conditions were much better in the past because of less development; the present reference condition reveals how much the system has declined. On the other hand, depending on how far back the historical record extends, it may be that the present reference condition is better. For example, compare the degradation of the cut-out-and-get-out era of logging in the early part of this century with the present-day forest reclamation and land management efforts. In this instance, we can be apprised of improving or declining trends in nutrient status over past performance.

3. Use of Models

Models that have been calibrated and verified can be used to extrapolate data to a projected nutrient condition where existing data are either insufficient or unavailable. Often this entails using data in a similar lake in the same region or making a reasoned projection, accompanied by a set of clearly stated assumptions, from data in one point in time to estimate conditions in the future. In some instances, surrogate information such as Secchi depth and chlorophyll *a* concentration can be used to estimate phosphorus concentration. Chapters 2 and 9 contain more information in this regard.

4. Expert Assessment of Information

Elements 1 through 3 are essentially data-gathering and data analysis processes. Elements 4 and 5 are interpretive processes because the information gathered should be assessed for veracity and application. To do so, each EPA Region has a Regional Technical Assistance Group (RTAG) of specialists to help the Agency and States establish the nutrient criteria for adoption into State water quality standards. RTAG members should be experts in limnology, water resource management, land resource management, and fisheries management as well as other appropriate specialties necessary to make an objective and exhaustive evaluation of the information. RTAGs are described in more detail in Chapter 1.

5. Attention to Downstream Effects

Before any criterion for any given class of lakes can be adopted, the potential impact on downstream waters must be considered. If the criteria do not provide for the attainment and maintenance of proximal downstream water quality, the criteria in question should be adjusted accordingly.

B. Development of Ecoregional Nutrient Criteria

1. Regional and Lake/Reservoir Type Classification

Initial efforts should deal with geographic classification. EPA has developed a national ecoregion-based classification system to initiate the process. The country has been divided into nutrient ecoregions using the initial EPA nutrient ecoregion map (see Figure 1.3). States and regions are encouraged to develop subregions within the 14 main nutrient ecoregions, as supported by new data evaluation. The subregions should be based on natural land forms and environmental characteristics such as soil type, parent material, slope, natural vegetative cover, climate, and hydrology, as opposed to cultural land uses.

The next step is to carry out physical classification procedures such as subdividing all lakes in the data set into similar classes, most commonly, lakes of similar size (e.g., 10 to 50 acres, 51 to 150 acres, 151 to 300 acres, and larger). Volume and retention time also should be used and are better related to likely biological responses in most nutrient loading models (see Chapters 6 and 9).

Once the system of physical classification has been established, data for all lakes or reservoirs in that class should be compiled and subsorted. EPA also is developing a nutrient database using STORET and other data sources that will be available as an initial data collection effort. This database will include information for TN, TP, chlorophyll *a*, and turbidity as the four main parameters, as well as other potentially relevant measures. EPA will use this database to support development of the ecoregional nutrient criteria. The database should be expanded by additional State, academic, and Federal information acquired from colleagues in the area. All data must be sorted for quality and applicability. Issues that should be addressed before incorporating a data set into the criteria development process (see also Chapter 4) include how carefully the samples were collected, from what season and locality the samples were taken (especially whether samples were taken from degraded or reference quality waters), how well analyzed the samples are, how well the sample locations were pinpointed, and how often the samples were replicated.

This physical classification process may reveal unique lakes or sets of lakes that defy the routine classification approach. Examples may include remarkably oligotrophic lakes perceived as exceptional natural resources, dystrophic or stained acid bog lakes that may have a separate biological response to enrichment, and lakes or reservoirs that are already intentionally overenriched. Each State or Tribe and EPA Region will have to address such conditions as most appropriate to that region, while still adhering to the objective of improving the trophic condition of those lakes by reducing cultural eutrophication.

2. Conversion of Ecoregional Data to a Reference Condition and Preliminary Nutrient Criteria

From metadata in the historical database, candidate reference sites (element 2) can be selected based on the location of the lakes and their relative lack of watershed development. This effort should divide all lakes (or reservoirs) into potential reference and potential test systems. The least developed systems should be candidate references. These sites should be visited and sampled to confirm their quality. It is important to recognize that seasonality must be accounted for, so the sampling and assessment process will take at least a year or two, and potential seasonal variability in the data should be assessed. (This is discussed in detail in Chapter 6.)

If data are scarce, modeling (element 3) may be necessary to help establish the reference condition (i.e., that compilation of reference site characteristics that best represents the optimal trophic condition for lakes or reservoirs of that class). Modeling, like paleolimnology, can be used in a weight-of-evidence approach to develop nutrient criteria, much like the frequency distribution approaches discussed in Section C (below), but the precision, accuracy, and suitability of the model(s) should be carefully assessed before deciding on this approach.

The RTAG then should assess the classification system and attendant data (elements 1-3) to establish the reference lakes and derived reference condition (element 4). This will involve selecting the appropriate cutoff point in the distribution of values for each set of reference lakes for each physical classification. These adjusted values becomes the candidate criteria.

The basic procedure described below is recommended to process available data to establish nutrient reference condition and subsequent nutrient criteria. This approach may be taken on a regional or State scale, and the sharing of data and reference condition information requires that a consistent methodology be employed. States may elect to use approaches distinct from the methods described in this manual, but such alternative approaches must be scientifically defensible and approved by EPA. They are not meant to be precluded from consideration simply because they are not described in this edition of the manual.

■ Data Compilation

Data should be compiled from STORET and other pertinent Government files as well as State, university, and other sources. All information should be reviewed and converted to the common database already established by the National Nutrient Criteria Program (specific information may be obtained from the EPA Regional Nutrient Coordinator or EPA Program Headquarters in Washington, DC).

Ideally, the data collection and compilation procedures used for classification and criteria development will be the same as those used for assessment purposes. However, it is recognized that at least initially the procedures may differ.

■ Data Reduction

Data reduction (from the data set that has been screened for impacted sites) should be conducted so that presumably most, if not all, data points remaining are candidate reference sites.

- If multiple data are recorded for a given site on the same date and are adjustable to a normal distribution, select the median value per station for each of the four primary variables of TP, TN, chlorophyll *a*, and Secchi depth (e.g., replicate samples or multidepth sampling). This equates multiple data from some stations with single grab samples at others.

- Where analytical results are reported as below detection limits and the method of analysis is an EPA-approved or “standard’ method, use the reported minimum detection limit to calculate the median value. If the median exceeds these minimum detection values, no further analysis is necessary. If any of the minimum detection limit values exceed the median, statistical methods applicable to censored data should be used.

- If indicated, separate data according to the season when the information was collected. In temperate regions, seasonal criteria may be needed.

- Compile a single seasonal median value for each given lake or reservoir from all median station values for that water body.

■ **Physical Classification**

Physical classification is based on the metadata provided in the data set for each lake within a given ecoregion or subecoregion. Area and depth can be used to establish a volume-based classification scheme. Unique systems should be separated out as distinct categories. Further subdivision may be done on the basis of watershed size if necessary. The process should be one of progressive subdivisions to smaller and smaller classes with less and less within-class variability. These classes then can be tested for statistically significant differences using analysis of variance techniques. This step may recombine some of the initial subdivisions so that an optimal set of lake classes results.

■ **Reference Condition Determination**

Reference condition determination can be based on a further review of the metadata to determine which lakes within a class have the least developed watersheds (e.g., perhaps 50 percent or more of the land area in natural vegetative cover, usually forested and with a fairly expansive area of the shoreline [perhaps 65 or 70 percent] undeveloped). These lakes then can be designated as reference sites and their median values for TP, TN, chlorophyll *a*, and Secchi depth arrayed respectively in a frequency distribution from higher to lower water quality. The upper 25th percentile then is selected as the ecoregional reference condition. When an adequate number of acceptable reference lakes is not available, the alternative is to use all of the data or take a random sample of what is available and use the lower 25th percentile as the ecoregional reference condition (see Figure 6.1 and accompanying text).

3. Refine Ecoregion Reference Condition Values

Newly collected data can be combined with existing information to refine the reference values for both the EPA regional reference conditions and the State or Tribal references as well. Grants/contracts may be awarded to States and Tribes via the regional coordinator to develop sufficient current databases, especially where information is lacking for particular water body types or geographic areas of the nutrient ecoregion.

4. Evaluation by Regional Teams to Establish Ecoregional Criteria

The RTAG obviously must incorporate all elements: history, reference condition, data models if employed, and downstream effects when establishing the ecoregional nutrient criteria. In doing so there are several key factors which should be noted:

■ **Reference Condition**

RTAGs will be asked to review the preliminary material described above and determine if the reference condition values are appropriate for the States in that EPA Region. Because RTAGs will include State agency members, regional or local concerns should be able to be addressed in a timely manner. The EPA National Nutrient Criteria Program data compilation and quality assurance procedures will help in the data sorting process. Headquarters also will award grants/contracts as needed to States to help fill in data gaps through the establishment of data collection programs.

■ Antidegradation

A critical requirement for the use of reference conditions associated with nutrient criteria is the EPA antidegradation policy, which protects against incremental deterioration of water bodies and reference conditions. An observed downward trend in the conditions of reference sites cannot be used to justify relaxing reference expectations, reference conditions, and the associated nutrient criteria. Once established, nutrient criteria should only be refined in a positive direction in response to improved conditions.

Without antidegradation safeguards, even the establishment of reference conditions and nutrient criteria could still allow for continual deterioration of water quality. For example, construction and development in watersheds containing lakes considered to be of excellent quality and which have been designated as reference lakes for a region could result in a degradation of nutrient levels and related variables and enhance eutrophication. If a number of the reference lakes in a region have suffered such deterioration, the reference conditions established from the set of reference lakes will have been degraded relative to their earlier state, and the comparative standard will have been lowered.

To combat this, the States should implement an effective antidegradation policy that promotes continually improving lake conditions. As an example, Maine has an antidegradation policy that requires that lakes remain stable or improve in trophic state (Courtemanch et al., 1989; NALMS, 1992). The RTAG should assume a comparable sense of antidegradation responsibility.

■ Establishing the Maximum Upper Limit of Eutrophication

The review of reference condition data, an understanding of regional nutrient dynamics, and the description from Chapters 1 and 2 of clearly over-enriched conditions should all contribute to a sense of just how much variation about the reference condition the RTAG should accept in establishing criteria.

The light-limited condition of *hypereutrophy* (TSI 70, TP of 0.1 mg L^{-1}) is characterized by dense algal and macrophyte communities and should be considered undesirable under all circumstances. It is recommended that no criterion ever be set higher than this value, regardless of designated use, unless it can be demonstrated that the natural reference condition is this high.

■ Designated Use

The States are expected to develop nutrient criteria to protect their designated uses. The EPA ecoregional criteria should be protective of at least most of these uses.

■ Endangered Species

In all instances, the EPA National Nutrient Criteria Program will strive to ensure that nutrient criteria are protective of any identified threatened or endangered species in involved waters. RTAGs also should keep this responsibility in mind as they evaluate proposed State/Tribal nutrient criteria. The RTAG should coordinate with the regional USFWS office to determine if any endangered species are involved. Where threatened or endangered species may be affected, the nutrient conditions appropriate to their support should be included in the criteria.

■ **Downstream Effects**

The final step in establishing the nutrient criteria is to assess the potential downstream effects (Section 131.10 (b) of the Clean Water Act) of setting a criterion for a given class of lakes. Will this level of nitrogen and phosphorus and attendant algae or turbidity levels when present in the water body have detrimental effects on the downstream receiving waters? Will it provide for the attainment and maintenance of water quality standards in these waters? Downstream receiving waters are considered to be those immediately below the lake or reservoir and within a few miles of it. The Nation's estuaries and coastal marine waters are ultimately the recipients of all discharges to surface waters and should benefit from such efforts, but the intent is to accomplish this indirectly by a sequential and cumulative improvement of our surface waters. For example, the Atlantic Ocean is eventually the beneficiary of lake enrichment improvements in the Cobbosee Lake Watershed in Maine, but the individual program manager need only worry about the downstream effects on the Kennebec River in setting nutrient criteria. The cumulative sequences of similar improvements progressing downstream are expected to help achieve coastal nutrient abatement.

Once the RTAG specialists agree and document their decision that no adverse effects will result and standards are met downstream, or that the downstream waters will be enhanced, then the tentative criteria can be adopted. However, if downstream waters are not adequately protected at the level of discharge associated with the proposed criteria, then that value should be adjusted accordingly. Loading estimation models will be helpful in making this judgment as will enlisting the assistance of managers associated with that downstream water body. It may be possible to coordinate management efforts and criteria to the benefit of both water resources and at a cost savings in management and monitoring by addressing conditions on both systems at the same time.

5. Examples of the Deliberation Associated with Development of a Nutrient Criterion

To help illustrate the role and responsibility of the RTAGs, an abbreviated hypothetical illustration of the reasoning applied to nutrient criteria development follows: Using the 33 µg/L TP reference condition as an example, this value can be evaluated against historical records for reference lakes. The reference condition of 33 µg/L suggests a gradual rise upward in ambient TP, from about 20 µg/L 100 years ago, with a projected further upward trend indicated by use of demographic, land use, and hydrological models. The RTAG therefore concludes that setting a criterion any higher than the present reference condition would eventually lead to an unacceptable trend in water quality degradation due to expected development increases. The group further determines that because many of the reference lakes are located in the upper reaches of larger watersheds, these nutrient levels are inherently lower than those in lakes and reservoirs further downstream. If the model projections are accurate, the downstream lakes also will be enriched, and any increased load implied by raising the criteria above reference levels will hasten their cultural eutrophication. The RTAG therefore concludes that it will be prudent to set the criterion at 28 µg/L TP.

Alternatively, the 33 µg/L reference condition is determined to represent very little change over time, suggesting a dynamic stability in the area. In fact, the historical record shows, and a paleolimnological study by a local college confirms, that matters were much worse just 50 years ago when postwar logging and land development efforts peaked in the area. Many farms are now reverting to woodlots, and much of the land is being purchased by the State for natural and recreational uses. The reference lakes are all much lower in nutrient loads because they were protected from development even 50 years ago. It is concluded by the RTAG that the criterion can be safely set at 37 µg/L, and when implemented, the lakes of the region will remain in their mesotrophic, recovered state. In fact, further reductions for the other lakes may be unlikely because of sediment releases of the phosphorus they originally received, while the demographic and loading projections strongly suggest that a manageable stability of between about 33 µg/L and 40 µg/L is very likely. Downstream waters will be unaffected by this action because ambient stream concentrations are presently in this range, and USFWS reports no endangered species in the area. Therefore, the specialists conclude that 37 µg/L is the appropriate criterion. We will use this hypothetical value as an illustration for the remainder of this chapter. (Keep in mind, however, that the alternative of 28 µg/L also is possible.)

Thus, the final derived ecoregional criteria for TP could be, depending on the circumstances, either the reference condition value of 33 µg/L, 28 µg/L, or 37 µg/L. The bracketed reference condition value in Figures 7.1, 7.2, and 7.3 shows this range of these hypothetical options.

State and Tribal nutrient criteria development can follow this same protocol described above except overall EPA ecoregional criteria should be used as a guide as States and Tribes establish their own nutrient criteria levels to protect designated uses.

C. Development of State Nutrient Criteria

EPA encourages States and Tribes to use the nutrient criteria technical guidance manuals and ecoregional nutrient criteria when developing their own nutrient criteria. EPA intends to issue the regional nutrient guidance under section 304(a) of the Clean Water Act (CWA). According to EPA's regulations, States/Tribes should establish their numeric water quality criteria values based on (1) EPA's section 304(a) guidance (in this case, the appropriate regional nutrient criteria), (2) EPA's 304(a) guidance modified to reflect site-specific conditions, or (3) other scientifically defensible methods. (See 40 CFR §131.11(b)(1).) If the State/Tribe has additional data that it believes justify adoption of a different value or set of values, the State/Tribe should be prepared to explain the site-specific conditions or scientifically defensible methods that make it reasonable to depart from the regional nutrient criteria guidance. If EPA approves the State's/Tribe's nutrient criteria, it becomes effective for the purposes of the CWA. If no action is taken by the State or Tribe involved, EPA may propose to promulgate criteria based on the regional values and best available supporting science at the time. These values then will be used as the nutrient criteria for that State or Tribe. It is important to note that although nutrient criteria may be new, the EPA–State criteria and standard process itself is already well established.

1. Designated Use

Section 303(c) of the CWA as amended (Public Law 92-500 [1972], 33 U.S.C. 1251, et seq.) requires all States to establish designated uses for their waters. EPA's interpretation of the CWA requires that wherever attainable, standards should provide for protection and propagation of fish, shellfish, and wildlife and provide for recreation in and on the water (section 101(a)). Other uses identified in the act include industrial, agricultural, and public water supply. However, no waters may be designated to be used as repositories for pollutants (see 40 CFR 131.10(a)). Each water body must have legally applicable criteria that protect and maintain the designated use of that water.

Changes in lake condition that begin to occur at points or in regions along the trophic continuum could be informative as States establish criteria to protect designated uses. Table 7.1 illustrates some use-related problems that tend to occur along the trophic spectrum for temperate U.S. lakes.

Also discussed below are general guidelines for developing criteria to protect selected designated uses. The values included here (and in Table 7.1) are *not* intended to represent proposed EPA or State ecoregional nutrient criteria. Rather, they illustrate ranges of parameters associated with the impairment of some traditional uses in some areas of the country. Criteria to protect these uses should be developed on a regional basis and should be consistent with EPA ecoregion criteria.

Table 7.1. Changes in Temperate Lake Attributes According to Trophic State (adapted from Carlson and Simpson, 1995)

TSI Value	SD (m)	TP (µg/L)	Attributes	Water Supply	Recreation	Fisheries
<30	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion			Salmonid fisheries dominate
30-40	8-4	6-12	Hypolimnia of shallower lakes may become anoxic			Salmonid fisheries in deep lakes
40-50	4-2	12-24	Mesotrophy: Water moderately clear but increasing probability of hypolimnetic anoxia during summer	Iron and manganese evident during the summer. THM precursors exceed 0.1 mg/L and turbidity >1 NTU		Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Iron, manganese, taste, and odor problems worsen		Warm-water fisheries only. Bass may be dominant
60-70	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems		Weeds, algal scums, and low transparency discourage swimming and boating	
70-80	0.25-0.5	96-192	Hypereutrophy (light limited). Dense algae and macrophytes			
>80	<0.25	192-384	Algal scums, few macrophytes			Rough fish dominate, summer fish kills possible

■ Outstanding Natural Resource Waters

Some waters of the State may require special criteria based on unique characteristics of that water body. Such characteristics might include undisturbed or unique watersheds that are markedly different from other watersheds in the State. In some States, naturally formed lakes are a rarity and may need to be protected by criteria different from those used for man-made lakes or reservoirs. Some lakes may include rare or endangered species of plants, invertebrates, or vertebrates that need to be protected. Such lakes are the very best of the reference set and are most in need of protection by rigid State and Tribal antidegradation policies and procedures.

■ Aquatic Life Uses

Aquatic life uses, including fisheries, are heavily dependent on the initial condition of the resource. Species will change as a function of trophic state, and it may be difficult to defend why one species is necessarily “better” than another. The use of reference lakes and their accompanying biota is one measure that can be used to predict the species that should be expected in a region.

Few taxonomic groups have been observed over the entire trophic spectrum. The best known are those that have been used as trophic state indicators because these are known to change with trophic state. Of these, perhaps the best, and oldest, indicators are the dipteran larvae of the family *Chironomidae*. The Chironomids were known to change drastically as a lake became anoxic, and one of the first distinctions between oligotrophic (oxic hypolimnia) and eutrophic (anoxic hypolimnia) was the shift from a domination by *Tanytarsus* to one by *Chironomus* (Thienemann, 1921).

Numerous algal groups also are known to change with trophic state. The dominance of blue-greens in eutrophic waters is perhaps the most notorious, but changes in diatoms are well documented, perhaps if their frustules remain in the sediments. The paleolimnological record can help in setting the aquatic life criterion. Macrophytic plants also are known to change in density, location, morphology, and species richness (see above).

Although our knowledge of the dynamics of change in the biota as a function of eutrophication requires further development, there is sufficient evidence to conclude that eutrophication will bring species changes. If a lake has an existing aquatic life use, then that use must be maintained. Eutrophication will cause some species to change in relative abundance and cause others to disappear; therefore, nutrient enrichment may be incompatible with the maintenance of a specific biota. The ultimate extension of this concept is in the use classification of outstanding natural resource waters.

Fisheries

Developing criteria to protect a specific fishery may be somewhat difficult because fish species in particular change as trophic state changes (Oglesby et al., 1987); therefore, different fishermen might be pleased or angry with each change in trophic state. For example, salmonids are dominant in waters with hypolimnetic oxygen but diminish as hypolimnetic anoxia develops (see Figure 5.2). This shift to a warm-water fishery may disappoint lake trout fishermen but delight walleye or perch fishermen. Carp and bullheads, which dominate the hypereutrophic waters, also have their advocates. It may be that criteria to protect specific designated uses could be established at the points of transition between dominant fish groups. Based on the work of Oglesby et al. (1987), the following general values (based on the available hypolimnetic dissolved oxygen response) might be suggested:

TSI Range	TP Concentration	Aquatic Life
<TSI 40-50	TP = <24 µg/L	Salmonid fishery
TSI 50-60	TP = 24-48 µg/L	Percid fishery
TSI 60-80	TP = 48-192 µg/L	Centrarchid fishery
>TSI 70-80	TP = >192 µg/L	Cyprinid fishery

Such a fishery categorization may present problems because some warm-water fisheries would thrive in waters falling below the reference condition (i.e., 50 TSI). However, consultation with fisheries managers and the public through the water quality standards review process should help resolve the issue of robust fish in otherwise overenriched waters.

Drinking Water

Only in the past decade have we come to a full realization of the effect of eutrophication on drinking water (Cooke and Carlson, 1989). For years, the drinking water industry has recognized the effect of certain species of algae on taste and odor. However, trihalomethanes and other chlorinated byproducts also become connected with the effects of eutrophication (Palmstrom et al., 1988). It is now recognized that as a lake eutrophies, the species of algae will shift to those that affect taste and odor; these species will increase in density and increasingly affect the raw water quality. Turbidity will increase as the algae become more dense. The need to chlorinate then increases, and thus chlorination byproducts will increase as algae increase. Hypolimnetic anoxia will also increase the problems of iron and manganese control.

The reality is that drinking water plants must deliver a safe and potable product. As the effects of eutrophication are seen in the raw water, the cost of treatment increases. Unfiltered systems must give way to filtered water, then powdered carbon, and finally activated carbon. The run times of filters and of GAC filters decrease with increased algal densities. In short, eutrophication dramatically changes the cost and even the treatment process itself.

Several points along the trophic state continuum are relevant for drinking water supplies. The first is at a trophic state index (TSI) of 40 to 50, when the hypolimnion becomes anoxic. This is when iron and manganese problems would first be evident. At a TSI of 50, the turbidity of the water might be expected to exceed 1 NTU, and filtration of the raw water would become necessary. It is at a TSI of 50 that Arruda (1988) found that trihalomethane concentrations in the finished water exceed 100 mg/L in some Kansas treatment plants. Therefore, it is at this trophic state that extra measures or changes in the treatment process are necessary to control taste and odor without increasing the chlorine dose.

Recreation

Swimming/Primary Contact Recreation. Criteria to protect a contact recreation use may be associated with the occurrence (or appearance) of certain phenomena that affect certain types of recreation. For example, in general, swimmers will not be affected by the trophic state of the lake, but resulting changes in transparency or change in species may be important. Some States and countries have prohibitions on swimming based on the depth from which a body can be seen on the bottom. This consideration is based on the possibility of seeing a drowning child. New Zealand has a swimming prohibition on transparencies of less than 1.5 m (Smith et al., 1991), and several States have prohibitions based on transparencies of 2 or 3 feet. These transparencies would be equivalent to a TSI value of approximately 60, which, if transparency is related to phosphorus, would be equivalent to a TP value of 45 to 50 µg/L. The density or frequency of algal scums also might discourage swimming. Because scums are often the result of dense populations of blue-green algae, then their frequency and density might be expected to increase as a lake becomes enriched. Excess nutrients feed not only nuisance algae growth, but potentially health-endangering bacteria, especially when human and animal waste may be involved.

Boating and Secondary Contact Recreation.. It might be expected that the transparency of the water or the presence of algal scums would not deter boating, unless water skiing were involved. However, boating may be affected by the presence of dense beds of tall or floating macrophytes. Little research has been done on the relationship of macrophyte type and trophic state, but a paper by Swindale and Curtis (1957) suggests that the dominant taller plant forms increased as the conductivity of Wisconsin lakes increased. Because conductivity has been related to the background levels of nutrients in the water, a rough approximation would suggest that the trophic state where taller plants predominate would have a transparency of approximately 0.5 m, or a TSI of 70 (TP = 98 µg/L).

2. Hypothetical Illustration of the Relationship of State Criteria to Protect Designated Uses Compared With an Ecoregional Criterion for TP

In this hypothetical illustration (not applicable to any specific region), TP has been evaluated by EPA regional and Headquarters specialists for all reference lakes of a given class in the EPA nutrient program data set for a particular nutrient ecoregion or subregion. The distribution of the data has been assessed, and the upper 25th percentile of this distribution has been chosen as the ecoregional reference condition for TP (Figure 7.1). In this illustration, the upper 25th percentile is 33 µg/L, and the RTAG has developed the criterion of 37 µg/L TP as described in Section B above.

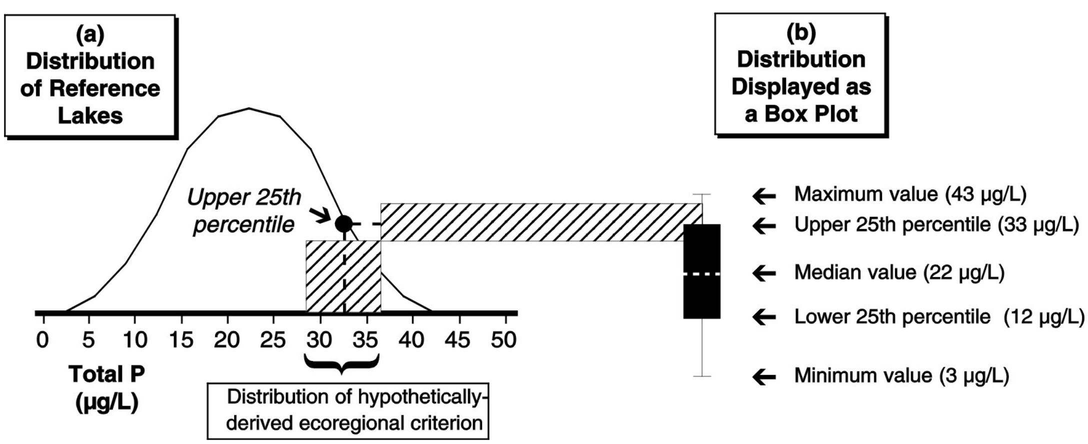

Figure 7.1. Development of a hypothetical ecoregional reference condition for TP from an ecoregion data set of reference lakes.

Calculations of these ecoregional criteria are done by the EPA National Nutrient Criteria Program in conjunction with the appropriate EPA RTAGs. The supporting data are obtained from Federal, State, and academic agencies and institutions in the region; all of these data become part of the national nutrient database. In establishing these regional criteria, EPA relies on the same five elements of criteria development described earlier for State and Tribal use (e.g., historical records, present reference site data, models if appropriate, regional expert interpretations, and consideration for downstream impacts).

The ecoregional criteria described in this manual are expected to be in part predicated on reference condition data gathered from at least high and low flow conditions, if not from year-round data. This is to make the process as straightforward and simple as possible while having consistent application of the methodology to all parts of the country, even those with seasonal variation.

However, it is evident that this approach may create a windfall gap between the criteria values and seasonally selected measurements in some localities. This would be analogous to conducting a perk test for a septic system in mid-August, which would have little bearing on the performance of the system during rainy April weather. States correct for this problem by setting their required test infiltration rates on a seasonal basis. Similarly, when large seasonal disparities exist in the reference data, the RTAG should develop two or more seasonal criteria instead of using an average criterion for each variable. One of these seasonal criteria should be for the growing season in that region.

Sampling to evaluate water body attainment with the subsequent standards employing these criteria will have to be carefully defined to ensure that State or Tribal sampling is compatible with the procedures used to establish the criteria. If State or Tribal observations are averaged over the year, balanced sampling is essential and the average should not exceed the criterion. In addition, to account for inherent variability, no more than 10 percent of the observations contributing to that average value should exceed the criterion (see also section D below).

Once an ecoregional criterion has been established and is subject to periodic review and calibration, any State or Tribe in the region may elect to use it as the basis to develop its own criteria to protect designated uses for each class of lakes in the State. This is entirely appropriate so long as the criterion is at least as protective as the basic EPA criterion for that region. This ecoregional criterion represents EPA's "304(a)" recommendation for protection of aquatic life use and is the value EPA would propose to promulgate in the absence of State or Tribal criteria.

Using this initial benchmark, the State or Tribe may proceed to classify its lakes first by size and other physical characteristics, and then further subclassify them by designated uses, e.g., criteria to protect large lakes and salmonids in a particular ecoregion or subecoregion. For each designated use class within the physical classifications, a set of reference lakes are again identified and the range of their TP concentrations plotted (from low to high), just done for the EPA regional criteria calculations. In this instance, the State may, if the data are known to be from all high-quality lakes, select an upper percentile (upper 25th percentile is recommended) of the distribution as the candidate criterion. If reference lakes are not available and the overall distribution of the lakes or a sample of the lakes is used instead, then the percentile should be selected from the lower end of the distribution (lower 25th percentile is recommended). The reader should bear in mind that the reference condition alone does not constitute the State criterion. It must be objectively assessed within an historical perspective and address downstream conditions before the criterion value is finally established.

3. Frequency Distribution Approach

The common characteristic of the frequency distribution approach is that it is data dependent. Usually, goals or criteria will be based on the data of the lakes themselves. This allows the construction of criteria based on the actual situation for the individual State or region. The establishment of nutrient criteria (much like establishing grades to reflect performance in education) requires both basic values or thresholds of expected accomplishment as well as sufficient flexibility to accommodate the uniqueness of each class. In this way, optimum performance is attained and the desired goal is reached.

The grading process, based on an accepted standard of performance (e.g., 75 percent is a passing grade), is analogous to the EPA ecoregional criteria derived from the best information available from existing reference lakes, paleolimnology, historical information and data sets, and appropriate models, as well as RTAG judgment and downstream consideration. Conversely, establishing criteria for each designated aquatic life use in this manner compares to "grading on the curve," where the data characteristics of each use set the curve.

The EPA regional criterion means that a minimum expectation is established to prevent any decline in performance. But above the "passing grade," the individual State or Tribe may develop its own criteria in accordance with the characteristics and designated use classification of its lakes. In Figure 7.3, most of the designated use criteria meet or exceed the passing grade.

Figure 7.2 is a hypothetical illustration of TP criteria developed for select designated use categories for an overall distribution of specific-sized lakes. The 37 µg/L TP criterion is derived from the approach illustrated in Chapter 6 (see Figure 6.1) and the example of RTAG deliberations presented earlier in this chapter. Thus, for this example:

- Boating TP criterion = 40 µg/L
- Warm-water fishing TP criterion = 30 µg/L
- Cold-water fishing TP criterion = 24 µg/L
- Exceptional natural resource lake TP criterion = 10 µg/L

When this process is completed, Figure 7.2 can be simplified to show a series of criteria based first on the common physical similarity of the water bodies (they are in the same classification, e.g., same ecoregion, size range, and average depth) and next on their subclassification by designated uses (Figure 7.3).

D. Developing Nutrient Criteria Implementation Procedures

However done, a State's or Tribe's nutrient criteria should include a procedural protocol to implement the newly adopted nutrient criteria. The criteria and procedures should be reviewed by the RTAGs for concurrence and are subject to further EPA review and approval if submitted as part of State or Tribal standards.

The four initial criteria variables include two causal variables (TN and TP) and two response variables (chlorophyll *a* and Secchi depth or a similar indicator of turbidity). Failure to meet either of the causal criteria should be sufficient to indicate a criteria "excursion," and usually the biological response, as measured by chlorophyll *a* and Secchi depth, will follow this nutrient trend. However, if the causal criteria are met but some combination of response criteria is not met, then there should be some

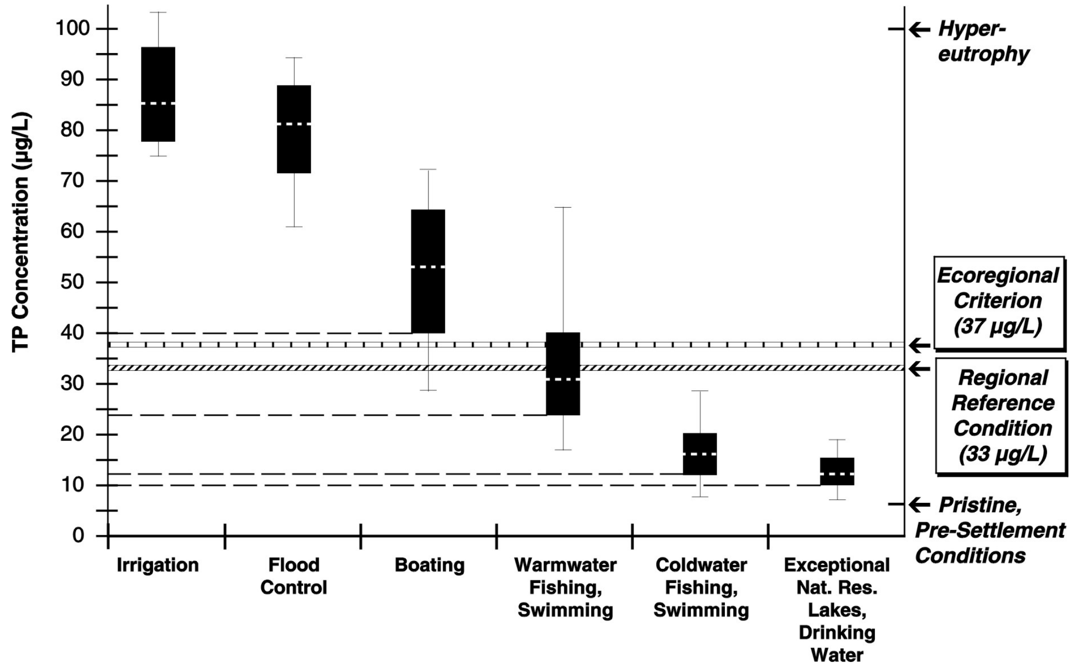

Figure 7.2. Development of TP criteria for select designated uses relative to the reference condition and ecoregional criterion for lakes of a specific size class.

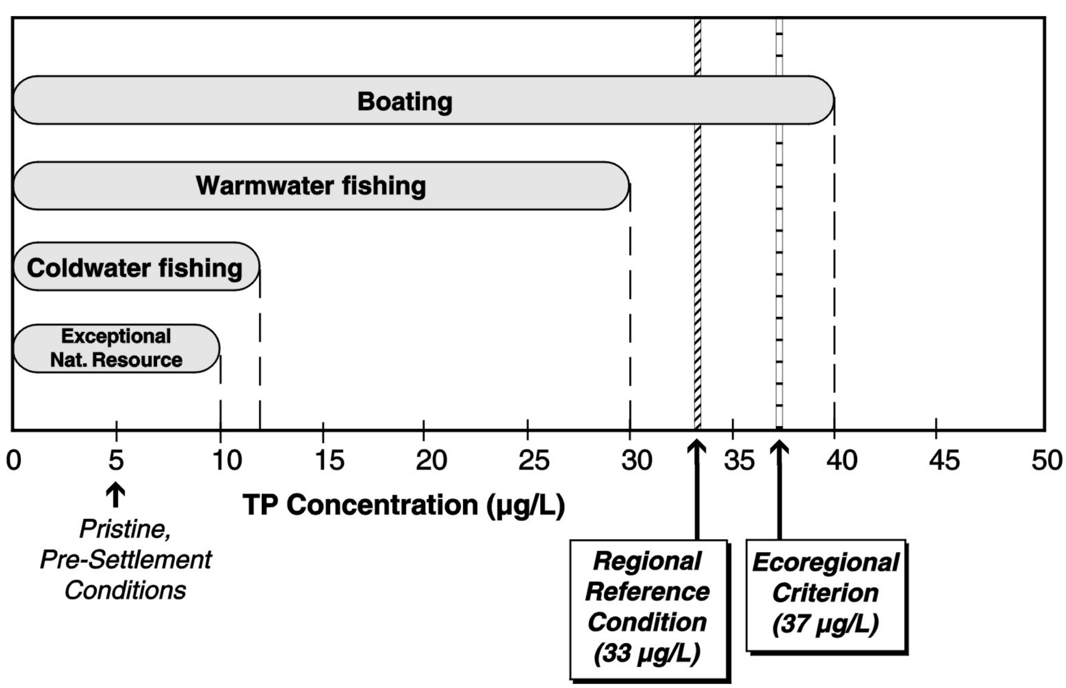

Figure 7.3. Simplified display of TP criteria for select designated uses in a specific size class.

means of determining if the lake in question meets the nutrient criteria. Two suggested approaches are described below.

1. Decisionmaking Protocol

One option is to establish a decisionmaking procedure equating all of the criteria. Such a rule might state: "Both TN and TP causal nutrient criteria must be met, and at least three out of five response criteria (e.g., chlorophyll *a*, turbidity, algal biomass, DO, macrophytes) must be met for three out of four sampling events during the June through August survey period over 2 consecutive calendar years of sampling. No sampling events may be less than 3 weeks apart [to avoid clustering sampling activities near a particular flow condition or runoff event], and flow conditions must be recorded as well so that watershed base flow and runoff events are evident and can be factored into the data assessment process."

2. Multivariable Enrichment Index

The second option is to establish an index that accomplishes the same result by inserting the data into an equation that relates the multiple variables in a nondimensional comprehensive score much the same way an index of biotic integrity (Karr, 1981) does. An example of an enrichment index approach is presented in Table 7.2.

Table 7.2. Example of an Enrichment Index Using a Hypothetical Lake

		Hypothetical Lake	
Variable	**Criterion**	**Mean Measured Value**	**Enrichment Index (EI) Score***
Causal variables			
Total P (mg/L)	≤0.020	0.048	5
Total N (mg/L)	≤0.250	0.502	5
Primary response variables			
Secchi depth (M)	≥1.0	0.6	3
Chlorophyll *a* (mg/L)	≤20	30	5
Macrophytes (% of phototrophic zone)	≤25	52	5
Algae (% blue-greens of spp. composition)	≤25	75	5
Secondary response variables			
Dissolved oxygen (mg/L in hypolimnion)	≥6.0	3.5	3
Fish kills (no in last 5 yr)	0	2	5
		Enrichment Index Value: = 36**	

* Each of the eight variables receives an EI score. The scoring procedure is: 0 = meets criterion; 2 = fails to meet criterion by 10%; 3 = fails to meet criterion by 25%; 5 = fails to meet criterion by 50% or more.
** Enrichment Index Value is the sum of the EI scores. The maximum score achievable is 40.

If necessary, the scoring process can be weighted by seasons. Thus, different emphasis can be given to the results of winter surveys as compared with summer surveys, and year-round work can be conducted if necessary or desired. For example, greater weight perhaps by a factor of 2 could be given to the primary response variables in winter for north temperate lakes because these variables would normally be expected to be improved at this time of year. Similarly, the criteria for TP and TN might both be changed to lower concentrations for winter because less runoff or fewer fertilizer applications are expected. In the example, the lake fails anyway because it failed the criterion for either TP or TN (in fact it failed both). With a score of 36 out of a possible 40, it is also a prime candidate for extensive remediation management.

Such enrichment index scores are not intended at this time to be surrogate nutrient criteria. They may, however, serve as a "translator" to implement multiparameter criteria. However, like biological criteria index scores such as the Index of Biotic Integrity, the enrichment index may be a useful assessment tool. The merit of the index approach is that all lakes of a given classification can be rank ordered by score. This helps the resource manager plan the distribution of effort and funds over the entire resource base in one procedure.

E. Frequency and Duration

Frequency and duration are important concerns when evaluating any lake with respect to meeting criteria. This is a difficult process at this initial phase of the program because the data sources for criteria development are presently so diverse. In general, however, the method of data gathering for compliance should be as near as possible to that used to establish the criteria. Once this consistency is established, excursions from the criteria based on frequency and duration can be evaluated whether based on a decision rule or a multivariable index.

Frequency of "excursion" from a criterion is a decision that can be best established by the State or Tribe on the basis of their knowledge of the local water resources. An excursion that occurs less than 10 percent of the times when sampling is conducted (at regularly spaced or random intervals) may be considered acceptable. Duration of the excursion may be stipulated as a set period of time (e.g., 2 weeks, or as to not exist over more than two consecutive sampling intervals, whichever is the lesser period). The State or Tribe in consultation with EPA will need to specifically define these terms as appropriate to the region and should also determine the combination of these factors that constitutes an "excursion."

Unique Aspects of Criteria Development for Reservoirs

Reservoirs are important and effective traps of nutrients and sediments (e.g., Kennedy 1999, Straškraba et al., 1995). As such, they are often significant in the regulation of the material budgets of entire drainage basins. The potential importance of total phosphorus retention by reservoirs and its modifying influence on riverine nutrient budgets are demonstrated by water quality data for a three-reservoir cascade on the White River in northwestern Arkansas and southern Missouri. The three CE reservoirs, Beaver Lake, Table Rock Lake, and Bull Shoals Lake, exhibit differing water residence times and phosphorus retention rates, and, despite their close proximity on the same river, receive inflows with markedly different total phosphorus concentrations due to variations in loads from point and nonpoint sources (Figure 1). Beaver Lake receives inflows with relatively high total phosphorus concentrations, owing to agricultural land uses, but retains approximately 74% of the phosphorus load and releases water with markedly reduced total phosphorus concentrations. Upstream reaches of the reservoir exhibit high algal production and reduced water clarity, due to ample availability of nutrients, whereas low algal production and increased water clarity are observed in downstream reaches coincident with declining nutrient availability.

Table Rock Lake, the next downstream reservoir in the cascade, benefits from phosphorus retention in Beaver Lake and receives inflows with relatively low total phosphorus concentrations. While release total phosphorus concentrations below Table Rock Lake are low, loading rates to the river are high immediately upstream from Bull Shoals Lake and total phosphorus concentrations are again elevated. However, the high rate of total phosphorus retention in Bull Shoals Lake (63%) again reduces total phosphorus concentrations in the White River below the dam. The net effect of the three-reservoir cascade is modulation of total phosphorus concentrations along this 200 km reach of the White River through phosphorus retention. In the absence of the three reservoirs, and given the occurrence of high rates of total phosphorus loading to the river, concentrations higher than those observed would be anticipated.

Kennedy (1999) reports that phosphorus retention by reservoirs is a function of water residence time and areal phosphorus loading rate (Figure 2), and that such retention has important implications for the phosphorus budgets of drainage basins. As demonstrated above for the White River, reservoirs can be viewed as nutrient sinks within a drainage basin and may serve to reduce loadings to downstream water resources, including other reservoirs. In the context of nutrient criteria, the value of this function for reservoirs should be a topic of discussion, since reservoirs identified as nutrient sinks may experience water quality conditions (e.g., high nutrient concentrations) that differ from those otherwise anticipated or desired. Nutrient criteria for such lakes could be modified accordingly.

Figure 1: Average inflow and outflow total phosphorus concentrations (vertical bars) and in-reservoir total phosphorus concentration (solid circle) for Beaver, Table Rock, and Bull Shoals Lakes on the white River, AR. R_T and R_P indicate water residence time (days) and total phosphorus retention (percent), respectively.

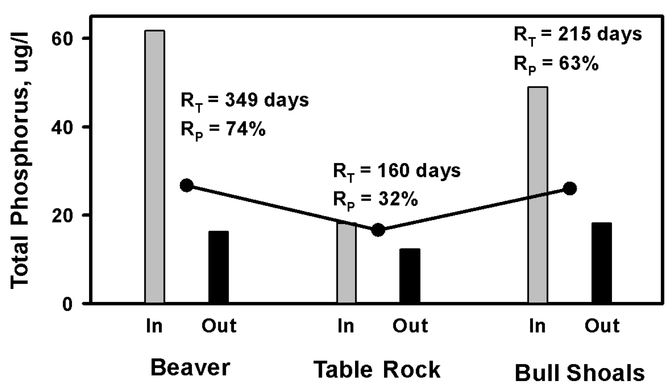

Figure 2: Relationship between total phosphorus retention and water residence time values for selected CE reservoirs with differing areal phosphorus loads. Curves and associated equations estimate relationships between total phosphorus retention (RP) and water residence time (RT) for each of three areal phosphorus loading categories (Kennedy 1999).