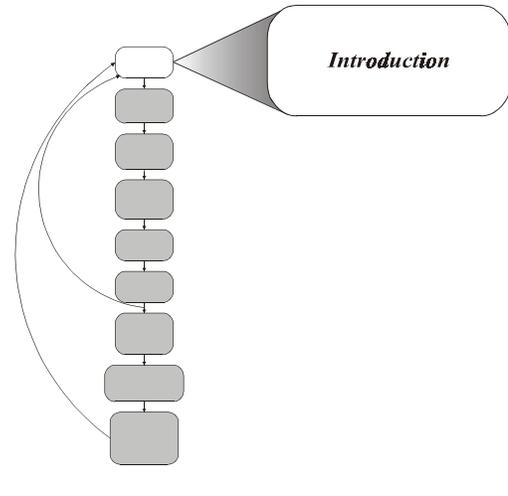


Chapter 1.

Introduction



1.1 PURPOSE OF THE DOCUMENT

The purpose of this document is to provide scientifically defensible technical guidance to assist States and Tribes in developing regionally-based numeric nutrient, algal, and macrophyte criteria for river and stream systems. Criteria are “elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use” (USEPA 1994). Water quality criteria are based on scientifically-derived relationships among water constituents and biological condition. “Water quality standards (WQS) are provisions of State or Federal law which consist of a designated use or uses for the waters of the United States, water quality criteria for such waters based upon such uses. Water quality standards are to protect public health or welfare, enhance the quality of the water, and serve the purposes of the Act (40 CFR 131.3)” (USEPA 1994). Water quality standards are comprised of three main components: criteria, which are scientifically based; designated uses, which involve economic, social and political considerations including effects on downstream receiving waters; and an anti-degradation policy, which protects the level of water quality necessary to maintain existing uses (Figure 1).

Water quality can be affected when watersheds are modified by alterations in vegetation, sediment balance, or fertilizer use from industrialization, urbanization, or conversion of forests and grasslands to agriculture and silviculture (Turner and Rabalais 1991; Vitousek et al. 1997; Carpenter et al. 1998). Cultural eutrophication (human-caused inputs of excess nutrients in waterbodies) is one of the primary factors resulting in impairment of U.S. surface waters (USEPA 1996). Both point and nonpoint sources of nutrients contribute to impairment of water quality. Point source discharges of nutrients are fairly constant and are controlled by USEPA National Pollutant Discharge Elimination System (NPDES) permitting (see Section 8.3) [Source: <http://www.epa.gov/owm/gen2.htm>]. Nonpoint pollutant inputs have increased in recent decades and have degraded water quality in many aquatic systems (Carpenter et al. 1998). Nonpoint sources of nutrients are most commonly intermittent and are usually linked to seasonal agricultural activity or other irregularly-occurring events such as construction or storm events.

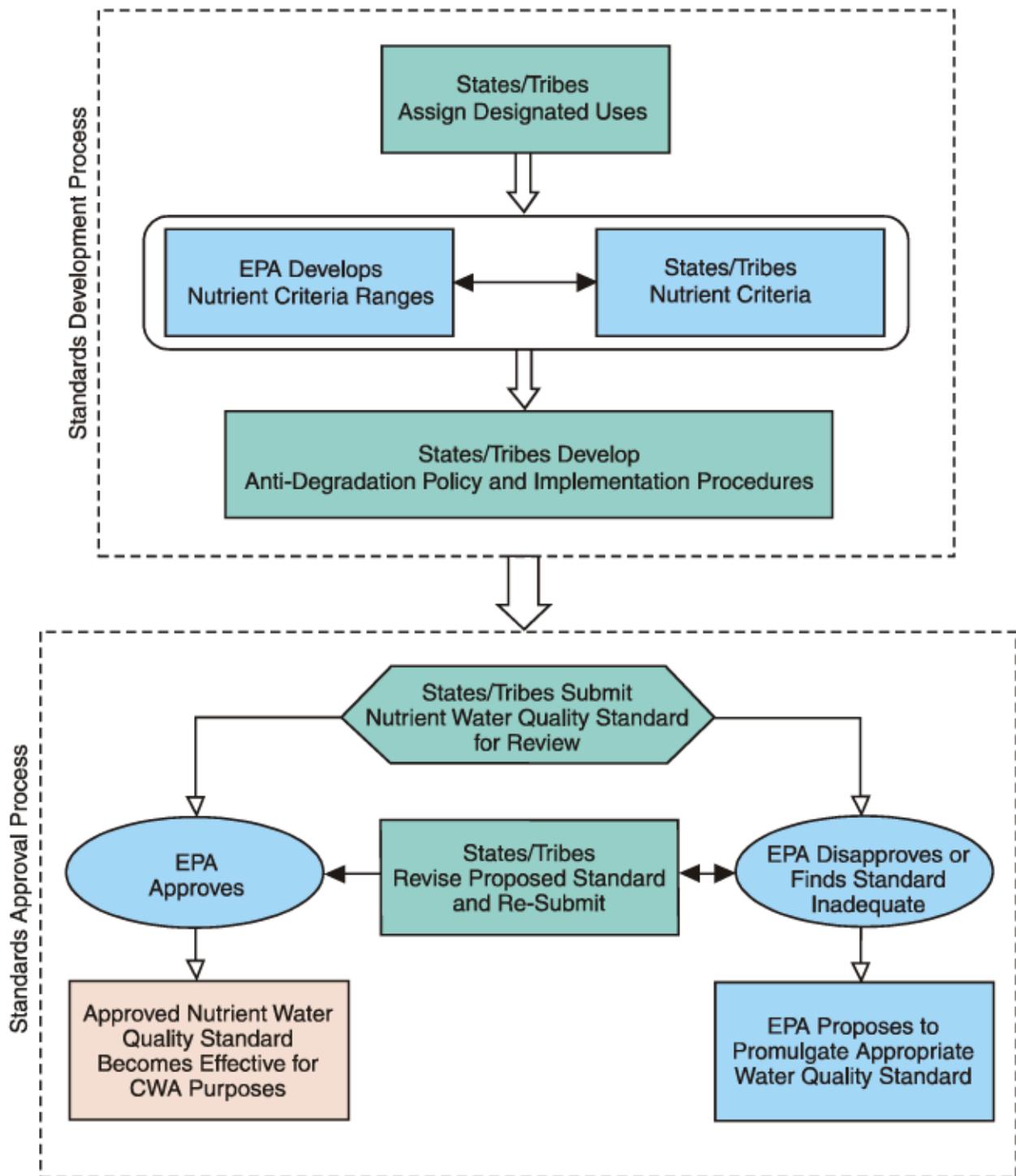


Figure 1. Developing water quality standards for nutrients.

Control of nonpoint source pollutants focuses on land management activities and regulation of pollutants released to the atmosphere (Carpenter et al. 1998).

Control of nutrients is further complicated by the cycling of nitrogen (N) and phosphorus (P) in aquatic systems. Nutrients can be re-introduced into a waterbody from the sediment, or by microbial transformation, potentially resulting in a long recovery period even after pollutant sources have been reduced. In flowing systems, nutrients may be rapidly transported downstream and the effects of nutrient inputs may be uncoupled from the nutrient source, further complicating nutrient source control (Turner and Rabalais 1991; Wetzel 1992; Vitousek et al. 1997; Carpenter et al. 1998). Recognizing cause-and-effect relationships between nutrient input and general waterbody response is the first step in mitigating the effects of cultural eutrophication. Once relationships are established, nutrient criteria can be developed to protect waterbodies. This document describes the process of developing numeric nutrient criteria, a new initiative by the USEPA to address the problem of cultural eutrophication (USEPA 1998a).

The Clean Water Action Plan, a presidential initiative released in February 1998, provides a blueprint for Federal agencies to work with States, Tribes and other stakeholders to protect and restore the Nation's water resources. The Clean Water Action Plan includes an initiative to address the nutrient enrichment problem. Building on this initiative, the USEPA developed a report entitled *National Strategy for the Development of Regional Nutrient Criteria* (USEPA 1998a). The report outlines a framework for development of waterbody-specific technical guidance that can be used to assess nutrient status and develop regional-specific numeric nutrient criteria. This technical guidance manual builds on the strategy and provides specific guidance for rivers and streams. Similar documents are being prepared for lakes and reservoirs, estuaries and coastal marine waters, and wetlands.

For the purposes of this document, river and stream systems are identified collectively as streams or stream systems, unless otherwise noted. Information presented here will provide water quality managers with an overview of the current state of the science, guidance on establishing and compiling a database, and suggested methods for data analyses. The process for setting stream nutrient and algal criteria ranges and a summary of appropriate regulatory and technical considerations are discussed. Diverse geomorphic and climatologic conditions throughout the nation require nutrient and algal criteria development to occur at the ecoregional, State, Tribal, or individual waterbody level to be scientifically valid. The framework for nutrient and algal criteria development follows a logical iterative process that begins with defining goals and needs for State and Tribal water quality. The steps of the process are described in this chapter and detailed in succeeding chapters.

1.2 NUTRIENT ENRICHMENT PROBLEMS IN RIVERS AND STREAMS

Nutrient enrichment frequently ranks as one of the top causes of water resource impairment. Systems are impaired when water quality fails to meet designated use criteria. The USEPA reported to Congress that of the systems surveyed and reported impaired, 40 percent of rivers, 51 percent of lakes, and 57 percent of estuaries listed and nutrients as a primary cause of impairment (USEPA 1996). The nutrient enrichment issue is not new; however, traditional efforts at nutrient control have been only moderately successful. Specifically, efforts to control nutrients in waterbodies that have multiple nutrient sources (point and nonpoint sources) have been less effective in providing satisfactory, timely remedies for

enrichment-related problems. The development of numeric criteria should aid control efforts by providing clear numeric goals for nutrient and algal/macrophyte levels. Furthermore, numeric nutrient criteria provide specific water quality goals that will assist researchers in designing improved best management practices.

Nutrient impaired waters can cause problems that range from annoyances to serious health concerns (Dodds and Welch 2000). Nuisance levels of algae and other aquatic vegetation (macrophytes) can develop rapidly in response to nutrient enrichment when other factors (i.e., light, temperature, substrate, etc.) are not limiting. High macrophyte growth can interfere with aesthetic and recreational uses of stream systems (Welch 1992). Algae in particular can grow rapidly when the nutrients N and P (primary nutrients that most frequently limit algal growth, see Section 6.2 Defining the Limiting Nutrient) are abundant, often developing into single or multiple species blooms. Algal bloom development involves complex relationships that are not always well understood. However, the relationship between nuisance algal growth and nutrient enrichment in stream systems has been well-documented in the literature (Welch 1992; Van Nieuwenhuysse and Jones 1996; Dodds et al. 1997; Chetelat et al. 1999). Taste and odor problems in drinking water supplies are usually caused by algal blooms and actinomycete (nitrogen-fixing filamentous bacteria) occurrence and other bacterial blooms that frequently follow (Silvey and Watt 1971; Dorin 1981; Taylor et al. 1981). Algal blooms of certain cyanobacterial species produce toxins that can affect animal and human health. Reports of livestock, waterfowl, and occasionally human poisonings after drinking from waterbodies with blue-green algal blooms are not uncommon (Darley 1982; Carmichael 1986, 1994).

Human health problems can be attributed to nutrient enrichment. One serious human health problem associated with nutrient enrichment is the formation of trihalomethanes (THMs). Trihalomethanes are carcinogenic compounds that are produced when certain organic compounds are chlorinated and bromated as part of the disinfection process in a drinking water treatment facility. Trihalomethanes and associated compounds can be formed from a variety of organic compounds including humic substances, algal metabolites, and algal decomposition products. The density of algae and the level of eutrophication in the raw water supply has been correlated with the production of THMs (Oliver and Schindler 1980; Hoehn et al. 1982).

Effects directly related to nutrients can also result in human health problems. A study of nitrate in groundwater (the primary source of drinking water in the US) indicated that nitrate contamination generally increased with high nitrogen input, greater proportions of well-drained soils, and low woodland to cropland ratios (Nolan et al. 1997). The USEPA has an established maximum contaminant level of 10 mg/L because nitrates in drinking water can cause potentially fatal low oxygen levels in the blood when ingested by infants (USEPA 1995). Nitrate concentrations as low as 4 mg/L in drinking water supplies from rural areas have also been linked to an increased risk of non-Hodgkin lymphoma (Ward et al. 1996). A more detailed discussion of human health concerns related to eutrophication can be found in Suess (1981).

Nutrient impairment can cause problems other than those related to human health. One of the most expensive problems caused by nutrient enrichment is the increased treatment required for drinking water. Nutrient enriched waters commonly cause drinking water treatment plant filters to clog with algae or macrophytes (Welch 1992) and can contribute to the corrosion of intake pipes (Nordin 1985). High algal

biomass in drinking water sources require greater volumes of water treatment chemicals, increased back-flushing of filters, and additional settling times to attain acceptable drinking water quality (Nordin 1985).

Adverse ecological effects associated with nutrient enrichment include reductions in dissolved oxygen (DO) and the occurrence of HABs (harmful algal blooms). High algal and macrophyte biomass may be associated with severe diurnal swings in DO and pH in some waterbodies (Wong et al. 1979; Welch 1992; Edmonson 1994; Correll 1998). Low DO can release toxic metals from sediments (Brick and Moore 1996) contaminating habitats of local aquatic organisms. In addition, low DO can cause increased availability of toxic substances like ammonia and hydrogen sulfide, reducing acceptable habitat for most aquatic organisms, including valuable game fish. Decreased water clarity (increased turbidity) can cause loss of macrophytes and creation of dense algal mats. Loss of macrophytes and increased algal biomass may also reduce habitat availability for aquatic organisms. Thus, nutrient enrichment may alter the native composition and species diversity of aquatic communities (Nordin 1985; Welch 1992; Smith 1998; Carpenter et al. 1998; Smith et al. 1999).

A large area (6,000 to 7,000 square miles) of hypoxia—water which contains less than 2 parts per million of DO—located off the Gulf of Mexico Texas-Louisiana Shelf is believed to be caused by a complicated interaction of excessive nutrients transported to the Gulf of Mexico from the Mississippi River drainage; physical changes to the river (e.g., channelization and loss of natural wetlands and vegetation along riverbanks); and the interaction of riverine freshwater with Gulf marine waters (Turner and Rabalais 1994; Rabalais et al. 1996; Brezonik et al. 1999). Hypoxia can cause stress or death in bottom dwelling organisms that cannot move out of the hypoxic zone. Abundant nutrients trigger excessive algal growth which results in reduced sunlight, loss of aquatic habitat, and a decrease in DO. Depletion of DO for the water column has resulted in virtually no biological activity in the hypoxic zone. Reductions in DO have also been implicated in fish kills leading to significant economic impacts on local recreational and commercial fisheries.

Harmful algal blooms (e.g., brown tides, toxic *Pfiesteria piscicida* outbreaks, and some types of red tides) are also associated with excess nutrients. Evidence suggests that nutrients may directly stimulate the growth of the toxic form of *Pfiesteria*, although more research is required to prove this conclusively (Burkholder et al. 1992; Glasgow et al. 1995). *Pfiesteria* has been implicated as a cause of major fish kills at many sites along the North Carolina coast and in several Eastern Shore tributaries of the Chesapeake Bay.

The primary limiting nutrients in freshwaters are phosphorus and nitrogen. Phosphorus is a mineral nutrient, i.e., it is introduced into the biological components of the environment by the breakdown of rock and soil minerals. The breakdown of mineral phosphorus produces inorganic phosphate ions (PO_4^{3-}) that can be absorbed by plants from the soil or water. Phosphorus moves through the food web primarily as organic phosphorus (after it has been incorporated into plant or algal tissue), where it may be released as phosphate in urine or other waste (by heterotrophic consumers) and reabsorbed by plants or algae to start another cycle (Figure 2a) (Nebel and Wright 2000).

The primary reservoir of nitrogen is the air. Plants and animals cannot utilize nitrogen directly from the air, but require nitrogen in mineral form such as ammonium ions (NH_4^+) or nitrate ions (NO_3^-) for uptake. However, a number of bacteria and cyanobacteria (blue-green algae) can convert nitrogen gas to the

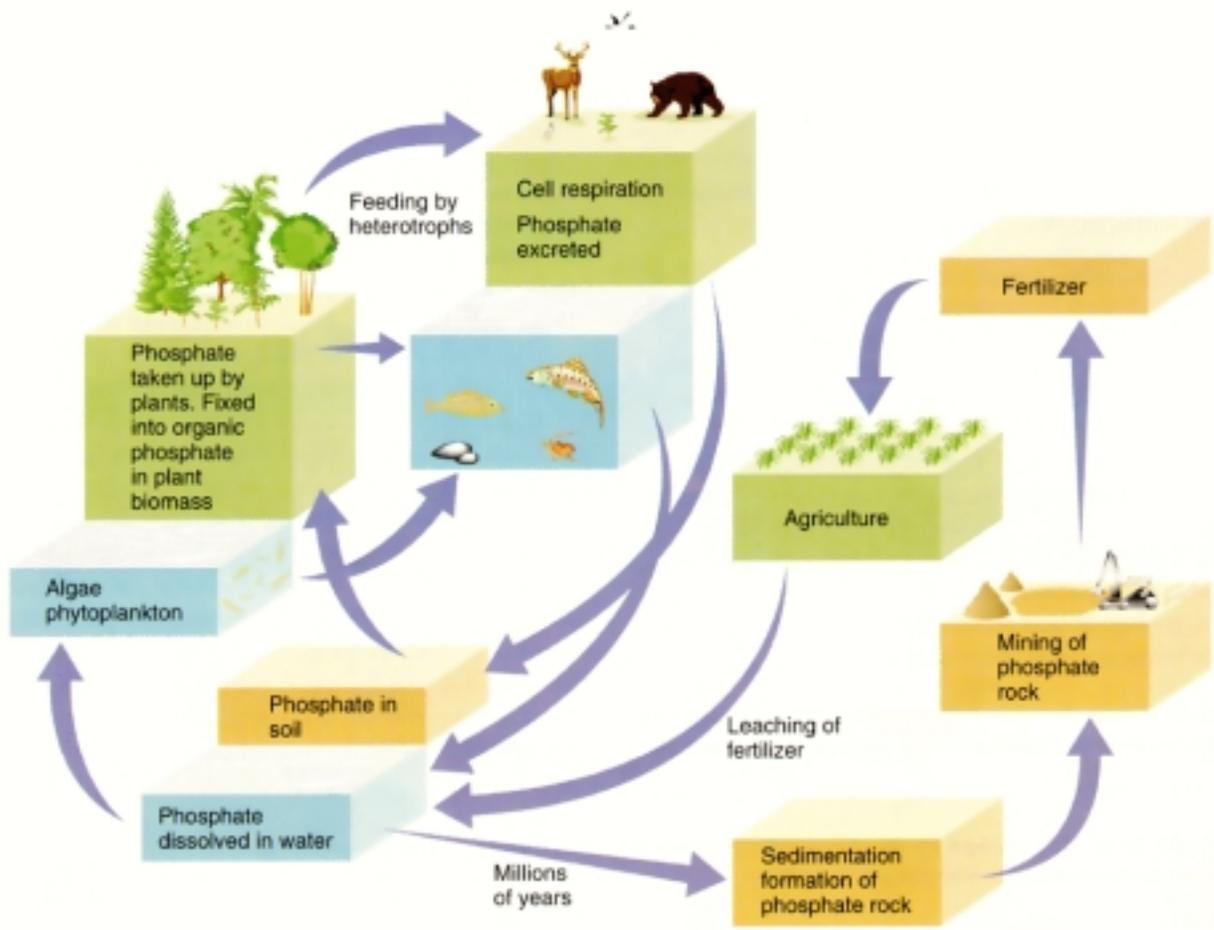


Figure 2a. The phosphorus cycle.

Source: Environmental Science: The Way the World Works 7/E by Nebel & Wright, ©2000. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ.

ammonium form through a process called biological nitrogen fixation. Mineral forms of nitrogen can be taken up by plants and algae, and incorporated into plant or algal tissue. Nitrogen follows the same pattern of food web incorporation as phosphorus, and is released in waste primarily as ammonium compounds. The ammonium compounds are usually converted to nitrates by nitrifying bacteria, making it available again for uptake, starting the cycle anew (Figure 2b) (Nebel and Wright 2000).

Nitrogen and P are transported to receiving waterbodies from rain, overland runoff, groundwater, drainage networks, and industrial and residential waste effluents. Once nutrients have been received in a waterbody they can be taken up by algae, macrophytes and micro-organisms (either in the water column or in the benthos); sorbed to organic or inorganic particles in the water and sediment; accumulated or recycled in the sediment; or transformed and released as a gas from the waterbody (denitrification).

Nitrogen and P have different chemical properties and therefore are involved in different chemical processes. Nitrogen gas dissolved in the water column may be converted to ammonia (a usable form of N) by nitrogen-fixing bacteria and algae when nitrate or ammonia are not readily available. However, receiving waters can lose N through denitrification—anaerobic transformation of nitrate or nitrite into gaseous N oxides (which are released into the air)—mediated by denitrifying bacteria (Atlas and Bartha 1993). Phosphorus is found primarily in two forms, organic and inorganic, in freshwater. The biologically available form of inorganic P in water is orthophosphate (PO_4^{-3}). Most P in surface water is bound organically, and much of the organic P fraction is in the particulate phase of living cells, primarily algae (Wetzel and Likens 1991). The remainder of the organic fraction is present as dissolved and colloidal organic P. Phosphorus readily sorbs to clay particles in the water column reducing availability for uptake by algae, bacteria and macrophytes. The exchange of P between the sediments and overlying water involves net movement of P into the sediments. Exchanges across the sediment interface are regulated by mechanisms associated with mineral-water equilibria, sorption processes, redox interactions, and the activities of bacteria, fungi, algae, and invertebrates. Therefore, P in the sediment is slow to recycle into the water column. Detailed discussions of N and P cycling in freshwater can be found in Wetzel (1983); Goldman and Horne (1983); Atlas and Bartha (1993); and other limnology texts.

Many lakes have been successfully treated for nutrient enrichment problems by an assortment of techniques (Cooke et al. 1993). Lake Washington is a well-recognized example of nutrient diversion. Nutrients were diverted from Lake Washington by eliminating direct discharge from wastewater treatment plants and other dischargers, effectively reducing nuisance algal blooms and improving water clarity (Edmonson 1994). Although many cases have been documented for controlling organic waste inputs to rivers (e.g., the Thames River, England [Goldman and Horne 1983]), nutrient control efforts to correct algal and/or macrophyte problems in streams and rivers have been either minimal or undocumented in the peer-reviewed, published literature. Two well-documented cases are described in detail in Appendix A: the Clark Fork River, MT, and the Bow River, Alberta. Despite these and other efforts, a greater percentage of stream systems surveyed are reported as being nutrient impaired (USEPA 1994; USEPA 1996).

Many States, Tribes, and Territories have adopted some form of nutrient criteria related to maintaining natural conditions and avoiding nutrient enrichment. Most States and Tribes have narrative criteria with no specific numeric criteria. Established criteria most commonly pertain to P concentrations in lakes. Nitrogen criteria, where they have been established, are usually in response to the toxic effects of

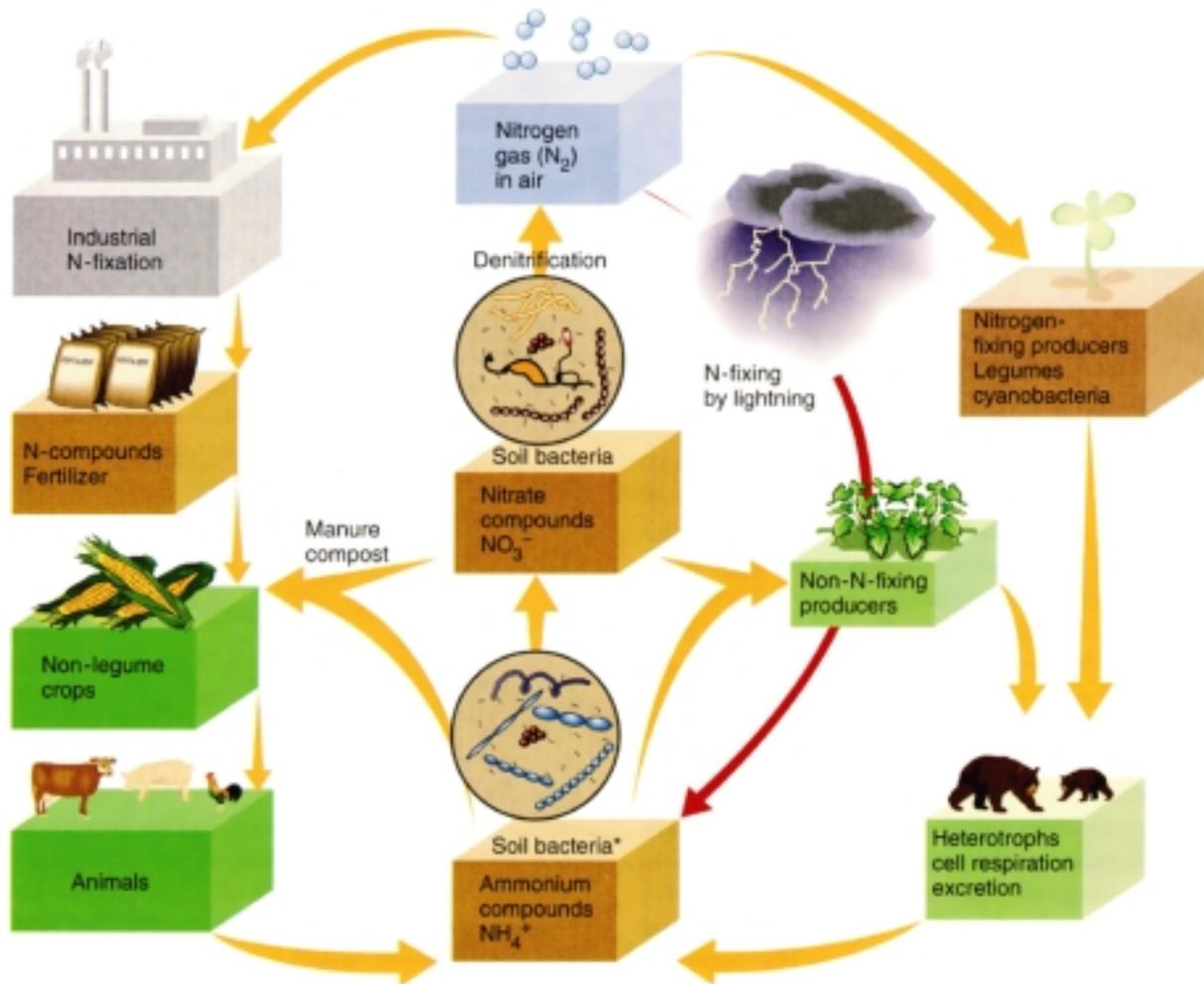


Figure 2b. The nitrogen cycle.

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ammonia and nitrates. In general, levels of nitrates (10 ppm for drinking water) and ammonia high enough to be toxic (1.24 mg N/L at pH = 8 and 25°C) will also cause problems of enhanced algal growth (USEPA 1986).

1.3 WATER QUALITY STANDARDS AND CRITERIA

States and authorized Tribes are responsible for setting water quality standards to protect the physical, biological, and chemical integrity of their waters (Figure 1). “Water quality standards (WQS) are provisions of State or Federal law which consist of a designated use or uses for the waters of the United States, water quality criteria for such waters based upon such uses. Water quality standards are to protect public health or welfare, enhance the quality of the water, and serve the purposes of the Act (40 CFR 131.3)” (USEPA 1994). A water quality standard defines the goals for a waterbody by designating its specific uses, setting criteria to protect those uses, and establishing an antidegradation policy to protect existing water quality. The three main components of water quality standards are based on different concerns: criteria are scientifically based; specific uses involve economic, social and political considerations including the protection of downstream receiving waters; and the anti-degradation policy protects the level of water quality necessary to maintain designated uses (Figure 1). A waterbody can be defined by an existing use (a use actually attained in the waterbody on or after November 28, 1975—the date of the promulgation by USEPA of the first water quality standards regulations) or designated use (a use specified in a water quality standard for each waterbody or segment, regardless of whether it is being attained). An established use cannot be removed unless it is being replaced by one requiring more stringent (protective) criteria. At a minimum, the uses must include recreation in and on the water, and propagation of fish and wildlife (Clean Water Act, Section 101[a] and 303[c]). Other uses, such as boating, cold water fisheries, or drinking water supply, may also be adopted.

Once designated uses of a waterbody have been established, the State or Tribe must adopt numeric or narrative criteria to protect and support the specified uses. Narrative criteria are verbal expressions of desired water quality conditions that are meant to describe the unimpaired condition of a waterbody. A narrative criterion from Vermont is shown below:

There shall be no increase, in any waters, of total phosphorus above background conditions that may contribute to the acceleration of eutrophication or the stimulation of the growth of aquatic biota in a manner that has an undue adverse effect on any beneficial values or uses of any adjacent or downstream waters.

(Source: <http://www.state.vt.us/wtrboard/rules/vwqs.htm#C1S1>)

Numeric criteria, on the other hand, attempt to quantify this ideal by building on and refining narrative criteria. Numeric criteria are values assigned to measurable components of water quality, such as the concentration of a specific constituent that is present in the water column (e.g., average total phosphorus [TP] concentration in a recreational stream shall not exceed 20 µg/L during the growing season). In addition to narrative and numeric criteria, some States and Tribes use numeric goals or assessment levels, an intermediate step between numeric criteria and water quality standards, that are not written into State or Tribal laws but are used internally by the State or Tribal agency for assessment and management purposes.

Numeric criteria can be more useful than narrative criteria in a number of ways. Numeric criteria provide distinct interpretations of acceptable and unacceptable conditions, form the foundation for responsible measurement of environmental quality, and reduce ambiguity for management and enforcement decisions. Despite these advantages, however, most of the Nation's waterbodies do not have numeric nutrient criteria. The lack of numeric criteria makes it difficult to assess the condition of rivers and streams and develop protective water quality standards, hampering the water quality manager's ability to implement management strategies.

Setting numeric nutrient criteria can provide a variety of benefits. For example, information obtained from compiling existing data and conducting new surveys can provide water quality managers and the public a better perspective on the condition of State and Tribal waters. The compiled waterbody information can be used to most effectively budget personnel and financial resources for the protection and restoration of river and stream systems. In a similar manner, data collected in the criteria development and implementation process can be compared before, during, and after specific management actions. Analyses of these data can determine the response of the waterbody and the effectiveness of management endeavors.

Nutrient criteria also support watershed-protection activities. Nutrient criteria can be used in conjunction with State/Tribal and Federal biocriteria surveys, National Estuary Program and Clean Lakes projects, and in development of TMDLs (Total Maximum Daily Loads) to improve resource management at local, State, Tribal, and national levels.

1.4 OVERVIEW OF THE CRITERIA DEVELOPMENT PROCESS

This section describes the five general elements of nutrient criteria development outlined in the National Strategy (USEPA 1998a) and is followed by a detailed overview of the steps taken to derive nutrient criteria for river and stream systems. A prescriptive approach is not appropriate due to regional differences that exist and the scientific community's limited technical understanding of the relationship between nutrients, algal growth, and other factors (e.g., flow, light, substrata). The approach chosen for criteria development must be tailored to meet the specific needs of each State or Tribe.

The USEPA has adopted the following principal elements as part of its *National Strategy for the Development of Regional Nutrient Criteria* (USEPA 1998a). This document can be downloaded in PDF format at the following website: www.epa.gov/OST/standards/nutrient.html.

1. Ecoregional nutrient criteria will be developed to account for the natural variation existing within various parts of the country. Different waterbody processes and responses dictate that nutrient criteria be specific to the waterbody type. No single criterion will be sufficient for each waterbody, therefore we anticipate system classification within waterbody type for appropriate criteria derivation (see Section 1.5, item 2).
2. Guidance documents for nutrient criteria will provide methodologies for developing nutrient criteria for four primary variables (total nitrogen [TN], TP, chlorophyll *a* [chl *a*], and a measure of turbidity) by ecoregion and waterbody type.

3. Regional Nutrient Coordinators will lead State/Tribal technical and financial support operations used to compile data and conduct environmental investigations. A team of agency specialists from USEPA Headquarters will provide technical and financial support to the Regions, and will establish and maintain communications between the Regions and Headquarters.
4. Nutrient criteria numeric ranges, developed at the national level from existing databases and additional environmental investigations, will be used to derive specific criterion values. Criteria values will be implemented into water quality standards by States and Tribes within three years of criteria publication. Ecoregional nutrient criteria will be used by States and Tribes either as a point of departure for the development of more refined criteria, or as numeric criteria. The USEPA will promulgate nutrient criteria in the absence of State or Tribal criteria development initiatives.
5. Nutrient and algal criteria will serve as benchmarks for evaluating the relative success of any nutrient management effort, whether protection or remediation. Criteria will be re-evaluated periodically to assess whether refinements or other improvements are needed.

Nutrient criteria will form the basis for regulatory values such as standards, NPDES permit limits, and TMDL values. Nutrient criteria will also be valuable as decision making benchmarks for management planning and assessment. The development of TMDLs may serve as an intermediate step between criteria development and watershed-based management planning.

The USEPA Strategy envisions a process by which State/Tribal waters are initially measured, reference conditions are established, individual waterbodies are compared to reference waterbodies, and appropriate management measures are implemented. This process is outlined in detail below.

1.5 THE CRITERIA DEVELOPMENT PROCESS

Figure 3 presents a flow chart of the nine key steps involved in the criteria development process. A brief discussion of each of the steps involved, and what ideally is accomplished at each stage, is given below:

1. *Identify water quality needs and goals with regard to managing nutrient enrichment problems.* State and Tribal water quality managers should define the water quality needs and goals for their rivers and streams. Well-defined needs and goals will help in assessing the success of the criteria development process, and will identify attainable water quality goals. This step should be revisited throughout the criteria development process to assure defined needs and goals are addressed.
2. *Classify rivers and streams first by type, and then by trophic status.* The intent of classification is to identify groups of stream systems that have comparable characteristics (i.e., biological, ecological, physical, chemical features). Classifying rivers and streams reduces the variability of stream-related measures (e.g., physical, biological, or water quality attributes) within classes and maximizes variability among classes. Classification will allow criteria to be identified on a broader rather than site-specific scale.

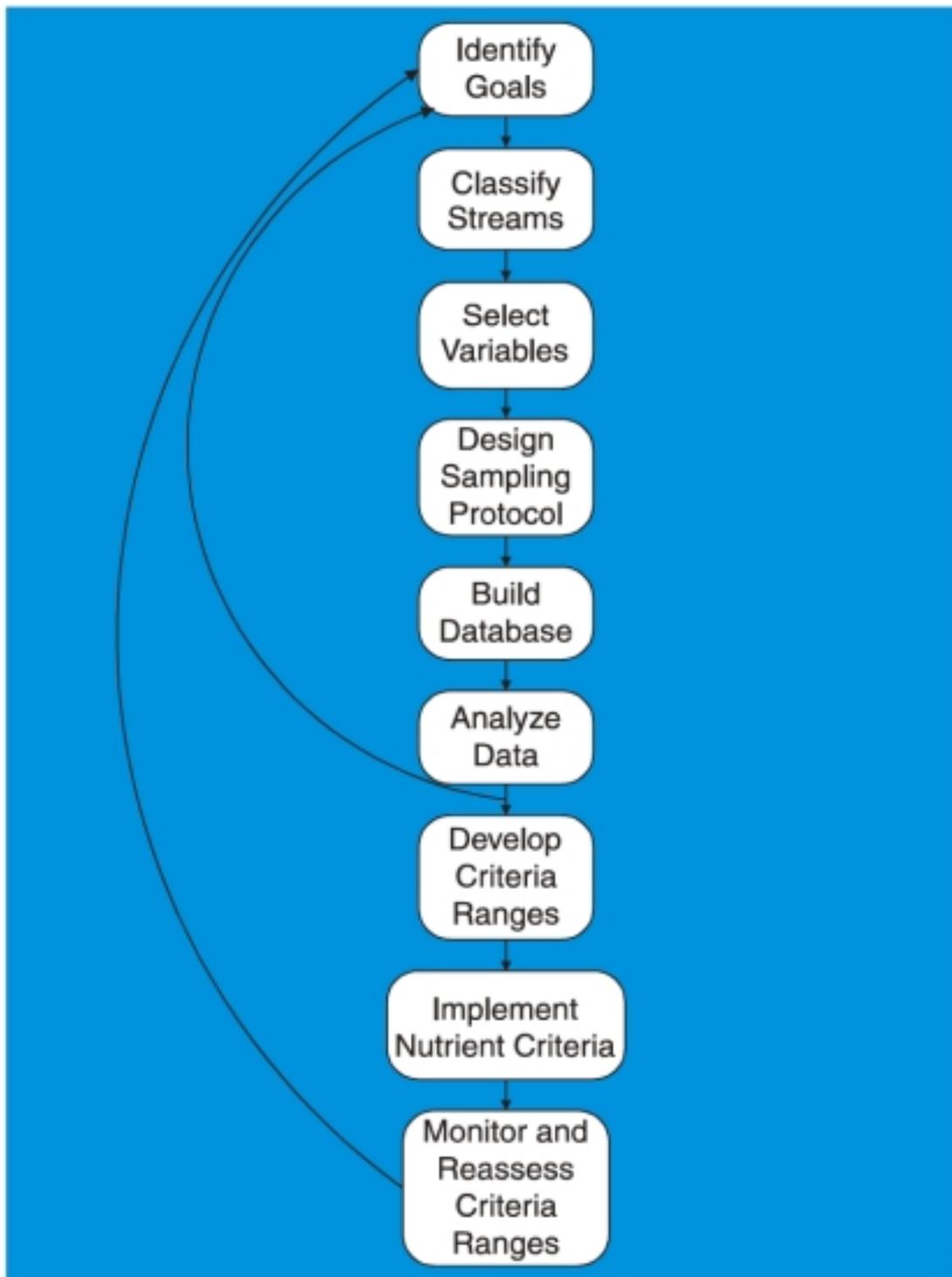


Figure 3. Criteria development flow chart.

3. *Select variables for monitoring nutrients.* Variables, in the context of this document, are measurable attributes that can be used to evaluate or predict the condition or degree of eutrophication in a water body. Four primary water quality variables that must be addressed are TN, TP, chl *a* as an estimate of algal biomass, and turbidity (see Section 3.2). Measurement of these variables provides a means to evaluate nutrient enrichment and can form the basis for establishing regional and waterbody-specific nutrient criteria. Additional secondary variables may also be monitored.

4. *Design a sampling program for monitoring nutrients and algal biomass in rivers and streams.* New monitoring programs should be designed to identify statistically significant differences in nutrient and algal conditions while maximizing available management resources (see Section 4.2). Initial monitoring efforts should focus on targeting reference stream reaches that can be used to assess impairment by nutrients and algae.

5. *Collect data and build database.* Potential sources of additional data for nutrient criteria development include current and historical water quality monitoring data from Federal, State, and local water quality agencies; university studies; and volunteer monitoring information. Databases can be used to organize existing data, store newly gathered monitoring data, and manipulate data as criteria are being developed. The USEPA is developing a national relational database for State/Tribal users to store, screen, and manipulate nutrient-related data.

6. *Analyze data.* Statistical analyses are used to interpret monitoring data for criteria development. Nutrient criteria development should relate nutrient concentrations in streams, algal biomass, and changes in ecological condition (e.g., nuisance algal accrual rate and deoxygenation). In addition, the relative magnitude of an enrichment problem can be determined by examining total nutrient concentration and chl *a* frequency distributions for stream classes. These analyses provide water quality managers with a tool for measuring the potential extent of overenrichment.

7. *Develop criteria based on reference conditions and data analyses.* Criteria selected must first meet the optimal nutrient condition for that stream class and second be reviewed to ensure that the level proposed does not result in adverse nutrient loadings to downstream waterbodies.

Three general approaches for criteria setting are discussed in this manual: (1) identification of reference reaches for each stream class based on best professional judgement (BPJ) or percentile selections of data plotted as frequency distributions, (2) use of predictive relationships (e.g., trophic state classifications, models, biocriteria), and (3) application and/or modification of established nutrient/algal thresholds (e.g., nutrient concentration thresholds or algal limits from published literature).

Initial criteria should be verified and calibrated by comparing criteria in the system of study to nutrients, chl *a*, and turbidity values in waterbodies of known condition to ensure that the system of interest operates as expected. **A weight of evidence approach that combines any or all of the three approaches above will produce criteria of greater scientific validity.** Selected criteria and the data analyzed to identify these criteria will be comprehensively reviewed by a panel of specialists in each USEPA Region. Calibration and review of criteria may lead to refinements of either derivation

techniques or the criteria themselves. In some instances empirical and simulation modeling, or data sets from adjacent States/Tribes with similar systems may assist in criteria derivation and calibration.

8. Implement nutrient control strategies. Much of the management work done by USEPA and the States and Tribes is regulatory. Nutrient criteria can be incorporated into State/Tribal standards as enforceable tools to preserve water quality. As an example, nutrient criteria values can be included as limits in NPDES permits for point source discharges. The permit limits for N, P and other trace nutrients emitted from wastewater treatment plants, factories, food processors and other dischargers can be appropriately adjusted and enforced in accordance with the criteria.

In addition, watershed source reduction responsibilities, especially with respect to nonpoint sources, can be established on the basis of nutrient criteria. Resource managers can use nutrient criteria to help define source load allocations for a watershed. Once sources have been identified, resource managers can begin land use improvements and other activities necessary to maintain or improve the system. System improvements from a watershed perspective must proceed on a reasonable scale so that protection and restoration can be achieved.

9. Monitor effectiveness of nutrient control strategies and reassess the validity of nutrient criteria. Nutrient criteria can be applied to evaluate the relative success of management activities. Measurements of nutrient enrichment variables in the receiving waters preceding, during, and following specific management activities, when compared to criteria, provide an objective and direct assessment of the success of the management project.

Throughout the continuing process of problem identification, response and remediation, and evaluation to protect and enhance our water resources, States, Tribes, and the USEPA are called upon by the U.S. Congress to periodically report on the status of the Nation's waters (Section 305 [b] of the Clean Water Act as amended). Establishment of nutrient criteria will add two causal and two response parameters (see Sections 3.2 - 3.3) to the measurement process required for the biannual Report to Congress. These measurements can be used to document change and monitor the progress of nutrient reduction activities.

The chapters that follow present detailed information that elaborates upon this outline of nutrient criteria development. For some water quality managers, components of certain criteria development steps may already be completed for existing stream monitoring programs (e.g., sampling design for specific stream systems). Thus, some steps can be excluded as the manager advances further through the process. However, should new or revised monitoring programs be envisioned, review by the water quality manager of each of the steps outlined in this guidance is recommended.

Although this document is meant to provide the best available scientific procedures and approaches for collecting and analyzing nutrient-related data, including examination of nutrient and algal relationships, a comprehensive understanding of nutrient and algal dynamics within all types of stream systems is beyond the current state of scientific knowledge. The National Nutrient Program represents a new effort and approach to criteria development that, in conjunction with efforts made by State and Tribal water quality managers, will ultimately result in a heightened understanding of nutrient/algal relationships. As the proposed process is put into use to set criteria, program success will be gauged over time through evaluation of management and monitoring efforts. A more comprehensive knowledge base pertaining to

nutrient and algal relationships will be expanded as new information is gained and obstacles overcome, justifying potential refinements to the criteria development process described here.

1.6 IDENTIFY NEEDS AND GOALS

The overarching goal of developing nutrient criteria is to ensure the quality of our national waters. Ensuring water quality may include restoration of impaired systems, conservation of high quality waters, and protection of systems at high risk for future impairment. The goals of a State or Tribal water quality program will be defined differently based on the needs of each State or Tribe, but should, at a minimum, protect established designated uses for the waterbodies within State or Tribal lands. Once goals and objectives are defined, they should be revisited regularly to evaluate progress and assess the need for refinements or revisions.

The first task of a water quality manager is to set a water quality goal, such as “no nuisance algal blooms such that swimming is restricted during summer months.” After such a goal is established, managers must develop a timeline, budget, and plan of action for accomplishing this goal. Needs of the program, such as funding, acquiring relevant data, and assigning employee responsibilities must be addressed. Well-defined needs and goals will help in assessing the success of the criteria development process and will identify attainable water quality goals.

1.7 DOCUMENT STRUCTURE

This manual comprises nine chapters that formulate the steps recommended for nutrient criteria development. The first step of the process, identifying goals and objectives, is unique to each water quality manager and should be revisited regularly to evaluate progress and assess the need for goal and/or objective refinements or revisions. The next step entails stream classification based on physical and nutrient gradient factors (Chapter 2). Sampling variables, including primary and appropriate secondary variables (Chapter 3), should be selected for monitoring efforts. Once these variables are determined, sampling designs for new monitoring programs can be developed (Chapter 4). Chapter 5 discusses potential data sources that can be used by water quality managers to develop criteria and addresses the usefulness of databases in compiling, storing, and analyzing data. A variety of data analysis methods and techniques used to derive criteria are presented in Chapters 6 and 7, respectively. These two chapters are meant to provide water quality managers with a range of options that may be useful for deriving criteria. Nutrient management programs (including nutrient control strategies for point and nonpoint sources) and points of contact or references that may be useful to water quality managers are provided in Chapter 8. Chapter 9 concludes the criteria development process with a brief discussion of continued monitoring and reassessment of goals and the established criteria.

It should be noted that completion of *each* previously described step may *not* be required by all water quality managers. Many State or Tribal water quality agencies already have established stream classes, monitoring programs, and/or databases for their programs and therefore can bypass those steps. This manual is meant to be comprehensive in the sense that all of the criteria development steps are described; however, the process can be adapted to suit existing water quality programs.

Appendix A of the manual contains five case studies: (1) Tennessee ecoregion streams (southeastern U.S.), (2) Clark Fork River (western forested mountains), (3) upper Midwest river basins (prairie-agricultural river systems), (4) Bow River (northern Rockies), and (5) desert streams (arid western U.S.). These case studies are meant to characterize some of the variability observed within North American stream systems and region-specific issues that should be considered when developing nutrient criteria. Appendices B and C provide water quality managers with information and additional references for laboratory/field methods and statistical tests/modeling tools, respectively. Appendix D defines frequently used acronyms and technical terms found throughout the document.