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# *Federal Water Quality Coalition*

## COMMENTS FOR EPA SAB NUTRIENT MEETING

The Federal Water Quality Coalition (the "FWQC") hereby submits the following comments on nutrient criteria development approaches, for consideration by the Science Advisory Board's Ecological Processes and Effects Committee (the "Committee") as it reviews the EPA draft document entitled "Empirical Approaches for Nutrient Criteria Derivation."

In addition to these brief comments, the FWQC is also submitting a scientific report for the Committee to consider, entitled "Guidance on Developing Nutrient Criteria for Protecting Designated Uses of Water Bodies." This report, by Dr. Ben Parkhurst and others, was prepared for the Coalition, in the interest of promoting the development of scientifically sound nutrient water quality criteria. We believe that it should be helpful to the Committee in its review of the EPA report on criteria approaches.

At the Committee's meeting on September 9-11, 2009, the FWQC plans to provide oral comments at the meeting, focused on key issues that we would like the Committee to consider in its review of the EPA report. These issues will include the following concepts (which the FWQC will expand on in its oral presentation):

1. We are concerned that some of the approaches discussed by EPA would lead to enormous compliance costs, without a significant environmental benefit. Requirements imposed under these approaches could be technologically infeasible to comply with. Also, the required control technologies would result in substantial additional energy use, leading to increased carbon footprints, and other adverse environmental impacts as well. For those reasons, it is critical that the Committee carefully review the approaches, to ensure that any criteria development options to be recommended by EPA be scientifically sound, based on what is needed to protect appropriate, attainable designated uses.

2. It is important that any EPA criteria guidance make a "causation connection" - in other words, if a particular pollutant is to be limited to a certain level, it needs to be determined that pollutant levels above that point actually lead to impairments of the designated uses. It is not appropriate to focus on levels in "pristine" waters and then set the criteria based on those levels - waters with levels above the "pristine" point are not necessarily impaired.

3. Any EPA guidance needs to acknowledge and address the multiple levels of uncertainty that exist in the assessment of eutrophication issues and their impacts on aquatic life. For example, if one is to make a linkage

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between nutrient levels and algae growth, and then make another linkage between algae growth and adverse impacts on fish populations, then one needs to recognize that there are uncertainties present in both of those linkages, and consider those uncertainties in developing appropriate criteria.

4. EPA also needs to recognize competing uses. Protection of aquatic life is usually not the only designated use for a waterbody, and conflicts can arise between that use and others, such as fishing and drinking - for example, if nutrient standards are set so low that the fish are deprived of needed sustenance. The guidance needs to address this issue, so standards are not set to protect one use that may interfere with the attainment or maintenance of another use.

5. The Agency needs to specifically address the role of confounding factors, which may make it difficult to establish a relationship between nutrient levels and impairments of designated uses. In many waters, for example, turbidity levels operate in this fashion.

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# GUIDANCE ON DEVELOPING NUTRIENT CRITERIA FOR PROTECTING DESIGNATED USES OF WATER BODIES

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## 1.0 DOCUMENT GOAL AND OBJECTIVES

This document provides guidance for deriving scientifically defensible nutrient criteria that are based on defined relationships among designated uses of water bodies, response variables, and nutrients. The guidance addresses the development of nutrient criteria for individual water bodies and classes of water bodies. The report is intended for use by (1) State and tribal regulatory agencies with the authority to derive criteria and standards; (2) regulated entities affected by the criteria, such as dischargers with National Pollutant Discharge Elimination System (NPDES) permits and those potentially affected by nonpoint source controls; and (3) other interested parties.

## 2.0 U.S. EPA'S NUTRIENT CRITERIA DEVELOPMENT PROCESS

On January 9, 2001, U.S. EPA announced the publication of recommended water quality criteria for nutrients under section 304(a) of the Clean Water Act (see 66 FR 1671). U.S.EPA developed these criteria with the intention that they serve as a starting point for states, authorized tribes, interstate commissions and others to develop more refined nutrient criteria, as appropriate, using U.S. EPA waterbody-specific technical guidance manuals ( U.S. EPA 2000a, 2000b, 2001) and other scientifically defensible approaches. In that announcement, EPA emphasized that states and authorized tribes have several options available to them in developing and adopting water quality criteria for nutrients. U.S. EPA recommended the following approaches, in order of preference: 1) wherever possible, develop nutrient criteria that fully reflect localized conditions and protect specific designated uses, using the process outlined in the technical guidance manuals; 2) adopt U.S. EPA's recommended section 304(a) criteria for nutrients, either as numeric criteria or as a translator for a state or tribal narrative criterion; or 3) use other scientifically defensible methods and appropriate water quality data to develop criteria protective of designated uses (Grubbs, G., Director, U.S. EPA, Office of Science and Technology, Washington, D.C., memorandum, November 14, 2001).

By the end of 2004, States and Tribes were required either to adopt the U.S. EPA's ecoregional nutrient criteria and standards, or prepare a plan for developing nutrient criteria. To date, most States have prepared nutrient criteria development plans. However, if States and Tribes failed to meet the 2004 deadline, the U.S. EPA may promulgate criteria for these entities based on ecoregional analyses and recommendations. States, Tribes, or other entities may propose alternative criteria if the organizations believe the U.S. EPA criteria are not appropriate for a particular water body, or a class of water bodies. State- or Tribal-defined criteria must be scientifically defensible and approved by the U.S. EPA and State regulatory agencies.

U.S. EPA (2000b) discussed three approaches for developing nutrient criteria: (1) use of data from reference and non-reference water bodies, (2) use of predictive relationships between nutrients and response variables, and (3) use of literature threshold values. U.S. EPA, however, then proceeded to only use the reference and non-reference water body approach in its development of ecoregional nutrient criteria for lakes and reservoirs and rivers and streams, which does not evaluate attainment of designated uses (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/). Reference water bodies, ideally, represent conditions where anthropogenic disturbances and pollution are absent (U.S. EPA 2000a, 2000b, 2001). Because most waters have been influenced by human activity, reference conditions in reality are those that are the least impacted (U.S. EPA 2000a). The U.S. EPA provides general guidance on selecting and classifying reference water bodies (2000a, 2000b, 2001).

For the reference and non-reference water body approach, two alternative approaches were presented. The first approach only uses data from reference water bodies located within an ecoregion to establish criteria, and the second uses data from both reference and non-reference water bodies located within an ecoregion. In the reference approach, waterbody data are used to establish a cumulative frequency distribution for each variable of interest, such as total phosphorus (TP), total nitrogen (TN), and chlorophyll a (Chl *a*). The upper 75th percentile of the distribution for each variable defines the ecoregional nutrient criterion. In the second

approach, nutrient data from both reference and non-reference water bodies in the ecoregion are used to establish a cumulative frequency distribution for each variable of interest. The lower 25th percentile of the distribution for each variable defines the ecoregional nutrient criterion.

## 3.0 LIMITATIONS TO U.S. EPA'S GUIDANCE FOR DERIVING ECOREGIONAL NUTRIENT CRITERIA

The U.S. EPA's approach for deriving ecoregional nutrient criteria has the following important limitations:

1. Because 75% of all water bodies in U.S. EPA's nutrient database exceed the ecoregional criteria, if extrapolated to all water bodies, use of the U.S. EPA's percentile approach potentially could result in the non-attainment of about 75% of all water bodies, without any direct determination of nutrient impairment or non-attainment of designated uses. It is likely that most of these water bodies are unimpaired by nutrients and/or are attaining designated uses potentially affected by nutrients.
2. The U.S. EPA's approach for setting nutrient criteria does not require the determination of causal relationships between nutrients and attainment of designated uses. As a result, efforts to reduce nutrient concentrations can result in adverse effects to some designated uses, such as recreational or commercial fishing. Such efforts may result in decreases in fish populations caused by decreases in primary production (VA WRRC 2004).
3. Causal relationships between nutrients and response variables, such as Chl *a*, dissolved oxygen and pH, are not determined using U.S. EPA's approach (VA WRRC 2004, Warren-Hicks et al. 2005). Consequently, in waters where such relationships are weak or may not exist because of confounding factors, changes in nutrient concentrations may not produce the expected changes in Chl *a* concentrations or other response variables.

## 4.0 NUTRIENT CRITERIA AND DESIGNATED USES FOR WATER BODIES

Water quality standards incorporate criteria and use designations. The Clean Water (CWA) Act and its implementing regulations require that criteria should be developed considering use designations. Given this CWA directive and the fundamental difference between nutrients and other pollutants that are more directly toxic to aquatic life, the VA WRRC (2004) recommended that the VA DEQ base its nutrient criteria development process upon the concept of designated uses. We agree with this recommendation and recommend that it be applied to all States.

All water bodies have one or more designated uses. Designated uses potentially affected by nutrients include those related to aquatic life, recreation, and public water supply (i.e., drinking water). In some multiple-use water bodies, protection of multiple uses may result in management conflicts. For example, many water bodies have both recreational fishery and public water supply uses. While the public water supply use may best be served by more restrictive criteria placing tight limits on algal populations, recreational fisheries may be better served by more moderate algal levels. An effective criterion should seek to balance such tradeoffs. Jensen et al. (2004, see Appendix 3) have proposed a conceptual approach for determining Chl *a* levels that optimize the support of multiple, competing designated uses. Analyses of this type will be required to derive nutrient criteria based on suitability of the water body for multiple, competing designated uses.

### 4.1 Aquatic Life

Aquatic life includes fish, amphibians, reptiles, invertebrates, plants, and microbes. Most state water quality management agencies have programs that monitor at least some of these types of aquatic life in most water bodies as part of their biological assessment and/or biocriteria programs. In addition, most State agencies that regulate sport and commercial fisheries collect monitoring data on fish populations and/or sport and commercial fishery statistics. These types of data should be useful for determining the suitability of all classes of water bodies for aquatic

life use. We recommend that these types of information be used to rate the level of use suitability on a scale of 1 – 5, with 1 as the lowest rating and 5 as the highest rating. These types of qualitative use ratings are frequently applied in biological assessment/biocriteria programs. Most commonly, bioassessments are conducted on fish, benthic macroinvertebrates and algae. For more information on these types of monitoring programs, please refer to http://www.epa.gov/waterscience/biocriteria/.

The Virginia Water Resources Resource Commission (VA WRRC 2004) recommended that recreational fish population status be interpreted as an indicator of aquatic life status in impoundments, because most impoundments are used or managed for recreational fishing and recreational fish species are generally at the upper trophic level of the ecosystem. In the absence of fish population data, the VA WRRC (2004) proposed that recreational fishery status, as rated by Virginia Department of Game and Inland Fisheries (VDGIF) biologists on a 1 – 5 scale with 1 as the lowest rating and 5 as the highest rating, be used as an indicator of aquatic life use suitability. The VDGIF compared indices of fisheries status with nutrient levels. Based on the results of these analyses, the VA WRRC (2004) believes that the State's impoundments should be classified for nutrient criteria development based on the types of fisheries the impoundments support. We believe that this approach can be applied to impoundments in other States. We recommend that this type of approach be used to supplement the other types of bioassessment data used for evaluating the aquatic life use.

## 4.2 Recreation

The recreation category includes recreation, aesthetics, swimming, fishing, boating, and whole or partial body contact uses. User perception surveys can be used to define relationships between these types of recreational use and Chl *a*. (Warren-Hicks et al. 2005, VA WRRC 2004). User perception surveys use questionnaires to survey public perceptions of water quality. These surveys can be combined with water quality assessments of nutrients and response variables, such as Chl *a*, dissolved oxygen, fishing success, etc., so that the results of the user perception

surveys can be compared with nutrient-related water quality data. The Texas Water Conservation Association (2004) is conducting a user perception survey designed to evaluate the relationship between the recreational use of reservoirs and Chl *a* concentrations and water transparency in Texas impoundments. User perception surveys should be of value in nutrient criteria development for water bodies where existing or potential recreational usage would be significant (VA WRRC 2004, Warren-Hicks et al. 2005). It should be noted, however, that conducting these surveys can be difficult (VA WRRC 2004). If these surveys are implemented in a scientifically indefensible manner (i.e., proper question design, pretest, sampling protocol, and statistical procedures, etc.), the results may be inaccurate. Therefore, user perception surveys should be applied to the criteria development process only if adequate resources are available for conducting the surveys. For example, the survey protocols should be pre-tested, and the data used to define the relationship of survey respondents to the population that those respondents are intended to represent (VA WRRC 2004).

### 4.3 Public (Drinking) Water Supply

The public water supply designation includes all uses of water for human consumption. Impacts of high nutrient concentrations on the public water supply include increased treatment costs, bad taste, and odor. In general, as Chl *a* concentrations increase, water treatment costs and taste and odor problems tend to increase (Jensen et al. 2004). Jensen et al. (2004) investigated relationships among taste and odor problems, treatment costs, levels of nutrients, and Chl *a* in some Texas reservoirs. Similar studies will be needed to define these relationships for the public water supply use in other states.

## 5.0 DEVELOPMENT OF THIS GUIDANCE

The primary sources of information used to develop this guidance include the following:

- *Technical Approaches for Setting Site-specific Nutrient Criteria* (Warren-Hicks et al. 2005).
- *Nutrient Criteria Development Plan for the Commonwealth of Virginia* (VA DEQ 2004).
- *Report of the Academic Advisory Committee to the Virginia Department of Environmental Quality - Freshwater Nutrient Criteria* (VA WRRC 2004).
- *U.S. EPA Nutrient Criteria Guidance Manuals* (U.S. EPA 2000a, 2000b, 2001).
- *Nutrient Criteria and Designated Uses for Reservoirs in the Trinity River Basin* (Jensen et al. 2004).

All of these sources, except Warren-Hicks et al. (2005) and the US EPA manuals, are attached as appendices. Warren-Hicks et al. (2005) can be obtained from the Water Environment Research Foundation (www.werf.org). The US EPA manuals can be downloaded at:

http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/#docs.

The guidance presented in this report is a synthesis of materials from these sources. We recommend that all of these reports be reviewed before initiating any effort to develop nutrient criteria. We also reviewed some other State nutrient development plans for guidance on developing effects-based nutrient criteria. These States included California, Florida, West Virginia, Texas, Colorado, and others. Most State plans did not provide detailed guidance on methods for developing nutrient criteria based on the relationships among nutrients, response variables, and designated uses of water bodies. At best, only general guidance was provided. Based on our review, the VA DEQ (2004) provided the most useful and comprehensive State nutrient development plan. In addition, highly useful and informative information is found in *The Report of the Academic Advisory Committee to the Virginia Department of Environmental*

*Quality - Freshwater Nutrient Criteria* (VA WRRC 2004), which evaluated and provided recommendations on many of the important issues involved in developing nutrient criteria.

The effort required to develop nutrient criteria appropriate for all water bodies in a state will be a time-and resource-intensive process (VA WRRC 2004). Data useful for developing nutrient criteria, for the most part, have been collected for other purposes and may not be optimally suited for developing nutrient criteria. For example, data for nutrients and response variables are generally collected during the growing season, while fish and benthic macroinvertebrate data are usually collected during the spring or fall. Consequently, rarely are the required data collected during the same time period. For many water bodies or classes of water bodies, adequate data may not exist; therefore, collection of new data will be required. However "adaptive management" approaches, which include procedures for evaluating and refining criteria as new data are collected, may be useful in the criteria setting process.

## 6.0 RECOMMENDED STEPS FOR DEVELOPING NUTRIENT CRITERIA

Figure 1 shows 12 steps in the process for developing nutrient criteria protective of designated uses for water bodies. This process is applicable to individual water bodies, segments of individual water bodies, or classes of water bodies. The steps include the following:

- Step 1. Prioritize water bodies for criteria development.
- Step 2. Determine data requirements for developing nutrient criteria.
- Step 3. Compile data and create database.
- Step 4. Evaluate data adequacy. If the data are inadequate for developing nutrient criteria, then collect the required data.
- Step 5. If the data are adequate, then classify water bodies into appropriate groups for criteria development.
- Step 6. Evaluate relationships between Chl *a*, P, and N concentrations and levels of designated use support, including the aquatic life, recreation, and public water supply uses. If no significant relationships are identified, then either (1) collect additional data and re-evaluate the relationships, or (2) develop non-effects-based criteria.
- Step 7. If significant relationships are found between Chl a, P and N and level of use support, then evaluate relationships between P and N, and response variables.
- Step 8. Select trial Chl *a*, P, and/or N criteria based on relationships among these variables and levels of designated use support using a stakeholder decision-making process.
- Step 9. If significant relationships are not found between Chl a, P and N and levels of use support, then determine which physical, chemical, and/or biological factors may be confounding these relationships.
- Step 10. Select trial criteria based on non-effects data.
- Step 11. Evaluate whether the trial criteria may cause unacceptable effects to upstream or downstream nutrient criteria, water quality, or designated uses. If these types of unacceptable effects are predicted to occur, then the criteria should be re-

evaluated and new criteria selected that will not cause these types of effects. If these effects are not predicted to occur, then proceed to Step 12.

- Step 12. Begin criteria adoption process through the state water quality regulatory agency.

In the following subsections, the details of each step in the process are described.

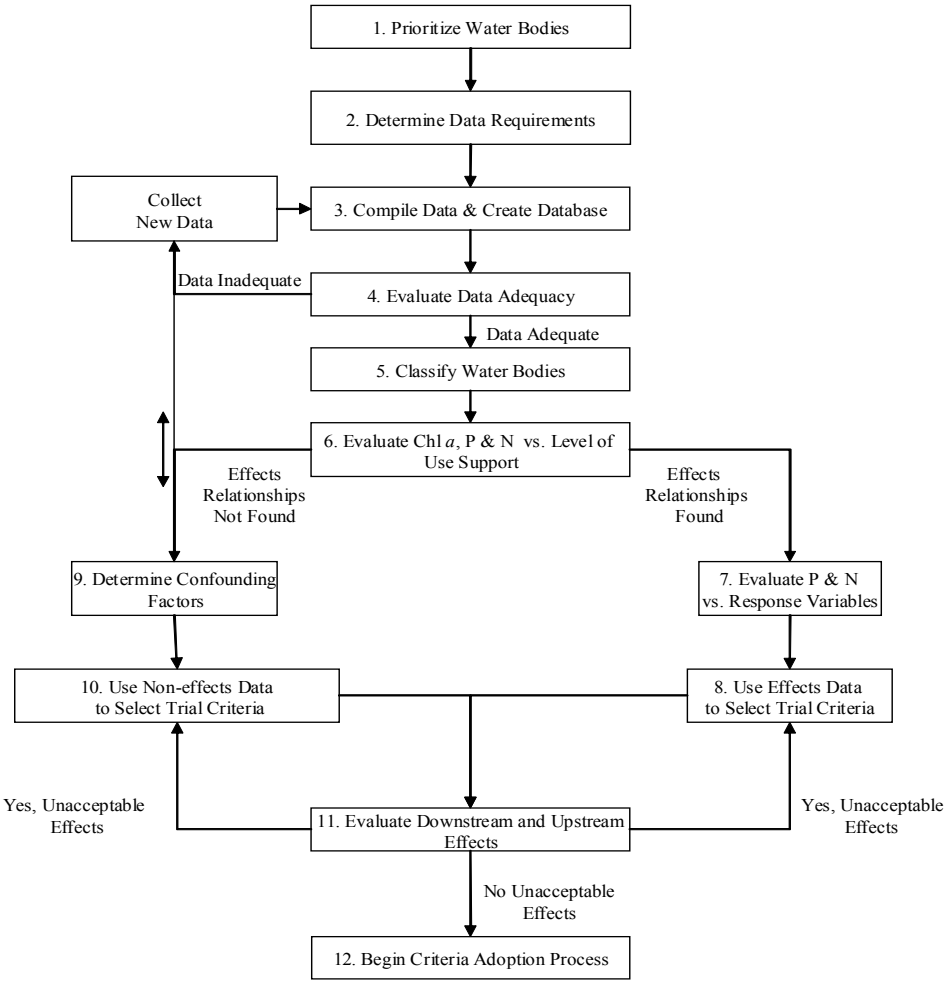


Figure 1. Steps in Nutrient Criteria Development Process.

## 6.1 Step 1: Prioritize Water Bodies

Nutrient criteria development will be time and resource intensive; therefore, prioritization of individual water bodies, classes of water bodies, or watersheds for criteria development may be required. Prioritization is largely a resource issue that will be based on the following:

- The amount of human and financial resources available;
- Evaluation of regulatory requirements, such as the 303(d) list identifying nutrient impaired waters, and requirements for conducting nutrient TMDLs;
- The results of user perception surveys, which may help identify waters with the nutrient issues of greatest concern;
- Stakeholder input aiding in the identification of water bodies with nutrient issues; and
- Watershed considerations.

The impact of proposed nutrient criteria on downstream and upstream water bodies is also an important consideration for prioritization of water bodies. The preferred approach is to initially evaluate potential nutrient criteria in downstream waters, followed by evaluations in upstream waters, so that potential impacts of upstream loads of nutrients on downstream water bodies can be evaluated. The evaluation should include nutrient concentrations, loadings, and effects on all important response variables.

## 6.2 Step 2: Determine Data Requirements

Tables 1 and 2 list the types of data useful for developing nutrient criteria. U.S. EPA (2000a, 2000b, 2001) and Warren-Hicks et al. (2005) provide descriptions of variables useful for developing nutrient criteria, sources for obtaining data for these variables, sampling designs for collecting new data, and creation of databases for developing nutrient criteria. These sources should be consulted for more information on these topics. Some these variables will be required

to develop nutrient criteria for a specific water body, but not all. The types of chemical and biological data required will be project-specific. At a minimum, the following types of data collected concurrently (or approximately so) during the growing season will be required:

- total and dissolved concentrations of phosphorus and nitrogen;
- concentrations of phytoplankton or periphyton Chl *a*;
- density and extent of submerged aquatic vegetation or periphyton;
- measures of transparency: secchi depth, turbidity, volatile and non-volatile suspended solids;
- measures of designated use suitability, including the following:
    - aquatic life: recreational and commercial fishing, fish, invertebrates, and/or plant monitoring data;
    - recreation: data that compare Chl *a* with perceptions of water quality for recreation; and
    - public water supply: data that compare drinking water odor, taste, or treatment costs with Chl *a*.

Data describing both nutrient concentrations and loading rates are preferred. Loading data are especially useful for lakes, reservoirs, and estuaries, because of the potential links among loads, primary production and designated uses. Relying solely on concentration data may not lead to successful nutrient criteria; consequently, nutrient criteria based on loading rates in addition to concentrations may be appropriate in some cases. Sufficient data are required to characterize the spatial and temporal variability of each variable evaluated. Data for at least one entire year, based on monthly or weekly sampling, may be adequate in some cases provided the year represents typical or average climatic and hydrological conditions. In most cases, several years of data are will be required so that long-term trends and variability can be evaluated.

| Table 1. Nutrient, Response, and Effects Data Useful For Criteria Development | |
|---|---|
| acid neutralization capacity (mg/L) | periphyton chlorophyll a (mg/m²) |
| algal community index | pH (units) |
| algal and periphyton community metrics* | pheophytin (µg/L) |
| anoxic factor | phosphorus loading (gms P per m² per yr) |
| areal hypolimnetic oxygen depletion rate (mg/m²/day) | phytoplankton chlorophyll a (µg/L) |
| benthic macroinvertebrate community metrics* | salinity (ppt) |
| benthic macroinvertebrate Index of Biological Integrity (IBI) | sample date |
| conductivity (µmol/cm) | sample depth (m) |
| discharge rate (m³/sec) | sample latitude |
| dissolved inorganic nitrogen (µg/L) | sample longitude |
| dissolved oxygen, surface (mg/L) | sample time |
| dissolved oxygen, epiliminion (mg/L) | Secchi depth (m) |
| dissolved oxygen, hypolimnion (mg/L) | soluble reactive phosphorus (µg/L) |
| drinking water odor | submerged aquatic vegetation (% of benthic substrate covered) |
| drinking water taste | submerged aquatic vegetation chlorophyll a (mg/m²) |
| drinking water treatment cost ($/L/yr) | total dissolved solids (mg/L) |
| fish community Index of Biological Integrity (IBI) | total nitrogen (µg/L) |
| fishery status (1-5) | total phosphorus (µg/L) |
| fish population metrics* | total sediment nitrogen (mg/kg) |
| fish species catch per unit effort | total sediment phosphorus (mg/kg) |
| habitat quality score | turbidity (ntu) |
| macrophyte community metrics* | velocity (m/sec) |
| nitrogen loading (gms N per m² per yr) | volatile suspended solids (mg/L) |
| non-volatile suspended solids (mg/L) | zooplankton community metrics* |
| *Biological community metrics may include number of taxa, total number of individuals, numbers of individuals per taxon, diversity indices, density, percent cover, and others. | |

| Table 2. Water Body Metrics Useful for Classifying Water Bodies In the Nutrient Criteria Development Process | |
|---|---|
| acid neutralization capacity (mg/L) | pH (units) |
| altitude (m) | reference or non-reference |
| conductivity (µmol/cm | salinity (ppt) |
| designated uses (aquatic life, recreation, public water supply) | stratification class (monomictic, dimictic) |
| discharge rate ($m^3$/sec) | stream classification (I-V) |
| effluent dominated (% effluent) | substrate composition (% muck, silt, sand, gravel, cobble, boulder, bedrock) |
| ephemeral, intermittent or perennial | total dissolved solids (mg/L) |
| fishery classification (coldwater, coolwater, warmwater) | trophic state index |
| gradient (%) | Velocity (m/sec) |
| habitat quality score | volume ($m^3$) |
| hydraulic residence time (yr) | water body area (ha) |
| latitude | water body name |
| Level III ecoregion | water shed area ($km^2$) |
| Level IV ecoregion | water body type (estuary, lake, impoundment, river or stream, wetland) |
| Longitude | watershed area/water body area ratio |
| maximum depth (m) | watershed geology (% composition by category) |
| mean depth (m) | watershed land use (% forested, cultivated, rangeland, urban) |
| natural trophic condition (oligotrophic, mesotrophic, eutrophic) | width (m) |

Data useful for determining the level of designated use support may be more difficult to obtain. Because use support for each designated use is measured using different metrics, an important issue is the comparison of the level of designated use support among competing uses. For ease

of comparison, we recommend that the level of use support for each designated use be rated on a scale of 1 -5, with five being excellent use support and 1 being poor use support. This type of rating system provides comparable metrics for each designated use. This type of rating system was recommended by the VA WRRC (2004) for evaluating aquatic life use in impoundments, as discussed below. A similar system is commonly used for user perception surveys for evaluating recreational uses (see Tables 3 and 4 and Appendix 4). It could also be used to evaluate the public water supply use (Jensen et al. 2004).

| Table 3. Hypothetical Lake Survey Part A . | | | | | |
|---|---|---|---|---|---|
| **A. Describe condition of lake today** | | **TN (ppb)** | **TP (ppb)** | **Secchi Depth (ft)** | **Chl *a* (ppb)** |
| 5 | Crystal clear | 30 | 15 | 10 | 3 |
| 4 | Some algae visible | 75 | 25 | 7 | 7 |
| 3 | Green color | 150 | 45 | 4 | 12 |
| 2 | Limited clarity, mild odor | 250 | 80 | 2 | 22 |
| 1 | Floating scums, foul odor, dead fish | 300 | 120 | 0.5 | 35 |

| Table 4. Hypothetical Lake Survey Part B . | | | | | |
|---|---|---|---|---|---|
| **B. Describe suitability of lake for recreation** | | **TN (ppb)** | **TP (ppb)** | **Secchi Depth (ft)** | **Chl a (ppb)** |
| 5 | Beautiful, couldn't be nicer | 30 | 15 | 10 | 3 |
| 4 | Minor aesthetic problems, excellent for enjoyment | 75 | 25 | 7 | 7 |
| 3 | Swimming and aesthetics slightly impaired by algae | 150 | 45 | 4 | 12 |
| 2 | Swimming & aesthetics severely impaired by algae | 250 | 80 | 2 | 22 |
| 1 | Swimming & other recreation nearly impossible | 300 | 120 | 0.5 | 35 |

### 6.2.1 *Data Requirements for Evaluating Aquatic Life Use*

State agencies are likely sources for aquatic life monitoring data, including recreational and commercial fishing catch rates, as well as fish, invertebrate and plant community metrics. We recommend that evaluation of the aquatic life use include both aquatic community and recreational or commercial fishery data, if available. The rating should be on a 1 – 5 scale, as discussed above. For impoundments lacking adequate aquatic community data for evaluation of aquatic life suitability, the VA WRRC (2004) approach may be appropriate. The VA WRRC (2004) method considers fish populations suitable for recreational fishing to be the primary biotic indicator of the capability of impoundments to support aquatic life. Dr. John Ney of Virginia Technical University is working with fishery biologists in the VDGIF to rate the fishery status of Virginia impoundments on a scale of 1 to 5 (VA WRRC 2004). Each impoundment will be classified as one of three primary fishery types: warm water, cool water, and cold water. The ability of the impoundment to support desirable species, achieving good growth and size is rated by fishery biologists using the following scale:

1 = poor: biologists recommend that anglers avoid such lakes;

2 = fair: biologists recommend that anglers fishing such lakes not much fishing success;

3 = average: the lake supports an adequate fishery;

4 = good: biologists recommend such a lake for fishing;

5 = excellent: biologists highly recommend such a lake for fishing.

As stated previously, the recommended approach is to use quantitative data on aquatic life to determine the level of aquatic life use support. By linking the qualitative perception survey results with quantitative nutrient and response variable measurements, nutrient criteria that are scientifically sound, yet meet the needs of users can be obtained. If states or other entities decide

to pursue the less data intensive, VA WRRC (2004) approach, there is a risk that the use of this more subjective type of analysis may lead to the development of less-scientifically defensible nutrient criteria. This is an important consideration in determining the type of approach to pursue.

### 6.2.2. *Data Requirements for Evaluating Recreation Use*

The most commonly used method for measuring the relationship between response variables, such as Chl *a*, and recreational uses of water bodies is the user perception survey. User perception surveys have been used to evaluate recreational uses, including swimming, boating, fishing, and aesthetics of lakes, reservoirs, rivers and streams (WA DOE 2000). The surveys compare stakeholder perceptions of water quality and stakeholder uses of the water body with measurements of P, N, Chl *a*, water clarity, total suspended solids, and other nutrient and response variables. An example of a user perception survey form and its results is presented in Appendix 4 (WA DOE 2000). A hypothetical example of the results of a user perception survey in which the results are rated on a scale of 1 -5 is presented in Tables 3 and 4. User perception surveys commonly are conducted by State and municipal agencies, U.S. EPA, and citizens' groups. Examples include the following:

- Washington Department of Ecology (WA DOE, 2000, Appendix 4): http://www.ecy.wa.gov/pubs/0003039.pdf
- Metropolitan Council (Twin Cities), MN: http://www.metrocouncil.org/environment/RiversLakes/Lakes/03LakeREPORT.pdf
- U.S. EPA: http://www.epa.gov/owow/monitoring/volunteer/newsletter/volmon13no1.pdf
- Minnesota Pollution Control Agency: http://www.pca.State.mn.us/publications/reports/csmp-report-2001.pdf

User perception surveys can be used for evaluating the suitability of the recreational use for all water bodies.

### 6.2.3 *Data Requirements for Evaluating the Public Water Supply Use*

Jensen et al. (2004, Appendix 3) describe the results of a study investigating relationships among taste and odor problems, treatment costs and levels of nutrients and Chl *a* in some Texas reservoirs. We recommend that the results of these studies be rated on a scale of 1 - 5, with 1 representing the highest treatment cost and 5 representing the lowest treatment costs. Data from similar types of studies will be necessary to evaluate the suitability of water bodies for the public water supply use.

## 6.3 Step 3: Compile Data and Create Database

Effective derivation of nutrient criteria requires high quality data collected from the water body or class of water bodies under evaluation. Actual *in situ* measurements of key nutrients and associated effects and response measurements, including levels of use support, provide a basis for building effects-based models or simply deriving descriptive statistics and graphics illustrating the current state of the water system. Data describing both nutrient concentrations and loading rates are critical.

The preferred data base will consist of data on both temporal and spatial scales. In general, the evaluation of nutrient-response relationships and, hence, the development of nutrient criteria will require both spatial and seasonal averaging of data. Total and dissolved nitrogen and phosphorus measurements in lakes at multiple sampling sites, collected over several seasons within multiple years, will provide information on the variability (seasonal and spatial) required to characterize each variable under evaluation. Data should include individual measurements and associated descriptive statistics of centrality (mean, median, minimum, maximum, and mode) and spread (standard deviation, range, upper and lower percentiles, coefficient of variation). The minimal

amount of data required for most effects-based models includes one entire year of measurements with weekly sampling. Rarely, however, will one year of data be adequate. We recommend three to five years of growing season data to account for annual variability. Table 5 lists sources of nutrient and other water quality data that can be used to develop nutrient criteria. Additional data and information might be available from State environmental agencies, universities, and county or local government organizations.

| Table 5. Data Sources Useful in Developing Nutrient Criteria. | | |
|---|---|---|
| **Organization** | **Description** | **Website** |
| U.S. EPA | Nutrient Criteria Database | http://www.epa.gov/waterscience/criteria/nutrient/database/index.html |
| U.S. EPA | STORET - data storage and retrieval system | http://epa.gov/storet/ |
| USGS[1] | National Water Information System – NWIS | http://water.usgs.gov/nwis |
| USGS/ U.S. EPA | National Hydrography Dataset | http://nhd.usgs.gov/ |
| U.S. EPA | Watershed Information Network – WIN | http://epa.gov/win/ |
| U.S. EPA | Surf Your Watershed | http://epa.gov/surf/ |
| [1]USGS = U.S. Geological Survey | | |

In some parts of the United States, nutrient data are available in a readily useable format. Examples include Iowa (Jones and Bachmann 1978), Texas (Ground and Groeger 1994), Minnesota (Heiskary and Walker 1988), Missouri (Jones and Knowlton 1993), Colorado (Morris and Lewis 1988), and Florida (Canfield and Hoyer 1988). Compilations of lake and reservoir data are available for some regions (e.g., Reckhow 1988). In many regions, however, considerable water quality information is available only for a small number of economically important water bodies, and data for the remaining systems are scant. Thus, characterizing water quality and levels of use support from existing data could prove difficult.

### 6.4 Step 4: Evaluate Data Adequacy

The determination of data adequacy is a difficult issue. The amount and type of data required for effective criteria development are dependent upon the type of water body, the current condition of the water body with respect to nutrient concentrations, designated uses potentially affected by nutrients, sources of nutrients in the watershed that may be impacting designated uses in the

particular water body under consideration, and anthropogenic growth and development issues influencing the nutrient concentrations and designated uses in the water body.

From a statistical perspective, data are adequate if they are representative of the nutrient concentrations within the water body for average or typical climatic conditions. Nutrient criteria should not be developed using data reflective of unusual hydrologic and physical conditions of the water body. For example, years of unusually high rainfall may result in larger than normal non-point source runoff of pesticides into the water body of interest. From this perspective, a key issue underlying data adequacy is determining average or standard conditions. The best way of attacking this problem is to gather long-term records of nutrient and response variable concentrations. Examination of these records using time-series plots may provide investigators insights into the typical patterns found in the water body. Box-and-whisker plots of consecutive seasonal or yearly data can provide a visual determination of patterns and trends. Current year data may not be representative of the water body. Therefore, the newest information may not be the best data for creating nutrient criteria. Investigators should carefully critique the amount and quality of data from the perspective of watershed protection.

Working groups examining the data within the context of watershed goals and anthropogenic growth can be used to create a conceptual model of the nutrient issues of concern. Data, both current and historical, need to be critically examined with respect to the conceptual model. For example, current data from water bodies in rural watersheds with decreasing agricultural growth may be more representative of future water quality conditions than historical survey efforts.

For many water bodies, available data may be inadequate for developing defensible nutrient criteria. Typically, measurements of TN, TP, water clarity, and basic water chemistry (conductivity, pH, DO, etc.) data will be available. However, data for Chl *a* and measures of use support will be available for a relatively few water bodies. In addition, the response variables (e.g., Chl *a*, DO, pH), predictor variables (N, P, water chemistry) and measures of use support (aquatic life, recreation, and water supply) must be closely matched in both space and time.

Therefore, for many water bodies, new data may need to be collected. The U.S. EPA (2000a, 2000b, 2001) provides recommended guidance on sampling plan designs for nutrient studies in lakes and reservoirs, rivers and streams, and estuaries.

## 6.5 Step 5: Classify Water Bodies

The first step in the classification process is to classify the water bodies in each State's Level III and IV ecoregions into the following areas:

- estuaries and coastal waters,
- natural lakes,
- man-made reservoirs and impoundments, or
- rivers and streams.

Individual water bodies may be further divided into subsegments, if water quality within that water body varies significantly, for example, among arms of an impoundment or estuary, or longitudinally in streams.

Within each class, water bodies can be classified as reference or non-reference, although VA WRRC (2004) recommends against classifying waters as reference and non-reference for nutrient criteria development. The VA WRRC (2004) suggests that reference and non-reference water bodies are not directly comparable because of large differences in many important watershed characteristics. In addition, classification as reference or non-reference is not done with respect to an evaluation of attainment of designated uses; consequently, classification as reference or non-reference is not necessary for nutrient criteria development. Depending on the numbers of water bodies in each of these classes and the variability in characteristics within each class, it may be useful to further sub-classify the water bodies based on physical, chemical, hydrological, geological, geographical, limnological, and/or biological characteristics. Designated uses and sub-classifications of uses may also be used as a basis of sub-classification. For example, all lakes with the same aquatic life designation within an ecoregion (i.e., coldwater,

cool water, warmwater) should be grouped together. Table 2 lists characteristics that could be used to sub-classify water bodies. The U.S. EPA nutrient criteria guidance manuals (U.S. EPA 2000a, 2000b, 2001) provide guidance on using these variables to classify river and streams, lakes and reservoirs, and estuaries and coastal waters, respectively. These should be referred to for more information on water body classification.

## 6.6 Step 6: Evaluate Chl *a*, P, and N vs. Level of Use Support

An important step in the building of effects-based models is to evaluate the magnitude of the response variable for specific designated uses, e.g., fish species catch per unit effort (CPUE), various metrics for aquatic communities, clarity, taste, odor, treatment costs, dissolved oxygen concentration, pH, etc. For example, examination of Chl *a* concentrations against fish species CPUE can be accomplished graphically or by using ordinary least squares (OLS) models. Similarly, determining the mean or median Chl *a* concentration associated with changes in water clarity, taste and order can be accomplished providing the data exist over time periods capturing the variability in the measurements. However, in many cases the relationships are not particularly strong due to large variability in both the response and predictor variables.

An alternative and particularly useful model for this kind of application is the multinomial model. In particular, this type of model has a higher chance of finding relationships by overcoming the statistical issues associated with highly variable data. And, the models provide a direct link between the level of use support and environmental measurements.

For example, within classes of lakes, data sets containing measurements from multiple lakes can be developed (i.e., a cross-sectional data base). Each observation in the data set would represent a sampling date for a specific lake with corresponding measurements of Chl *a*, N, or P as well as results from the user perception survey. In Virginia impoundments, a project rating the recreational fishery on a scale of 1 to 5 is currently underway (described above, see VA WRRC 2004) with corresponding measurements of key nutrients. The measurements of Chl *a*, N, or P

in each of the corresponding lakes results in a data set appropriate for fitting multinomial models. Here, the rating (1 to 5) is modeled as a function of either Chl *a*, N, or P. For individual water bodies, multiple measurements over time would be required. We suggest fitting all three models, if possible.

Multinomial models apply to data sets where observations fall into one of k categories (k>2). Binary models, like logistic functions, are special cases where k = 2. Multinomial models are general linear models (GLM) with specified link functions. In our case, the model can be written as:

$$g(P_{i\,r}) = \mu_r + \beta \text{ Chl } a$$

where,

g = a generalized link function like the logit or probit

i = the number of observations in class r

r = a category, r = 1,.., k total categories (in the above example k = 5)

$\mu$ = 1,...,k - 1 intercept terms that depend only on the categories

$\beta$ = generalized slope term common to each of the k categories

This same approach could be developed for other designated uses. For example, the recreational use of a water body could be rated on a scale from 1 to 5 based on user perception surveys or expert elicitation (see Tables 4 and 5 and Appendix 4). The same approach would work for water treatment costs to evaluate the public water supply use. Here, the ratings would reflect the relative cost of water treatment as a function of Chl *a*, N or P. The resulting cross-sectional data base should include enough observations to capture the range of possible ratings (e.g., 1 to 5) and the variability of the predictor variables in the lake population for which the criteria will be developed.

For example, Figures 2-4 (from Jensen et al. 2004) present hypothetical outputs that could be derived from the multinomial model (described below). One model is developed for each of the designated use categories using the associated scaled endpoints. The independent level of use models are comparable because both the x-axis (e.g., Chl *a*) and the y-axis (level of scaled response) have been normalized to comparative units. Graphics where the x-axis represents N or P could also be developed from models using N or P as predictor variables. The shapes of the curves vary, but the response variable is the same for all models as illustrated in the hypothetical plots. Therefore, the curves could be placed on the same graphic without loss of continuity or inference (Figure 5).

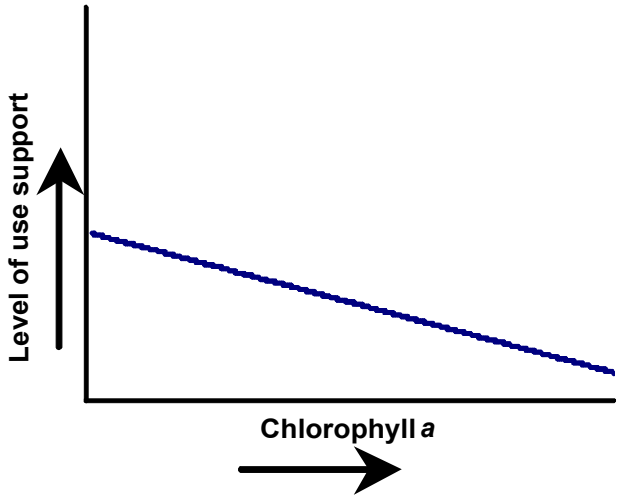


**Figure 2. Theoretical Relation Between Chlorophyll *a* and Level of Use Support for Recreation**

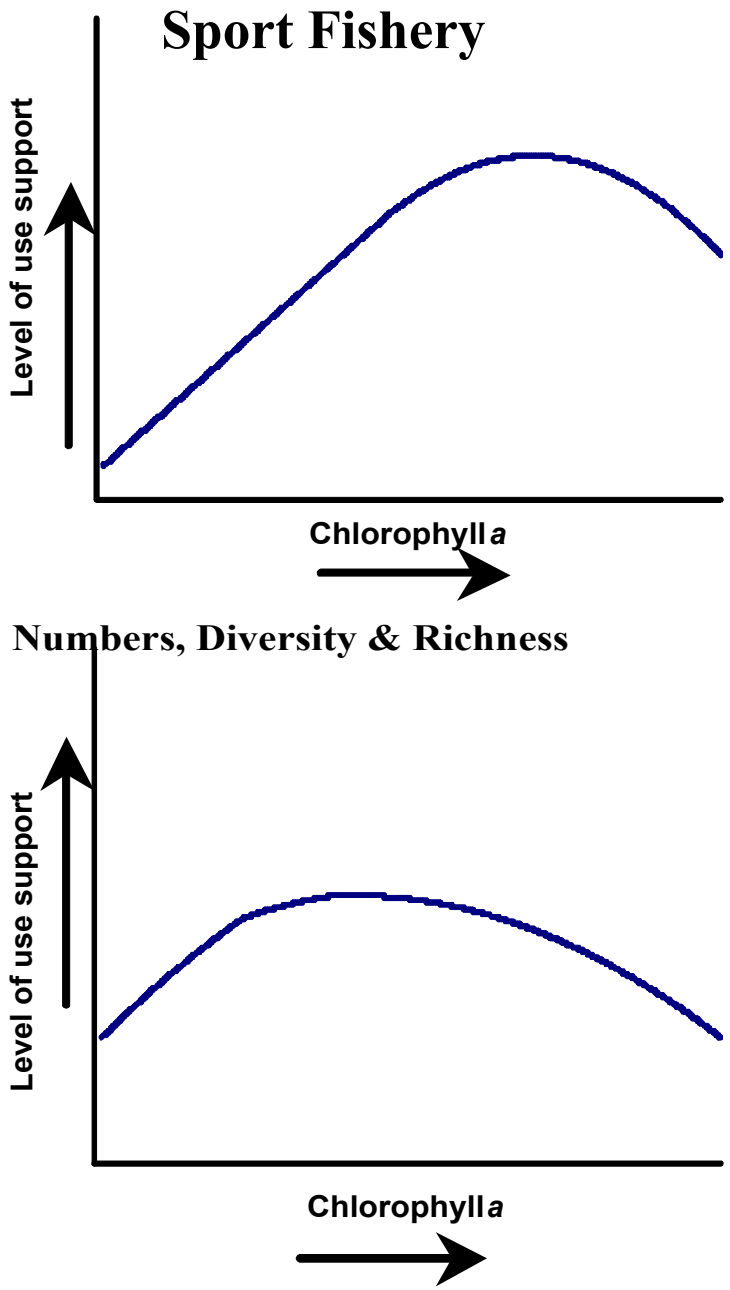


**Figure 3. Theoretical Relation Between Chlorophyll *a* and Level of Aquatic Life Support, Including Sport Fishery and Aquatic Biota Numbers, Diversity and Species Richness.**

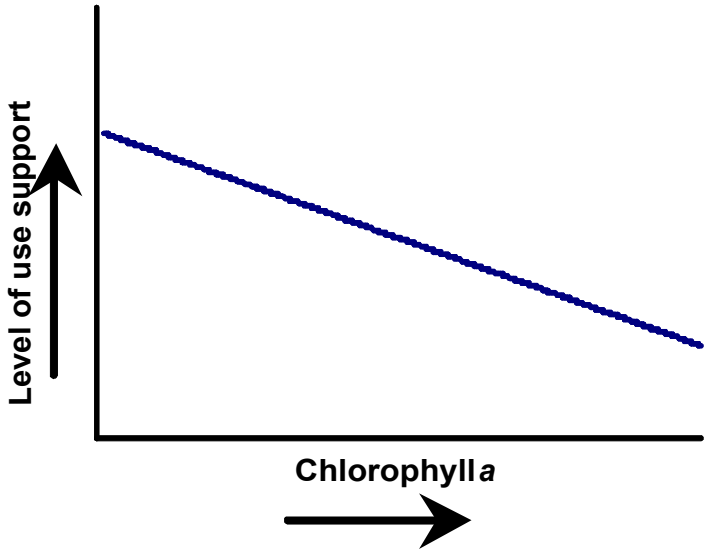


**Figure 4. Theoretical Relation Between Chlorophyll *a* and Level of Water Supply Use Support**

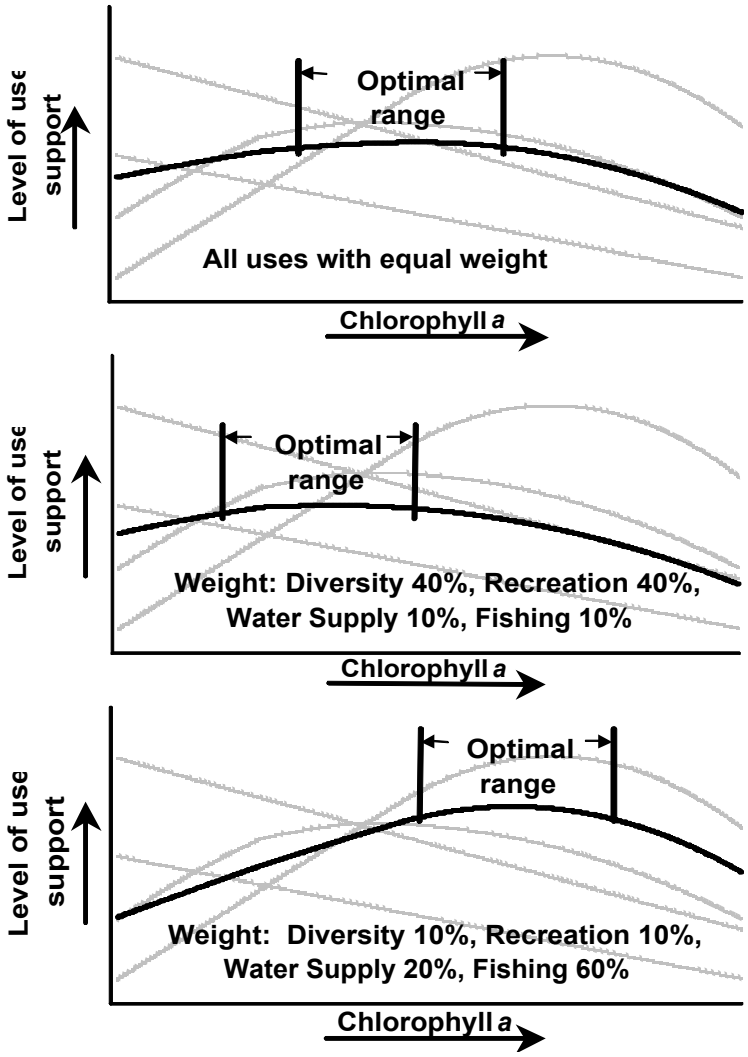


**Figure 5. Theoretical Relationship Between Overall Level Of Use Support and Chl *a* (taken from Jensen et al. 2004).**

For individual water bodies, the data set could represent changes in the water body over time, or it could represent differences in individual opinions of the same water body. Again, the final data set should capture the range of variability in both the response and predictor variables as described above.

The multinomial models described above are used in Step 8 (below) to select an optimal value or range of Chl *a* and associated N and P values that minimizes adverse impacts to all competing designated uses. The multinomial model framework allows decision makers to view competing uses graphically. This framework also overcomes issues in interpretation between multiple use models because the response is on the same scale (e.g., 1 to 5). If each designated use has a different response variable (e.g., fish species CPUE, benthic macroinvertebrate community score, recreation, treatment cost, etc.) then relating the relative importance of these metrics becomes an issue. For these models, some sort of normalization scheme must be developed if competing uses are to be discussed and debated. These types of multinomial analyses can be done using most commonly available statistical software packages, such as SAS or Minitab.

If significant relationships are not found in Step 6 analyses, then either (1) such relationships do not exist, or (2) the existing data were inadequate to identify the relationships. In this case, proceed to Step 9 to attempt to determine the factors that are confounding relationships between nutrients and response variables, or collect new data and then re-evaluate the relationships.

## 6.7 Step 7: Evaluate P and N vs. Response Variables

We strongly recommend the level of use suitability models discussed in Step 6. After these analyses are completed, the direct evaluation of relationships among total and dissolved P and N and primary and secondary response variables (e.g., D.O., pH) generally will be required, for example, in helping to select appropriate P and/or N criteria that will achieve the desired Chl *a* levels or secondary response levels. If significant relationships are found, they may be used to support the decisions made using the designated use models. In this case proceed to Step 8.

Primary response variables include Chl *a* (phytoplankton or periphyton) and SAV. Secondary response variables might include DO, pH, and various measures of the structure of the fish, algal (phytoplankton or periphyton), SAV, and benthic macroinvertebrate communities. Data for the other variables that affect primary production are necessary for developing relationships between nutrients and Chl *a* concentrations, as well as for evaluating designated uses. Examples of direct assessments based on field measurements of P, N, and Chl *a* and response variables are explored in this section.

Figure 6 summarizes trends in TN, TP, Chl *a* and TSS in the Neuse River near Kinston, NC from 1982-1995. From 1982-1995, TN concentrations remained fairly consistent. Beginning in 1988; however, TP concentrations declined when detergents containing phosphorus were banned from use in the watershed. Chl *a* levels also decreased during this period, suggesting that it may have responded to the decline in TP. In the Neuse River at Kinston, analysis of the data compiled from 1982–1995 indicates that TP averaged 136 µg/L, TN averaged 1481 µg/L, and the N:P ratio averaged about 9.0, suggesting that the river was P-limited.

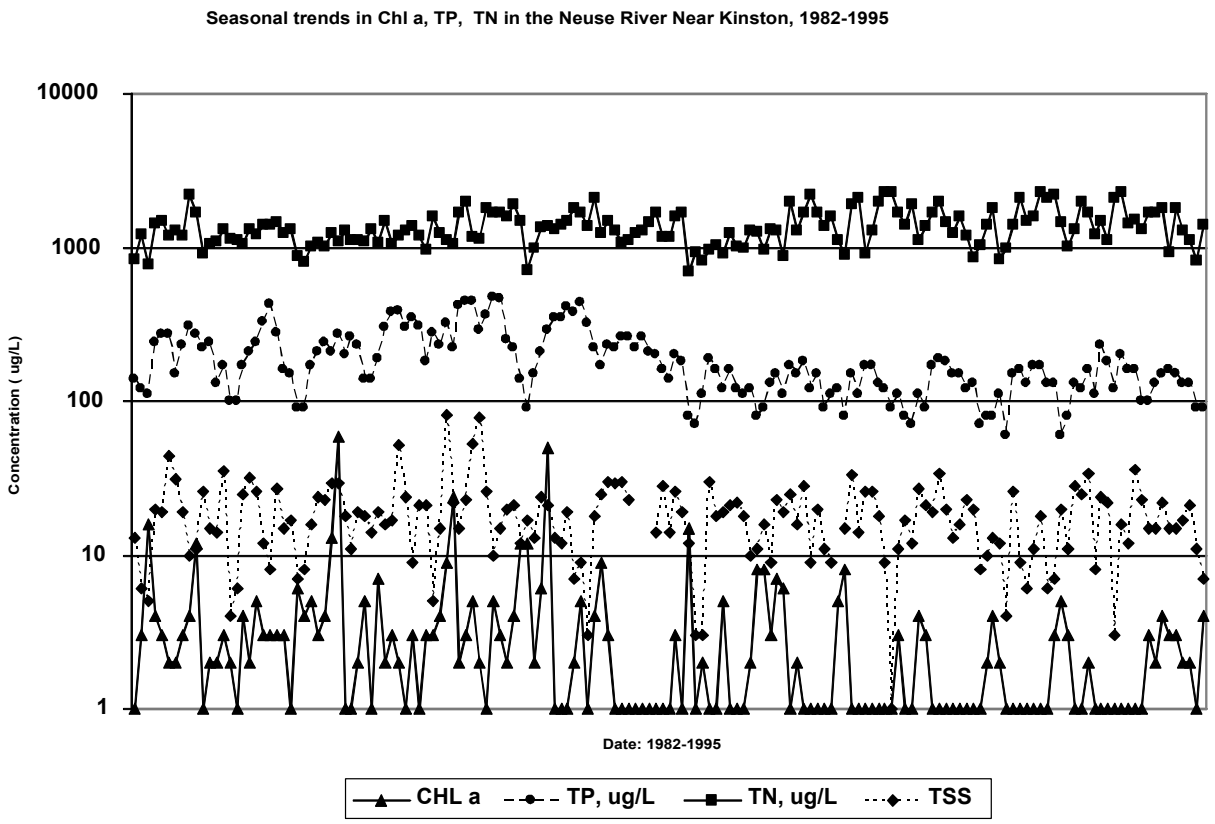


**Figure 6. Seasonal Trends in Chl a, TP, TN, and TSS in the Neuse River Near Kinston, North Carolina, 1982-1995.**

Box-and-whisker plots (Figure 7) are useful tools for examining shifts in the nutrient concentrations over growing seasons. From the box-and-whisker plot, investigators can visualize shifts in the mean, and median over time. Also, the presence of both low and high values in various years can be identified. Scatter plots examining relationships among response and effects variables are useful for visually assessing potential relationships among variables that can be incorporated into a predictive model. Generally, these plots are done on a base 10 logarithmic scale or on log10-transformed data. The following comparisons are useful for defining relationships between nutrients and algal biomass:

- measurements of Chl a, N, and P among seasons;
- growing season comparisons of Chl *a*, N, and P;

- summer mean total limiting nutrient concentration with summer mean and maximum Chl *a*;
- pre-maximum growth period (i.e., spring, pre-runoff) mean dissolved limiting nutrient concentration with maximum algal biomass;
- mean annual dissolved nutrient concentration with the 75th percentile mean algal biomass;
- cellular concentrations of the limiting nutrient with maximum algal biomass.

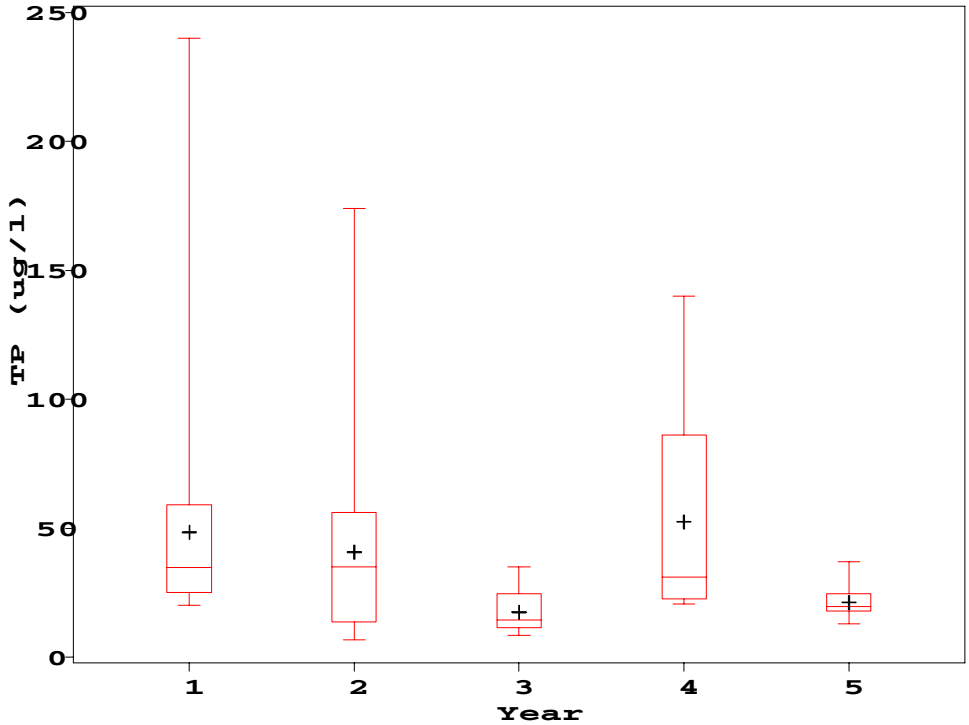


**Figure 7. Comparison of TP (ug/l) in Summer Growing Seasons During Five Consecutive Years in the Neuse River.**

Effects-based models are typically derived using ordinary least squares (OLS) regression techniques. These types of analyses can be done in Excel and most commonly available statistical software packages. Models of the form:

Response variable = f(effects variables)

are typically used to develop the predictive relationships. The New England Interstate Water Pollution Control Commission commissioned a literature review of OLS regression models applicable to rivers and streams (2001). Regression models for different stream and river types with various substrates are presented in the document.

In most cases, a large amount of variability is seen in bivariate relationships. For example, a case study of Hinkson Creek, MO, was presented in Warren-Hicks et al. (2005). A significant relationship between daily TN and sestonic Chl *a* was observed (Figure 8) throughout the year, but no such relationships were apparent for data from the growing season. The $R^2$ for the relationship for the entire year was 0.43, indicating that TN accounted for about 43% of the variability in Chl *a*.

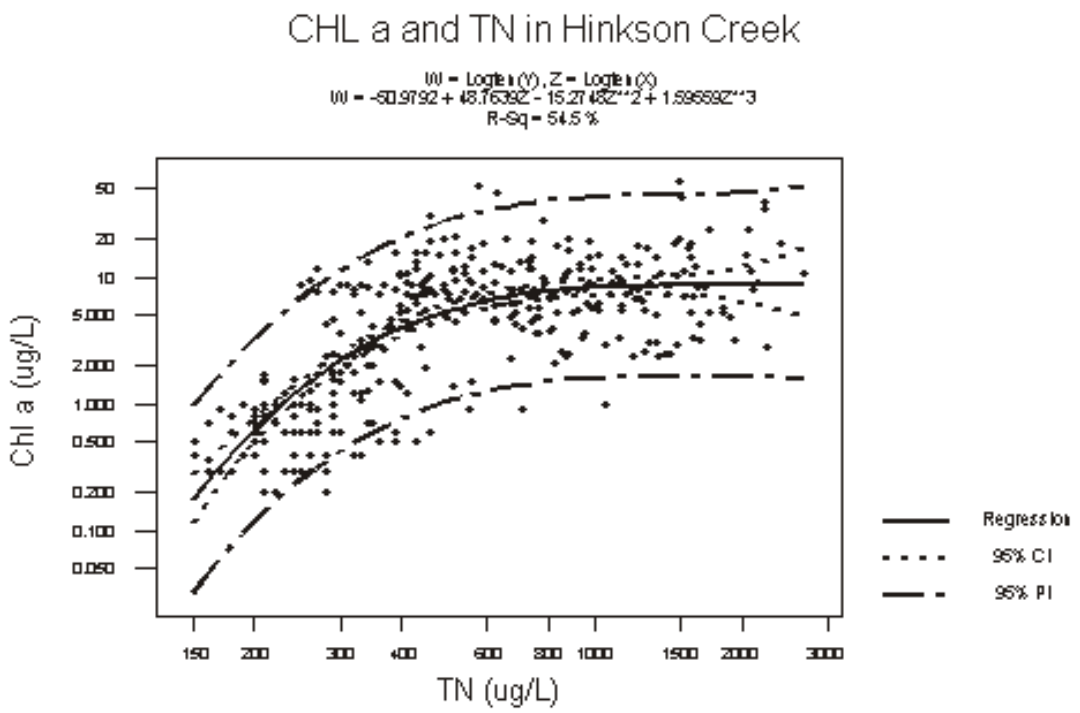


**Figure 8. Linear Regression Model of Sestonic Chl a and TN in Hinkson Creek Near Columbia, Missouri, February 1995–January 1996.**

By fitting a cubic, polynomial model to the data (Figure 9), the $R^2$ increased to about 0.55. The $R^2$ for the relationship between TP and Chl *a* was only 24% (Figure 10). The $R^2$ for the multiple regression between TP, TN and Chl *a* also was 43%, but in this equation the coefficient for TP was negative, which indicates that the variability in TN is dominating the relationship.

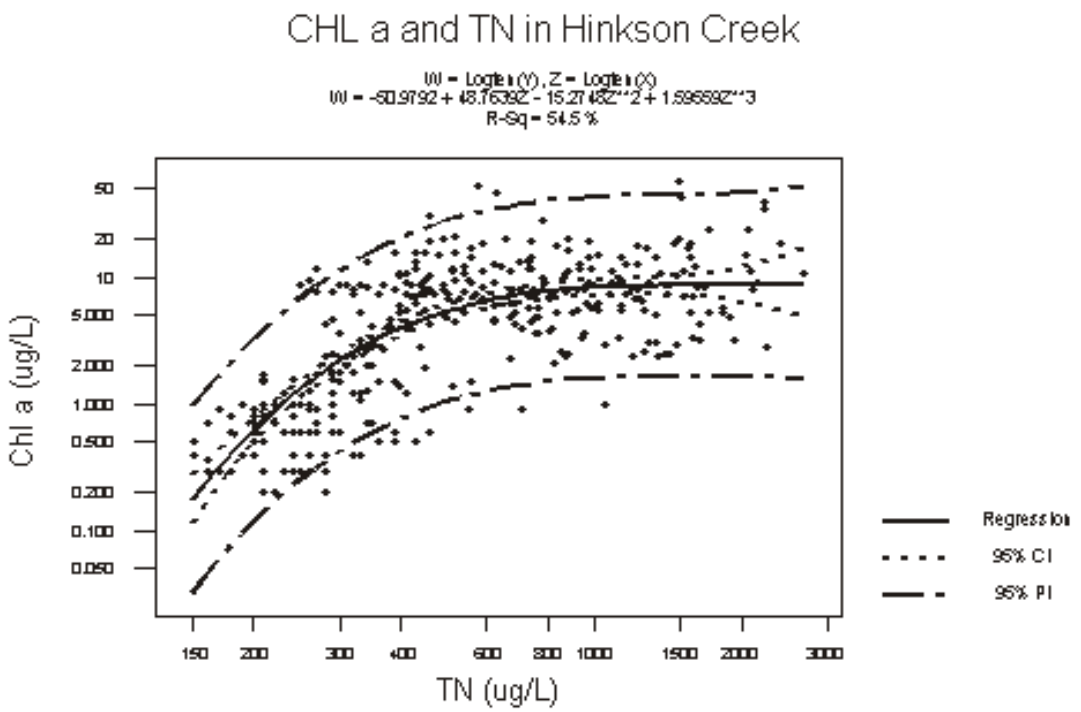


**Figure 9. Cubic Model of Sestonic Chl a and TN in Hinkson Creek Near Columbia, Missouri, February 1995–January 1996.**

The largest issue in the development of effects-based models is dealing with the variability in the response and predictor measurements. In many cases, linear relationships between the response and predictors variables are weak or non-existent (see Figure 10). Models developed from these data will have a large error in model prediction. Therefore, using the models to select nutrient criteria may result in selection of criteria that are over-protective or under-protective of

designated uses. Investigators must factor the model prediction error into any management decisions.

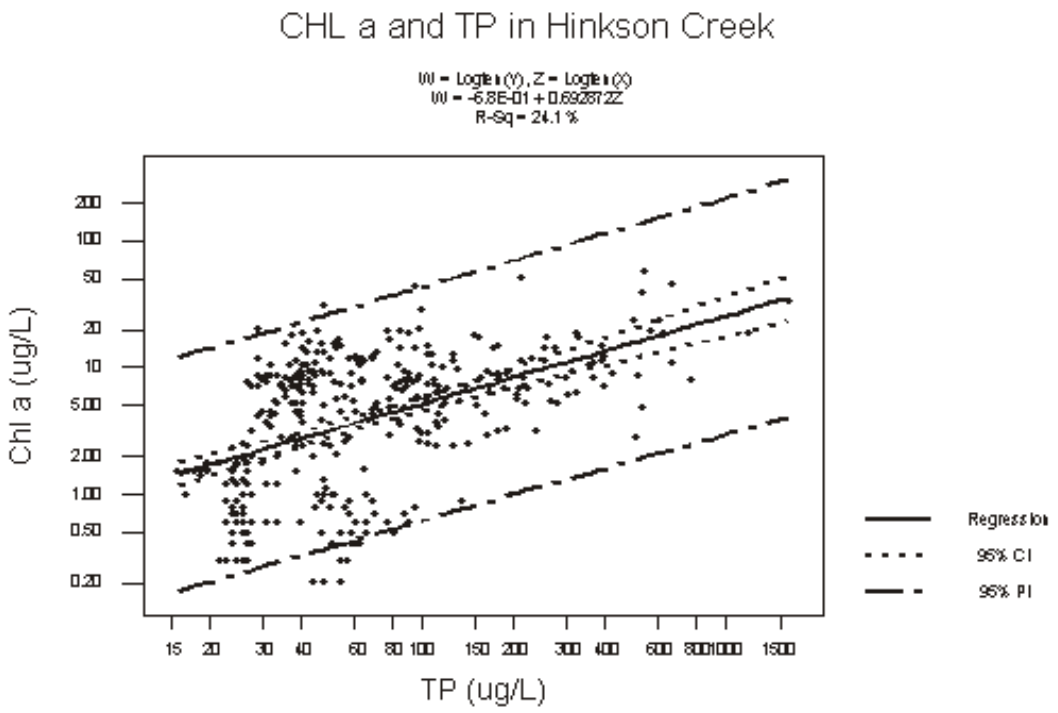


**Figure 10. Linear Regression Model of Chl a and TP in Hinkson Creek Near Columbia, Missouri, February 1995–January 1996.**

## 6.8 Step 8: Use Effects Data to Select Trial Criteria

We recommend that the selection of trial nutrient criteria be a based on the results of discussions among a group of stakeholders selected to represent all parties that have an interest in nutrient criteria for the water body or class of water bodies under evaluation. A net benefits approach to selecting trial criteria, such as discussed in Jensen et al. (2004), is recommended for reaching consensus or agreement. Jensen et al. (2004) studied the relationship between designated uses and nutrient data in nine Texas reservoirs. All of the study reservoirs had four uses that were evaluated: aquatic life diversity, sport fishing, recreation and water supply. The study

determined that Chl *a* was the parameter most directly related to all uses, and that it should be the parameter selected for numerical criteria development.

Each designated use was evaluated in relation to Chl *a* concentrations. In no case were precise quantitative relationships available, but the general patterns and directions were clearly established. Jensen et al. (2004) proposed a conceptual model of the general relationship between Chl *a* and each designated use (Figures 2-4, from Jensen et al. 2004). These types of plots can be developed using the multinominal analyses described in Step 6.

The role of the stakeholders is to select the Chl *a* concentration or range of concentrations that maximizes the net benefit among competing designated uses. Figure 5 (from Jensen et al. 2004) presents a graphical illustration for selecting an optimal concentration or range of concentrations for competing designated uses (for more on this topic, see Jensen et al. 2004). Plots such as Figure 5, can be generated using the analyses described in Step 6. Based on the perceived value of each of the uses, each use could be given a different weight and then the relationships re-evaluated. Once the optimum range for Chl *a* is selected, it would become the trial Chl *a* criterion. Next, the models of P and/or N vs. response variables developed in Step 7 would used to set trial P and/or N criteria. Criteria for P and/or N would only be necessary if they were shown to be significantly related to designated uses and response variables. If no significant relationships are identified, then it would be inappropriate to set P and N criteria, because of the lack of cause and effect relationships. In such cases, it would be appropriate to only have a Chl *a* criterion.

In waters with a clearly defined limiting nutrient (i.e., atomic N:P ratio >16, or >7 by weight), nutrient criteria development should focus on that nutrient (i.e., P). In most freshwater bodies, derivation of phosphorus criteria should be the primary focus for nutrient criteria development (VA WRRC 2004), while in estuaries and coastal marine waters derivation of nitrogen criteria should be the primary focus for nutrient criteria development (US EPA 2001).

Several mathematical methods are available for optimizing the choice of Chl *a,* N, or P criteria. For example, Figure 5 shows an average of optimized curves with the individual use curves in the background. Bayesian statistical methods provide a means of finding an average curve (Gelmen et. al 1998). Multi-attribute decision analysis may provide a means for optimizing the curves for choice of Chl *a* (or N or P) without loss of information (Clemen 1996). These methods are beyond the scope of this document.

## 6.9 Step 9: Determine Confounding Factors

For water bodies in which significant relationships among nutrients, designated uses, and response variable cannot be identified, these relationships may not exist because of confounding factors. Variables that may confound the relationships between nutrient concentrations and algal (phytoplankton and periphyton) and submerged aquatic vegetation (SAV) production include nutrient bioavailability, suspended sediments, turbidity, shading, transparency, stream scouring, stream velocity, invertebrate grazing, and stream substrate. For example, if the waterbody of interest has decreased transparency because of naturally high concentrations of dissolved organic carbon or suspended sediments, photosynthesis may be inhibited and algal biomass reduced. Such relationships could justify higher nutrient criteria provided downstream conditions would not be adversely affected, or indicate no linkage between designated uses and nutrients. The same types of procedures described in Step 7 should be used to evaluate the significance of these potentially confounding factors.

## 6.10 Step 10: Use Non-Effects-Based Data to Select Trial Criteria

For water bodies or classes of water bodies for which relationships among Chl *a*, levels of use support, and response variables cannot be adequately defined, either because of high variability or confounding factors, criteria development could be based solely on (1) the results of user perception surveys, or (2) ambient Chl *a* levels. User perception surveys compare user perceptions of water quality and designated uses of the water body with measurements of P, N,

Chl *a*, water clarity and/or other nutrient and response variables. Tables 3 and 4 present results of an example survey for a hypothetical lake. With these kinds of qualitative data, relationships between user perception and response variables could be developed using the methods in Step 6. If significant relationships are identified, then Figures, such as 2-5 (Jensen et al. 2004), can be generated using multinominal analyses. The results are then used by the stakeholder group to select the Chl *a* concentration or range of concentrations that maximizes the net benefit among competing designated uses using the same process as in Step 8. If no significant relationships between P and/or N vs. response variables are identified, which is likely if none were present for Chl *a* and designated use support, then it would be inappropriate to set P and N criteria, because of the lack of cause and effect relationships. In such cases, it would be appropriate to only have Chl *a* criteria. For such waters, the Chl *a* criterion could be set it as an upper estimate of long-term average levels, such as the mean plus 99% confidence level or the upper 99$^{th}$ percentile, which cannot be exceeded for some fixed percent of the time, (e.g., 10%).

The literature shows that user perception differs regionally as well as on a site-specific basis. One good example is taken from Minnesota, where large regional differences occur in the concentration of TP, an indicator of lake trophic state, which is considered acceptable for drinking water supply and primary contact recreation (Table 6). Perception regarding the level of algal biomass that constitutes a nuisance condition (Table 7) also varies across the region. In Oregon, Chl *a* levels >15 µg/L are considered to impair the beneficial uses of natural lakes, reservoirs, rivers, and estuaries. However, in North Carolina, the Chl *a* criterion is 40 µg/L. Chl *a* criteria for Ontario lakes are quite restrictive relative to other regions in North America (Table 8). These differences reflect regional water quality objectives and related uses that are locally attainable.

As stated previously, the recommended approach is to use quantitative data to determine relationships between the level of use support and Chl *a*. By linking the qualitative perception survey results with quantitative nutrient and response variable measurements, nutrient criteria that are scientifically sound, yet meet the needs of users can be obtained. If states or other

entities decide to pursue a more subjective approach that would rely on non-effects-based data, there is a risk that it may lead to the development of less-scientifically defensible nutrient criteria. This is an important consideration in determining the type of approach to pursue.

**Table 6. Most Sensitive Lake Uses by Ecoregion and Corresponding Phosphorus Criteria for Minnesota (Heiskary and Walker 1988) .**

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

**Table 7. Aesthetic or Use Impairment Classification Systems Based on Chl *a* or Transparency (Heiskary and Walker 1988) .**

| Author/Location | Chl *a* (µg/L) | Rating |
|---|---|---|
| Walmsley (1984)<br>South African Reservoir | 0–10<br>10–20<br>20–30<br>>30 | No Problems<br>Scums Evident<br>Nuisance<br>Severe Nuisance |
| Barica (1975)<br>Canadian Prairie Ponds | 0–25<br>25–100<br>100–200 | Clear, No Blooms<br>Moderate Blooms<br>Dense Colonies and Scums |
| McGhee (1983)<br>North Carolina | >15<br>>40 | Unsuitable for Trout<br>Severe Nuisance |
| Lillie and Mason (1983)<br>Wisconsin | <1<br>1–5<br>5–10<br>10–15<br>15–30<br>>30 | Excellent<br>Very Good<br>Good<br>Fair<br>Poor<br>Very Poor |

**Table 8. Potential Lake Uses Identified by Chlorophyll Levels for Lakes in Southern Ontario (Dillon and Rigler 1975) .**

| Chl *a* (µg/L) | Use Category |
|---|---|
| 2 | Body contact recreation and cold water fishery. |
| 5 | Water recreation where a cold water fishery is not imperative. |
| 10 | Body contact recreation of little importance, emphasis is on warm water fish. |
| 25 | Suitable for warm water fishery. |

## 6.11 Step 11: Evaluate Potential Unacceptable Downstream and Upstream Effects of Trial Criteria Effects

Nutrient criteria should be developed with a full understanding of potential impacts to downstream and upstream water quality. In some watersheds, it is possible that nutrient concentrations resulting in acceptable levels of algal biomass in rivers or streams may cause unacceptable levels of algal biomass in downstream lakes, reservoirs, and estuaries. For example, in waters bodies that undergo thermal stratification, hypolimnetic oxygen depletion may occur, with adverse effects to benthic and pelagic communities. In addition, discharges of low DO hypolimnetic waters from reservoirs may adversely impact aquatic life in downstream waters. In such cases, if nutrient loads from upstream sources cause unacceptable effects to one or more designated uses in downstream water bodies, then more stringent nutrient criteria may be required in the upstream water bodies. It is also possible that restrictive downstream criteria may limit upstream recreational opportunities by reducing overall fish production. Evaluation of potential downstream and upstream impacts of trial criteria will require a loading analysis, such as is done in a Total Maximum Daily Load (TMDL) analysis. If the trial criteria are predicted to prevent attainment or development of upstream or downstream criteria, then the trial criteria may have to be revised to preclude those impacts.

## 6.12 Step 12: Begin Criteria Adoption Process

If the proposed criteria are acceptable to the regulatory and regulated entities involved in developing the criteria, they could be submitted to the State water quality management agency and implemented as water quality standards. Implementation would occur through the State rulemaking process for updating water quality standards, which is required of each State by the Clean Water Act every three years (the “triennial review”).

## LITERATURE CITED

Clemen, R. T. 1986. Making Hard Decisions: An Introduction to Decision Analysis, 2 nd Edition, Duxbury Press, Belmont, CA.

Dillon, P.J., and G.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Bd. Can. 32:1519-1531.

Gelmen, A., Carlin, J.B., Stern, H. S., Rubin, D. B. 1998. Bayesian Data Analysis. Chapman and Hall, London, UK.

Jensen, P., A. Labay, K-L Lee, and G. Clingenpeel. 2004. Nutrient Criteria and Designated Uses for Reservoirs in the Trinity River Basin. Trinity River Authority, Dallas, TX.

Heiskary, S.A. and W.W. Walker, Jr. 1988. Developing phosphorus criteria for Minnesota Lakes. Lake Reserv. Manage. 4:1-9

Logit and Probit: Ordered and Multinomial Models. 2004. Vani Kant Borooah. Sage Publications, San Francisco.

New England Interstate Water Pollution Control Commission. 2001. The relationship between nutrient concentrations and periphyton levels in rivers and streams – a review of the scientific literature. Prepared by ENSR Corp., August 2001.

Texas Water Conservation Association. 2004. Investigation to support the development of nutrient criteria based on recreational uses of reservoirs. Presented to Texas Commission on Environmental Quality, Nutrient Criteria Development Advisory Workgroup, January, 2004.

U.S. Environmental Protection Agency (US EPA). 2000a. Nutrient criteria technical guidance manual for lakes and reservoirs. EPA-822-B00-001. U.S. Environmental Protection Agency, Washington, D.C.

U.S. EPA. 2000b. Nutrient criteria technical guidance manual for river and streams. EPA-822-B-00-002. United States Environmental Protection Agency, Washington, D.C.

U.S. EPA. 2001. Nutrient criteria technical guidance manual for estuaries and coastal waters. EPA-822-B-00-003. United States Environmental Protection Agency, Washington, D.C.

Virginia Water Resources Research Center (VA WRRC). 2004. Report of the Academic Advisory Committee to the Virginia Department of Environmental Quality - Freshwater Nutrient Criteria. Report submitted to Virginia Department of Environmental Quality.

Virginia Department of Environmental Quality (VA DEQ). 2004. Nutrient criteria development plan for the Commonwealth of Virginia. Water Division, Office of Water Quality Programs.

Warren-Hicks, W., B.R. Parkhurst, S. Bartell, and M. Smart. 2005. Technical Approaches for Setting Site-Specific Nutrient Criteria. Project 99-WSM-3. Water Environment Research Foundation, Alexandria, VA.

Washington State Department of Ecology (WA DOE). 2000. Water quality assessments of selected lakes within Washington State. Publication No. 00-03-039, Environmental Assessment Program, Olympia, WA.

# APPENDIX 1

## Example State Nutrient Criteria Development Plan: Virginia

# APPENDIX 2

## Report Of The Academic Advisory Committee To The Virginia Department of Environmental Quality – Freshwater Nutrient Criteria

# APPENDIX 3

## Developing Uses and Nutrient Criteria For Reservoirs In The Trinity River Basin

# APPENDIX 4

## Water Quality Assessments of Selected Lakes Within Washington State