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EPA

Protocol for Developing Nutrient TMDLs

First Edition

Acknowledgments

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Protocol for Developing Nutrient TMDLs

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Watershed Branch
Assessment and Watershed Protection Division
Office of Wetlands, Oceans, and Watersheds
Office of Water
United States Environmental Protection Agency
Washington, DC 20460

Foreword

Although many pollution sources have implemented the required levels of pollution control technology, there are still waters in the nation that do not meet the Clean Water Act goal of “fishable, swimmable.” Section 303(d) of the Act addresses these waters that are not “fishable, swimmable” by requiring states, territories, and authorized tribes to identify and list impaired waters every two years and to develop total maximum daily loads (TMDLs) for pollutants in these waters, with oversight from the U.S. Environmental Protection Agency. TMDLs establish the allowable pollutant loadings, thereby providing the basis for states to establish water quality-based controls.

Historically, wasteload allocations have been developed for particular point sources discharging to a particular waterbody to set effluent limitations in the point source’s National Pollutant Discharge Elimination System (NPDES) discharge permit. This approach has produced significant improvements in water quality by establishing point source controls for many chemical pollutants. But water quality impairments continue to exist in the Nation’s waters. Some point sources need more controls, and many nonpoint source impacts (from agriculture, forestry, development activities, urban runoff, and so forth) cause or contribute to impairments in water quality. To address the combined, cumulative impacts of both point and nonpoint sources, EPA has adopted a watershed approach, of which TMDLs are a part. This approach provides a means to integrate governmental programs and improve decision making by both government and private parties. It enables a broad view of water resources that reflects the interrelationship of surface water, groundwater, chemical pollutants and nonchemical stressors, water quantity, and land management.

The *Protocol for Developing Nutrient TMDLs* is a TMDL technical guidance documents prepared to help state, interstate, territorial, tribal, local, and federal agency staff involved in TMDL development, as well as watershed stakeholders and private consultants. Comments and suggestions from readers are encouraged and will be used to help improve the available guidance as EPA continues to build experience and understanding of TMDLs and watershed management.

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Preface

EPA has developed several protocols as programmatic and technical support guidance documents for those involved in TMDL development. These guidance documents, developed by an interdisciplinary team, provide an overall framework for completing the technical and programmatic steps in the TMDL development process. The *Protocol for Developing Nutrient TMDLs* is one of the three TMDL technical guidance documents prepared to date. The process presented here will assist with the development of rational, science-based assessments and decisions and ideally will lead to the assemblage of an understandable and justifiable nutrient TMDL. It is important to note that this guidance document presents a suggested approach, but not the only approach to TMDL development.

This document provides guidance to states, territories and authorized tribes exercising responsibility under section 303(d) of the Clean Water Act for the development of nutrient TMDLs. This protocol is designed as programmatic and technical support guidance to those involved in TMDL development. The protocol does not, however, substitute for section 303(d) of the Clean Water Act or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, territories, authorized tribes or the regulated community and may not apply to a particular situation based upon the circumstances. EPA and state, territory and authorized tribe decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this protocol where appropriate. EPA may change this protocol in the future.

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Introduction and Purpose of This Protocol

Objective: This Total Maximum Daily Load (TMDL) protocol was developed at the request of EPA regions, states, and tribes and is intended to provide users with an organizational framework for the TMDL development process for nutrients. The process presented here will assist with the development of rational, science-based assessments and decisions and ideally will lead to the assemblage of an understandable and justifiable TMDL.

Audience: The protocols are designed as tools for state TMDL staff, EPA regional TMDL staff, tribal TMDL staff, watershed stakeholders, and other agencies and private consultants involved in TMDL development.

OVERVIEW

Section 303(d) of the Clean Water Act provides that states, territories, and authorized tribes are to list waters for which technology-based limits alone do not ensure attainment of water quality standards. Beginning in 1992, states, territories and authorized tribes were to submit their lists to the EPA every two years. Beginning in 1994, lists were due to EPA on April 1 of each even numbered year. States, territories, and authorized tribes are to set priority rankings for the listed waters, taking into account the severity of the pollution and the intended uses of the waters.

EPA's regulations for implementing section 303(d) are codified in the Water Quality Planning and Management Regulations at 40 CFR Part 130, specifically at sections130.2, 130.7, and 130.10. The regulations define terms used in section 303(d) and otherwise interpret and expand upon the statutory requirements. The purpose of the *Protocol for Developing Nutrient TMDLs* is to provide more detailed guidance on the TMDL development process for waterbodies impaired due to nutrients.

On August 23, 1999, EPA published proposed changes to the current TMDL rules at 40 CFR 130.2, 130.7, and 130.10. These changes would significantly strengthen the Nation's ability to achieve clean water goals by ensuring that the public has more and better information about the health of their watersheds, States have clearer direction and greater consistency as they identify impaired waters and set priorities, and new tools are used to make sure that TMDL implementation occurs. The text box on the following page summarizes these proposed changes.

The TMDL protocols focus on Step 3 (Development of TMDLs) of the water quality-based approach, depicted in Figure 1-1 (USEPA, 1991a, 1999). This specific step is divided into seven components common to all TMDLs, and each component is designed to yield a product that is part of a TMDL submittal document. Although some of the submittal components (e.g., TMDL calculation and allocations) are part of the legally approved TMDL and others are recommended as part of the administrative record supporting the TMDL and providing the basis for TMDL review and approval, this protocol discusses each component equally. The following components may be completed concurrently or iteratively depending on the site-specific situation (Figure 1-2) and are provided as a guide and framework for TMDL development:

- Problem identification
- Identification of water quality indicators and targets
- Source assessment
- Linkage between water quality targets and sources
- Allocations
- Follow-up monitoring and evaluation
- Assembling the TMDL

A TMDL is the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background (40 CFR 130.2) with a margin of safety (CWA Section 303(d)(1)(c)). The TMDL can be generically described by the following equation:

$$TMDL = LC = \sum WLA + \sum LA + MOS$$

where:
- LC = loading capacity,[a] or the greatest loading a waterbody can receive without violating water quality standards;
- WLA = wasteload allocation, or the portion of the TMDL allocated to existing or future point sources;
- LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background; and
- MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

[a]TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures.

Summary of Proposed Regulatory Requirements for Establishing TMDLs

A TMDL must be established for all waterbody and pollutant combinations on Part 1 of the list. TMDLs are not required for waterbodies on Part 2, 3, or 4 of the list (§ 130.31(a)).

A TMDL must be established according to the priority rankings and schedules (§ 130.31(b)).

TMDLs must be established at a level necessary to attain and maintain water quality standards, as defined by 40 CFR 131.3(I), considering reasonably foreseeable increases in pollutant loads (§ 130.33(b)(9)).

TMDLs must include the following minimum elements (§ 130.33(b)):

1. The name and geographic location, as required by §130.27(c), of the impaired or threatened waterbody for which the TMDL is being established and the names and geographic locations of the waterbodies upstream of the impaired waterbody that contribute significant amounts of the pollutant for which the TMDL is being established;
2. Identification of the pollutant for which the TMDL is being established and quantification of the pollutant load that may be present in the waterbody and still ensure attainment and maintenance of water quality standards;
3. Identification of the amount or degree by which the current pollutant load in the waterbody deviates from the pollutant load needed to attain or maintain water quality standards;
4. Identification of the source categories, source subcategories, or individual sources of the pollutant for which the wasteload allocations and load allocations are being established consistent with §130.2(f) and §130.2(g);
5. Wasteload allocations to each industrial and municipal point source permitted under §402 of the Clean Water Act discharging the pollutant for which the TMDL is being established ; wasteload allocations for storm water, combined sewer overflows, abandoned mines, combined animal feeding operations, or any other discharges subject to a general permit may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated to attain or maintain water quality standards may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that wasteload allocations when implemented, will attain and maintain water quality standards;
6. Load allocations, ranging from reasonable accurate estimates to gross allotments, to nonpoint sources of a pollutant, including atmospheric deposition or natural background sources; if possible, a separate load allocation must be allocated to each source of natural background or atmospheric deposition; load allocations may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that load allocations, when implemented, will attain and maintain water quality standards;
7. A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant;
8. Consideration of seasonal variation such that water quality standards for the allocated pollutant will be met during all seasons of the year;
9. An allowance for future growth which accounts for reasonably foreseeable increases in pollutant loads; and
10. An implementation plan.

As appropriate to the characteristics of the waterbody and pollutant, the maximum allowable pollutant load may be expressed as daily, monthly, seasonal or annual averages in one or more of the following ways (40 CFR 130.34(b)):

- The pollutant load that can be present in the waterbody and ensure that it attains and maintains water quality standards;
- The reduction from current pollutant loads required to attain and maintain water quality standards;
- The pollutant load or reduction of pollutant load required to attain and maintain riparian, biological, channel or geomorphological measures so that water quality standards are attained and maintained; or
- The pollutant load or reduction of pollutant load that results from modifying a characteristic of the waterbody, e.g., riparian, biological, channel, geomorphological, or chemical characteristics, so that water quality standards are attained and maintained.

The TMDL implementation plan must include the following (§ 130.33(b)(10)):

- A description of the control actions and/or management measures which will be implemented to achieve the wasteload allocations and load allocations, and a demonstration that the control actions and/or management measures are expected to achieve the required pollutant loads;
- A time line, including interim milestones, for implementing the control actions and/or management measures, including when source-specific activities will be undertaken for categories and subcategories of individual sources and a schedule for revising NPDES permits;
- A discussion of your reasonable assurances, as defined at 40 CFR §130.2(p), that wasteload allocations and load allocations will be implemented;
- A description of the legal under which the control actions will be carried out;
- An estimate of the time required to attain and maintain water quality standards and discussion of the basis for that estimate;
- A monitoring and/or modeling plan designed to determine the effectiveness of the control actions and/or management measures and whether allocations are being met;
- A description of measurable, incremental milestones for the pollutant for which the TMDL is being established for determining whether the control actions and/or management measures are being implemented and whether water quality standards are being attained; and
- A description of your process for revising TMDLs if the milestones are not being met and projected progress toward attaining water quality standards is not demonstrated.

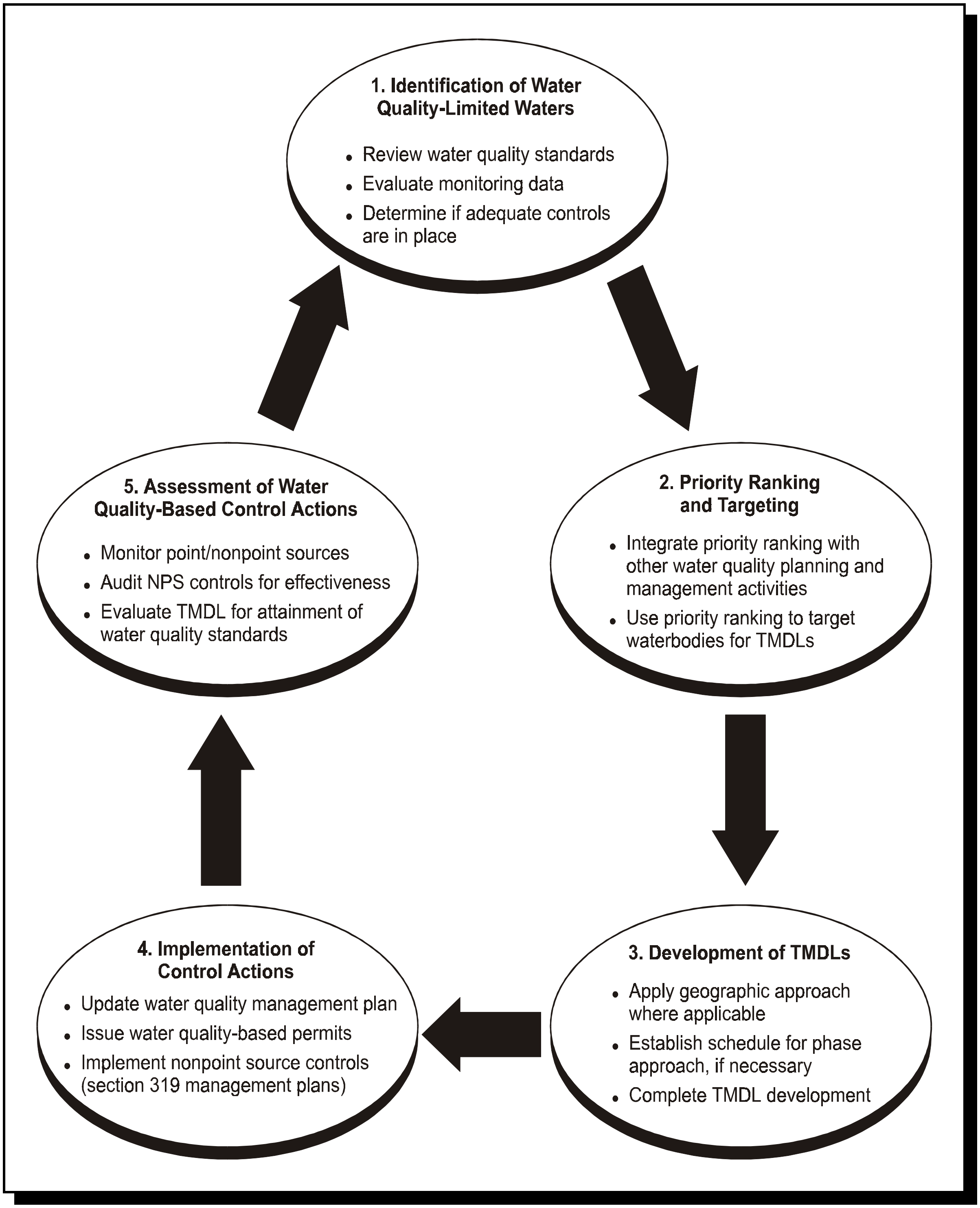

Figure 1-1. General elements of the water quality-based approach (adapted from USEPA, 1991a)

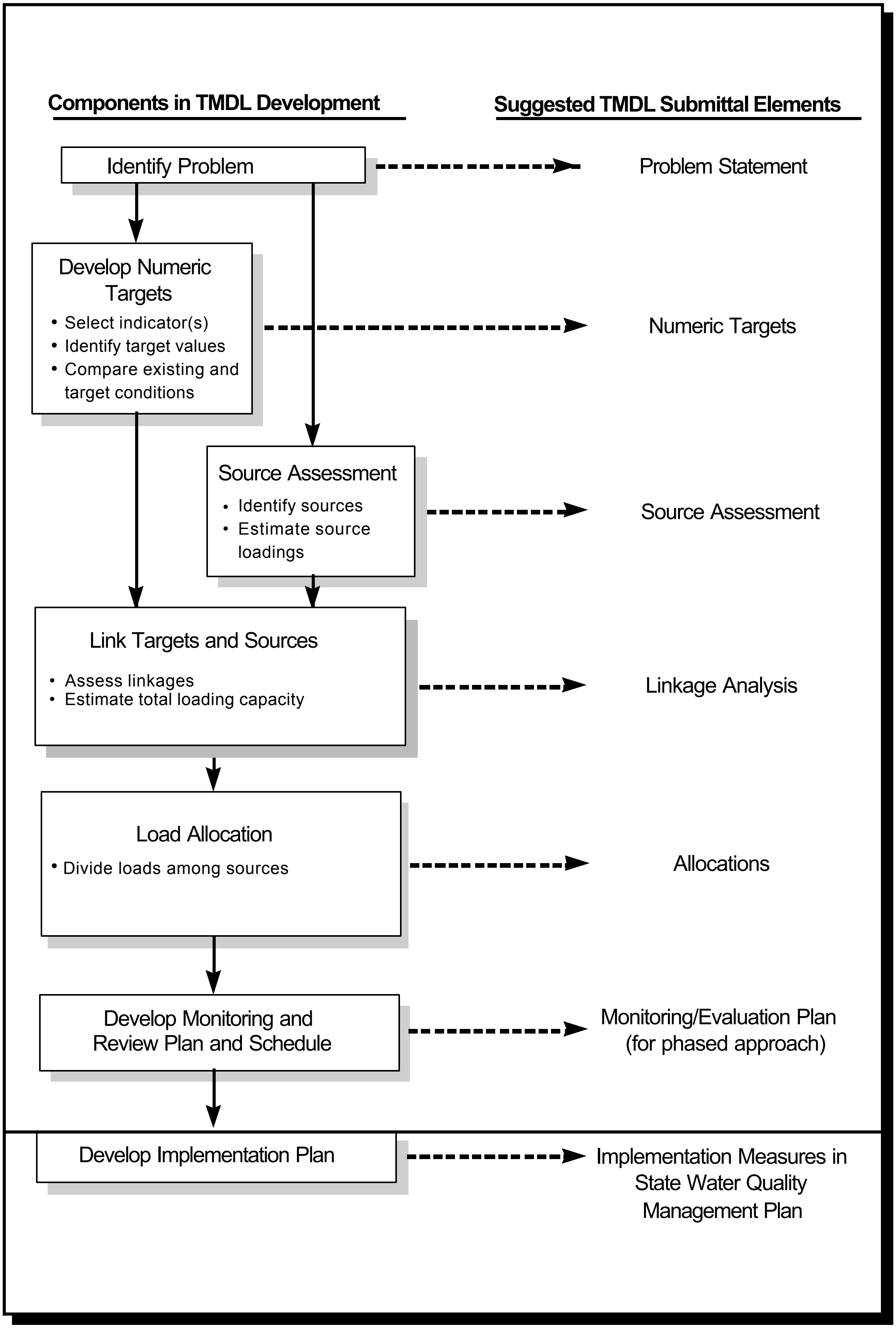

Figure 1-2. General components of TMDL development

Problem Identification

The objective of problem identification is to identify the key factors and background information for a listed waterbody that describe the nature of the impairment and the context for the TMDL. Problem identification is a guiding factor in development of the remaining elements of the TMDL process.

Identification of Water Quality Indicators and Target Values

The purpose of this component is to identify numeric or measurable indicators and target values that can be used to evaluate attainment of water quality standards in the listed waterbody. Often the TMDL target will be the numeric water quality standard for the pollutant of concern. In some cases, however, TMDLs must be developed for parameters that do not have numeric water quality standards. When numeric water quality standards do not exist, impairment is determined by narrative water quality standards or identifiable impairment of designated uses (e.g., no fish). The narrative standard is then interpreted to develop a quantifiable target value to measure attainment or maintenance of the water quality standards.

Source Assessment

During source assessment, the sources of pollutant loading to the waterbody are identified and characterized by type, magnitude, and location.

Linkage Between Water Quality Targets and Sources

To develop a TMDL, a linkage must be defined between the selected indicator(s) or target(s) and the identified sources. This linkage establishes the cause-and-effect relationship between the pollutant of concern and the pollutant sources. The relationship can vary seasonally, particularly for nonpoint sources, with factors such as precipitation. Once defined, the linkage yields the estimate of total loading capacity.

Allocations

Based on the established linkage, pollutant loadings that will not exceed the loading capacity and will lead to attainment of the water quality standard can be determined. These loadings are distributed or "allocated" among the significant sources of the pollutant of concern. The allocations are a component of the legally approved TMDL. Wasteload allocations contain the allowable loadings from existing or future point sources, while load allocations establish the allowable loadings from natural background and from existing and future nonpoint sources. The margin of safety is usually identified during this step to account for uncertainty in the analysis, although it may also be identified in other TMDL components. The margin of safety may be applied implicitly by using conservative assumptions in the TMDL development process or explicitly by setting aside a portion of the allowable loading.

Follow-up Monitoring and Evaluation

TMDL submittals should include a monitoring plan to determine whether the TMDL has resulted in attaining water quality standards and to support any revisions to the TMDL that might be required. Follow-up monitoring is recommended for all TMDLs, given the uncertainties inherent in TMDL development (USEPA 1991a; 1997a; 1999). The rigor of the monitoring plan should be based on the confidence in the TMDL analysis: a more rigorous monitoring plan should be included for TMDLs with greater uncertainty and where the environmental and economic consequences of the decisions are greatest.

Assembling the TMDL

In this component, those elements of a TMDL submittal required by statute or regulation are clearly identified and compiled, and supplemental information is provided to facilitate TMDL review.

For each component addressed in this protocol, the following format is used:

- Guidance on key questions or factors to consider
- Brief discussions of analytical methods
- Discussions of products needed to express the results of the analysis
- Examples of approaches used in actual settings to complete the step

By addressing each of the seven TMDL components, TMDL developers can complete the technical aspects of TMDL development. Although public participation requirements are largely outside the scope of this document, because of the complex and often controversial nature of TMDLs, early involvement of stakeholders affected by the TMDL is strongly encouraged. The protocols also do not discuss issues associated with TMDL implementation (note the rule across Figure 1-1). Methods of implementation, such as National Pollutant Discharge Elimination System (NPDES) permits, state nonpoint source (NPS) management programs, Coastal Zone Act Reauthorization Amendments (CZARA), and public participation are discussed in *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA, 1991a, 1999) and in the August 8, 1997, memorandum “New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs)” (USEPA, 1997b).

PURPOSE

This protocol provides a description of the TMDL development process for nutrients and includes case study examples to illustrate the major points in the process. It emphasizes the use of rational, science-based methods and tools for each step of TMDL development to assist readers in applying a TMDL development process that addresses all regulatory requirements.

References and recommended reading lists are provided for readers interested in obtaining more detailed background information. This protocol has been written with the assumption that users have a general background in the technical aspects of water quality management and are familiar with the statutory and regulatory basis for the TMDL program. A glossary is included at the end of the document with definitions of some commonly used terms.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

USEPA. 1991a. Guidance for water quality-based decisions: The TMDL process. EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA. 1997a. New policies for establishing and implementing Total Maximum Daily Loads (TMDLs). U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA 1999. *Draft guidance for water quality-based decisions: The TMDL process (second edition)*. EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/proprule.html>

Nutrients and Water Quality

Objective: To develop a nutrient TMDL, it is important to have a basic understanding of nutrient processes in a watershed and how excessive or insufficient nutrients can affect water quality and designated uses of water. This section provides background information on nutrient impacts on designated uses, nutrient sources and transport, and potential control strategies.

GENERAL PRINCIPLES

This section briefly addresses the role nutrients play in the environment and provides background information on nutrient cycling, nutrient sources and transport, and potential control strategies. A more detailed discussion of these basic principles and how they relate to TMDL development is in Chapter 2 of EPA's *Technical Guidance Manual for Developing Total Maximum Daily Loads,* Book II *(Streams and Rivers),* Part 1 *(Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication)* (USEPA, 1995a).

Impact of Nutrients on Designated Uses

Excess nutrients in a waterbody can have many detrimental effects on designated or existing uses, including drinking water supply, recreational use, aquatic life use, and fishery use. For example, drinking water supplies can be impaired by nitrogen when nitrate concentrations exceed 10 mg/L and can cause methemoglobinemia (Blue Baby Syndrome) in infants. Water supplies containing more than 100 mg/L of nitrate can also taste bitter and can cause physiological distress (Straub, 1989).

Although these are examples of the direct impacts that can be associated with excessive nutrient loadings, waters more often are listed as impaired by nutrients because of their role in accelerating eutrophication. Eutrophication, or the nutrient enrichment of aquatic systems, is a natural aging process of a waterbody that transforms a lake into a swamp and ultimately into a field or forest.[1] This aging process can accelerate with excessive nutrient inputs because of the impact they have without other limiting factors, such as light.

A eutrophic system typically contains an undesirable abundance of plant growth, particularly phytoplankton, periphyton, and macrophytes. Phytoplankton, photosynthetic microscopic organisms (algae), exist as individual cells or grouped together as clumps or filamentous mats. Periphyton is the assemblage of organisms that grow on underwater surfaces. It is commonly dominated by algae but also can include bacteria, yeasts, molds, protozoa, and other colony-forming organisms. The term macrophyte refers to any larger than microscopic plant life in aquatic systems. Macrophytes may be vascular plants rooted in the sediment, such as pond weeds or cattails, or free-floating plant life, such as duckweed or coontail.

The eutrophication process can impair the designated uses of waterbodies as follows:

- *Aquatic life and fisheries.* A variety of impairments can result from the excessive plant growth associated with nutrient loadings. These impairments result primarily when dead plant matter settles to the bottom of a waterbody, stimulating microbial breakdown processes that require oxygen. Eventually, oxygen in the hypolimnion of lakes and reservoirs can be depleted, which can change the benthic community structure from aerobic to anaerobic organisms. Oxygen depletion also might occur nightly throughout the waterbody because of plant respiration. Extreme oxygen depletion can stress or eliminate desirable aquatic life and nutrients, and toxins also might be released from sediments when dissolved oxygen and pH are lowered (Brick and Moore, 1996).

  Breakdown of dead organic matter in water also can produce un-ionized ammonia, which can adversely affect aquatic life. The fraction of ammonia present as un-ionized ammonia depends on temperature and pH. Fish may suffer a reduction in hatching success, reductions in growth rate and morphological development, and injury to gill tissue, liver, and kidneys. At certain ammonia levels fish also might

[1]The term *eutrophication* as used in this document refers to the nutrient enrichment of both lakes and rivers, although it is recognized that rivers do not have the same natural aging process.

suffer a loss of equilibrium, hyperexcitability, increased respiratory activity and oxygen uptake, and increased heart rate. At extreme ammonia levels, fish may experience convulsions, coma, and death (USEPA, 1986a; revised 1998b).

- *Drinking water supply.* Diatoms and filamentous algae can clog water treatment plant filters and reduce the time between backwashings (the process of reversing water flow through the water filter to remove debris). Disinfection of water supplies impaired by algal growth also might result in water that contains potentially carcinogenic disinfection by-products, such as trihalomethanes. An increased rate of production and breakdown of plant matter also can adversely affect the taste and odor of the drinking water.

- *Recreational use.* The excessive plant growth in a eutrophic waterbody can affect recreational water use. Extensive growth of rooted macrophytes, periphyton, and mats of living and dead plant material can interfere with swimming, boating, and fishing activities, while the appearance of and odors emitted by decaying plant matter impair aesthetic uses of the waterbody.

Nutrient Sources and Transport

Both nitrogen and phosphorus reach surface waters at an elevated rate as a result of human activities. Phosphorus, because of its tendency to sorb to soil particles and organic matter, is primarily transported in surface runoff with eroded sediments. Inorganic nitrogen, on the other hand, does not sorb as strongly and can be transported in both particulate and dissolved phases in surface runoff. Dissolved inorganic nitrogen also can be transported through the unsaturated zone (interflow) and ground water. Because nitrogen has a gaseous phase, it can be transported to surface water via atmospheric deposition. Phosphorus associated with fine-grained particulate matter also exists in the atmosphere. This sorbed phosphorus can enter natural waters by both dry fallout and rainfall. Finally, nutrients can be directly discharged to a waterbody via outfalls for wastewater treatment plants and combined sewer overflows. Table 2-1 presents common point and nonpoint sources of nitrogen and phosphorus and the approximate associated concentrations.

Once in the waterbody, nitrogen and phosphorus act differently. Because inorganic forms of nitrogen do not sorb strongly to particulate matter, they are more easily returned to the water. Phosphorus, on the other hand, can sorb to sediments in the water column and on the substrate and become unavailable. In lakes and reservoirs, continuous accumulation of sediment can leave some phosphorus too deep within the substrate to be reintroduced to the water column, if left undisturbed; however, a portion of the phosphorus in the substrate might be reintroduced to the water column. The activities of benthic invertebrates and changes in water chemistry (such as the reducing conditions of bottom waters and sediments often experienced during the summer months in a lake) also can cause phosphorus to desorb from sediment. A large, slow-moving river also might experience similar phosphorus releases. The sudden availability of phosphorus in the water column can stimulate algal growth. Because of this phenomenon, a reduction in phosphorus loading might not effectively reduce algal blooms for many years (Maki et al., 1983).

Table 2-1. Sources and concentrations of nutrients from common point and nonpoint sources

Source	Nitrogen (mg/L)	Phosphorus (mg/L)
Urban runoff	3 - 10	0.2 - 1.7
Livestock operations	6 - 800[a]	4 - 5
Atmosphere (wet deposition)	0.9	0.015[b]
Untreated wastewater	35	10
Treated wastewater (secondary treatment)	30	10

[a] As organic nitrogen; [b] Sorbed to airborne particulate
Source: Novotny and Olem, 1994

Nutrient Cycling

The transport of nutrients from their sources to the waterbody of concern is governed by several chemical, physical, and biological processes, which together compose the nitrogen or phosphorus cycle. Nutrient cycles are important to understand for developing a TMDL because of the information they provide about nutrient availability and the associated impact on plant growth.

Nitrogen

Nitrogen is plentiful in the environment. Almost 80 percent of the atmosphere by volume consists of nitrogen gas (N_2). Although largely available in the atmosphere, N_2 must be converted to other forms, such as nitrate (NO_3^-), before most plants and animals can use it. Conversion into usable forms, both in the terrestrial and aquatic environments, occurs through the four processes of the nitrogen cycle. Three of the processes—nitrogen fixation, ammonification, and nitrification—convert gaseous nitrogen into usable chemical forms. The fourth process, denitrification, converts fixed nitrogen back to the gaseous N_2 state.

- **Nitrogen fixation.** The conversion of gaseous nitrogen into ammonia ions (NH_3 and NH_4^+). Nitrogen-fixing organisms, such as blue-green algae (cyanobacteria) and the bacteria *Rhizobium* and *Azobacter*, split molecular nitrogen (N_2) into two free nitrogen molecules. The nitrogen molecules combine with hydrogen molecules to yield ammonia ions.

- **Ammonification.** A one-way reaction in which decomposer organisms break down wastes and nonliving organic tissues to amino acids, which are then oxidized to carbon dioxide, water, and ammonia ions. Ammonia is then available for absorption by plant matter.

- **Nitrification.** A two-step process by which ammonia ions are oxidized to nitrite and nitrate, yielding energy for decomposer organisms. Two groups of microorganisms are involved in the nitrification process. First, *Nitrosomonas* oxidizes ammonia ions to nitrite and water. Second, *Nitrobacter* oxidizes the nitrite ions to nitrate, which is then available for absorption by plant matter.

- **Denitrification.** The process by which nitrates are reduced to gaseous nitrogen by facultative anaerobes. Facultative anaerobes, such as fungi, can flourish in anoxic conditions because they break down oxygen-containing compounds (e.g., NO_3^-) to obtain oxygen.

Once introduced into the aquatic environment, nitrogen can exist in several forms—dissolved nitrogen gas (N_2), ammonia (NH_4^+ and NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and organic nitrogen as proteinaceous matter or in dissolved or particulate phases. The most important forms of nitrogen in terms of their immediate impact on water quality are the readily available ammonia ions, nitrites, and nitrates[2] (dissolved nitrogen). Particulate and organic nitrogen, because they must be converted to a usable form, are less important in the short term. Total nitrogen (TN) is a measurement of all forms of nitrogen.

Nitrogen continuously cycles in the aquatic environment, although the rate is temperature-controlled and thus very seasonal. Aquatic organisms incorporate available dissolved inorganic nitrogen into proteinaceous matter. Dead organisms decompose, and nitrogen is released as ammonia ions and then converted to nitrite and nitrate, where the process begins again. If a surface water lacks adequate nitrogen, nitrogen-fixing organisms can convert nitrogen from its gaseous phase to ammonia ions.

Phosphorus

Under normal conditions, phosphorus is scarce in the aquatic environment. Unlike nitrogen, phosphorus does not exist as a gas and therefore does not have gas-phase atmospheric inputs to aquatic systems. Rocks and natural phosphate deposits are the main reservoirs of natural phosphorus. Release of these deposits occurs through weathering, leaching, erosion, and mining. Terrestrial phosphorus cycling includes immobilizing inorganic phosphorus into calcium or iron phosphates, incorporating inorganic phosphorus into plants and microorganisms, and breaking down organic phosphorus to inorganic forms by bacteria. Some phosphorus is inevitably transported to aquatic systems by water or wind.

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[2]Note that plants cannot directly use nitrate but must first convert it to ammonium using the enzyme nitrate reductase. Because the ability to do this is ubiquitous, nitrate is considered to be bioavailable.

Phosphorus in freshwater and marine systems exists in either an organic or inorganic form.

- **Organic phosphorus.** Organic particulate phosphorus includes living and dead particulate matter, such as plankton and detritus. Organic nonparticulate phosphorus includes dissolved organic phosphorus excreted by organisms and colloidal phosphorus compounds.

- **Inorganic phosphorus.** The soluble inorganic phosphate forms $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3}, known as soluble reactive phosphorus (SRP), are readily available to plants. Some condensed phosphate forms, such as those found in detergents, are inorganic but are not available for plant uptake. Inorganic particulate phosphorus includes phosphorus precipitates, phosphorus adsorbed to particulate, and amorphous phosphorus.

The measurement of all phosphorus forms in a water sample, including all the inorganic and organic particulate and soluble forms mentioned above, is known as total phosphorus (TP). TP does not distinguish between phosphorus currently unavailable to plants (organic and particulate) and that which is available (SRP). SRP is the most important form of phosphorus for supporting algal growth because it can be used directly. However, other fractions are transformed to more bioavailable forms at various rates dependent on microbial action or environmental conditions. In streams with relatively short residence times, it is less likely that the transformation from unavailable to available forms will have time to occur and SRP is the most accurate estimate of biologically available nutrients. In lakes, however, where residence times are longer, TP generally is considered an adequate estimation of bioavailable phosphorus.

Phosphorus undergoes continuous transformations in a freshwater environment. Some phosphorus will sorb to sediments in the water column or substrate and be removed from circulation. Phytoplankton, periphyton, and bacteria assimilate the SRP (usually as orthophosphate) and change it into organic phosphorus. These organisms then may be ingested by detritivores or grazers, which in turn excrete some of the organic phosphorus as SRP. Some previously unavailable forms of phosphorus also convert to SRP. Continuing the cycle, the SRP is rapidly assimilated by plants and microbes.

Human activities have resulted in excessive loading of phosphorus into many freshwater systems. Overloads result in an imbalance of the natural cycling processes. Excess available phosphorus in freshwater systems can result in accelerated plant growth if other nutrients and other potentially limiting factors are available.

Other Limiting Factors

Many natural factors combine to determine rates of plant growth in a waterbody. First of these is whether sufficient phosphorus and nitrogen exist to support plant growth. The absence of one of these nutrients generally will restrict plant growth. In inland waters, typically phosphorus is the limiting nutrient of the two, because blue-green algae can “fix” elemental nitrogen from the water as a nutrient source. In marine waters, either phosphorus or nitrogen can be limiting. Although carbon and trace elements are usually abundant, occasionally they can serve as limiting nutrients. However, even if all necessary nutrients are available, plant production will not necessarily continue unchecked. Many natural factors, including light availability, temperature, flow levels, substrate, grazing, bedrock type and elevation, control the levels of macrophytes, periphyton, and phytoplankton in waters. Effective management of eutrophication in a waterbody may require a simultaneous evaluation of several limiting factors.

- **Light availability.** Shading of the water column inhibits plant growth. Numerous factors can shade waterbodies, including: (1) as plant production increases in the upper water layer, the organisms block the light and prevent it from traveling deeper into the water column; (2) riparian growth along waterbodies provides shade; and (3) particulates in the water column scatter light, decreasing the amount penetrating the water column and available for photosynthesis.

  With seasonally high particulate matter or shading (e.g., in deciduous forests), the high nutrients may cause excessive growth only during certain times of the year: for example, streams where snowmelt is common in the spring. Snowmelt could lead to high levels of suspended particulate matter and low algal biomass. During stable summer flows, however, there will be lower levels of suspended matter and hence higher algal biomass.

- **Temperature.** Temperature affects the rates of photosynthesis and algal growth, and composition of algal species. Depending on the plant, photosynthetic activity increases with temperature until a maximum photosynthetic output is reached, when photosynthesis declines (Smith, 1990). Moreover, algal community species composition in a waterbody often changes with temperature. For example, diatoms most often are the dominant algal species at water temperatures of 20 ° to 25 °C, green algae at 30 ° to 35 °C, and blue-green algae (cyanobacteria) above 35 °C (Dunne and Leopold, 1978; USEPA, 1986b).

- **Water Velocity.** Water movement in large lakes, rivers, and streams influences plant production. Stream velocity has a two-fold effect on periphyton productivity: increasing velocity to a certain level enhances biomass accrual but further increases can result in substantial scouring (Horner et al., 1990). Large lakes and estuaries can experience the scouring action of waves during strong storms (Quinn, 1991). In rivers and streams, frequent disturbance from floods (monthly or more frequently) and associated movement of bed materials can scour algae from the surface rapidly and often enough to prevent attainment of high biomass (Horner et al., 1990). Rapid flows can sweep planktonic algae from a river reach, while low flows may provide an opportunity for proliferation.

- **Substrate.** Macrophytes and periphyton are influenced by the type of substrate available. Macrophytes prefer areas of fine sediment in which to root (Wright and McDonnell, 1986, in Quinn, 1991). Thus, the addition and removal of sediment from a system can influence macrophyte growth. Periphyton, because of its need to attach to objects, grows best on large, rough substrates. A covering of sediment over a rocky substrate decreases periphyton biomass (Welch et al., 1992).

- **Grazing.** Dense populations of algae-consuming grazers can lead to negligible algal biomass, in spite of high levels of nutrients (Steinman, 1996). The existence of a “trophic cascade” (control of algal biomass by community composition of grazers and their predators) has been demonstrated for some streams (e.g., Power, 1990). Managers should realize the potential control of algal biomass by grazers, but they also should be aware that populations of grazers can fluctuate seasonally or unpredictably and fail to control biomass at times. Consideration of grazer populations might explain why some streams with high nutrients have low algal biomass.

- **Bedrock.** The natural effects of bedrock type also might help explain trophic state. Streams draining watersheds with phosphorus-rich rocks (such as rocks of sedimentary or volcanic origin) can be enriched naturally and, therefore, control of algal biomass by nutrient reduction in such systems might be difficult. Review of geologic maps and consultation with a local soil scientist might reveal such problems. Bedrock composition has been related to algal biomass in some systems (Biggs, 1995).

The Relationship Between Water Quality and Flow in Streams and Rivers

The relationship between water quality and flow in streams and rivers deserves special mention because some impairments are aggravated (or caused primarily) by flow modifications that result from in-stream diversions or catchments. For nutrient TMDLs, stream flow directly influences many physical features (e.g., depth, velocity, turbulence, reaeration, and volatilization), while also indirectly influencing nutrient uptake by attached algae. The velocity and depth associated with a specific flow regime also define the residence time in a reach, which directly influences reach temperature and the spatial expression of decay rates. During TMDL development, it is important to identify the flow regimes necessary to satisfy designated uses and to identify situations where flow modifications might make use attainment difficult or impossible. Because of the difficulties associated with addressing these types of impairments, more time might be required to identify and implement acceptable solutions. In some instances, states or territories might choose to undertake a Use Attainability Analysis (UAA) to assess the factors affecting the designated use.

NUTRIENT TMDLS

TMDL development is site-specific. The primary focus of this protocol is on developing nutrient TMDLs for lakes or rivers. Future material will explain developing nutrient TMDLs in estuarine waters. The availability of data influences the types of methods that developers can use. Ideally, extensive monitoring data are available to establish baseline water quality conditions, pollutant source loading, and waterbody system dynamics. However, without long-term monitoring data, the developer will have to use a combination of monitoring, analytical tools (including models), and qualitative assessments to collect information, assess system processes and responses, and make decisions.

Range of Approaches for Developing Nutrient TMDLs

TMDL analysts should be resourceful and creative in selecting TMDL approaches and should learn from the results of similar analytical efforts. The degree of analysis required for each component of TMDL development (e.g., selection of indicators and targets, source analysis, link between sources and water quality, and allocations) can range from simple, screening-level approaches based on limited data to detailed investigations that might need several months or even years to complete. Various interrelated factors will affect the degree of analysis for each approach: the type of impairment (e.g., violation of a numeric criterion versus designated use impairment); the physical, biological, and chemical processes occurring in the waterbody and its watershed; the size of the watershed; the number of sources; the data and resources available; and the types and costs of actions needed to implement the TMDL (see Figure 2-1).

Decisions regarding the extent of the analysis must always be made on a site-specific basis as part of a comprehensive problem-solving approach. TMDLs are essentially a problem-solving process to which no "cookbook" approach can be applied. Not only will different TMDL studies vary in complexity, but the

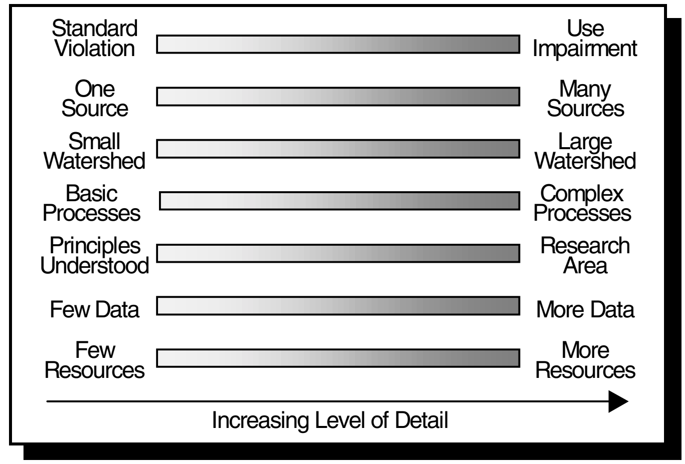


Figure 2-1. Factors influencing the level of detail for the TMDL analysis

degree of complexity in the methods used *within* individual TMDL components also may vary substantially. Simpler approaches can save time and expense and can be applied by a wider range of personnel. Simple approaches also generally are easier to understand than more detailed analyses.

The trade-offs associated with using simple approaches include a potential decrease in predictive accuracy and often an inability to make predictions at fine geographic and time scales (e.g., watershed-scale source predictions versus parcel-by-parcel predictions, and annual versus seasonal estimates). When using simple approaches, analysts should consider these two shortcomings in determining an appropriate margin of safety.

The advantages of more detailed approaches, presumably, are an increase in predictive accuracy and greater spatial and temporal resolution. Such advantages can translate into greater stakeholder "buy-in" and smaller margins of safety that usually reduce source management costs. Detailed approaches might be necessary when analysts have tried the simple approaches and have proven them ineffective, or when it is especially important to "get it right the first time." More detailed approaches also may be warranted when there is significant uncertainty whether nutrient discharges relate to human or to natural sources and the anticipated cost of controls is especially high. However, more detailed approaches are likely to cost more, require more data, and take more time to complete.

EXAMPLE NUTRIENT TMDLS

Brief summaries of four final and one preliminary nutrient TMDLs show that a range of methods is appropriate for TMDL development and that individual TMDLs often combine relatively detailed analysis for certain elements with simple analysis supporting other elements. The preliminary example is based on a TMDL that has not yet been completed. Two detailed case studies are provided in the Appendix.

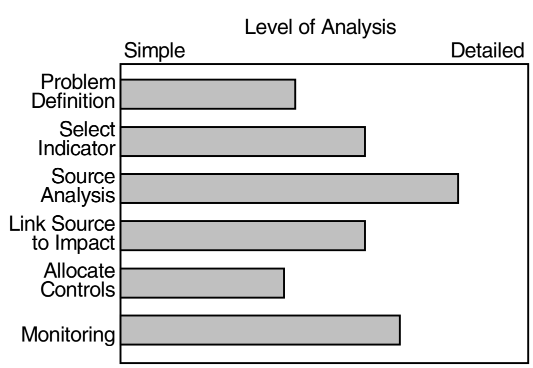
Lake Chelan, Washington

Lake Chelan, Washington, located in the northern Cascades, serves as a water supply for more than 6,000 residents, provides irrigation water for approximately 18,000 acres, and produces hydroelectric power for the region. The lake, used also for water-related recreation and fisheries production, is considered one of the pristine waters in North America. The lake is classified as ultra oligotrophic, meaning it has low levels of nutrients and high dissolved oxygen concentrations throughout. The Washington State Department of Ecology developed a Section 303(d)(3) TMDL for the lake in 1991, to preserve its good quality and to prevent degradation from increasing development in the watershed. The Department of Ecology conducted the Lake Chelan Water Quality Assessment (LCWQA) to determine the baseline conditions in the lake and to compile the technical data necessary for developing the TMDL. The data collected during this intensive study detailed the lake's present condition and provided information for all aspects of TMDL development, including the establishment of a numeric target, identification and estimation of sources, and calculation and allocation of loads. During the study, analysis of water column and particulate matter nitrogen-to-phosphorus ratios identified phosphorus as the principal nutrient controlling algal growth in the lake. Therefore, a numeric target was established for phosphorus. To preserve the ultra oligotrophic condition of Lake Chelan, the in-lake target value for total phosphorus (TP) concentration was established at 4.5μg/L, a value generally accepted for the ultra oligotrophic classification. The sources of phosphorus were then identified and quantified to develop the TMDL and the appropriate allocations.

The upper basin of the Lake Chelan watershed is heavily wooded and primarily undisturbed, while the lower basin is a mixture of forest, apple orchards, and urban land. The LCWQA estimated that 75 percent to 90 percent of the phosphorus input to the lake comes from natural sources, largely forest runoff and direct precipitation. The remaining 10 percent to 25 percent was anthropogenic in nature, with approximately half due to agricultural activities. The remaining portion of the phosphorus load to the lake was estimated to come from storm water runoff and septic system inputs. The only point sources in the basin were chinook salmon net pens. These large, floating, barge-like structures contain dense populations of fish and contribute an estimated 0.01 kg of phosphorus per day per 2,000 lb of fish.

The Department of Ecology used a steady-state mass balance model and Monte Carlo analysis techniques to link the source loadings to the numeric target. The modelers considered three different growth scenarios

Lake Chelan



Water Quality Indicators	TMDL	Controls
4.5 μg/L P	51 kg/day P	Various controls being considered
Source Assessment: Lake Chelan Water Quality Assessment Study Link to Indicator: Steady-state mass balance with Monte Carlo simulation		

and calculated load allocations for each scenario, considering the corresponding impacts of each scenario (e.g., greater loading can be permitted for growth in the upper basin because the upper basin allows for greater TP settling than the lower basin). The TMDL was developed for the more likely scenario of little to no growth in the upper basin and moderate growth in the lower basin. To achieve the 4.5 μg/L goal, the TMDL established a TP loading at 51 kg P per day. (The Department of Ecology calculated the allowable loadings conservatively so that the probability of remaining ultra oligotrophic would be 95 percent, thereby incorporating a margin of safety.)

The Department of Ecology decided that allocation of the loads to the specific sources in the watershed would depend on future development. Therefore, the Lake Chelan Water Quality Plan considered load allocations among the sources (homes using on-site disposal, homes on sewer systems, Chinook net pens, and agricultural activities) based on the different development scenarios and then developed a schedule of actions to implement the established loads for the most likely development pattern. The 51 kg/day allowable load was divided among future growth (0.5 kg/ day), existing sources (6.3 kg/day) and background loads (44.2 kg/day).

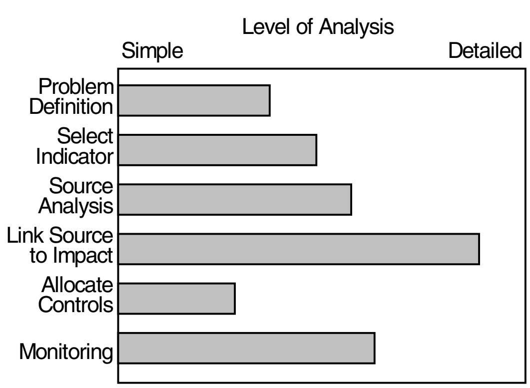
In addition to the schedule for implementation, a long-term water quality monitoring strategy was established with permanent stations and parameters. The monitoring plan was to assess water quality trends and runoff from agricultural drains to evaluate pollutant loading during worst-case conditions. Another goal of the monitoring plan was to help growers minimize potential pollutant loads by reducing the amount of water leaving their site in runoff or deep percolation. This reduction would be accomplished by conducting an extensive soils analysis to determine the optimum procedure for managing irrigation rate, timing, and duration.

Wolf Lake TMDL (Preliminary)

This preliminary example is based on a study that was conducted of Wolf Lake, Mississippi. The results of the study have not yet been used to prepare a TMDL submittal. The discussion of the technical approach is therefore factual but the discussion of implementation is merely suggested. Wolf Lake was included despite its preliminary nature because it provides an example of a TMDL for which the prediction of loads was based on a relatively simple technique, and more detailed investigations were dedicated to predicting in-lake water quality impacts.

Wolf Lake, an oxbow lake in the southeastern United States, was included on the 303(d) list because of violations of the dissolved oxygen water quality standard. The TMDL developers identified excessive nutrient loadings from fertilized crops and catfish ponds in the watershed as the primary cause of impairment and identified no point source discharges to the lake. Water quality data were limited to a previously released EPA Clean Lakes study that included in-lake and tributary concentrations of a variety of pollutants for a 2-year period. The TMDL developers were able to determine general land use information in the watershed, based on

Wolf Lake



Water Quality Indicators	TMDL	Controls
Minimum daily dissolved oxygen concentration of 5.0 mg/L	Reduce current phosphorus loading by 35%	BMPs for ag fields BMPs for catfish ponds
Source Assessment: GWLF model Link to Indicator: CE-QUAL-ICM model		

an existing, 3-year-old coverage. The land uses were broadly categorized by acreage into agricultural, residential, forested, and barren lands. Estimates of source loadings (in kilograms per month) for each of these land uses were derived using the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992). This desktop model uses literature values for runoff, sediment, and ground water relationships based on different regions of the country. Streamflow, nutrient loading, soil erosion, and sediment yield values were estimated using GWLF based on the Wolf Lake watershed land uses and regional soil and meteorologic conditions.

Because of the complex nature of the waterbody (e.g., varying in-lake conditions and vertical stratification), simplified receiving water models were not considered appropriate for predicting in-lake response or load reduction alternatives. Instead, analysts used the CE-QUAL-W2 hydrodynamic and water quality model (Cole and Buchak, 1995) to simulate eutrophication processes. Model simulations were conducted for the time periods corresponding to available in-lake water quality monitoring data to determine a relationship between the estimated loading conditions and water quality response.

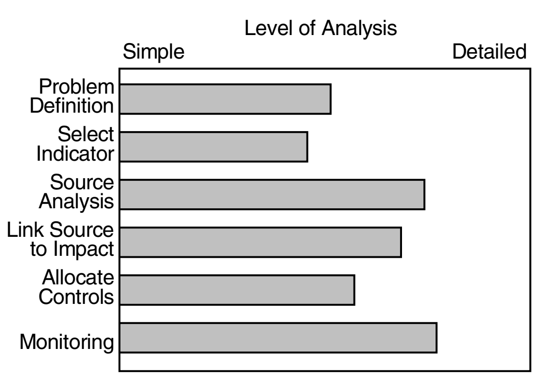
Based on the modeling results, the TMDL developers evaluated several scenarios that would allow the lake to meet its dissolved oxygen standard. These scenarios considered the developers' knowledge of the various land uses in the watershed and the feasibility of different types of controls. The TMDL was established so that phosphorus loadings were to be reduced by approximately 35 percent annually and load allocations were established for both row crops and the catfish ponds. Additional monitoring will be performed to further evaluate the magnitude of the different sources and to evaluate the effectiveness of best management practices (BMP) for restoring lake water quality.

Tualatin River TMDL

The Tualatin River TMDL in Oregon is an example of a situation where relatively more time and effort were expended to identify a target and allocate loads than were spent to estimate loads from specific nutrient sources. The impaired portion of the Tualatin River is approximately 40 miles long and drains an urbanizing watershed east of Portland. According to several water quality surveys, the Tualatin River was not supporting the following uses, in part because of nuisance algal growths: fishing, contact recreation, aesthetics, and aquatic life. Moreover, the lake to which the Tualatin River drains was not supporting several of its designated uses because of nuisance algal growth.

The Oregon Department of Environmental Quality decided to develop a total phosphorus TMDL to address these problems. The state's Nuisance Phytoplankton Growth Rule (OAR 340-412-150) established a phytoplankton concentration of 15 μg/L chlorophyll *a* (average concentration) as the applicable numeric criterion for the lake and the river. For the TMDL, a local university conducted a series of algal growth studies to determine the total phosphorus target that would achieve this criterion. The researchers found that a noticeable reduction in algal growth occurred at 100 μg/L phosphorus and that at approximately 50 μg/L phosphorus, low growth conditions prevailed. Using

Tualatin River



Water Quality Indicators	TMDL	Controls
Average chlorophyll *a* 15 μg/L Average TP 70 μg/L (May to Oct)	LA's specified for various attainment points for different flow conditions	Various BMPs determined by local municipalities

this information and after consulting with various stakeholders, the state agency adopted a total phosphorus target of 70 μg/L (to be applied as a monthly mean from May 1 to October 31).

A source assessment indicated that the following were the primary sources of phosphorus in the watershed: two wastewater treatment plants, confined animal feeding operations, agricultural and forestry practices, failing septic systems, urban storm water runoff, and county road ditches. An in-depth source assessment estimating the loadings from each of these activities was not conducted. Instead, the required nonpoint source reductions were allocated to 16 specific locations along the main stem of the river and to the major tributaries. The loading capacities also were divided into four hydrologic categories (flow conditions) based on typical flows observed between May and October. For example, the nonpoint source phosphorus load allocation for the Tualatin River and other tributaries upstream of Golf Course Road were specified as follows:

Flow	< 50 cfs	50 to 100 cfs	100 to 200 cfs	> 200 cfs
NPS Load	7.4 lb/day	14.8 lb/day	29.7 lb/day	59 lb/day

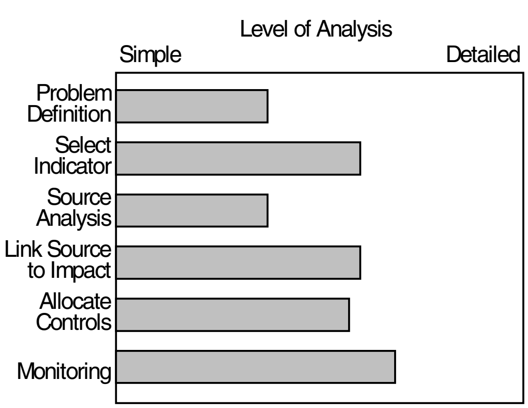
These allocations are expected to keep the monthly mean total phosphorus concentration below 45 μg/L at this location in the river (which will, in turn, contribute to keeping the downstream main stem concentration below the specified target of 70 μg/L). Each municipality within the various subbasins is responsible for determining how load reductions should occur, and a Technical Advisory Committee and a Citizens' Advisory Committee will help develop plans. An ambient monitoring program specifying the parameters to be sampled and the minimum frequency of monitoring also will track progress toward the goal.

Port Tobacco River TMDL

The Port Tobacco River TMDL in Maryland is an example of a situation where modeling was used extensively in determining the effectiveness of a proposed TMDL approach. The Port Tobacco River is approximately 8.5 miles long and drains a predominantly forested watershed in Charles County. Land use within the watershed consists of 60 percent forest, 21 percent mixed agriculture and 19 percent urban land. According to water quality surveys, the Port Tobacco River was not supporting the following uses, in part because of nuisance algal growths and low dissolved oxygen: water contact recreation and protection of aquatic life, and shellfish harvesting (Code of Maryland Regulations 26.08.02 Use I and II, respectively).

The Maryland Department of the Environment (MDE) decided to develop nitrogen and phosphorus TMDLs to address these problems. The state's narrative nitrogen and phosphorus water quality criteria are listed in Section 26.08.02.03B of the Code of Maryland Regulations. MDE uses a numerical limitation on chlorophyll-*a* as a surrogate measure to determine

Port Tobacco River



Water Quality Indicators	TMDL	Controls
5 mg/L DO 52 μg/L chlorophyll-*a*	Summer: 8,710 lbs/month N 871 lbs/month P Annual Average: 243,310 lbs/year N 15,570 lbs/year P	Biological Nitrogen Removal (BNR), Chemical Phosphorus Removal (CPR) on point sources
Source Assessment: MD Office of Planning land use data and HSPF land use loading coefficients (nonpoint source), MDE DMR reports (point source) Link to Indicator: WASP5		

compliance with the narrative criteria. In addition, the TMDLs are designed to achieve compliance with Maryland's dissolved oxygen water quality criterion of 5 mg/L. MDE used a predictive model to demonstrate that the TMDLs will ensure compliance with both the narrative criteria and the dissolved oxygen criterion by maintaining nitrogen and phosphorus loads at the targeted levels. The model, Water Quality Analysis Simulation Program, can simulate the transport and transformation of conventional and toxic pollutants in the water column and benthos of ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters.

The critical season for excessive algal growth in the Port Tobacco River occurs during the low-flow summer months, when the system is poorly flushed and slow-moving, warm water is susceptible to excessive algal growth. As a result, MDE developed individual nitrogen and phosphorus TMDLs for both the summer (May 1 through October 31) and annual average flow conditions. The summer TMDLs for nitrogen and phosphorus are 8,710 and 871 lbs/month, respectively. The annual average flow TMDLs for N and P are 243,310 and 15,570 lbs/year, respectively. A summary of the TMDLs is presented below.

Load	Summer Low Flow		Annual Avg. Flow	
	N (lb/mo)	P (lb/mo)	N (lb/yr)	P (lb/yr)
TMDL	8,710	871	243,310	15,570
LA[1]	5,776	696	190,470	12,500
WLA[2]	1,597	88	24,920	1,060
MOS[3]	173	21	5,840	400
FA[4]	1,164	66	22,080	1,610

[1] Load Allocation; [2] Waste Load Allocation; [3] Margin of Safety (also implicit); [4] Future Allocation

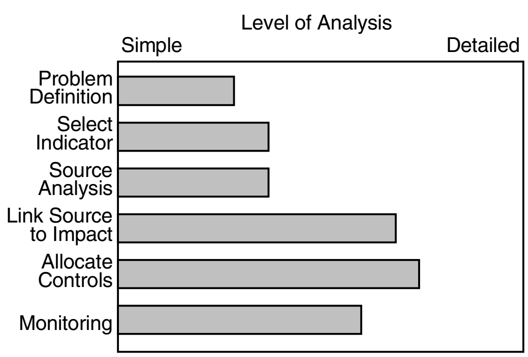
In addition to the explicit MOS allocations presented above, MDE also applied an implicit MOS by setting an upper model target on chlorophyll-*a* concentrations of 52 μg/L, which is conservative given the generally acceptable range of 50 μg/L to 100 μg/L. Other implicit MOS features include the "worst case" scenario assumption that point sources in the watershed are discharging at their permitted levels under high-temperature, low-flow conditions.

The WLAs will be implemented through the NPDES permit process. The nonpoint source controls (LAs) will be implemented through Maryland's Lower Potomac Tributary Strategy, developed as part of Maryland's commitments under the Chesapeake Bay Agreement. In addition, follow-up monitoring within five years will be conducted as part of Maryland's Watershed Cycling Strategy, which will help determine whether these TMDLs have been implemented successfully.

Garrison Lake TMDL

Garrison Lake, a 90-acre lake adjacent to the City of Port Orford in southwestern Oregon, is relatively shallow, with an average depth of eight feet and a maximum depth of 26 feet. The lake consists of a large upper basin containing about 84 percent of the lake volume and a smaller lower basin containing about 16 percent of the lake volume. Approximately 85 percent of the shoreline consists of private lands and land use in the watershed at the time the TMDL was developed (1988) was 61 percent forested, 25 percent urban, 10 percent sand dunes, and 4 percent water.

Garrison Lake



Water Quality Indicators	TMDL	Controls
Average chlorophyll *a* 15 μg/L	Entire TMDL specified as LAs (WLA eliminated)	City of Port Orford WWTP relocated out of Garrison Lake
Source Assessment: Clean Lakes Phase I Diagnostics and Feasibility Study Link to Indicator: Modified Vollenweider relationship		

Garrison Lake is designated to support several beneficial uses, including:

- Public Domestic Water Supply
- Water Contact Recreation
- Aesthetic Quality
- Boating
- Resident Fish and Aquatic Life
- Fishing

According to Oregon regulations(OAR 340-41-150), beneficial uses may be impaired by excessive algal growth in shallow lakes when average chlorophyll *a* values exceed 15 μg/L. This concentration was commonly exceeded in the lower basin of Garrison Lake (67 percent of measurements) and occasionally exceeded in the upper lake basin (10 percent of the measurements). Excessive macrophyte growth also was observed in the shallow areas of the lake.

A modified version of the Vollenweider total phosphorus loading and mean depth and hydraulic residence time relationship (Vollenweider, 1968) was used to establish a draft total phosphorus TMDL for Garrison Lake. Based on the modified Vollenweider relationship, the TMDL for Garrison Lake was calculated as 562 lbs per year total phosphorus. Because lakes are sensitive to pollutant loadings received throughout the year, the TMDL was expressed as an annual loading. The Oregon Department of Environmental Quality next conducted a Clean Lakes Phase I Diagnostics and Feasibility Study to more thoroughly identify and evaluate the nonpoint nutrient sources. These sources included in-lake loadings or resuspension and release of nutrients from the sediment. The data gathered from this study resulted in only a slight modification to the TMDL (576 lbs per year total phosphorus).

The potential nutrient sources identified in the Garrison Lake watershed were the City of Port Orford wastewater treatment plant, failing septic systems, road building, and fertilizer application. Researchers estimated, based on the available sampling data, that the wastewater treatment plant contributed about 68 percent of the phosphorus load while the contribution from the lake's tributaries was 32 percent and the TMDL was established as follows:

TMDL = 576 lbs/yr TP = Load Allocations (576 lbs/yr) + Wasteload Allocations (0 lbs/yr)

To implement the TMDL, DEQ negotiated an agreement with the City of Port Orford to relocate the existing waste discharge out of Garrison Lake. This agreement resulted in a decrease in nutrient loading and a significant decrease in nuisance algal growths. The lake continues to be monitored to ensure that the 15 μg/L chlorophyll *a* target is met.

NUTRIENT CONTROLS

As suggested by the preceding TMDL examples, many BMPs are available for nutrient control from rural (agricultural) and urban nonpoint sources. BMPs can be classified into three categories—management, structural, and vegetative. To select the most effective BMP or combination of BMPs, a manager must determine the primary source of the pollutant and its method of transport to the waterbody (as discussed in section 5—Source Assessment). Table 2-2 describes various BMPs designed to reduce nonpoint source pollution.

BMPs achieve pollution reduction by either preventing pollution first or controlling pollutants at the sources. Management BMPs are used to prevent pollution by controlling land use with laws (zoning ordinances, discharge permits) and planning (nutrient management plans, road maintenance programs). Structural and vegetative BMPs control pollution by intercepting the flow of water from the source before it reaches a waterbody. Most structural and vegetative BMPs are targeted for control of a particular pollution problem. Many, such as porous pavement and infiltration basins, are designed to encourage infiltration of runoff. Other BMPs, including cover crops, diversions, conservation tillage, and critical area planting, are used to minimize soil erosion. Many BMPs serve as multipurpose controls. For example, retention ponds and constructed wetlands not only hold runoff water (allowing pollutants to settle out of the water) but also provide vegetation that can absorb some of the nutrients. Implementation of a combination of BMPs is usually the most successful method of controlling numerous pollutants from a nonpoint source.

Table 2-2. Common BMPs employed to control nutrient transport from agricultural and urban nonpoint sources

Nutrient Source	Management BMPs	Structural BMPs	Vegetative BMPs
Agriculture[a]	• Nutrient management • Range and pasture management • Proper livestock-to-land ratio • Waste composting plan • Irrigation management • Lagoon waste level management • Crop residue management • Livestock waste management	• Animal waste system (lagoon, controlled storage area) • Fences (livestock exclusion) • Diversions • Terraces • Tailwater pit • Retention/detention pond • Constructed wetland • Waste composting facility • Stream bank stabilization • Sediment pond	• Cover crop • Strip cropping • Riparian buffer • Crop types (identify nutrient needs) • Conservation tillage • Vegetated filter strips • Critical area planting
Urban[b]	• Zoning ordinances • Restrictive covenants • Growth management • Buffers and setbacks • Site plan review • Public education • Permitting for pollutant discharge • Pollution prevention programs • Spill control programs • Road maintenance programs (street sweep) • Septic system pump-out schedule	*Developing urban:* • Extended detention ponds • Constructed wetlands • Multiple pond systems • Infiltration trenches and basins *Highly urban:* • Illicit connection controls • Porous pavement • Storm water detention or wetland retrofits • Sand filters	• Vegetated filter strips • Riparian buffer • Vegetative cover

[a] Adapted from Novotny and Olem, 1994.
[b] Adapted from USEPA, 1993.

Problem Identification

Objective: Identify background information and establish a strategy for specific 303(d) listed waters that will guide the overall TMDL development process. Summarize the nutrient-related impairment(s), geographic setting and scale, sources of concern, and other information needed to guide the TMDL development process and provide a preliminary assessment of the complexity of the TMDL (what approaches are justified and where should resources be focused).

Procedure: Inventory and collect data and information needed to develop the TMDL. Information collected should include an identification of the pollutant water quality standards impairment and preliminary identification of sources, numeric targets, proposed analytical methods, data needs, resources required and possible management and control techniques. Interview watershed stakeholders and local, state, tribal, and federal agency staff to identify all information relevant to the waterbody and its watershed. Establish plans for incorporating public involvement in the development of the TMDL. Revise the problem definition as new information is obtained during TMDL development.

OVERVIEW

Developing a TMDL requires formulating a strategy that addresses the potential causes of the water quality impairment and available management options. The characterization of the causes and pollutant sources should be an extension of the process originally used to place the waterbody on the 303(d) list. Typically, the impairment that caused the listing will relate to water quality standards being violated—either pollutant concentrations that exceed numeric criteria or waterbody conditions that do not achieve a narrative water quality standard or a designated use. In many cases, the problem is self-evident and its identification will be relatively straightforward. In other cases, the complexity of the system might make it more difficult to definitively state the relationship between the nutrient sources and the impairment.

The following key questions should be addressed during this initial strategy-forming stage. Answering these questions results in defining the approach for developing the TMDL. A problem statement based on this problem identification analysis is an important part of the TMDL because it relates the TMDL to the 303(d) listing and clearly identifies the purpose of the TMDL, thereby making the TMDL more understandable and useful for implementation planning.

KEY QUESTIONS TO CONSIDER FOR PROBLEM IDENTIFICATION

1. What are the designated uses and associated impairments?

The goal of developing and implementing a TMDL is to attain and maintain water quality standards in an impaired waterbody to support designated uses. With that in mind, TMDL developers should stay focused on addressing the nutrient-related problem interfering with the designated uses. Some common designated uses and their associated nutrient problems are presented in Table 3-1. The problem identification should answer the following:

- What nonattainment of standards caused the listing? What data or qualitative analyses were used to support this decision?
- Where in the waterbody are designated uses supported and where are they impaired?
- How are water quality criteria expressed (narrative, numeric)?

Key Questions to Consider for Problem Identification

1. What are the designated uses and associated impairments?
2. What data are readily available?
3. What is the geographic setting of the TMDL?
4. What temporal considerations will affect development of the TMDL?
5. What are the nutrient sources and how do they affect water quality?
6. How will margin of safety and uncertainty issues be addressed in the TMDL?
7. What are some potential control options?
8. What changes does the proposed rule speak to?

Table 3-1. Impacts of nutrients on designated uses

Designated Use	Problems Associated with Plant Growth Stimulated by Nutrient Loading
Aquatic Life Support	• Low dissolved oxygen concentrations caused by nighttime respiration of large populations of aquatic plants and algae or by the decay of plant matter • Fish kills (via toxicity, or low dissolved oxygen) • Reduced light penetration • Nuisance plants outcompeting desired species
Drinking Water Supply	• Blockage of intake screens and filters • Taste and odor problems • Production of toxins (by blue-green algae) • Disruption of flocculation and chlorination processes in water treatment plants • High nitrates in drinking water, which can cause methemoglobinemia (reduced ability of the blood to carry oxygen), especially in infants
Recreation/Aesthetics	• Reduced clarity by sloughed material • Macrophyte interference with boating, swimming, water skiing, and other recreation • Sloughed material fouling anglers' nets • Floating mats • Slippery beds that make wading dangerous
Industrial	• Blockage of intake screens and filters
Agricultural	• Clogged stream channels, reducing drainage by raising water level and increasing risk of flooding adjacent land

Source: Adapted from Quinn, 1991.

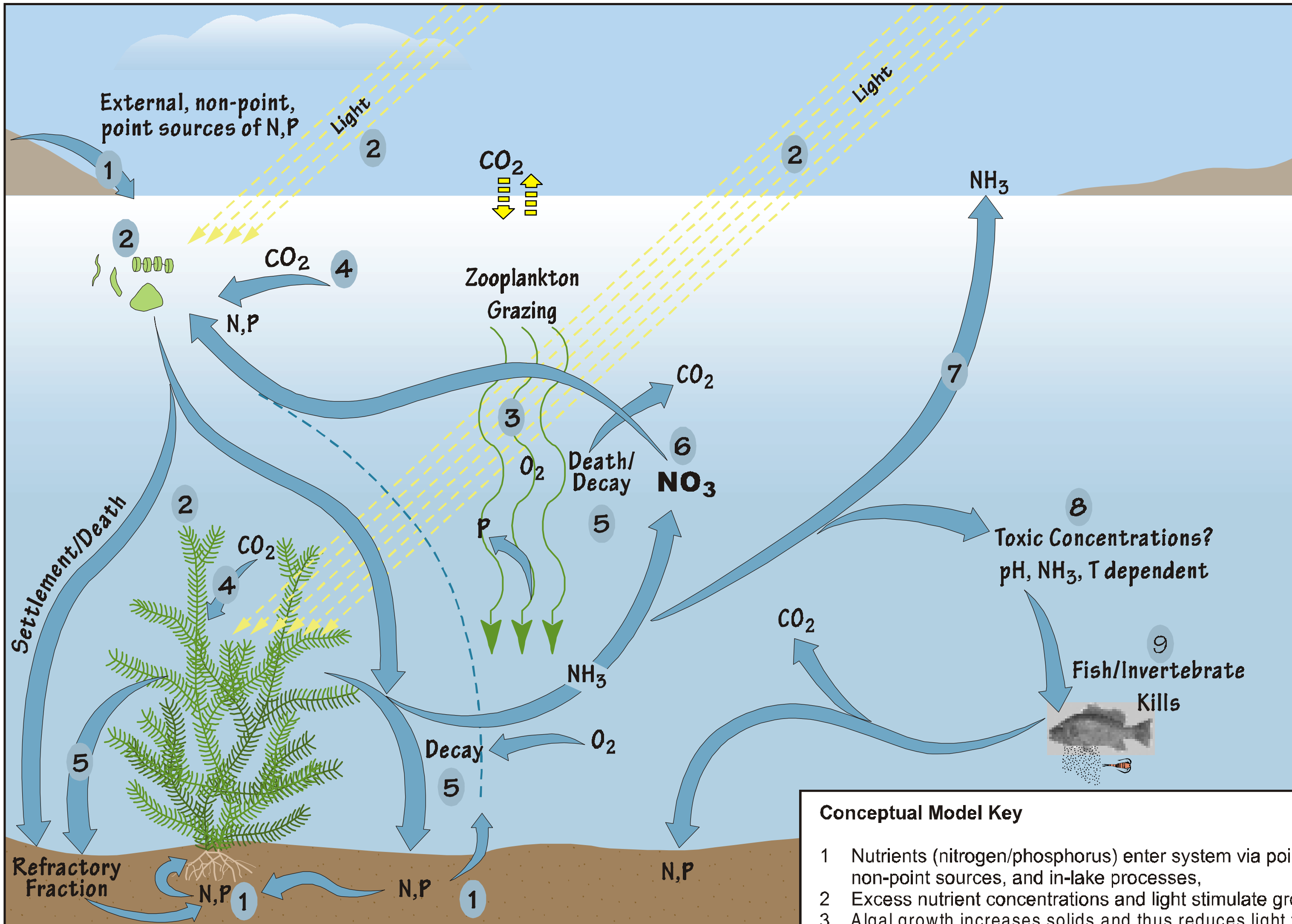
- What are the critical conditions, in terms of flow and season of the year, during which designated uses are not supported?
- How do nutrients affect the designated uses of concern (e.g., phosphorus loading stimulates excessive algal growth that interferes with recreational use of the waterbody)?
- Are there additional use concerns (e.g., presence of threatened or endangered species)?

Recommendation: Identify and summarize in a problem statement the events leading to the listing and the data to support the listing. Prepare a flowchart or schematic detailing the processes that might affect impairment of the waterbody. Figure 3-1 is an example of what such a schematic might look like for an impaired lake or reservoir.

2. What data are readily available?

As much as possible, managers should identify the problem based on currently available information, including water quality monitoring data, watershed analyses, best professional judgment, information from the public, and any previous studies of the waterbody (e.g., state and federal agency reports, university-sponsored studies, reports prepared by environmental organizations). These data ideally will provide insight into the nature of the impairment, potential nutrient sources, and the pathways by which nutrients enter the waterbody. Managers also should compile data that will be needed for actual development of the TMDL during the problem identification stage. These data likely will include the following:

- Water quality measurements (e.g., nutrient, algae, and dissolved oxygen concentrations)
- Waterbody size and shape information (e.g., volume, depth, area, length)



Conceptual Model Key

1 Nutrients (nitrogen/phosphorus) enter system via point sources, non-point sources, and in-lake processes,
2 Excess nutrient concentrations and light stimulate growth,
3 Algal growth increases solids and thus reduces light transparency,
4 Aquatic plants consume carbon dioxide and cause pH to rise,
5 Aquatic plants fragment or die releasing ammonia, phosphorus, carbon dioxide, and consume oxygen into water column or sediments,
6 Ammonia undergoes nitrification to yield nitrate. Nitrate is recycled back into system,
7 Ammonia diffuses into atmosphere,
8 Ammonia can become toxic if pH and ammonia concentrations are high enough, and
9 High concentrations of unionized ammonia can cause fish and invertebrate kills and release ammonia into the water column and consume additional dissolved oxygen.

Figure 3-1. Nutrient conceptual model.

- Waterbody flow and residence times
- Tributary location and contributions (flow and water quality)
- Biological information (e.g., fish, invertebrate, and riparian vegetation information)
- Watershed land uses and land use issues
- Temperature and precipitation data
- Soil surveys and geologic information
- Topographical information

Maps of the watershed also will be invaluable, either hard copies, such as USGS quad maps, or (if available) electronic files for GIS systems. Point sources, known nonpoint sources, and land uses should be identified on these maps to provide an overview of the watershed and to identify priority areas for nutrient loading caused by human activities.

Information on related assessment and planning efforts in the study area should also be collected. TMDL development should be coordinated with similar efforts to reduce TMDL analysis costs, to increase stakeholder participation and support, and to improve the outlook for timely implementation of needed control or restoration activities. Examples of related efforts that should be identified include:

- State, local, or landowner-developed watershed management plans
- Natural Resource Conservation Service (NRCS) conservation plans, Environmental Quality Incentives Program (EQUIP) projects, and Public Law 566 (PL-566) small watershed plans.
- Land management agency assessment or land use plans (e.g., Federal Ecosystem Management Team [FEMAT] watershed analyses or Bureau of Land Management [BLM]) proper functioning condition assessments)
- Nonpoint source control projects
- Clean Lakes program projects
- Stormwater management plans and permits
- Habitat conservation plans developed under the Endangered Species Act
- Comprehensive monitoring efforts (e.g., National Water Quality Assessment [NAWQA]) and Environmental Monitoring and Assessment Program [EMAP] projects)

Recommendation: Contact agency staff responsible for the waterbody listing and collect any information they have available. Contact other relevant agencies, such as the NRCS or state natural resources, water resources, fish and wildlife, and public health agencies and prepare an inventory of available information. Universities are often a good source of data for a waterbody.

3. What is the geographic setting of the TMDL?

TMDLs can be developed to address various geographic scales. The geographic scale of the TMDL primarily will be a function of the impairment that prompted the waterbody listing, the type of waterbody impaired, the spatial distribution of use impairments, and the scale of similar assessment and planning efforts already under way.

The selection of TMDL scale may involve trade-offs between comprehensiveness in addressing all designated use and source issues of concern and the precision of the analysis (MacDonald et al., 1991; Bisson et al., 1997). Table 3-2 summarizes the advantages and disadvantages of developing TMDLs for larger (e.g., greater than 50 mi^2) and smaller (less than 50 mi^2) watersheds.

Recommendation: When the designated use impairments are at the bottom of a watershed (e.g., in a lake or reservoir), address the entire watershed at once by using less-intensive, screening-level assessment methods. Follow-up monitoring can assess the effectiveness of the nutrient reduction and, if necessary, more in-depth analysis can target specific high-priority areas within the watershed that have local problems.

When impairments occur throughout a watershed, the analysis should be conducted for smaller, more homogenous analytical units (i.e., subwatersheds). For example, specific river reaches that are impaired might require detailed TMDLs to address upstream point and nonpoint sources. If this subwatershed approach is chosen, care should be taken to apply consistent methodologies from one subwatershed to the next so that an additive approach eventually can apply to the larger watershed.

Table 3-2. Advantages and disadvantages of different TMDL watershed analysis scales.

	Large TMDL Study Units (> 50 square miles)	**Small TMDL Study Units (< 50 square miles)**
Advantages	• Accounts for watershed processes operating at larger scales • More likely to account for cumulative effects • Avoids need to complete separate studies for multiple tributaries	• Easier to identify and address fine-scale source-impact relationships, and to identify needed control actions • Possible to use more accurate, data-intensive methods.
Disadvantages	• Confounding variables obscure cause-effect relationships • Numeric target setting harder for heterogeneous waterbody features • Source estimation more difficult because land areas more heterogeneous • Lag time between nutrient discharge and instream effects potentially longer, effectiveness of source controls therefore harder to detect • Analysis at coarse scale may cause TMDL to "miss" source-impact relationships at fine scale	• May miss cause-effect relationships detectable only at broad scale (cumulative impacts) • May necessitate many separate TMDL studies in a basin

4. What temporal considerations will affect development of the TMDL?

TMDLs must consider temporal (e.g., seasonal or interannual) variations in discharge rates, receiving water flows, and designated use impacts. These considerations are especially important for stream nutrient TMDLs because both point and nonpoint nutrient sources can discharge at different rates during different time periods and plant growth can vary considerably by season. A frequent critical period for a nutrient stream TMDL is the summer low-flow, high-temperature period, because these conditions are favorable for nuisance plant growth. Critical conditions also can occur during other times of the year, however. For example, in the fall, upstream organic carbon sources from phytoplanton and aquatic plants can result in large depressions in levels of dissolved oxygen. Spring floods that pick up large amounts of organic debris from adjacent floodplains also can result in severe dissolved oxygen depletion or phytoplankton blooms (USEPA, 1995a).

Seasonal variations are also important for lake nutrient TMDLs. For example, a key aspect of plant dynamics in temperate lakes is the magnitude of the spring phytoplankton bloom. Algal growth typically is greatly reduced or negligible during the winter low light and temperatures; it then usually increases during the spring under increasing sunlight. The spring maximum is generally short-lived (less than one to two months) and a period of low algal numbers and biomass often follows that can extend throughout the summer (Wetzel, 1983). The effects of nutrient inputs to reservoir main stems also may vary with the reservoir's thermal regime and hence with the time of year. The mixing of in-flows during winter and spring may affect the entire waterbody, while in-flows during stratified periods may enter as underflow and might not affect the photic zone, especially in bottom-discharging reservoirs.

In addition to the seasonal variation in the onset and die-off of algal blooms, there also may be temporal variation, or succession, in the composition of blooms. In some systems, the blooms begin with diatoms and then shift to green algae and finally to blue-green algae. An example of this sequence of succession is the San

Francisco Bay, although the final blue-green algal bloom no longer occurs, presumably because of copper toxicity in the bay. In other systems, two separate blooms occur. For example, there are separate spring and fall blooms of *Cladophora* in Lake Huron, where higher summer temperatures impair algal growth (Auer et al., 1982).

A variety of temporal considerations will affect each stage of TMDL development. For example, the water quality indicator chosen to develop the TMDL should closely link to the problems impairing the water's use. A useful indicator for a river impaired by nuisance periphyton growth that primarily occurs during the summer might, therefore, be a maximum algal biomass for May to October. Alternatively, if nutrient loadings contribute to depressed dissolved oxygen concentrations, the water quality indicator used to develop the TMDL might be appropriately expressed for a much shorter time period (i.e., daily).

TMDL developers also must consider time scale issues when conducting the source assessment and when linking the estimated loadings to the indicators of water quality. For situations involving both point and nonpoint sources of nutrients, it might be possible to link episodic loading models with steady-state receiving water models or to use an average wet-weather loading rate. This technique is often appropriate for developing nutrient TMDLs in lakes with long residence times because these waters might be relatively insensitive to short-term variations in nutrient loading rates and their response will take weeks or months, rather than days.

Determining the Limiting Nutrient

The limiting nutrient, generally nitrogen or phosphorus, is defined as the nutrient that limits plant growth when it is not available in sufficient quantities. A first cut at determining the limiting nutrient can be accomplished by comparing the levels of nutrients in the waterbody with the plant stoichiometry. The ratio of nitrogen to phosphorus in biomass is approximately 7.2:1. Therefore, an N:P ratio in the water that is less than 7.2 suggests that nitrogen is limiting. Alternatively, higher ratios suggest that phosphorus is limiting. (Chapra, 1997).

Recommendation: Address temporal considerations during the problem identification stage of TMDL development to ensure that a good strategy is in place as the specific technical components of the TMDL are completed. Specific guidance on addressing temporal issues is provided in each section of this protocol.

5. What are the nutrient sources and how do they affect water quality?

During the problem identification, the TMDL developer should first understand the relative magnitude of the various nutrient sources, including identifying when loading occurs and how nutrients enter the waterbody. It might be sufficient to locate known point and nonpoint sources on a map, or some routine monitoring might be needed. A more detailed source analysis eventually will be needed. (This topic is covered in Section 5). A qualitative assessment of the significance of sediment cycling, groundwater sources, and atmospheric sources should also be made at this time, and an attempt should be made to determine the limiting nutrient (see box).

In addition to assessing nutrient sources, TMDL developers should identify the specific role that nutrients play in affecting designated uses, because many impairments associated with nutrient loadings also can be caused by other stressors. For example, low dissolved oxygen levels that affect aquatic life can be caused by high biochemical oxygen demand, reduced flows, or warm temperatures. Moreover, nutrients might not always be the limiting factor controlling nuisance plant growth. Several other constraints, such as light availability, flow, availability of trace elements, substrate conditions, management ($CuSO_4^+$, grazing, and temperature) potentially could be limiting (refer to Section 2). Nutrients are often the focus because they are usually more readily controlled. In some cases, however, it might be more practical to control nuisance growth through other mechanisms, such as channel modifications, restoration of riparian canopy, increased flow, or introduction of biological controls.

Recommendation: Conduct an inventory of available information on point sources using information available from state or local agencies or databases such as the national Permit Compliance System (PCS). For nonpoint sources, identify all possible land use-specific sources through analysis of aerial photographs, land cover maps or databases and information from federal, state, and local agencies. When using maps or GIS coverages to determine land uses, document the scale, resolution, and date of the information. In large watersheds, the only available data might exist at a small scale and the ability to conduct field verification will be limited. In smaller watersheds, the utility of the same data might be limited because the scale and minimum mapping unit might hide important details, but field verification of the data is possible. In all cases, rely on the best and most relevant data set, document all issues related to scale and date, and verify analysis with field visits.

6. How will margin of safety and uncertainty issues be addressed in the TMDL?

Considerable uncertainty is usually inherent in estimating nutrient loading from nonpoint sources, as well as predicting water quality response. The effectiveness of management measures (e.g., support of agricultural BMPs) in reducing loading is also subject to significant uncertainty. These uncertainties, however, should not delay development of the TMDL and implementation of control measures. EPA regulations (40 CFR 130.2(g)) state that load allocations for nonpoint sources "are best estimates of the loading which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading.” USEPA (1991a; 1999) advocated the use of a phased approach to TMDL development as a means of addressing these uncertainties. Under the phased approach, load allocations and wasteload allocations are calculated using the best available data and information, recognizing the need for additional monitoring data to determine if the load reductions required by the TMDL lead to attainment of water quality standards. The approach provides for the implementation of the TMDL while additional data are collected to reduce uncertainty.

When using models during the development of the TMDL, either to predict loadings or to simulate water quality, managers should address the inherent uncertainty in the predictions. Various techniques for doing so include sensitivity analysis, first-order analysis, and Monte Carlo analysis. These techniques are briefly summarized in Section 6 and are also discussed in various documents (e.g., IAEA, 1989; Cox and Baybutt, 1981; Chapra, 1997; Reckhow and Chapra, 1983).

TMDLs also address uncertainty issues by incorporating a margin of safety into the analysis. The margin of safety is a required component of a TMDL and accounts for the uncertainty about the relationship between pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(c)). The results of the uncertainty analysis performed for any modeling predictions can be factored into the decision regarding a margin of safety. The margin of safety is traditionally either implicitly accounted for by choosing conservative assumptions about loading or water quality response, or is explicitly accounted for during the allocation of loads. (For example, the TMDL is expressed as 250 lbs/day phosphorus from point sources, 400 lbs/day phosphorus from nonpoint sources (including background sources) and 100 lbs/day for the margin of safety.) Table 3-3 lists several approaches for incorporating margins of safety into nutrient TMDLs.

Table 3-3. Approaches for incorporating margins of safety into nutrient TMDLs.

Type of MOS	Available Approaches
Explicit	• Do not allocate a portion of available nutrient loading capacity; reserve for MOS
Implicit	• Conservative assumptions in derivation of numeric targets • Conservative assumptions in nutrient loading and transport rates • Conservative assumptions in the estimate of nutrient control effectiveness

Recommendation: During the problem identification process, the TMDL developer should decide, to the extent possible, how to incorporate a margin of safety into the analysis. The degree of uncertainty associated with the source estimates and water quality response should be considered, with the value of the resource and the anticipated cost of controls. In general, greater margins of safety should be included when there is more uncertainty in the information used to develop the TMDL. It may also prove feasible to include margins of safety in more than one TMDL analytical step. For example, relatively conservative numeric targets and source estimates could be developed that, in combination, create an overall margin of safety adequate to account for uncertainty in the analysis.

7. What are some potential control options?

The problem identification should begin to identify potential management alternatives. A general level of understanding should be reached concerning the relative load reductions that must be obtained from point versus nonpoint sources and whether uncontrollable nutrient sources are a significant factor. If no level of nutrient control is predicted to achieve the designated use of the waterbody, the appropriateness of the water quality standard should be evaluated through UAA.

If nutrient controls will be able to address the impairment, the problem statement should identify and stress the opportunity to take advantage of other watershed protection efforts. This statement will include coordinating with various state agencies (e.g., natural resource and pollution control agencies), federal agencies (e.g., BLM, U.S. Forest Service [USFS]) and tribal authorities to avoid duplicate or contradictory efforts. Other stakeholders also should be encouraged to become involved with development of the TMDL, to contribute to the process and to ensure that their concerns are addressed.

8. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the problem identification step, an approvable TMDL will need to include the name and geographic location of the impaired or threatened waterbody for which the TMDL is being established. The TMDL will also need to list the names and geographic locations of the waterbodies upstream of the impaired waterbody that contribute significant amounts of the pollutant for which the TMDL is being established.

RECOMMENDATIONS FOR PROBLEM IDENTIFICATION

- Identify events leading to the listing and the data to support the listing. Include any data or anecdotal information that supports qualitative approaches to develop the TMDL.
- Identify the specific role nutrients play in affecting designated uses and attempt to determine which nutrient is limiting. (Many impairments associated with nutrients are also caused by other stressors.)
- Contact agency staff responsible for the waterbody listing and collect any available information.
- Prepare a flowchart or schematic detailing the processes that might affect waterbody impairment.
- Conduct an inventory of available information on point or nonpoint sources using information available from state or local agencies or databases.
- Identify temporal and seasonal factors affecting such issues as discharge rates, receiving water flows, and designated use impacts. Temporal considerations will affect all subsequent stages of TMDL development for nutrients.
- Identify and document all current watershed restoration or volunteer monitoring efforts.
- Identify any characteristics or future uses of the watershed or waterbody that might affect the TMDL analysis.

RECOMMENDED READING

(Note that the full list of references for this section is at the end of the document.)

- USEPA. 1991a. *Guidance for water quality-based decisions: The TMDL process*. EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

- USEPA. 1995b. *Watershed protection: A statewide approach*. EPA 841-R-95-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1995c. *Watershed protection: A project focus*. EPA 841-R-95-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1996a. *TMDL development cost estimates: Case studies of 14 TMDLs*. EPA R-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. *TMDL Case Study Series.* <http://www.epa.gov/OWOW/tmdl/case.html>

Identification of Water Quality Indicators and Target Values

Objective: Identify numeric or measurable indicators and target values that can be used to evaluate the TMDL and the restoration of water quality in the listed waterbody.

Procedure: Select one or more indicator(s) appropriate to the waterbody and local conditions. Key factors to consider include both scientific and technical validity, and practical issues (e.g., cost, available data). Identify target values (for the indicator[s]) that represent achievement of water quality standards and link (through acceptable technical analysis) to the reason for waterbody listing.

OVERVIEW

To develop a TMDL, it is necessary to have one or more quantitative measures that can be used to evaluate the relationship between pollutant sources and their impact on water quality. Such measurable quantities are termed indicators in this document. Examples of indicators for a nutrient TMDL include total phosphorus concentration, total nitrogen concentration, chlorophyll concentration, algal biomass, and percent macrophyte coverage. Once an indicator has been selected, a target value for that indicator must be established that seeks to distinguish between the impaired and unimpaired state of the waterbody (e.g., summer chlorophyll concentrations of attached algae will not exceed 100 mg/m^2, or, total phosphorus concentrations will not exceed 0.05 mg/L). Although such discrete impaired and unimpaired cutoffs do not exist in natural systems, quantifiable goals nevertheless are a necessary component of TMDLs.

Key Questions to Consider for Identification of Water Quality Indicators and Target Values

1. What is the water quality standard that applies to the waterbody?
2. What factors affect the selection of an indicator?
3. What water quality measures potentially could be used as indicators?
4. What target value will be used and how does it compare to existing conditions?
5. What changes does the proposed rule speak to?

This section of the protocol provides background on water quality standards and their relationship to TMDL indicators, lists various factors that should be addressed in choosing a TMDL indicator, and provides recommendations for setting target values under different circumstances.

KEY QUESTIONS TO CONSIDER FOR IDENTIFICATION OF WATER QUALITY INDICATORS AND TARGET VALUES

1. What is the water quality standard that applies to the waterbody?

States, territories, and authorized tribes are responsible for setting water quality standards to protect the physical, biological, and chemical integrity of their waters. The three components of water quality standards include:

- Designated uses (such as drinking water supply, aquatic life protection, recreation, etc.) for each waterbody
- Narrative and numeric criteria designed to protect these uses
- An antidegradation policy

For some waters, the indicators and target values needed for TMDL development already are specified as numeric criteria in state water quality standards. For instance, EPA issues "criteria guidance" on the human health and ecological effects of specific pollutants that is generally reflected in state standards. An example would be a standard that specifies that the daily minimum dissolved oxygen concentration in a river designated for warm water aquatic life support must be 5.0 mg/L. However, water quality standards vary considerably from state to state and often only narrative criteria exist for nutrient issues. In these situations, development of the TMDL will require the identification of one or more appropriate indicators to quantify the attainment of water quality standards. The steps for linking the designated use of a water to a TMDL are outlined in Figure 4-1.

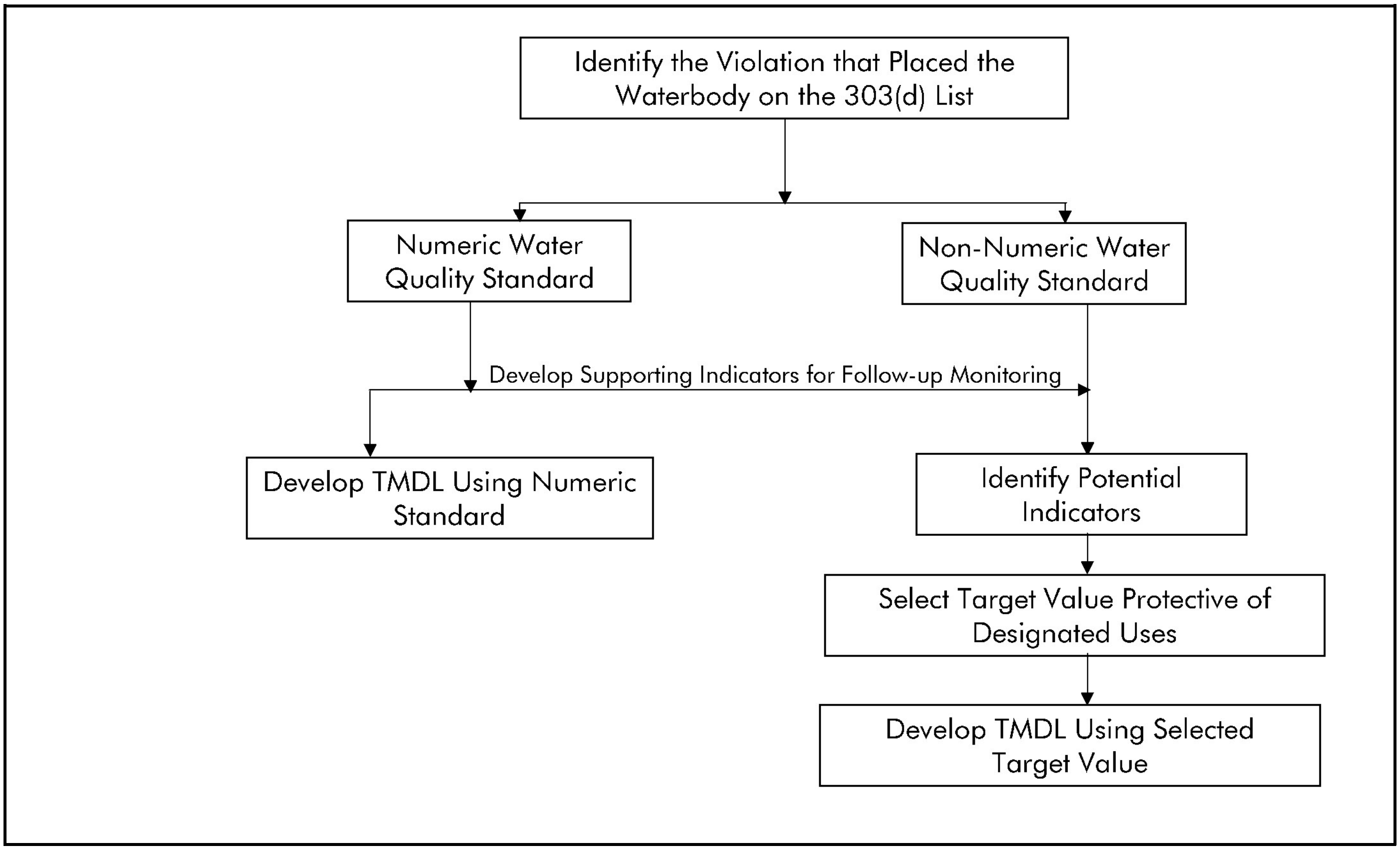


Figure 4-1. Factors for determining indicators and target values

Recommendation: Determine the water quality standard for the waterbody. Use the numeric water quality standard if it exists. Use supplementary indicators when no numeric standard exists and only a narrative standard is available. When using a numeric standard, note any important issues, including where the standard is applied, number of samples required, averaging period, and number of exceedances allowed.

> EPA has developed a National Strategy for the Development of Regional Nutrient Criteria (USEPA, 1998a) that outlines the agency's role in providing guidance to states and tribes for developing nutrient criteria. It is anticipated that guidance documents organized according to waterbody type will be produced as a result of this Strategy. The lakes and reservoirs, and rivers and streams documents being developed will address such issues as how to develop criteria for algae and nutrients, how to develop a monitoring plan, and how to implement management objectives. Much of the information in this section of the protocol is based on work in progress during the development of these documents.

2. What factors affect the selection of an indicator?

Various factors will affect the selection of an appropriate TMDL indicator. These factors include issues associated with the indicator's scientific and technical validity, as well as practical management considerations. The importance of these factors will vary for each waterbody, depending, for instance, on the time and resources available to develop the TMDL, the availability of already existing data, and the water's designated uses. Final selection of the indicator should depend on site-specific requirements. The following sections identify some factors to keep in mind during indicator selection.

Scientific or technical validity considerations

The purpose of the indicator(s) is to provide a quantitative estimate of when water quality supports the designated uses. Different indicators might be needed for different uses (e.g., dissolved oxygen concentration for aquatic life support, extent of algae for recreational uses). Indicators might also vary depending on waterbody type.

Indicators should be sensitive to where sources are and when and where impacts occur. TMDL developers should be aware that nutrient problems tend to be seasonally expressed and in many cases might result from the accumulation of year-round loadings. The indicator chosen also should lend itself well to available techniques and methods that can be used to link nutrient concentrations to water quality response.

Practical considerations

Measurement of the indicator should cost as little as possible, while still meeting other requirements. Indicators that can be suitably monitored through volunteer monitoring programs or other cost-effective means should be evaluated for adequate quality control and assurance of sample collection, preservation, laboratory analysis, data entry, and final reporting. Monitoring should introduce as little stress as possible on the designated uses of concern.

It is advantageous to select an indicator consistent with already available data. Choice of an indicator also should take into account how "obvious" it is to the public that the target value must be met to ensure the desired level of water quality. (For example, the public understands Secchi depth and chlorophyll indicators fairly well.)

Recommendation: Scientific and technical issues should be balanced against practical considerations when deciding upon a water quality indicator.

3. What water quality measures potentially could be used as indicators?

Various water quality measurements can be selected as nutrient TMDL indicators. They include both "causal factor" indicators (primarily, the nutrients that stimulate plant growth) and "biological response" indicators (which provide information concerning the impacts on water quality). Because of the site-specific nature of TMDLs and the complexity of watershed processes, no one indicator will satisfactorily meet all of the requirements above. (See Table 4-1 for examples of indicators from nutrient TMDLs or similar assessment projects.). Below are brief summaries of several water quality measurements and their advantages and disadvantages for use as TMDL indicators.

Phosphorus

Nuisance plant growth in many freshwater lakes and rivers is limited by the availability of phosphorus. For this reason, many nutrient TMDLs include phosphorus concentration as an indicator. Phosphorus can be

Table 4-1. Examples of indicators for TMDL targets and similar assessment projects

Waterbody	Indicators Selected
Boulder Creek, CO	• 0.06 mg/L un-ionized ammonia
Appoquinimink River, DE	• 5.5 mg/L dissolved oxygen (daily average) • 4.0 mg/L dissolved oxygen (instantaneous minimum)
Lake Chelan, WA	• 4.5 μg/L total phosphorus
Truckee River, NV	• 0.05 mg/L total phosphorus • 210 mg/L total dissolved solids
Clark Fork River, MT	• 100 mg/m^2 chlorophyll *a* (summer mean) • 300 μg/L total nitrogen • 20-39 μg/L total phosphorus (depending on stretch of the river)
Laguna de Santa Rosa, CA	• 0.025 mg-N/L un-ionized ammonia • 7.0 mg/L dissolved oxygen (minimum)

measured in several ways, including as either total phosphorus (TP) or as soluble reactive phosphorus (SRP). TP has been used throughout North America as a basis for setting criteria for lake and reservoir management and related modeling efforts (NALMS, 1992). SRP more often is used for setting criteria in rivers and streams because it is more representative of the form of phosphorus directly available to plants. TMDL developers should recognize that SRP is the most significant form of phosphorus in terms of plant growth, but because of the ability of bacteria to convert organic phosphorus to a bioavailable form, TP loading is also important. If possible, numeric targets for TMDLs should be expressed as both SRP and TP to address the nutrient availability issue.

Phosphorus indicators are not as easy to implement in rivers and streams as they are in lakes and reservoirs. Use of phosphorus indicators is especially difficult in fast-flowing, gravel or cobble bed streams, which are impaired more by attached algae than free-floating algae. The relationship between phosphorus concentration and plant growth is not as well established in these systems, and in many systems the limiting concentration might be so low as to be difficult to reasonably achieve. For example, Welch et al. (1989) report for the Spokane River, Washington, that biomass levels exceeding 200 mg chlorophyll *a* per m^2 can persist farther than 10 km downstream from a point source, unless soluble reactive phosphorus concentrations are held below 10 μg/L. Bothwell (1985, 1988) reports that streams can be phosphorus-saturated at concentrations as low as 1 to 4 μg/L.

Nitrogen

Nitrogen concentrations can serve as useful indicators in those systems where nitrogen is potentially the limiting factor. This situation might be the case in waters receiving wastewater with a low N/P ratio and in waters with naturally phosphorus-rich bedrock (Welch et al, 1992). Some studies indicate that nitrogen might have more importance as a limiting factor in streams than in lakes (Chessman et al., 1992; Welch et al., 1989).

Nitrogen can be measured in several different forms (total nitrogen, nitrate-nitrogen, nitrite-nitrogen, and ammonia). The directly available forms are mainly inorganic (nitrate-nitrogen and ammonia), although some algae can use organic forms. As with total phosphorus, total Kjeldahl nitrogen (TKN) is often a good predictor of algal biomass in lakes and reservoirs because much of the particulate fraction already is in the algae. (TKN is the total of organic and ammonia nitrogen in a sample, determined by the Kjeldahl method.) The correlation between algal biomass and total Kjeldahl nitrogen in streams and rivers, however, is not as strong because measurements of total nitrogen include detritus and because none of the incorporated nutrients are in the periphyton algal mat (Dodds et al., 1997).

As with phosphorus, limiting concentrations of nitrogen in severely enriched waters are often very low, especially for rivers affected by the filamentous green species *Cladophora* (Ingman, 1992). In these instances, the limiting concentration can serve as the long-term goal, while somewhat higher values could be adopted as intermediate goals of the TMDL. Nitrogen indicators also could be used to control the extent of nuisance growth, if not the total yield. Data suggest, for example, that nutrient additions beyond the range of 40 to 100 μg/L dissolved inorganic nitrogen will not increase the periphyton *yield* immediately downstream of a discharge, but might increase the downstream *extent* of periphyton proliferations (Quinn, 1991). A nitrogen indicator that aims to limit the distance downstream at which algal biomass reaches nuisance levels therefore could be instituted.

Dissolved oxygen concentration

Dissolved oxygen concentrations are useful indicators where the primary designated use of concern is aquatic life. Dissolved oxygen concentrations already are established in state water quality standards and generally are expressed as a minimum daily value and as an average value over a certain period (e.g., a daily, 7-day, or 30-day mean). Note that analysis of dissolved oxygen dynamics in shallow, periphyton-dominated streams is complicated by a number of factors, including significant local variability and strong daily cycles of dissolved oxygen concentration, both affected by temperature (Butcher and Covington, 1995). Further, the most frequently used dissolved oxygen stream models do not adequately address periphyton.

Determining Indicator Target Values in the Spokane River, Washington

Welch et al. (1989) developed an approach for estimating the critical phosphorus concentration to prevent nuisance periphytic biomass in the Spokane River, Washington. The methodology is based on various factors, including uptake kinetics, that affect periphyton growth. A model calibrated to the growth of filamentous periphyton in artificial channels was applied to the growth of periphyton on natural and artificial substrate in the lower Spokane River. Because nuisance thresholds of periphyton growth (150 mg chlorophyll a per m^2) were shown to occur at very low concentrations of soluble reactive phosphorus (SRP) (1-4 μg/L), an equation was derived to provide a method for estimating the stream length for which biomass potentially could exceed the threshold. The equation is as follows:

$$D_c = \frac{Qr(SRP_i - SRP_c)}{[(P_c)B_nTW]}$$

where:

- D_c = stream length (m) for which periphyton biomass potentially could exceed the nuisance threshold;
- SRP_c = concentration (mg/m^3) producing the threshold nuisance biomass (e.g., 150-200 mg chlorophyll *a*/m^2) in the growth period;
- SRP_i = influent concentration (ambient river and ground water, mg/m^3) to the stream segment;
- Q = daily flow in m^3/day;
- r = a constant to account for the recycle rate (unitless; 1.5 after Newbold et al., 1982);
- P_c = average uptake rate by the periphyton mat per day, taken as 0.2;
- T = trophic (consumer) retention factor (1.2, representing a 20% conversion: chosen as an intermediate value based on observations ranging from 0.1 to 2.4 mg P/mg chl *a*-day; Horner et al., 1983; Seeley, 1986);
- W = average stream width (m); and
- B_n = nuisance threshold biomass (150 mg chl *a*/m^2).

When this equation is applied to the Spokane River, the results indicate that the stream length for which the biomass might exceed the nuisance threshold is proportional to the amount that influent SRP exceeds 1 to 4 μg/L.

This is an example development of a nutrient indicator for a river expressed in terms of stream length impaired by nuisance periphyton. Some of the more traditional indicators identified above (i.e., SRP concentration and periphyton biomass) serve as intermediates to the determination of this indicator.

Chlorophyll a

Chlorophyll *a,* the dominant pigment in algal cells, is fairly easy to measure and is a valuable surrogate for algal biomass (Carlson, 1980; Watson, et al., 1992). Chlorophyll *a* is desirable as an indicator because algae are either the direct (e.g., nuisance algal blooms) or indirect (e.g., high/low dissolved oxygen and pH and high turbidity) cause of most problems related to excessive nutrient enrichment. Both seasonal mean and instantaneous maximum concentrations can be used to determine impairments, and many monitoring programs already include measurements for chlorophyll *a*.

Several states have adopted chlorophyll *a* concentrations as standards or as goals for lake quality. Oregon has set an endpoint of 10 μg/L for natural lakes that thermally stratify and 15 μg/L for natural lakes that do not thermally stratify, to identify waterbodies where phytoplankton may impair uses (NALMS, 1992). Similarly, North Carolina uses a target of 40 μg/L for warm waters and 15 μg/L for cold waters (NALMS, 1992). On the regional level, Raschke (1994) has proposed a mean growing-season limit of 15 μg/L for water supply impoundments in the southeastern United States and a value of 25 μg/L for waterbodies primarily used for other purposes (e.g., viewing pleasure, safe swimming, fishing, boating).

Chlorophyll *a* might not be an appropriate indicator where use impairment is more closely related to excessive macrophyte growth. The relationship between nutrient concentrations and chlorophyll response also may be highly variable and difficult to predict. Laws and Chalup (1990), for example, have shown that growth rate and chlorophyll *a* respond differently under nutrient-limited conditions and under nutrient-saturated (light-limited) conditions.

Periphyton biomass

Periphyton biomass directly measures the biomass of attached algae. Periphyton biomass can be measured either qualitatively (e.g., no visible growths on hand-held stones) or quantitatively (e.g., ash-free dry weight or milligrams of chlorophyll *a* per square meter) (Quinn, 1991). The primary advantage of this measurement is that it directly reflects the water quality characteristic that impairs use. In this way, biomass indicators force managers to focus on all of the factors that contribute to periphyton growth, instead of relying only on nutrient controls to provide relief. One disadvantage associated with using periphyton biomass as an indicator is the cost and difficulty associated with its monitoring. Further, developing predictive relationships between nutrient load and periphyton biomass can present considerable challenges because well-known and validated water

Indicators and Target Values in the Clark Fork River, Montana

Dense mats of filamentous algae and heavy growths of diatom algae have caused problems recently with the irrigation and recreational uses of the Clark Fork River in western Montana. Segments of the river have been placed on the state's list of impaired waters, and several studies have been conducted to determine the extent and magnitude of the excessive algae production and to develop nutrient level and biological response criteria (Ingman, 1992).

As a preliminary step toward TMDL development, nutrient assessment indicators for the Clark Fork River were developed by the Nutrient Target Subcommittee of the Tri-State Implementation Council. Because Montana does not have statewide numeric criteria for nutrients, development of these indicators was based on a review of academic studies, literature values, and public input. The subcommittee selected a summer mean algal biomass chlorophyll *a* concentration of 100 mg/m^2 as distinguishing between the impaired and unimpaired condition of the river.

To determine the nutrient concentrations that would keep algal growths below this level, the subcommittee relied on several sources of information:

- The University of Montana conducted a series of experiments to measure water quality response to various concentrations of nitrogen and phosphorus (Watson et al., 1990). Artificial stream channels were constructed and fed with Clark Fork River water that was spiked with various concentrations of each nutrient. The response of algal growth rates and of maximum standing crops to changes in nutrient levels was carefully measured. The experimental findings indicated that levels of attached diatom algae in the middle of the Clark Fork River would be reduced if concentrations of soluble reactive phosphorus were held below 30 μg/L and concentrations of soluble nitrogen levels were held below 250 μg/L.
- Clark Fork water quality measurements for total nitrogen, total phosphorus, and chlorophyll *a* were entered into a regression model that contained data from more than 200 distinct river sites (Dodds and Smith, 1995). The results indicated that if summer mean total nitrogen concentrations were held below 350 μg/L, chlorophyll *a* concentrations should not exceed 100 mg/m^2 in most areas of the Clark Fork. The corresponding summer mean total phosphorus concentration recommended by this regression approach was 45.5 μg/L.
- Another method of estimating the required nutrient concentrations was to set them equal to nutrient concentrations in reaches of the Clark Fork where algae are not a frequent problem. Based on this "reference site" technique, the proposed summer target levels were 6 μg/L or less for soluble phosphorus and 30 μg/L or less for soluble nitrogen (Ingman, 1992). These concentration ranges are typical of relatively unimpaired portions of the Clark Fork during July through September.

Based on the information from these various sources, the subcommittee adopted nutrient target values of 300 μg/L total nitrogen, 20 μg/L total phosphorus upstream from Missoula, and 39 μg/L total phosphorus downstream from Missoula. The subcommittee said that one reason for choosing these relatively conservative target values was to explicitly account for a margin of safety.

The subcommittee also noted in its report that, although the management focus would be on the total form of these nutrients, both total and soluble forms should be monitored to give the best picture of bioavailability and of the breakdown between point and nonpoint sources.

quality models are not available. Relying on periphyton biomass also may neglect the important role of emergent macrophytes in stream nutrient cycling.

Transparency

Because of its simplicity and low cost, Secchi depth is likely the most widely used surrogate for estimating algal biomass and, subsequently, trophic state (Michaud, 1991). It is, however, a much more indirect measure and subject to interferences from a variety of sources (e.g., fine sediment). Secchi depth correlates to chlorophyll *a* concentrations (Rast and Lee, 1978) and is a particularly important measure because the public easily perceives water clarity. Secchi depth might be a reliable indicator of the trophic state of a waterbody, provided that its water clarity depends primarily on algal biomass (i.e., the amounts of inorganic turbidity and color present in the water column are negligible).

Macrophyte coverage or density

Newbry et al. (1981) recommend using macrophyte coverage percentage as a potential nutrient enrichment indicator in lakes and reservoirs. Specifically, for the portion of a waterbody with a depth of 2 meters or less, the indicator would be the percentage of the waterbody impaired by macrophyte growth during peak recreation use. Other researchers have suggested a similar approach, but a somewhat deeper cutoff point (Porcella, 1989). This indicator might be particularly appropriate for those shallow lakes and reservoirs where users are aware of and sensitive to changes in the abundance and distribution of macrophytes (e.g., the southeastern United States). One confounding issue related to macrophyte density is the positive relationship between increasing water clarity and the extent of macrophyte beds (Quinn, 1991).

Biological indicators

Several states have used biological indicators to assess water quality. For example, the Ohio EPA uses the index of biotic integrity (IBI) to assess the aquatic life in its rivers and streams (Hughes et al., 1992), and many states use fish yield to indicate the health of their fisheries. Proposed biological indicators have attempted to incorporate information on fish, benthic invertebrates, zooplankton assemblages, algae, macrophytes, etc. EPA's Rapid Bioassessment Protocols (Plafkin et al, 1989) also are used frequently as a cost-effective approach to evaluating whether a stream is supporting aquatic life uses. An advantage of using biological indicators is that they are not as subject to time variability as are chemical pollutants (NALMS, 1992). The difficulty in quantifying the linkage between biological indicators and source loadings, however, can present problems for their use in developing TMDLs. Most importantly, their use in developing TMDLs requires (1) knowledge of the appropriate reference or unimpaired conditions and (2) ability to discriminate between effects of nutrient enrichment and other factors, including physical habitat condition, on biotic integrity. It also may be difficult to establish a target value for a biological indicator representing impairment in a stream.

pH

Algal biomass above nuisance levels often can produce wide diel swings in pH. For example, pH levels in gravel-bottom rivers with large periphyton biomass can be as high as 10, which severely restricts the ability of stream organisms to function normally. pH is very inexpensive and easy to monitor and can be sampled by nontechnical personnel. Because aquatic organisms are most sensitive to extreme pH levels rather than daily means, monitoring should include afternoon hours when pH is likely to be at its maximum. A difficulty associated with this parameter is that factors other than eutrophication (e.g., turbulence, light, temperature) might affect water acidity.

Nutrient ratios

Ratios of the summer:winter concentration of soluble nutrients might indicate the relative intensity of algal activity in a particular stream. The intensity of algal activity could be estimated by evaluating the fraction of the nutrient supply (winter, nongrowth period) assumed to be removed and incorporated by algae (winter-summer soluble concentration). It should be noted, however, that the use of this approach assumes that ground water and upstream inflow concentrations are constant between summer and winter (which might not be a valid assumption for many watersheds). Ratios of total to soluble nutrients in winter, compared with summer, would provide a similar index of algal use, but would account for changing inflow concentrations (i.e., of total nutrients). Such indicators have not yet been tested in streams and therefore would require some evaluation.

Others

Numerous other water quality measurements potentially could serve as nutrient overenrichment indicators. Some of these might be appropriate for certain regions or for specific waterbodies with unique considerations. Many of the following measurements are not ideal indicators because they describe conditions that might be unrelated to nutrient loading. They might best be used in combination with some of the other measurements described previously.

- Odor and taste indicators
- Total and volatile suspended solids concentrations
- Dissolved organic material
- Extent of submerged aquatic vegetation
- Benthic community metabolism
- Sediment composition (organics, size fraction, nutrients, profile, sediment fluxes)
- Secondary production (meiofauna, macroinvertebrates, fish)
- Production and respiration
- Aesthetics (foam, scum)

Recommendation: For many nutrient TMDLs, it might be appropriate to have an indicator directly tied to nutrient loadings (e.g., phosphorus or nitrogen) and one or more indicators that more directly relate to the designated uses (e.g., algal biomass or dissolved oxygen concentration). Moreover, for large watersheds with complex problems, it might be useful to choose several indicators to gauge water quality. A "nested approach" of selecting certain, perhaps more costly indicators for critical subwatersheds and of using more easily monitored indicators in other subwatersheds is one way to address this dilemma.

Although selecting the indicator or indicators is necessarily a site-specific decision, Figure 4-2 provides some guidance for which of various indicators might be most appropriate for different types of waterbodies and several representative designated uses. Note that phosphorus and nitrogen are included in each case because of their primary role in stimulating nuisance plant growth. Because indicator selection requires a careful consideration of the unique mix of issues, opportunities, and characteristics present in each watershed, TMDL developers are encouraged to use this information as a starting point and to consult key references and local experts in the final selection of indicators.

4. What target value will be used and how does it compare to existing conditions?

For each indicator used in developing a nutrient TMDL, a desired or target condition must be established to provide measurable environmental management goals and a clear linkage to attaining water quality standards. As mentioned previously, target values for some indicators already will be established directly through numerical criteria in water quality standards. Otherwise, various mechanisms determine an appropriate target value, including comparing the conditions in the listed water to those at an appropriate reference site, conducting user surveys, using an existing trophic classification system, and comparing to literature values.

Note that all of these methods require some interpretation of what constitutes an impaired versus an unimpaired condition. In many cases, this determination is subjective. For example, different persons might have different opinions of which chlorophyll *a* concentration is associated with the recreational impairment of a reservoir. Regardless of the method used to establish the indicator value, it is important to solicit comment from as many stakeholders as possible, including the public and regulatory agencies. Stakeholder comment is an important component of the Watershed Approach (USEPA, 1996b), and it can be particularly useful for interpreting narrative standards. For instance, in a stream designated for support of a cold-water fishery, a biological indicator aimed at assessing the health and diversity of the fish population could be refined into a quantitative target based on stakeholder consensus as to what constitutes a sufficiently viable fishery.

Factors to consider in establishing target conditions

Degree of experience applying the indicator(s) in the area or in similar settings

Where local experience has been gained in applying nutrient indicators, it is often possible to identify target

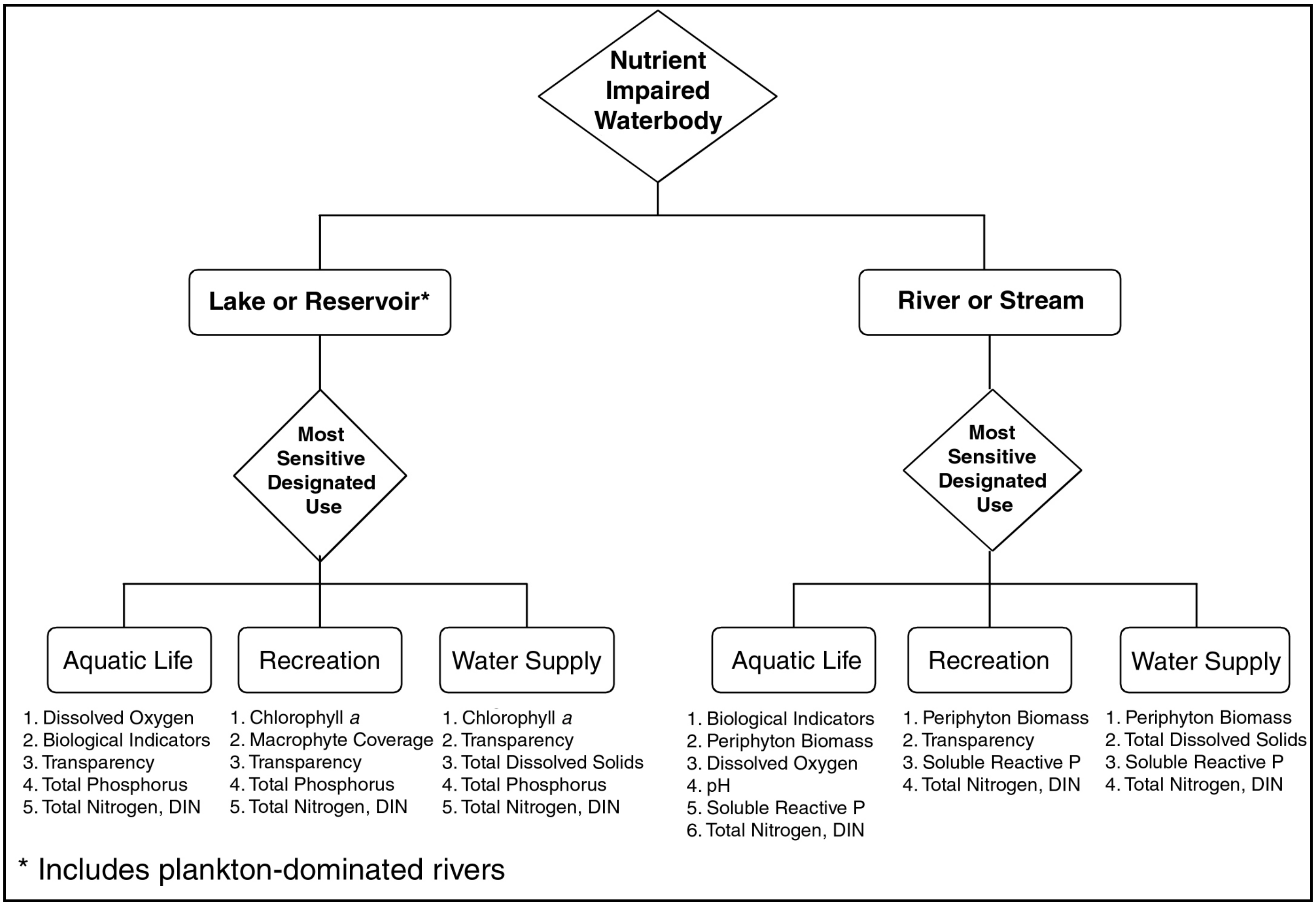


Figure 4-2. Guidelines for selecting indicators based on waterbody type and several representative designated uses

conditions through analysis of historical conditions or reference stream conditions in relatively high quality parts of the watershed. Where less local or directly analogous experience is available, it might be appropriate to establish more conservative targets.

Variability of conditions in the watershed

The larger the study area for the TMDL and the more heterogeneous the waterbody characteristics in the watershed, the more important it will be to consider establishing multiple target conditions for the TMDL. It may be useful to stratify the targets based on spatial distinctions (e.g., fast-flowing versus slow-moving reaches, main stems vs. tributaries). Similarly, it may be appropriate to account for seasonal variations in setting target conditions (e.g., require that a stricter target condition apply to peak growing periods).

Margin of safety considerations

Factors to consider in defining the margin of safety include the expected accuracy or reliability of the indicator for the designated use of concern and the degree to which the use is impaired.

Comparison to reference sites

One method for establishing target values is through a comparison to reference sites. This is typically done by comparing data collected from the impaired site with data from one or more similar sites not impaired or "least impacted." It might also include comparing current data from the impaired site to historic data from the site before the impairment. Conditions at the reference site (e.g., nutrient concentrations) can be interpreted as approximate target values for the TMDL. A disadvantage to this approach is that it might not always establish the actual conditions beyond which impairment is expected. Reference sites may represent the completely unaffected state, a relatively unaffected state, or increasing degrees of existing impact, as deemed appropriate. Selection of an appropriate reference site should reflect a clear understanding of the overall system of which the receiving water is a part.

User surveys

Minnesota and Vermont have surveyed users to determine indicator target values, especially in lakes and reservoirs (Heiskary, 1989; Heiskary and Wilson, 1989; Smeltzer and Heiskary, 1990). This approach is especially useful when the impaired designated use of the waterbody is recreation. Survey results can correlate with simultaneous water quality measurements to establish a range of values between acceptable and unacceptable conditions. If 90 percent of those surveyed agree that their aesthetic enjoyment of a lake is impaired at chlorophyll *a* concentrations exceeding 30 μg/L, this value represents a possible biomass target value. The survey approach recognizes that the overall water quality of a waterbody is highly subjective and may vary considerably by region or user group.

Comparison to an existing classification system

A third means of identifying site-specific target values for nutrient TMDLs is through comparison with an existing classification system. The Carlson trophic status classification system is a good example of an existing classification systems for lakes (see box on next page).

For the development of site-specific nutrient criteria, the trophic classification system can be used to evaluate the condition of the waterbody (trophic status), determine the water quality goal (e.g., oligotrophic), and help determine the appropriate nutrient target value. Several approaches have been taken to develop a trophic state classification system based on the value of certain commonly measured water quality parameters (e.g., total phosphorus, chlorophyll *a*, Secchi depth, and hypolimnetic oxygen depletion) and general limnological relationships. Ideally, observed water quality values can be compared to these established classification systems to determine the trophic status of any particular waterbody. (This comparison assumes, of course, that trophic status can link directly to use impairment. For instance, many reservoirs in the southeastern United States are naturally borderline eutrophic.) One such classification system is in Table 4-2. As Vollenweider and Kerekes (1980) observed, these values are subject to overlap between different categories and, therefore, the parameters serve more as relative indicators than as discrete descriptors.

User Surveys in Lake Champlain, Vermont

In 1991 Vermont established numeric eutrophication criteria for Lake Champlain based on the relationship between a variety of trophic parameters and user perceptions of lake aesthetics and recreational viability (Smeltzer, 1992). This example illustrates one way of assessing use attainment of narrative standards and a method for setting target values once an indicator has been chosen.

The Vermont Department of Environmental Conservation (VDEC) supervises a volunteer monitoring program of Lake Champlain. Since 1987, the volunteers participating in the program have completed a user survey form each time a water quality sample is taken. The frequency distributions produced from the surveys and associated water quality data were analyzed to establish quantitative relationships between the trophic parameters and user responses. This process includes two steps. First, the survey data are used to define “algal nuisance” in terms of instantaneous values for the trophic parameters. The second step is to analyze the distribution of water quality data over time and choose a mean water quality value that produces an acceptable frequency of the instantaneous value.

Using an algorithm developed by Walker (1985), VDEC considered the statistical distribution of measurements over time to derive seasonal mean water quality values corresponding to an acceptably low frequency occurrence of nuisance conditions. The Vermont Water Resources Board used this methodology to establish a total phosphorus criterion of 14 μg/L for portions of Lake Champlain. This result corresponds to a 1 percent frequency of occurrence of a “moderate” nuisance condition.

Carlson Trophic Status Index

A frequently used biomass-related trophic status index is that developed by Carlson (1977). Carlson's trophic status index (TSI) uses Secchi depth (SD), chlorophyll *a* (Chl), and total phosphorus (TP), each producing an independent measure of trophic state. Index values range from approximately 0 (ultraoligotrophic) to 100 (hypereutrophic). The index is scaled so that TSI = 0 represents a Secchi transparency of 64 m. Each halving of transparency represents an increase of 10 TSI units. For example, a TSI of 50 represents a transparency of 2 m, the approximate division between oligotrophic and eutrophic lakes (Olem and Flock, 1990). A TSI is calculated from each of Secchi depth, chlorophyll concentration, and phosphorus concentration (Carlson, 1977; Carlson and Simpson, 1996):

$$\text{TSI (Chl)} = 30.6 + 9.81 \ln \text{(Chl)}$$
$$\text{TSI (TP)} = 4.15 + 14.42 \ln \text{(TP)}$$
$$\text{TSI (SD)} = 60 - 14.41 \ln \text{(SD)}$$

Trophic state indices can be used to infer trophic state of a lake and whether algal growth is nutrient or light limited. If the three indices are approximately equal, then phosphorus limits algal growth. If the three are not equal, then other interpretations exist (see related box). The following classification can be used to interpret the TSI:

$TSI < 40$	most oligotrophic lakes
$35 < TSI < 45$	mesotrophic lakes
$TSI > 45$	eutrophic lakes
$TSI > 60$	hypertrophic lakes

A trophic status index also has been developed for total nitrogen (TN) (Kratzer and Brezonik, 1981; Carlson, 1992):

$$\text{TSI (TN)} = 54.45 + 14.43 \ln \text{(TN)}$$

When considering the results of TSI calculations, one should recall the assumptions on which the carbon formulae are based: 1) Secchi transparency is a function of phytoplankton biomass; 2) phosphorus is the factor limiting algal growth; and 3) total phosphorus concentration directly correlates with algal biomass (Davenport, 1983)

For a more complete discussion of trophic state indices and their interpretation, see Carlson (1992) and Carlson and Simpson (1996).

Table 4-2. Trophic status classification (for lakes) by Vollenweider and Kerekes (1980)

	Oligotrophic		Mesotrophic		Eutrophic	
Water Quality Parameter	**mean**	**range (n)**	**mean**	**range (n)**	**mean**	**range (n)**
Total phosphorus	8	3-18 (21)	27	11-96 (19)	84	16-390 (71)
Total nitrogen	660	310-1,600	750	360-1,400	1900	390-6,100
Chlorophyll *a*	1.7	0.3-4.5 (22)	4.7	3-11 (16)	14	2.7-78 (70)
Peak chlorophyll *a*	4.2	1.3-11 (16)	16	5-50 (12)	43	10-280 (46)
Secchi depth (m)	9.9	5.4-28 (13)	4.2	1.5-8.1 (20)	2.4	0.8-7.0 (70)

Note: Units are μg/L (or mg/m^3), except for Secchi depth; means are geometric annual means (log10), except for peak chlorophyll *a*.

Table 4-3. A trophic status classification based on water quality parameters

Water Quality	Oligotrophic	Mesotrophic	Eutrophic	Source
Total P (*µg/L*)	< 10	10-20	>20	USEPA (1974)
Chlorophyll *a* (µg/L)	<4	4-10	>10	USEPA (1974)
Secchi disc depth (m)	4	2-4	<2	USEPA (1974)
Hypolimnetic oxygen (% of saturation)	>80	10-80	<10	USEPA (1974)

Source: Adapted from Novotny and Olem, 1994.

Vollenweider (1968) and Sawyer (1947) categorized trophic status according to phosphorus concentration. Lakes with phosphorus concentrations below 10 µg/L are classified as oligotrophic, phosphorus concentrations between 10 and 20 µg/L are indicative of mesotrophic lakes, and eutrophic lakes have phosphorus concentrations exceeding 20 µg/L. This classification is consistent with the data from the National Eutrophication Survey (USEPA, 1974), which also used several other parameters in the classification system (Table 4-3). Note that much of the work conducted on trophic status classification systems has focused on northern, temperate lakes. Applying these systems to lakes in other regions, rivers, streams, or reservoirs must therefore be done carefully. Although the ranges identified in Tables 4-2 and 4-3 can serve as a starting point, analysts should investigate the availability of local studies. Raschke (1994), for example, gathered data for 17 small southeastern piedmont impoundments to establish a management relationship between algal bloom frequency and seasonal mean chlorophyll *a* concentrations. Based on the bloom frequency analysis, literature values, and experience, Raschke proposed a mean growing season limit of ≤15 µg/L chlorophyll *a* for attaining drinking water supply use in small southeastern impoundments. For other uses, such as fishing and swimming, a mean growing season limit of ≤25 µg/L is recommended[1].

Literature values

Several authors have suggested potential target values for nutrient indicators. Welch et al. (1988), summarizing 22 studies in U.S. and Swedish streams, suggest that "a biomass range of 100-150 mg chlorophyll *a*/m^2 may represent a critical level for an aesthetic nuisance." Moreover, EPA's 1986 criterion document (USEPA, 1986a) specifies target values for nitrate when it relates to toxic effects on fish. The report concludes that nitrate-nitrogen concentrations at or below 90 mg/L should protect warm-water fishes, while concentrations at or below 0.06 mg/L should protect salmonid fish. (Note that the guideline for salmonids is based on very limited data, and many natural salmonid waters have nitrate concentrations

Interpretations of deviations from typical conditions associated with TSI values

TSI Relationships	Possible Interpretation
TSI (CHL) = TSI (SD)	Algae dominate light attenuation
TSI (CHL) > TSI (SD)	Large particulates, such as Aphanizomenon flakes, dominate
TSI (TP) = TSI (SD) > TSI (CHL)	Nonalgal particulate or dissolved color dominate light attenuation
TSI (SD) = TSI (CHL) ≥ TSI (TP)	Phosphorus limits algal biomass (TN/TP ratio greater than 33:1)
TSI (TP) > TSI (CHL) = TSI (SD)	Zooplankton grazing, nitrogen, or some factor other than phosphorus limits algal biomass

[1] It should be noted, however, that these limits are not achievable in many southeastern United States impoundments, and a target value will need to be evaluated on a site-specific basis.

exceeding this level.) This document also suggests as a guideline to prevent nuisance algal growths that total phosphates as phosphorus should not exceed 0.1 mg/L in any stream or other flowing water or exceed 0.05 mg/L in any stream at the point where it enters a lake or reservoir.

Golterman (1975) suggests that, in general, eutrophication may occur in surface waters that have nitrate-nitrogen concentrations above 0.3 mg/L and phosphate-phosphorus concentrations above 0.02 mg/L. Experiments in phosphorus-limited flowing systems suggest that very low soluble reactive phosphorus (SRP) concentrations may be required to avoid periphytic biomass at nuisance levels. For example, less than 1 μg/L SRP was recommended for the Spokane River (Welch et al., 1989), and less than 25 μg/L SRP from experiments in laboratory channels (Horner et al., 1983).

Best professional judgment

It is sometimes infeasible to develop numerical targets based on the methods described above because inadequate information is available or relationships between the designated uses and the selected indicators are not well understood. In this case, it might be feasible to develop target values based on the best professional judgment of resource professionals involved in TMDL development. To ensure that these targets are defensible, analysts are advised to:

- Consult with several experts with local experience rather than relying on a single opinion.
- Thoroughly document the thinking underlying the target, including assumptions, related experience, or other factors considered in identifying the targets.
- Remember that targets must be set at levels believed to result in full support of the impaired designated uses (i.e., water quality “improvements” may be inadequate).

Recommendation: The target value(s) for the chosen indicator(s) can be established using a variety of approaches. The most technically defensible approach should consider the water quality standard, the available data, and the current understanding of the system.

5. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the water quality indicators and target values step, an approvable TMDL will need to include the following information:

1. Identification of the pollutant for which the TMDL is being established and quantification of the maximum pollutant load that may be present in the waterbody and still ensure attainment and maintenance of water quality standards; and

2. Identification of the amount or degree by which the current pollutant load in the waterbody deviates from the pollutant load needed to attain or maintain water quality standards.

RECOMMENDATIONS FOR SELECTING WATER QUALITY INDICATORS AND TARGET VALUES

- If available, the numeric standard should be used as the TMDL indicator and target value.

- If numerical criteria are not available, or if supplemental indicators are needed, the TMDL developer should base selection on both scientific or technical considerations and practicality and cost considerations. The selection must necessarily consider site-specific factors, although Figure 4-2 provides general guidelines.

- The target value for the chosen indicator can be based on: comparison to similar but unimpaired waters; user surveys; empirical data summarized in classification systems; literature values; or best professional judgment.

RECOMMENDED READING

(Note that the full list of references for this section is at the end of the document.)

- Carlson, R., and J. Simpson. 1996. *A coordinator’s guide to volunteer lake monitoring methods*. North American Lake Management Society and the Educational Foundation of America.

- Duda, A.M., M.L. Iwanski, R.J. Johnson, and J.A. Jaksch. 1987. Numerical standards for managing lake and reservoir water quality. *Lake and Reservoir Management* 3:1-27.

- NALMS,1992. *Developing eutrophication standards for lakes and reservoirs. A report prepared by the Lake Standards Subcommittee, May 1992*. North American Lake Management Society, Alachua, FL.

- USEPA. 1998a. *National strategy for the development of regional nutrient criteria*. EPA 822-R-98-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Source Assessment

Objective: Characterize the type, magnitude, and location of sources of nutrient loading to the waterbody.

Procedure: Compile an inventory of all possible sources of nutrients to the waterbody. Sources may be identified through assessment of maps, data, reports, or field surveys. It is likely that a combination of techniques will be needed, depending on the complexity of the source loading and watershed delivery processes. After compiling an inventory, use monitoring, statistical analysis, modeling, or a combination of methods to determine the relative magnitude of source loadings, focusing on the primary and controllable sources of nutrients.

OVERVIEW

The source assessment is needed to evaluate the type, magnitude, timing, and location of loading to an impaired waterbody. It further describes the sources initially identified during the problem identification. The source assessment determines nutrient inputs, measured as loads or concentrations, that will support the formulation of the load allocation and the wasteload allocation of the TMDL. Several factors should be considered in conducting the source assessment. These factors include identifying the various types of sources (e.g., point, nonpoint, background, atmospheric), the relative location and magnitude of loads from the sources, the transport mechanisms of concern (e.g, runoff, infiltration), and the time scale of loading to the waterbody (i.e., duration and frequency of nutrient discharge to receiving waters).

The evaluation of loading typically uses a variety of techniques, including relying on existing monitoring data, doing simple calculations, spreadsheet analysis using empirical methods, or a range of computer modeling systems. The selection of the appropriate technique is an outgrowth of the problem identification and watershed characterization performed during the initial phase of TMDL development.

A TMDL should include an evaluation of all the significant sources contributing to the nutrient loading of the waterbody. The detail of the assessment will vary, however, depending on the overall approach best suited to the site-specific conditions. The selection of the appropriate method for estimating loads should be based on the complexity of the problem, time constraints, the availability of resources and monitoring data, and the management objectives under consideration. Generally, it is advantageous to select the simplest method that addresses the questions at hand, uses existing monitoring information, and considers the available resources and time constraints for completing the TMDL. This section of the protocol describes various types of sources, identifies procedures for characterizing loadings, and introduces a process for selecting a source assessment technique.

QUESTIONS TO CONSIDER FOR THE SOURCE ASSESSMENT

1. What sources are contributing to the problem and how can they best be characterized?

Individual nutrient sources in the watershed should be inventoried to develop a targeted approach for estimating and eventually allocating loads. The inventory should include an evaluation of the processes, pathways, and potential effects that the loads might have on the waterbody and the TMDL indicator or indicators that have been

Key Questions to Consider for the Source Assessment

1. What sources are contributing to the problem and how can they best be characterized?
2. How should sources be grouped to facilitate load estimation and TMDL allocation?
3. What are the primary processes or delivery mechanisms from the various source categories under consideration?
4. What is the appropriate level of spatial and temporal detail for determination of the source loading?
5. What analysis techniques are appropriate for estimating the source loads?
6. What changes does the proposed rule speak to?

selected. The goal of the inventory is to understand both the individual and aggregate effects of the sources.

A source inventory is performed by dividing the sources in the watershed into manageable categories, or groupings, that can be further examined to determine nutrient delivery mechanisms. A first step is to divide the watershed into broad land use categories that are known to generate nutrients, such as agricultural or industrial land uses. Specific operations within each broad category should also be identified. For example, agricultural land uses can be subdivided by type of productive livestock or crop then further subdivided such as cattle farming, dairy production, row crops, etc. In some circumstances it might be warranted to further subdivide these operations into specific waste generating activities such as manure generation. Dairy production, for example, would include manure storage, spreading, and milking parlor wash water. Sources of information that can be used to identify and document these activities include land use maps, aerial photographs, local conservation organizations, tax maps, field surveys, and point source discharge permits.

The initial inventory can be entered into a table or database for more effective management. The inventory also can be mapped or summarized at the subwatershed level to determine the resolution and scale of analysis that should be conducted. The depth (or detail) of the inventory is a function of the size of the watershed, the magnitude of the impairment, the variability of the sources in the watershed, and other specific considerations (e.g., time and resources available).

Once the sources within the watershed have been inventoried and mapped, each activity should be evaluated to determine its individual pollutant generating mechanisms, processes, and potential magnitude. This evaluation will include identifying the primary mechanisms of transmission (atmospheric deposition, erosion, snowmelt, ground water, etc.), the variability of loadings (steady, rainfall or snowmelt related, seasonal, etc.), and the significance of biochemical and physical processes (nitrification, denitrification, adsorption, etc.).

Figure 5-1 identifies several common sources and pathways associated with nutrient loading to a reservoir.

Recommendation: Develop a comprehensive list of the potential nutrient sources to the waterbody. Use the list of potential sources and the watershed inventory to identify actual sources and to develop a plan for estimating their magnitude. Use GIS or maps to document the location of sources and the processes important for delivery to the waterbody.

2. How should sources be grouped to facilitate load estimation and TMDL allocation?

The grouping of the various source categories should be carefully considered during the source assessment stage of TMDL development. The appropriate selection of the various loading categories will facilitate completion of the subsequent analytical and allocation steps. The grouping of source categories can be by type, ownership, subwatershed, distance from the stream, etc. The source category groupings should consider the relative magnitude of the loads, potential management options, and economic considerations. The sources should be grouped to highlight a recognizable link between the source categories and the allocation of loads.

Another factor to consider when grouping sources is the degree to which various sources contribute bioavailable or other forms of a nutrient. This is especially important for phosphorus because some sources might contribute largely nonbioavailable phosphorus and therefore a reduction in their loadings will not be as significant as would a comparable reduction in loads of bioavailable phosphorus. As mentioned in Section 1, this might be a significant issue in rivers because the shorter residence times (compared to lakes) do not allow for effective decomposition of organic phosphorus. Similarly, loads of highly refractory

Factors to Consider for Grouping Sources

- Delivery mechanisms
- Type and location of sources relative to waterbody of concern
- Management options under consideration
- Social, political, and economic factors
- Physical characteristics of the watershed including slope, geology, soils, and drainage network

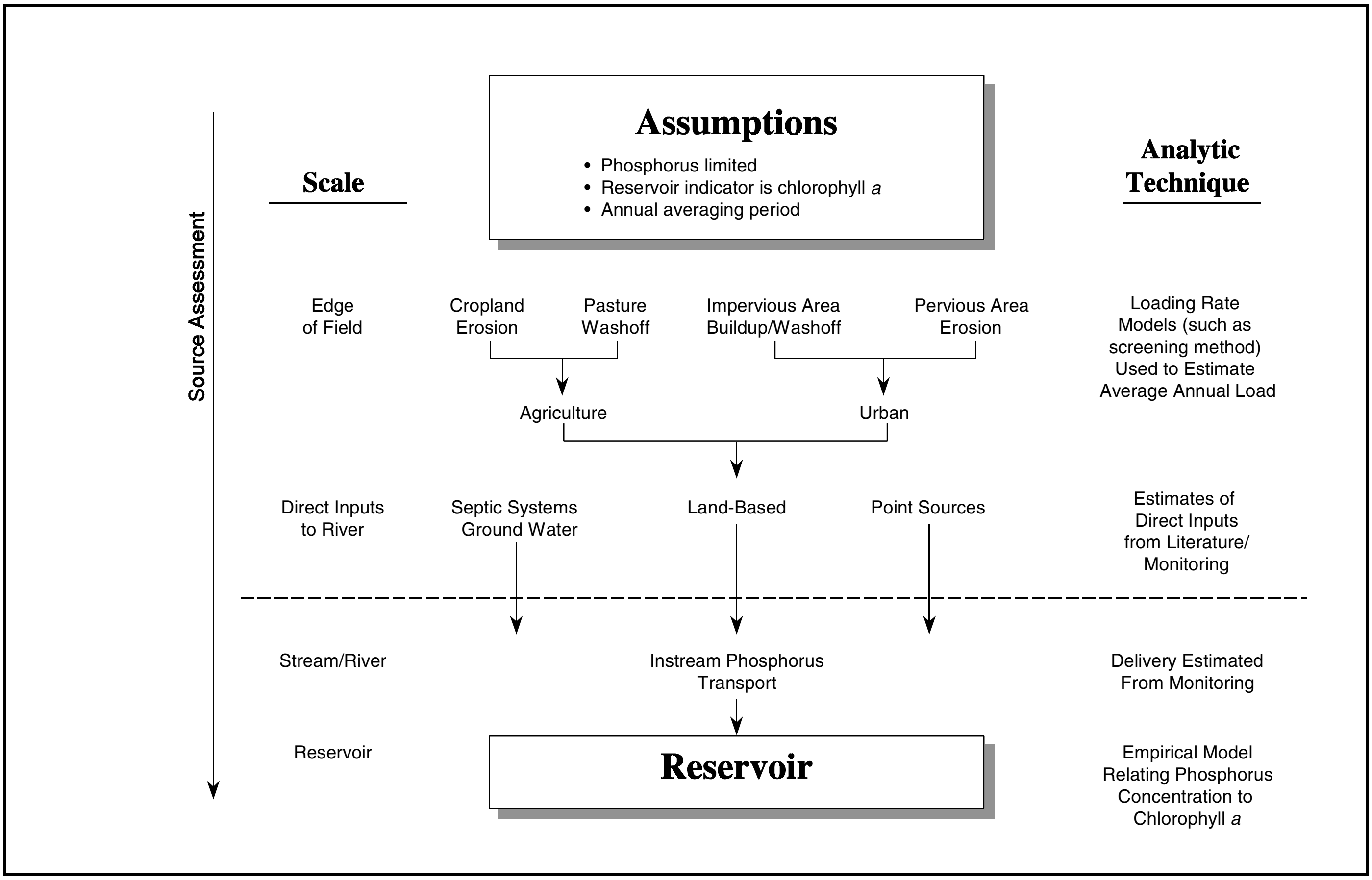


Figure 5-1. Common mechanisms and sources associated with nutrient loading to a reservoir.

organic nitrogen may need to be weighted differently from loads of biovailable inorganic nitrogen.

3. What are the primary processes or delivery mechanisms from the various source categories under consideration?

Various mechanisms transmit nutrients to receiving waters. The following section provides a description of the primary pathways of nutrient loading, with brief descriptions of key mechanisms or factors to consider when estimating loads.

Surface water

Surface water runoff occurs when the sources of contaminants (such as manure or chemicals) directly wash into receiving waters or when sediment particles absorb contaminants and then transport them during storm or snowmelt events. The types of soils and vegetation directly influence the absorption rate of nutrients into the soils. Land management practices, such as grazing patterns and no-till planting, also have effects on the rate of erosion and nutrient concentration (Doran et al, 1981). Enrichment rates of nutrients in soils that wash into receiving waters during storm or snowmelt events can be based on potency factors of the parent soils (Novotny and Chesters, 1981). Table 5-1 provides example literature values for dissolved nutrients in agricultural runoff.

Ground water

Ground water contamination from nutrients can occur from various sources, including septic systems, fertilizer application, animal waste, waste-lagoon sludge, and soil mineralization (Boyce et al., 1976; Kreitler, 1975; Moody, 1990; Spalding and Exner, 1991; cited in Gosselin et al., 1997). Estimating loading from septic systems is typically conducted by using a per-capita nutrient load estimate from literature values and a characterization of the number and location of regional septic treatment systems. Additionally, some knowledge of the local soil's ability to retain nitrogen

Table 5-1. Example literature values for dissolved nutrients in agricultural runoff

Land Use	Nitrogen (mg/L)	Phosphorus (mg/L)
Fallow[a]	2.6	0.10
Corn[a]	2.9	0.26
Small grains[a]	1.8	0.30
Hay[a]	2.8	0.15
Pasture[a]	3.0	0.25
Barnyards[b]	29.3	5.10
Snowmelt runoff from manured land[c]		
Corn	12.2	1.9
Small grains	25.0	5.0
Hay	36.0	8.7

[a]Dornbush et al. (1974); [b]Edwards et al. (1972); [c]Gilbertson et al. (1979).

and phosphorus is used to estimate how much of the per-capita load reaches surface water sources through ground water transport. In the absence of site-specific monitoring information, per-capita nutrient loading and soil retention rates can be estimated from literature values and professional judgment.

Quantifying loads from fertilizer application, animal waste, waste-lagoon sludge, and soil mineralization through ground water transport works best using site-specific monitoring information. Without monitoring information, however, literature surveys and professional judgment may be used to characterize loading from these sources. Because of the complex relationship between factors contributing to ground water concentrations of nutrients, literature values should be used cautiously. Factors influencing nutrient levels in ground water can include land use, characteristics of ground water flow, local soil quality and conditions, landscape characteristics, well construction, and distance of point sources from the waterbody.

Atmospheric deposition

Inputs of nutrients in rainfall may be a significant source of loading in larger lake and reservoir systems. Rainfall inputs can be particularly important when the waterbody is large compared to the watershed area drained. Quantifying rainfall sources of nutrients involves estimating average seasonal rainfall, the surface area of the waterbody of concern, and estimates of nutrient concentration in the rainfall. Nutrient concentrations in rainfall can be measured through monitoring or by using literature values. Dryfall, deposited from dry-weather airborne organic material, also may be an important source of loading. Dryfall inputs may vary with local land uses along the shore, so if dryfall monitoring is conducted, several site-specific samples should be obtained (USEPA, 1983). Dryfall sources of nutrient loading also may be quantified through monitoring information or from literature values.

Sediment release (phosphorus)

Under certain conditions, bottom sediments can be important sources of phosphorus to the overlying waters of lakes and impoundments, particularly if the lake or impoundment is shallow or has an anaerobic hypolimnium (Chapra, 1997). Phosphorus flux from sediment deposits is strongly affected by sediment composition and oxygen levels in the water column; sediment release can contribute significant nutrient loadings during low-oxygen conditions. Typically, larger lakes and reservoirs are susceptible to low oxygen levels during periods of stratification, which usually occurs in mid- to late-summer in monomictic systems. For dimictic systems, low oxygen also can occur under the ice in winter. Under low-oxygen conditions, phosphorus may be released from the sediment layer, entering the water column and contributing to loading. Indicators of potential nutrient loading from sediment sources might include probable high concentrations of phosphorus in the sediment and known low-oxygen conditions in the waterbody, or evidence of algal blooms following turnover in the late summer or early fall.

Without site-specific monitoring information, literature values can be used to estimate phosphorus loading from the sediment. Such values should be used very cautiously, because the loading parameter will be site-specific, depending on the iron content and other sediment characteristics. Note that sediment release will change over time in response to changes in loadings. Where the sediment release comprises a significant portion of the system load, it should be modeled. Model frameworks are available to compute sediment phosphorus release (e.g., Nurnberg, 1988, Seo and Canale, 1999).

Background or natural sources

Natural or background inputs of nitrogen and phosphorus in stream and river systems will contribute to increased nutrient concentrations. Typically, such sources can be estimated from regional reference streams. Reference sites are relatively undisturbed by human influences or represent least-impaired conditions; their levels of nitrogen and phosphorus reflect background loading from stream erosion, wild animal wastes, leaf fall and other natural or background processes. If possible, reference streams should be located in similar geophysical and hydrologic watersheds, having similar stream morphology and stream order. A wide variety of state and local agencies may collect information about reference streams. Without site-specific or regional reference stream information, literature values may be used to estimate background sources. Some literature values from the National Eutrophication Study are shown in Table 5-2.

4. What is the appropriate level of spatial and temporal detail for determination of the source loading?

A broad range of issues, including availability of data, time and resource constraints, relative significance of the source loading, influence of geographic issues, and the need to quantify episodic versus steady-state problems will determine the appropriate level of detail for the source analysis.

Availability of data

When a large amount of data is available, a more detailed analysis might be appropriate for estimating sources. In situations with minimal site-specific monitoring information, and time or resource constraints preclude long-term or expensive monitoring plans, simplified loading analysis using literature values and simple methods may be used. If other TMDLs or watershed-based studies have been conducted in the area, these should be the prototype to develop and calibrate the source analysis.

Time scale

One of the first questions to address in selecting an appropriate source assessment technique is the time scale of the problem to be considered. Examining a problem that occurs only at low-flow periods might require primarily an estimate of the loads delivered during a critical low-flow condition. This calculation may be based on gauging station records or a simplified analysis of contributing sources. Low-flow conditions are often dominated by point-source discharges and baseflow (ground water) sources. In this situation, source loadings may be quantified by a combination of in-stream monitoring and point-source discharge records. For those situations where low-flow nonpoint sources are believed to be significant (e.g., because of septic systems or irrigation return flows), these sources also will need to be estimated.

Factors to Consider in Determining the Level of Detail for the Analysis

- Data availability
- Time scale
- Spatial scale
- Delivery mechanisms
- Land use types
- Management activities considered
- Value of resource and management cost

Table 5-2. Mean dissolved nutrients measured in streamflow by the National Eutrophication Survey

Watershed Type	Concentrations (mg/L)		
	Eastern United States	**Central United States**	**Western United States**
Total Inorganic Nitrogen			
>90% Forested	0.19	0.06	0.07
>75% Forested	0.23	0.10	0.07
>50% Forested	0.34	0.25	0.18
>50% Agriculture	1.08	0.65	0.83
>75% Agriculture	1.82	0.80	1.70
>90% Agriculture	5.04	0.77	0.71
Total Orthophosphorus			
>90% Forested	0.006	0.009	0.012
>75% Forested	0.007	0.012	0.015
>50% Forested	0.013	0.015	0.015
>50% Agriculture	0.029	0.055	0.083
>75% Agriculture	0.052	0.067	0.069
>90% Agriculture	0.067	0.085	0.104

Source: Omernik, 1977.

Another category of time scale are those waters where longer-term loadings are of concern. In receiving waters with longer residence times, including some lakes and estuaries, it is appropriate to estimate loads monthly or even annually. Techniques appropriate for these situations include unit-loading rate calculations and use of simple models or methods. For evaluation of monthly loadings, with some year-to-year variability, mid-range models (or those that combine empirical approaches with some aspects of modeling) can be used.

Episodic load estimates might be needed in waterbodies with short residence times and will require the consideration of a series of individual storms or a continuous (hourly or daily) simulation of the loading processes. Simulation models can consider loadings from rainfall- and snowmelt-driven processes continuously. Interpretation of the time-variable loads can be used to examine the frequency and magnitude of loading.

Phasing

Later phases of a TMDL may include consideration of more complex analysis methods, including conducting additional monitoring or modeling to confirm or modify the original estimates.

Recommendation: In general, a steady-state analysis should be widely useful for developing a nutrient TMDL. Point sources, sediment oxygen demand, ground water inflows, and upstream background loads are approximately constant or can be adequately averaged (USEPA, 1995a). A dynamic analysis might be justified when standards require that minimum dissolved oxygen levels be maintained at all times and nutrient loads are known to cause varied levels of dissolved oxygen in the stream.

5. What analysis techniques are appropriate for estimating the source loads?

A range of analytical tools and methods is available for estimating nutrient loads, depending on the appropriate time scale and available resources. They include the use of monitoring data, empirical methods, and computer models. Consider the following factors when selecting a tool to estimate nutrient loads:

- Availability of data and funds to support data collection
- Familiarity with the analysis tool
- Staff support
- Degree of accuracy required
- Physical, chemical, and biological processes to consider

Monitoring data

Site-specific monitoring data can help to determine load estimates when water quality and flow measurements are readily available. Monitoring at gauging stations, upstream of the area of concern, can help to estimate the boundary conditions or loads. Many gauging stations have long-term records of flow; however, monitoring for nutrient and related chemical concentrations (e.g., biochemical oxygen demand) is much less frequent. Depending on the particular station, the monitoring frequency might range from several samples per year to several per month. Load estimates at the station typically derive from a relationship between the flow and associated nutrient concentration. This relationship, represented by a regression equation, can be used to calculate the total estimated load or to develop a series of upstream boundary conditions.

Because significant increases in nutrient inputs may occur during wet-weather flows, sufficient dry-weather flow and concentration data should be collected to avoid overestimating load contributions during wet-weather periods. Nutrient input then can be estimated by multiplying an average flow by the flow-weighted concentration or by a regression equation of nutrient input effect on flow. Also note that monitoring data can be combined with stream water quality modeling to estimate nonpoint sources. For example, Warwick et al., (1997) interpreted data collected by the Nevada Division of Environmental Protection with a modified version of WASP5 (a dynamic in-stream water quality simulation program) to estimate nonpoint source loads for a complex river and channel portion of the Carson River.

The advantage of using monitoring data is that it is a quick, easy, and inexpensive method. One disadvantage is that specific sources of loading are difficult to characterize (i.e., the monitoring data alone do not necessarily identify the loads associated with the various source categories). Another limitation of using monitoring information is that the method provides little information for areas outside the monitoring station drainage area.

Empirical methods

Empirical methods use statistical relationships to relate land use to loadings. For example, EPA has published probability-distribution graphs for various pollutants at sites across the country in *Results of the Nationwide Urban Runoff Program* (USEPA, 1983). These graphs can be used to estimate event mean concentration (EMC) levels; such estimates are best taken from sites with similar geological, hydrologic, and physiographic patterns to the area under consideration. Straightforward spreadsheet analysis, using values and equations from previous studies, then may be used to estimate loadings, given a set of EMC and flow volume measurements. Calculation of pollutant loading in this manner necessitates a large data set to best capture the probability distribution of pollutant concentrations at a given locale; the probability distribution of the EMC is used to provide upper and lower estimates of contaminant loading. Without comprehensive site-specific water quality measurements, statistical methods may be used to determine probable EMC levels for a given source. An example of typical phosphorus and nitrogen loading rates is provided in Table 5-3.

In the Albemarle-Pamlico case study described on the following page, a literature search was conducted to obtain high, medium, and low estimates of export coefficients for the various land use categories in the basin. Export coefficients are average annual unit-area nutrient loads associated with various land uses. The percentage of land in

Table 5-3. Typical phosphorus and nitrogen loading ranges for various land uses.

	Total Phosphorus (kg/ha-y)			Total Nitrogen (kg/ha-y)		
Land Use	**Minimum**	**Maximum**	**Median**	**Minimum**	**Maximum**	**Median**
Roadway	0.59	1.50	1.10	1.3	3.5	2.4
Commercial	0.69	0.91	0.80	1.6	8.8	5.2
Single-family low density	0.46	0.64	0.55	3.3	4.7	4.0
Single-family high density	0.54	0.76	0.65	4.0	5.6	5.8
Multifamily residential	0.59	0.81	0.70	4.7	6.6	5.6
Forest	0.10	0.13	0.11	1.1	2.8	2.0
Grass	0.01	0.25	0.13	1.2	7.1	4.2
Pasture	0.01	0.25	0.13	1.2	7.1	4.2

Multiply loadings in kg/ha-y by 0.89 to get lb/acre-y.
As with all literature values, this table should be used discriminately and only in the absence of site-specific data.
Source: Horner et al., 1994.

Source Assessment in Albemarle-Pamlico Estuary, North Carolina and Virginia

In a study of the Albemarle and Pamlico Sounds, a screening analysis of the A-P watersheds was conducted to determine which watersheds were contributing the most excess nutrients to surface waters (NCDEHNR, 1993). The Albemarle-Pamlico source assessment demonstrates use of simple empirical equations combined with GIS tools. The analysis, developed by North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR), Division of Environmental Management (NCDEM), used a combination of export coefficients, nutrient mass balances and GIS analysis to calculate preliminary nutrient loadings from the 68 North Carolina and 44 Virginia watersheds in the study area.

Point source discharges were identified from Discharger Monitoring Reports through NCDEM and the Virginia Water Control Board. Nitrogen and phosphorus inputs were determined by using the median value of monthly records of flow and concentration data. The discharges were identified by latitude and longitude coordinates and entered into a GIS system. The watershed boundaries were overlaid onto this map to locate each discharge site by watershed.

Nonpoint sources were calculated in two ways: (1) using export coefficients for each land use, and (2) by estimating agricultural inputs through a more detailed mass balance approach. In the first method, LANDSAT land use and cover data were used to identify types of land use in the basin. This information was entered into a GIS system to determine how much of each land use was contained in each watershed. A literature review of export coefficients was used to generate high, medium, and low estimates of loading from each land use category. Land use areas were multiplied by the appropriate export coefficients to determine loading for each of the 68 watersheds.

A mass balance approach also was used to further refine nonpoint source loadings from agricultural areas in the 16 gauged watersheds of the study area. This approach attempted to balance and account for the input, output, and storage of nutrients in each watershed. Inputs into the mass balance included fertilizer, precipitation, livestock wastes, and nitrogen fixation. Outputs included the nutrients in harvested crops, soil fixation, denitrification, loss to swamp forests, and river export. Estimates of nutrient flux were determined by a combination of literature searches, professional judgment, and estimates of county-specific information, such as livestock numbers. For example, livestock inputs were determined using county estimates of livestock data combined with per-animal estimates of nutrient generation to calculate total production. Based on literature review and professional judgment, 3 percent, 5 percent, and 10 percent were chosen as the low, most likely, and high estimates of the percentage of nutrients entering the water.

each land use category was multiplied by the export coefficients to determine estimates of nutrient loading for each watershed in the basin.

A mass balance approach also may be used to estimate nutrient loading. In this method, estimates of nutrient inputs, outputs, and storage are used to determine loadings. Flow-gauging information is required to assist in the estimate of nutrient fluxes. Literature values can be used to estimate inputs and outputs for each category of nutrient supply or loss. In the Albemarle-Pamlico study, literature values were used to estimate inputs and outputs: inputs included fertilizer application, precipitation, livestock wastes, and nitrogen fixation; outputs included the nutrients in harvested crops, soil fixation, denitrification, loss to swamp forests, and river export. To complete the mass balance, a storage term can be used to account for the differences in inputs and outputs to the system; such differences might be attributable to soil, ground water, and biomass nutrient storage.

Computer models

The development of TMDLs often requires the use of watershed loading models to evaluate the effects of land uses and practices on pollutant loading to waterbodies. These loading models typically are divided into categories (i.e., simple, mid-range, or complex) based on complexity, operation, time step, and simulation technique. Simple methods are usually used for studies that are not data intensive, whereas complex methods may be long-term approaches that require extensive resources, monitoring, and calibration. Mid-range methods combine techniques of both, often bridging the gap in data and available resources.

Figure 5-2 depicts a decision process for the selection of the appropriate tool for nutrient loading assessment and TMDL development in cases where modeling techniques are deemed necessary. The flowchart identifies a series of key decision points that can help guide the user in the selection of the appropriate model.

Simple methods

Simple methods are compilations of expert judgment and empirical relationships between physiographic characteristics of the watershed and pollutant export. They may use existing literature values, and typically can be applied by using a spreadsheet program or hand-held calculator. Simple models and methods are often used when data limitations and budget and time constraints preclude the use of more sophisticated methods. Simple models are probably most appropriate for load estimates in the following instances:

1. Only rough or relative estimates of nutrient loadings and limited predictive capability are needed.

2. The water quality problems of concern occur seasonally or annually (i.e., simple methods are not usually appropriate where loadings of shorter duration are important).

The major advantage of simple methods is that they can provide a rapid means of identifying critical loading areas with minimal effort and data requirements. The major disadvantage of using most simple methods is that the assumptions used provide only gross estimates of nutrient loads and are of limited value for determining loads on a seasonal or finer time scale. Another disadvantage is that the methods are of limited use for evaluating the effect of control measures.

Examples of readily available simple models or methods include EPA Screening Procedures, the Simple Method, the USGS Regression Method, and the Watershed spreadsheet model. Application of a simple method should use locally derived default data (e.g., EMCs, monitoring, loading analysis) or data from areas with similar physical characteristics. Site-specific monitoring data should be used whenever possible to check the accuracy of the predictions. For example, the predicted load can be compared with monitoring data at a gauging station. Some simple methods are best applied to smaller watersheds, because they do not consider transport processes or losses.

The *Simple Method* may be used to estimate pollutant concentration runoff from urban drainage areas and is based on storm event calculations. Runoff is estimated using runoff coefficients for the fraction of rainfall converted to runoff. A correction factor is used to account for those storms that do not produce runoff. Pollutant concentrations

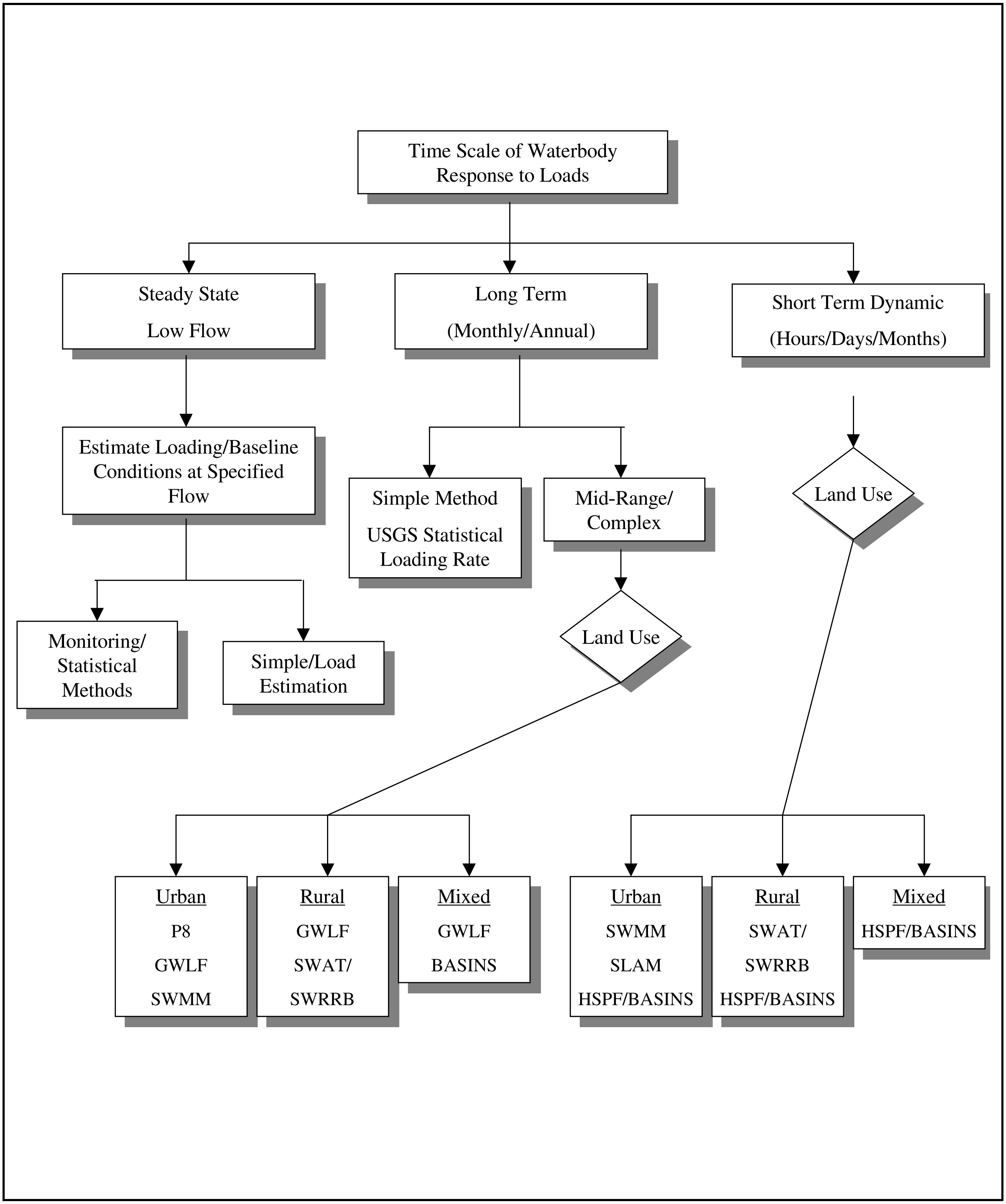


Figure 5-2. Decision tree with preferred model selection options

in runoff depend on the land use activity and can be obtained from sampling programs such as the National Urban Runoff Program (NURP) or from site-specific monitoring data. Potential applications of the Simple Method are to estimate pollutant loading from an uncontrolled development site or to estimate expected extreme concentrations that will occur over a specified time period. The Simple Method is best adapted for use in small watersheds of less than 1 square mile.

EPA Screening Procedures can be used to assess point and nonpoint source loadings and atmospheric deposition loads. Agricultural nonpoint loads are based on the Universal Soil Loss Equation (USLE), the Soil Conservation Service (SCS, now the Natural Resource Conservation Service [NRCS]) runoff curve number procedure, and loading functions using enrichment ratios. Urban nonpoint loads are estimated using the buildup-washoff concept (the buildup-washoff concept accounts for incremental buildup of nutrients between storms). Receiving water analyses use a mass balance approach that assumes steady-state conditions. Accuracy is limited when default parameters are substituted for site-specific data. The procedure neglects seasonal variation in predicting annual loadings and considers only steady-state conditions for receiving water analysis.

The *USGS Regression Method* is an example of a statistical or empirical method. This method estimates source loading as a function of land-use, percentage of imperviousness, drainage area, mean annual rainfall, and mean minimal monthly temperature. The USGS Regression Method gives mean storm event pollutant loads and corresponding confidence intervals. The USGS Regression Method is used to estimate pollutant concentration from urbanized watersheds and relies upon a statistical approach to estimate annual, seasonal, or storm event mean pollutant loads. The method uses regression equations for estimating mean storm event pollutant loads, and it provides users with a confidence interval to bracket estimates of loading. The method is valid only for areas where regression coefficients are obtainable (i.e., regional transferability is limited). The method applies to smaller watersheds.

The *Watershed* method is a spreadsheet application for estimating urban, rural noncropland, and rural cropland loads. Urban loads are calculated from point estimates of flow and concentration, rural noncropland loads are estimated by unit area, and rural cropland loads are based on the Universal Soil Loss Equation. The method was applied to estimate loading from point sources, CSOs, septic tanks, rural cropland, and noncropland rural sources for the Delavan Lake watershed in Wisconsin (Walker et al., 1989). The spreadsheet program also can be used to calculate program costs and cost-effectiveness per unit load nutrient reduction.

The *Federal Highway Administration Model* (FHWA) is a screening-level statistical model to estimate nutrient loadings and the variability of loadings as estimated from runoff volume distributions and event mean concentrations for the median runoff event at highway or urban sites.

Simple Method
Metropolitan Washington Council of Governments
777 North Capitol Street
Suite 300
Washington, DC 20002
(202) 962-3200

EPA Screening Procedure
National Technical Information Services
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650
Refer to document number
NTIS P.B. 86122496
(EPA/600/6-85/002a).

USGS Regression Method
U.S. Geological Survey
430 National Center
Reston, VA 22092
(703) 648-5892

Watershed
U.S. Geological Survey
6417 Normandy Lane
Madison, WI 53719-1133
(608) 821-3853

Federal Highway Administration Model
Office of Engineering and Highways
Federal Highway Administration
6300 Georgetown Pike

USGS Regression Method for Estimating Source Loadings

The regression approach USGS researchers developed is based on a statistical description of historic records of storm runoff responses on a watershed level (Tasker and Driver, 1988). This method may be used for rough preliminary calculations of annual pollutant loads when data and time are limiting. Simple regression equations were developed using available monitoring data for pollutant discharges at 76 gauging stations in 20 states. Separate equations are given for 10 pollutants, including for dissolved and total nutrients. Input data include drainage area, percentage imperviousness, mean annual rainfall, general land use pattern, and mean minimum monthly temperature. Application of this method provides storm-mean pollutant loads and corresponding confidence intervals. The general form of the regression model follows:

$$W = 10^{[a + b\sqrt{DA} + cIA + dMAR + eMJT + fX_2]} \, BCF$$

where:

W	=	mean load, in pounds, associated with a runoff event
DA	=	drainage area in square miles
IA	=	impervious area, in percentage of DA
MAR	=	mean annual rainfall, inches
MJT	=	mean minimum January temperature, in degrees Fahrenheit
X_2	=	land-use indicator variable
BCF	=	bias correction factor

The appropriate regression coefficients for a, b, c, d, e, and f can be obtained from Tasker and Driver (1988). For example, to compute the mean annual load of total nitrogen, in pounds, at a 0.5-mi^2 basin that is 90 percent residential with impervious area of 30 percent and in a region where the mean number of storms per year is 79, first compute the mean load for a storm, W, using the appropriate regression coefficients. Plugging in the values from Tasker and Driver (1988) provides a mean load, in pounds, of 16.9. The mean annual load can be calculated by multiplying this value by 79, the average number of storms per year, to yield a mean annual load of 1,335 pounds of total nitrogen per year.

Selected values from Tasker and Driver (1988).

Dependent Variable	Regression Constant a	SQRT (DA) b	IA c	MAR d	MJT e	X_2 f	Bias Correction Factor
Total N	– 0.2433	1.6383	0.0061	-	-	– 0.442	1.345
Total NH_3+N	– 0.7282	1.6123	0.0064	0.0226	– 0.0210	– 0.4345	1.277
Total P	– 1.3884	2.0825	-	0.0234	– 0.0213	-	1.314
Dissolved P	– 1.3661	1.3955	-	-	-	-	1.469

Rainfall is converted to runoff, using a runoff coefficient calculated from the percentage of impervious land use. Pollutant buildup is based on traffic volumes and surrounding area characteristics. The model is used to evaluate lake and stream impacts for stormwater discharges and provides an uncertainty analysis of runoff and pollutant concentrations or loads. The method does not consider the soluble fraction of pollutants or the precipitation and settling of phosphorus in lakes. The Federal Highway Administration has used the FHWA model to evaluate the impacts of storm-water runoff from highways and their surrounding drainage areas.

Mid-range methods

Mid-range methods attempt a compromise between the empiricism of the simple methods and the complexity of detailed mechanistic models. Mid-range methods are probably most appropriate for load estimates for the following conditions:

- Nonpoint or storm-driven sources are the primary concern.
- Slightly more detailed assessment is needed.
- The water quality problems of concern require the evaluation of specific storms or monthly or annual variability.
- Available data and resources are insufficient to support the development of a more detailed model formulation.

The advantage of mid-range watershed-scale models is that they evaluate nutrient sources and impacts over broad geographic scales and therefore can assist in defining target areas for mitigation programs in a watershed. Several mid-range models are designed to interface with geographic information systems, which greatly facilitate parameter estimation (e.g., AGNPS). Greater reliance on site-specific data gives mid-range models a relatively broad range of regional applicability. However, the use of simplifying assumptions or default values can limit the accuracy of their predictions to within about an order of magnitude (Dillaha, 1992) and can restrict their analysis to relative comparisons.

Site-specific monitoring data should be used whenever possible to verify the predictions. For example, the predicted load can be compared with monitoring data at a sampling station to test the accuracy of the predictions.

The *Generalized Watershed Loading Functions (GWLF)* model can be used to estimate nutrient loads from urban and agricultural watersheds, including septic systems (Haith et al., 1992). GWLF is based on simple runoff, sediment and ground water relationships combined with empirical chemical parameters. It evaluates streamflow, nutrients, soil erosion and sediment yield values from complex watersheds. Runoff is calculated with the NRCS curve number equation. Urban nutrient loads are calculated by exponential accumulation and wash-off functions. Nutrient loads from septic systems are calculated by estimating the per capita daily load from each type of septic system considered and the number of people in the watershed served by each type. GWLF can apply to relatively large watersheds with multiple land uses and point sources. It tracks total and dissolved nutrients and sediment. Stormwater storage and treatment are not considered. It has been used in an 85,000-hectare watershed from the West Branch Delaware River Basin in New York using a 3-year period of record (Haith and Shoemaker, 1987). GWLF also has been used for TMDL development in the Tar-Pamlico Basin of North Carolina. Input data requirements are daily precipitation and temperature data, runoff source areas, transport parameters including runoff curve numbers, soil-loss factor, evapotranspiration-cover coefficient, erosion product, ground water recession and seepage coefficients, sediment delivery ratio, and chemical parameters including urban nutrient accumulation rates, dissolved nutrient concentrations in runoff, and solid-phase nutrient concentrations in sediment.

The *Agricultural Nonpoint Source Pollution Model 98 (AGNPS 98)* is a joint USDA NRCS and Agricultural Research Service system of computer models developed to predict nonpoint source pollutant loadings within agricultural watersheds. It contains a continuous simulation, surface runoff model designed for risk and cost/benefit analyses. The set of computer programs consists of (1) input generation and editing, as well as associated databases; (2) the "annualized" science and technology pollutant loading model (AnnAGNPS); and (3) output reformatting and analysis. The model allows the

**Mid-Range Methods:
List of Contacts**

GWLF Model
Department of Agricultural and Biological Engineering
Cornell University
Ithaca, NY 14853
(607) 255-2802

AGNPS
USDA NRCS National Water and Climate Center
Water Science and Technology Team
11710 Beltsville Drive
Suite 125
Beltsville, MD 20705
www.sedlab.olemiss.edu/index.html

comparison of the effects of implementing various conservation alternatives within a watershed. However, AGNPS lacks nutrient transformation and in-stream processes and needs further field testing for its pollutant transport component. Input data requirements include topography and soil characteristics, meteorologic data, land-use data (cropping history and nutrient applications), point source data, and a global parameter for characterizing channel geometry and stream length. AGNPS output includes storm runoff volume and peak rate, sediment output (various sediment parameters such as sediment yield and concentration) and pollutant concentration and load. Nutrient concentrations from feedlots and other point sources can be modeled, and individual feedlot potential ratings also can be derived using the model.

Detailed methods

Detailed methods provide the best representation of the current understanding of watershed processes affecting pollution generation. Detailed models depict how watershed processes change continuously over time rather than relying on simplified terms for rates of change (Addiscott and Wagenet, 1985). Algorithms in detailed models more closely simulate the physical processes of infiltration, runoff, pollutant accumulation, in-stream effects, and ground water and surface water interaction. Detailed models provide information on source loadings from specific portions of watersheds and can predict the effect of different management practices. The input and output of detailed models also have greater spatial and temporal resolution. If appropriately applied, models such as HSPF and SWMM can accurately estimate pollutant loads and the expected impacts on water quality. New interfaces developed for HSPF and SWMM, and links with GISs, can facilitate the use of complex models for environmental decision-making. However, their added accuracy might not always justify the amount of effort and resources they require. Detailed methods are probably most appropriate for load estimates when:

- More explicit analysis of the runoff and pollutant transport processes is required.
- The water quality problems of concern require the consideration of short-term (i.e, hours, days) and time-variable effects.
- A higher degree of accuracy and refinement are required for the load estimates because of the complexity of the watershed system or the cost of potential controls.

The advantages of using detailed models are that they can provide relatively accurate predictions of variable flows and water quality at numerous points within a watershed if properly applied and calibrated. The additional accuracy they provide, however, comes at the expense of considerably more time and resources. Detailed models also require significantly longer implementation time, because they usually require an appropriate model calibration, validation, and verification procedure to document model accuracy. Formulation and calibration may require a data monitoring and collection strategy.

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a multipurpose environmental analysis system developed by EPA's Office of Water to help regional, state, tribal, and local agencies perform watershed- and water quality-based studies. BASINS integrates data on water quality and quantity, land uses, and point and nonpoint source loading, providing the ability to perform preliminary assessments of any watershed in the continental United States.

Three models are integrated into BASINS within an ArcView GIS environment. The Nonpoint Source Model (NPSM) estimates land-use-specific nonpoint source loadings for selected pollutants in a watershed (cataloging unit or user-defined subwatershed scale). QUAL2E is a one-dimensional, steady-state water quality and eutrophication model that allows fate and transport modeling for both point and nonpoint source loadings. TOXIROUTE is a screening-level stream routing model that

Model Calibration, Validation, and Verification

Calibration: model testing with known input and output to adjust or estimate factors.
Validation: comparison of model results with an independent data set (without further adjustment).
Verification: examination of the numerical technique in the computer code to ascertain that it truly represents the conceptual model with no inherent numerical problems.
See Reckhow and Chapra, 1983, Chapra, 1997, or Oreskes et. al, 1994, for more information.

performs simple dilution and decay calculations under mean or low-flow conditions for a stream system within a given watershed (cataloging unit). ArcView geographic data preparation, selection routines, and visual output streamline the use of the models, and a postprocessor is provided to graphically display model results.

The *Hydrological Simulation Program-Fortran (HSPF)* model is used to calculate pollutant load and transport from complex watersheds to receiving waters. HSPF provides capabilities for continuous and storm event simulation. Input data requirements include continuous rainfall, evapotranspiration, temperature, and solar intensity records. Many other parameters need to be specified in the HSPF model, although some default values are available. The model output includes a time series of the runoff flow rate, sediment load, nutrient and pesticide concentrations, and water quantity and quality at any location in the watershed. The Chesapeake Bay Program has used HSPF to model total watershed contributions of flow, sediment, and nutrients to the tidal region of the bay (Donigian et al., 1990; Donigian and Patwardhan, 1992).

DR3M-QUAL, a multi-event urban runoff quality model, may be used to assess urban storm water pollutant loads and simulates impervious areas, pervious area, and precipitation contributions to runoff quality and the effects of street sweeping or detention storage. Variation of runoff quality is simulated for user-specified storm runoff periods. Between these storms, a daily accounting of the accumulation and washoff of water quality constituents is maintained. Input data requirements include: daily rainfall, evaporation and storm-event rainfall at a constant time step; subcatchment data including area, imperviousness, length, slope, roughness, and infiltration parameters; trapezoidal or circular channel dimensions and kinematic wave parameters; stage-area-discharge relationships for storage basins; and water quality parameters, including buildup and washoff coefficients. Model output includes time series of runoff hydrographs and quality graphs (concentration or load versus time) at any location in the drainage system, summaries for storm events, and graphical output of water quality and quantity analysis.

The *Storm Water Management Model (SWMM)* simulates overland water quantity and quality produced by storms in urban watersheds. Several modules or blocks are included to model a wide range of quality and quantity watershed processes. Model components include rainfall and runoff processes, water quality analysis, and point-source inputs. Either continuous or storm event simulation is possible, with variable and user-specified time steps (wet and dry weather periods). Input data requirements include rainfall hyetographs, antecedent conditions, land use, topography, soil characteristics, dry-weather flow, hydraulic inputs (gutters or pipes), pollutant accumulation and washoff parameters, and hydraulic and kinetic parameters. Model output includes time series of flow, stage, and constituent concentrations at any location in the watershed. Seasonal and annual summaries are available.

Detailed Methods: List of Contacts

BASINS
EPA OST (4305)
Standards and Applied Science Division
401 M Street, SW
Washington, DC 20460
(202) 260-9821
http://www.epa.gov/ostwater/BASINS/

DR3M-QUAL
415 National Center
Mail stop 437
U.S. Geological Survey
Reston, VA 20192
(703) 648-5313
http://water.usgs.gov/software/

HSPF* and *SWMM
Model Distribution Coordinator
CEAM USEPA
960 College Station Road
Athens, GA 30605-2700
ftp://ftp.epa.gov/epa_ceam/wwwhtml/software.htm

6. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the source assessment step, an approvable TMDL will need to include an identification of the source categories, source subcategories, or individual sources of the pollutant for which the wasteload allocations and load allocations are being established.

RECOMMENDATIONS FOR SOURCE ASSESSMENT

- Using all available information, develop a comprehensive list of the potential and actual nutrient sources to the waterbody of concern. Develop a plan for identifying and accounting for the load originating from the identified sources in the watershed.
- Use GIS or maps to document the location of sources and the processes important for delivery to the waterbody.
- Group sources into some appropriate management unit (e.g., by delivery mechanism or common characteristics) for evaluation using the available resources and analytical tools.
- Ideally, monitoring data should be used to estimate the magnitude of loads from various sources. Without such data, some combination of literature values, best professional judgment, and appropriate analytical tools or models will be necessary. In general, the simplest approach that provides meaningful predictions should be used.
- In general, a steady-state analysis should be widely useful for developing a nutrient TMDL. Point sources, sediment oxygen demand, ground water inflows, and upstream background loads are approximately constant or can be adequately averaged (USEPA, 1995c).

RECOMMENDED READING

(Note that the full list of references for this section is included at the end of the document.)

- Novotny, V., and H. Olem. 1994. *Water quality: Prevention, identification, and management of diffuse pollution*. Van Nostrand Reinhold Company, New York, NY.

- USEPA. 1983. *Results of the Nationwide Urban Runoff Program*. NTISPB84-185552. U.S. Environmental Protection Agency, Water Planning Division, Washington, DC.

- USEPA. 1986b. *Stream sampling for wasteload allocation applications*. EPA 625/6-86-013. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

- USEPA. 1990. *The lake and reservoir restoration guidance manual*. EPA-440/4-90-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1991b. *Modeling of nonpoint source water quality in urban and nonurban areas*. EPA/600/3-91/039. U.S. Environmental Protection Agency, Washington, DC.

- USEPA. 1992b. *A quick reference guide: Developing nonpoint source load allocations for TMDLs.* EPA 841-B-92-001. U.S. Environmental Protection Agency, Washington, DC.

- USEPA. 1997a. *Compendium of tools for watershed assessment and TMDL development.* EPA841-B-97-006. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Linkage Between Water Quality Targets and Sources

Objective: Define a linkage between the selected water quality targets and the identified pollutant sources to characterize total assimilative capacity for nutrient loading or total load reduction needed.

Procedure: Determine the cause-and-effect relationship between the water quality target and the identified pollutant sources through data analysis, best professional judgment, models, or previously documented relationships. Use the linkage to determine what loadings or nutrient concentration are acceptable to achieve the desired level of water quality. Develop approaches for determining an appropriate margin of safety.

OVERVIEW

One of the essential components of developing a TMDL is to establish a link or relationship between predicted nutrient loads and the numeric indicators that have been chosen to measure the attainment of uses. Once this link has been established, it is possible to determine the total capacity of the waterbody to assimilate nutrient loadings while still supporting its designated uses, and allowable loads can be allocated among the various pollutant sources. The linkage is essentially used to answer the question: How much nutrient loading reduction is necessary to attain the desired water quality (as evaluated through numeric targets)? The link can be established by using one or more analytical tools. Ideally, the link can be based on a long-term set of monitoring data that allows the TMDL developer to associate certain waterbody responses to flow and loading conditions. More often, however, the link must be established by using a combination of monitoring data, statistical and analytical tools (including simulation models), and best professional judgment.

This section provides recommendations of the appropriate techniques that can be used when establishing the source-indicator link. As with the prediction of pollutant source loadings, the analysis can be conducted using methods that range from the simple to the complex. This section also provides guidance for selecting specific analytical tools, given certain conditions, and provides brief descriptions of these tools with their advantages and disadvantages for developing nutrient TMDLs. Readers should note that there are other analytical tools in addition to those described here, which have been selected for their availability, applicability to a wide range of conditions, and history of use. Several other documents are referenced at the end of this section for additional information.

KEY QUESTIONS TO CONSIDER FOR LINKAGE BETWEEN WATER QUALITY TARGETS AND SOURCES

1. Considering the indicator to be evaluated, available monitoring data, hydraulic characteristics of the system, and temporal and spatial factors, what is an appropriate level of analysis?

Choice of an analytical tool to link the nutrient loads to the TMDL indicator(s) depends on the interaction of several technical and practical factors. Several suggestions on how to address these factors were included in the numeric targets and source assessment sections and are not repeated here. Other key factors to consider in determining the appropriate level of analysis for TMDL linkages include the following:

- Physical and hydraulic characteristics of the waterbody (e.g., lake versus stream).
- Temporal representation needs. (Are seasonal averages sufficient, or must dynamic events on a shorter time scale be evaluated?)

Key Questions to Consider for Linkage of Water Quality Targets and Sources

1. Considering the indicator to be evaluated, available monitoring data, hydraulic characteristics of the system, and temporal and spatial factors, what is an appropriate level of analysis?
2. Considering the advantages and disadvantages of various approaches, what is the appropriate technique to establish a relationship between sources and water quality response?

- Spatial representation needs. (Are there significant spatial variations in the indicator and does spatial variability in the waterbody need to be represented?)
- User requirements (including availability of resources, time constraints, and staff familiarity with specific analysis techniques).
- Stakeholder interests and outreach needs.
- Degree of accuracy needed.

Indicators and sources can be linked at many different levels of complexity in the TMDL process. In some cases, previously documented empirical relationships such as those described in Section 3 (Identification of Water Quality Indicators and Target Values) can be used. For example, the Carlson Trophic Status Index (Carlson, 1977) can be used to predict the in-lake chlorophyll concentrations associated with various total phosphorus concentrations. In other cases, literature values or best professional judgment might be sufficient to describe the linkage. Simplified computer models often can be used to easily apply these empirical relationships or literature values. Under certain conditions, more sophisticated simulation models might need to be used for more detailed analysis.

In many cases, the TMDL process commences without sufficient data to support application of sophisticated modeling techniques. Analysis of the linkage for many nutrient TMDLs will start with the use of simple steady-state concentration-response analyses for scoping the problem. If the simple representation of the linkage is unsatisfactory because the uncertainties in the analysis are too great, additional, more sophisticated methods can be used for the analysis. The process of moving from simple, lower cost representations to more complex, higher cost representations can be viewed as a ladder. How far is it necessary to climb? This determination must be made as a trade-off among cost (and available resources), priority of the TMDL, the complexity and type of processes under consideration, and accuracy (acceptable size of the margin of safety). The exact specification of the steps of this ladder will vary from waterbody to waterbody. For instance, there are times when a high-priority TMDL involves a high level of detail (e.g., multiple episodic loadings), but an empirical simplified model coupled with a high margin of safety is acceptable because the level of point source treatment and nonpoint source management practices required are well within the financial capability of the watershed community. There are also instances where increasing the level of detail, although increasing cost, yields no corresponding reduction in uncertainty.

2. Considering the advantages and disadvantages of various approaches, what is the appropriate technique to establish a relationship between sources and water quality response?

Because of the interaction of the factors identified above, it is not possible to specify an appropriate technique or model choice using a "cookbook" approach, although some general considerations applicable to this decision are summarized in the decision tree shown in Figure 6-1.

This decision tree first distinguishes between streams and rivers (dominantly advective systems) and lakes and reservoirs (dominantly dispersive systems). Note that

Waters Impaired Primarily by Point Sources

In instances where the primary source of nutrients is point sources, the source-indicator link can be established using a traditional design condition approach that relies on steady-state analytical methods. The approach works because, with constant loads, the maximum impact is expected to occur at low flows. EPA's *Technical Guidance Manual for Performing TMDLs and Waste Load Allocations* provides information on developing TMDLs for this type of situation.

Technical Guidance Manual for Performing TMDLs. Book II, *Streams and Rivers:* Part 1. BOD/Dissolved Oxygen and Nutrient/ Eutrophication (EPA 823-B-97-002)

Technical Guidance Manual for Performing Waste Load Allocations. Book IV, *Lakes, Reservoirs, and Impoundments:* Chapter 2. Nutrient/ Eutrophication Impacts (EPA 440/4-84-019)

To order these documents, contact the National Service Center for Environmental Publications at (800) 490-9198 or *http://www.epa.gov/ncepihom/index.html*

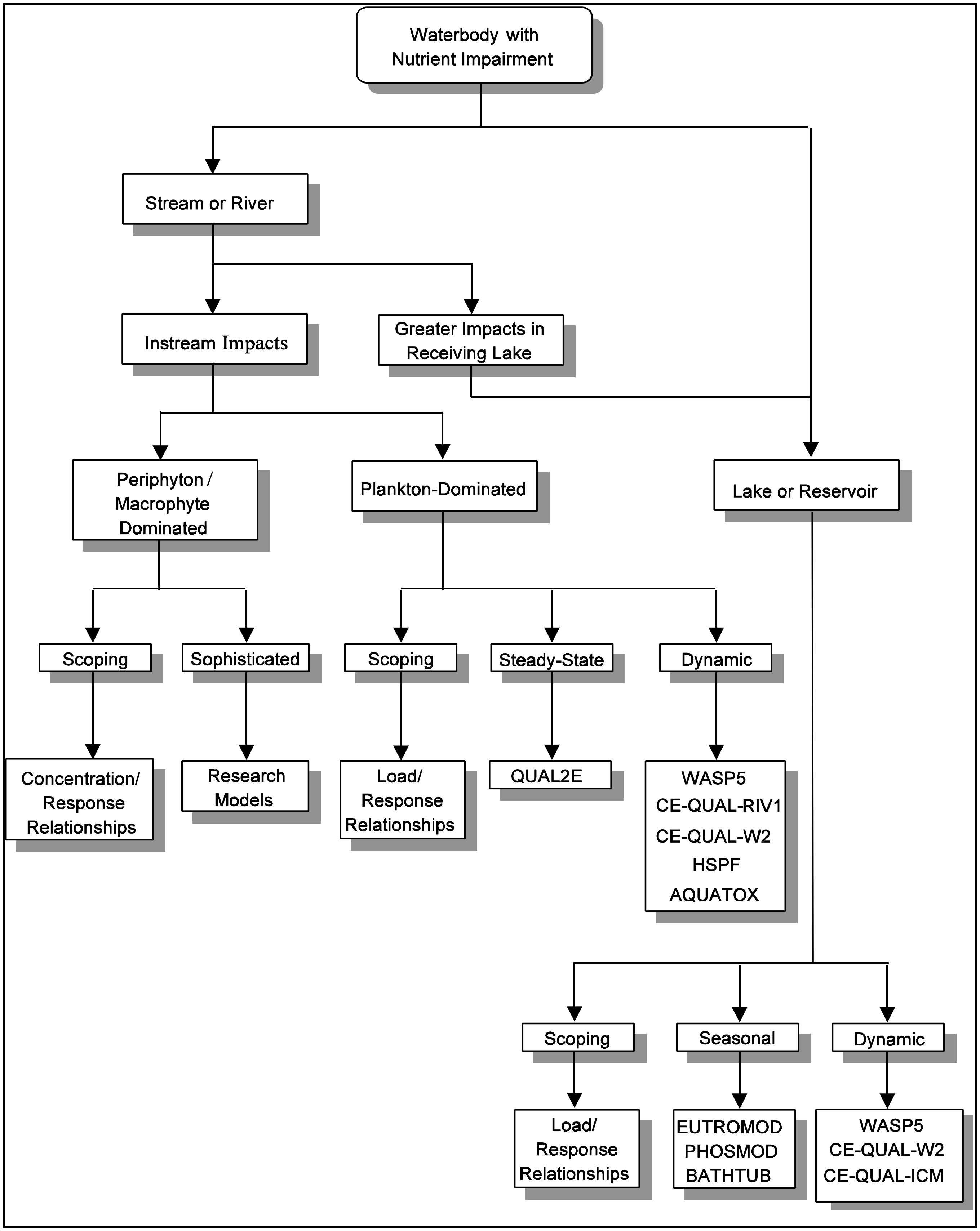


Figure 6-1. Decision tree for selecting an appropriate model technique

this distinction is not always clear-cut; some short-residence reservoirs behave more like rivers. Streams and rivers are then subdivided into systems dominated by planktonic algae and systems dominated by periphyton or macrophytes. Again, the distinction between the two types might blur in the real world. On each pathway, choices will need to be made regarding the complexity of the chosen technique. Finally, an example selection of available techniques or models is included at each terminal branch. Again, final choice of an appropriate technique or model will require careful examination of the properties of the individual techniques to match analytical requirements of the assessment.

Some detailed comments are warranted about several portions of this decision tree. First, note there is a connection from the "streams" branch back to the "lakes" branch. In many cases, the nutrient loads that impair rivers and streams also result in impairment in the lakes, reservoirs, or estuaries into which the rivers and streams discharge. Because of longer residence times, the receiving waterbody may be more sensitive than the river. If, ultimately, more stringent allocations will be required to protect this receiving water, it makes sense to base the analysis and TMDL on the most sensitive impacted water. Whether the resulting TMDL also protects the less sensitive river can be determined later.

Note also the absence of any sophisticated models for periphyton-dominated rivers and streams. At present, detailed predictive modeling of periphyton-dominated systems is limited by poor understanding of their growth processes, and this is an identified area for future research. Simplified representations of periphyton are within HSPF. The USGS has a water quality model (USGS-QW, Bauer et al, 1979) that simulates attached algae. This model was applied to a section of the south Platte River, Colorado (Spahr and Blakely, 1985). QUAL2E also has been applied where attached algae must be simulated by applying a benthic sink, rather than a source of ammonia nitrogen (Paschal and Mueller, 1991). Finally, Warwick et al. (1997) have modified WASP5 to simulate attached algae, with applications on the Carson and Truckee rivers.

Special consideration also will be needed for analysis of streams in semiarid areas. In alluvial valley sections of semiarid streams, surface flow is typically seasonal or ephemeral, and during much of the year the dominant flow in areas of thick alluvium occurs in the subsurface hyporheic zone. Studies of a Sonoran desert stream (Valett et al., 1990) revealed that average interstitial water volume was nearly four times that of surface water and contained levels of nutrients substantially higher than those observed in surface water. In such areas, observations of surface water concentrations can provide a very incomplete picture of total nutrient cycling in the stream.

Descriptions of Various Approaches and Their Advantages and Disadvantages[1]

Concentration and Response Relationships

For lakes and reservoirs, a strong quantitative framework has been developed during the past two decades that allows for the prediction of algal biomass and other associated water quality parameters from nutrient loading and water column nutrient concentrations. (Refer to the Indicators section of this document for more complete discussions of these frameworks.) These concentration-response relationships are based on a large set of empirical data and have proven to be useful management techniques worldwide. For many lakes and reservoirs, the link between pollutant sources and water quality response required for TMDL development can be based on these relationships. When using this type of approach, TMDL developers should consider the types of waterbodies included in the empirical databases they are using and apply them to their situation accordingly. For example, much of the work on trophic status classification systems has focused on northern, temperate lakes; applications of these techniques to other regions must therefore be done carefully. Moreover, users should understand that such correlations are usually highly uncertain, which must be considered when they are used to establish TMDLs.

Compared to lakes and reservoirs, much less work has been done to develop empirical models for periphyton biomass in natural streams and rivers (e.g., Biggs and

[1] Further summary information on available models is in the *Compendium of Tools for Watershed Assessment and TMDL Development* (USEPA, 1997a)

Close, 1989 and Lohman et al., 1992, as cited in Dodds and Smith, 1995). One example is presented by Dodds and Smith (1995), who report on constructing a database containing data from more than 200 distinct sites or rivers throughout North America, Europe, and New Zealand. They found that total nitrogen and total phosphorus concentrations were more highly correlated to stream chlorophyll than were nonnutrient factors such as latitude, temperature, stream gradients, or hydrodynamics. They also found that total nitrogen and phosphorus more highly correlate with algal growth than soluble reactive phosphorus and dissolved inorganic nitrogen. Applying their results to the Clark Fork River, the authors suggest that summer mean total nitrogen concentrations should not exceed 350 μg/L and total phosphorus 45.5 μg/L to keep chlorophyll concentrations below 350 mg/m^2.

Simulation models

If an appropriate concentration-response relationship cannot link indicators and sources, an appropriate simulation model can be used. A key aspect of model identification is the complexity, cost, and effort of implementation, which must be balanced against the benefits achieved by using the model to estimate the TMDL (refer to the Problem Identification section above). Public understanding and communication also can be crucial to choosing an analytical technique. This is particularly important for TMDLs that must rely on voluntary management measures to control nonpoint loads. Using a model that is overly complex, poorly documented, not peer reviewed, proprietary, or not well known will increase the difficulty of understanding, communicating, and gaining acceptance of the results. The following brief descriptions identify relevant characteristics of available models with their advantages and disadvantages for application to developing nutrient TMDLs.

CE-QUAL-RIV1. The Hydrodynamic and Water Quality Model for Streams (CE-QUAL-RIV1) was developed to simulate water quality conditions associated with the highly unsteady flows that can occur in regulated rivers. The model has two submodels for hydrodynamics (RIV1H) and water quality (RIV1Q). Output from the hydrodynamic solution is used to drive the water quality model. Water quality constituents modeled include temperature, dissolved oxygen, carbonaceous biochemical oxygen demand, organic nitrogen, ammonia nitrogen, nitrate nitrogen, and soluble reactive phosphorus. The effects of algae and macrophytes on water quality also can be included as external forcing functions specified by the user. A limitation of CE-QUAL-RIV1 is that it is applicable only to situations where flow is predominantly one-dimensional.

QUAL2E. The Enhanced Stream Water Quality Model (QUAL2E), originally developed in the early 1970s, is a one-dimensional water quality model that assumes steady-state flow but allows simulation of diel variations in temperature or algal photosynthesis and respiration (Brown and Barnwell, 1987.) QUAL2E represents the stream as a system of reaches of variable length, each subdivided into computational elements of the same length in all reaches. The basic equation used in QUAL2E is the one-dimensional advection-dispersion mass transport equation. An advantage of QUAL2E is that it includes components that allow quick implementation of uncertainty analysis using sensitivity analysis, first-order error analysis, or Monte Carlo simulation. The model has been used widely for stream wasteload allocations and discharge permit determinations in the United States and other countries. QUAL2E has been applied where attached algae need to be simulated by applying a benthic sink rather than a source of ammonia nitrogen (Paschal and Mueller, 1991). EPA's Office of Science and Technology developed a Microsoft Windows-based interface for QUAL2E that facilitates data input and output evaluation, and QUAL2E is one of the models included in EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS).

WASP5. WASP5 is a general-purpose modeling system for assessing the fate and transport of conventional and toxic pollutants in surface waterbodies. Its EUTRO5 submodel is designed to address eutrophication processes and has been used in a wide range of regulatory and water quality management applications. The model may be applied to most waterbodies in one, two, or three dimensions and can be used to predict time-varying concentrations of water quality constituents. It might be somewhat limited for lake applications by a lack of internal temperature simulation. The model reports a set of parameters, including dissolved oxygen concentration, carbonaceous biochemical oxygen demand (CBOD), ultimate CBOD, phytoplankton, carbon, chlorophyll *a*, total nitrogen, total inorganic nitrogen, ammonia, nitrate, organic nitrogen, total inorganic nitrogen, organic phosphorus, and inorganic phosphorus. Although zooplankton dynamics are not simulated in EUTRO5, their effect can be described by user-specified forcing functions. Lung and Larson (1995) used EUTRO5 to evaluate phosphorus loading reduction scenarios for the Upper Mississippi River and Lake Pepin, while Warwick et al. (1997) have modified WASP5 to simulate attached algae, with applications on the Carson and Truckee rivers, respectively.

EUTROMOD. EUTROMOD, a spreadsheet-based watershed and lake modeling procedure developed for eutrophication management, emphasizes uncertainty analysis. The model estimates nutrient loading, various trophic state parameters, and trihalomethane concentration using data on land use, pollutant concentrations, and lake characteristics. The model was developed using empirical data from EPA's national eutrophication survey, with trophic state models used to relate phosphorus and nitrogen loading to in-lake nutrient concentrations. The phosphorus and nitrogen concentrations then are related to maximum chlorophyll level, Secchi depth, dominant algal species, hypolimnetic dissolved oxygen status, and trihalomethane concentration. EUTROMOD allows for uncertainty analysis by considering the error in regression equations using an annual mean precipitation and coefficient of variation to account for hydrologic variability. EUTROMOD is limited in its application because it is designed for watersheds in the southern United States and it provides predictions only of growing season averages.

PHOSMOD. PHOSMOD uses a modeling framework described by Chapra and Canale (1991) for assessing the impact of phosphorus loading on stratified lakes. A total phosphorus budget for the water layer is developed with inputs from external loading, and recycling from the sediments, and considering losses from flushing and settling. The sediment-to-water recycling depends on the levels of sediment total phosphorus and hypolimnetic oxygen concentration, the latter estimated with a semi-empirical model. PHOSMOD can be used to make daily or seasonal analyses and was developed to assess long-term dynamic trends. Output includes tabular and graphical output of lake total phosphorus, percentage of total phosphorus in sediment, hypolimnetic dissolved oxygen concentrations, and days of anoxia.

BATHTUB. BATHTUB applies a series of empirical eutrophication models to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network that accounts for advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (total phosphorus, total nitrogen, chlorophyll *a*, transparency, and hypolimnetic oxygen depletion) are predicted using empirical relationships derived from assessment of reservoir data (Walker, 1985, 1986). Applications of BATHTUB are limited to steady-state evaluation of relationships between nutrient-loading, transparency and hydrology, and eutrophication responses. BATHTUB has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

CE-QUAL-W2. CE-QUAL-W2 is a two-dimensional, longitudinal and vertical water quality model that can be applied to most waterbody types. It includes both a hydrodynamic component (dealing with circulation, transport, and deposition) and a water quality component. The hydrodynamic and water quality routines are directly coupled, although the water quality routines can be updated less frequently than the hydrodynamic time step to reduce the computational burden in complex systems. Water quality constituents that can be modeled include algae, dissolved oxygen, ammonia-nitrogen, nitrate-nitrogen, phosphorus, total inorganic carbon, and pH.

Several limitations are associated with using CE-QUAL-W2 to model nutrient overenrichment in lakes and reservoirs. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies that exhibit strong longitudinal and vertical water quality gradients. It might be inappropriate for large waterbodies. The model also has only one algal compartment, and algal succession, zooplankton, and macrophytes cannot be modeled.

The Hydrological Simulation Program - FORTRAN (HSPF). HSPF is a comprehensive package developed by EPA for simulating water quantity and quality for a wide range of organic and inorganic pollutants from agricultural watersheds (Bicknell et al., 1993). The model uses continuous simulations of water balance and pollutant generation, transformation, and transport. Time series of the runoff flow rate, sediment yield, and user-specified pollutant concentrations can be generated at any point in the watershed. The model also includes in-stream quality components for nutrient fate and transport, biochemical oxygen demand, dissolved oxygen, pH, phytoplankton, zooplankton, and benthic algae. Statistical features incorporated into the model allow for frequency-duration analysis of specific output parameters. Data requirements for HSPF can be extensive, and calibration and verification are recommended. The program is maintained on IBM microcomputers and DEC/VAX systems. Because of its comprehensive nature, the HSPF model requires highly trained personnel. It is recommended that its application to real case studies be a team effort. The model has been extensively used for both screening-level and detailed analyses. Moore et al. (1992) describe an application to model BMP effects on a Tennessee watershed. Scheckenberger and Kennedy (1994) discuss how HSPF can be used in subwatershed planning.

CE-QUAL-ICM. CE-QUAL-ICM incorporates detailed algorithms for water quality kinetics and can be applied to most waterbodies in one, two, or three dimensions. Interactions among input variables are described in 80 partial differential equations that apply more than 40 parameters (Cerco and Cole, 1993). Model outputs include temperature; inorganic suspended solids; diatoms; blue-green algae (and other phytoplankton); dissolved, labile, and refractory components of particulate organic carbon; organic nitrogen; organic phosphorus; ammonium; nitrate and nitrite; total phosphate; and dissolved oxygen. Although the model has full capabilities to simulate state-of-the-art water quality kinetics, it is potentially limited by available data for calibration and verification. The model also might require significant technical expertise in aquatic biology and chemistry to be used appropriately.

It should be pointed out that few models described in this section are able to mechanistically simulate sediment oxygen demand (SOD). That is, most of the models represent SOD as a constant input parameter. Such models are not able to simulate how SOD may change following reduction in loads, and it is necessary to either assume that SOD remains unchanged or impose an empirical relationship between SOD and the load reduction (see Chapra, 1997). In fact, the relationship is likely to be nonlinear, and to have a slow response time. As discussed in Section 2, SOD is an important factor in nutrient TMDLs because significant nutrient load can be released from anoxic bottom sediments. Modelers

CE-QUAL-RIV1, CE-QUAL-W2, and CE-QUAL-ICM
U.S. Army Corps of Engineers Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180
(601) 634-3670

BASINS/QUAL2E (Windows)
EPA OST (4305)
Standards and Applied Science Division
401 M Street, SW
Washington, DC 20460
(202) 260-9821
http://www.epa.gov/OST/BASINS/

QUAL2E (DOS)
Center for Exposure Assessment Modeling (CEAM)
USEPA
960 College Station Road
Athens, GA 30605-2700
(706)355-8400
ftp://ftp.epa.gov/epa_ceam/wwwhtml/software.htm

WASP5 and HSPF
CEAM USEPA
960 College Station Road
Athens, GA 30605-2700
(706) 355-8400
ftp://ftp.epa.gov/epa_ceam/wwwhtml/software.htm

EUTROMOD and PHOSMOD
North American Lake Management Society
PO Box 5443
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should recognize that holding SOD constant when evaluating various allocation scenarios might result in conservative predictions (i.e., SOD is likely to decrease if loads are reduced), while assumptions of a linear decline with load may overestimate improvements.

RECOMMENDATIONS FOR LINKAGE BETWEEN WATER QUALITY TARGETS AND SOURCES

- Select an appropriate technique on a site-specific basis and consider the nature of the indicator to be evaluated, hydraulic characteristics of the waterbody, user requirements, and relevant temporal or spatial representation needs.
- Use all available and relevant data; ideally, the linkage will be supported by monitoring data, allowing the TMDL developer to associate waterbody responses to flow and loading conditions.
- Most nutrient TMDLs will start with the use of simple steady-state concentration-response relationships to scope the problem. If the simple representation of the linkage is unsatisfactory, more sophisticated techniques can be used. Figure 6-1 displays recommended models for several types of waterbodies and use impairments.
- When selecting a technique to establish a relationship between sources and water quality response, generally use the simplest technique that adequately addresses the factors identified above.

How can the expected accuracy of models be estimated?

An important step in the model calibration and validation process is to make some sort of estimate, either qualitative or quantitative, of the accuracy or reliability of model predictions. This estimate, of course, will be an important factor in deciding how to use the model results in the estimation of the TMDL. The basic point is that models produce only an approximation of reality. Model predictions cannot be any better than the calibration and validation effort, and will always have some uncertainty associated with the output. If model predictions are to be the basis of decisions, it is essential to have some understanding of the uncertainty associated with the model prediction. For instance, suppose a model predicts an instream chlorophyll *a* concentration of 20 μg/L given a certain set of flow and nutrient loading conditions. However, the model prediction is not exact, as sampling of the stream during those flow and loading conditions would likely demonstrate. The model must thus provide additional information specifying how much variability to expect around the "most likely" prediction of 20. Obviously, it makes a significant difference if the answer is "likely between 15 and 25" or "likely between 10 and 100."

Evaluating these issues involves the closely related concepts of model accuracy and reliability. "Accuracy" can be defined as a measure of the agreement between the model predictions and observations. "Reliability" is a measure of confidence in model predictions for a specific set of conditions and for a specified confidence level. Unfortunately, it is not easy to assess relative accuracy among models. The formality and degree to which model reliability must be assessed will vary case-by-case, from narrative statements to detailed quantitative analysis. A quantitative analysis is usually advisable when model results are used as the major basis for significant management decisions.

In terms of the probability that the numeric targets of the TMDL will be exceeded, consider two separate sources of temporal variability, *natural variability* and *model uncertainty*. Natural variability concerns the variability in loading and waterbody response that occurs as a result of precipitation sequences, and so on. Model uncertainty adds an additional layer of "noise." For instance, the simulated response to a precipitation sequence may not be quite right. The probability of exceedances from natural variability alone can be assessed through continuous simulation over a sufficiently long period of precipitation and flow records. However, assessment of the risk of impairment to a waterbody should also consider the accuracy of the model.

In the following sections, we provide a brief review of techniques available to assess the reliability, or uncertainty, associated with simulation model predictions. Many different techniques are used to assess model reliability. This review focuses on three of the most commonly used methods: sensitivity analysis, first-order analysis, and Monte Carlo simulation. Listed in increasing order of complexity and detail, each method is useful for specific purposes. Many published reports document model reliability analysis techniques (e.g., IAEA, 1989; Cox and Baybutt, 1981; Inman and Helton, 1988; Marin, et al., 1989).

Sensitivity Analysis

Sensitivity analysis is the least sophisticated and easiest analysis of the three to conduct. However, this ease of use produces only rudimentary results. Consequently, sensitivity analysis is best suited to preliminary reliability analysis and model selection and screening.

The object of a sensitivity analysis is most clearly described by its name. This method is used primarily to assess the sensitivity of model output to perturbations of individual model parameters. The means of conducting such an analysis are fairly straightforward. First, identify one or more parameter of interest. In most cases, all of the model parameters are chosen for the analysis. Vary each selected parameter through its range of values, while holding all other parameters at their median, or "best-estimate" values, and calculate the model output for each scenario. In many cases, it is sufficient to run the model with the selected parameter at only two points, its realistic upper and lower bounds. The analysis is then repeated for each parameter identified earlier. If the model output varies considerably for a given parameter, that parameter is determined to have a large effect on the uncertainty in model output. If the effect is small, the model is determined to be less sensitive to the parameter.

First-Order Analysis

First-order analysis (also called variance or analytical uncertainty propagation) is a slightly more sophisticated approach to assessing model reliability. It is used to determine the variance of the model output as a function of the variances and covariances of model inputs and parameters. Like sensitivity analysis, variance propagation examines the effects of uncertainty in individual parameters on the model prediction; however, first-order analysis produces a numerical estimate of the additional variability. If the modeler can reasonably assume (and justify) a specific distribution on the predicted values (e.g., a normal distribution), then this estimated variance can be used to compute confidence intervals for estimated values.

Depending on the nature of the model, the variance associated with one parameter may propagate through the model very differently from the variance of another parameter with the same level of uncertainty. That is, uncertainty in "important" parameters will have a relatively large effect on the uncertainty associated with model prediction, while less important variables will have a smaller impact. Clearly then, the effect of variance propagation depends on both the uncertainty associated with model parameters and the structure of the model itself.

Monte Carlo Simulation Analysis

The third method, Monte Carlo simulation, is a form of probabilistic uncertainty analysis. The objective of this method is to build up an empirical picture of the complete distribution function of model output over the possible range of input parameters. Evaluation of the distribution function is accomplished by a "brute force" approach, involving running the model over and over with randomly varied parameter values and collecting the results.

The Monte Carlo method yields not only a variance estimate but also a probability distribution for the model prediction. This distribution is an important piece of information, allowing the modeler to compute interval estimates and draw probability-based conclusions about the model output.

To use the Monte Carlo technique, the modeler first assigns probability distributions to each parameter. These distributions should be based on a solid combination of past experience, preliminary data screening, and expert opinion. No inherent restrictions are placed on the form of these distributions, making Monte Carlo analysis an easily generalized technique. After distributions for the parameters are specified, the Monte Carlo simulation model randomly generates a parameter value from the appropriate distribution and inserts these values into the model equations, yielding a predicted value. Autocorrelation in time series parameters can be represented by using a moving average or autoregressive approach, in which the next estimate depends on the prior values or the random component of the prior estimate. This process is repeated many (several hundred or thousand) times, from which a sample cumulative probability distribution is generated for the model output. This distribution reflects the overall response to the overall variability or uncertainty in the input parameters.

For water quality simulations, it is important to recognize that cross-correlation frequently exists between different input variables. For instance, there is often a lagged correlation between ambient temperature and pH, so that the highest temperatures will not coincide generally with the lowest pH values. Failure to represent such cross-correlation can lead to erroneous conclusions. This problem can be resolved by generating the correlated parameters simultaneously from their joint distribution, which, however, requires an estimate of the cross-correlation structure. The mathematical techniques for addressing these issues are outside the scope of this document but have been extensively covered elsewhere (see, for instance, Hammersley and Handscomb, 1964; Loucks et al., 1981; Bras and Rodriguez-Iturbe, 1985).

The Monte Carlo technique provides several advantages over the previously discussed approaches to reliability analysis. Most importantly, this method provides the modeler with a probability distribution for model prediction, rather than simply an estimate of its variance. This distribution forms the basis for computing various estimates (e.g., mean, median, 95th percentile) and appropriate confidence intervals for these estimates. As mentioned above, the Monte Carlo method also can apply to a wide variety of circumstances. For example, its use is not restricted to linear models, wide classes of distributions may be used for input parameters, and the computations are very straightforward. However, these advantages do not come without some cost. Most notably, the modeler must specify distributions for the input parameters. Careful thought must be put into assigning these distributions, as they form the basis for the model output distribution. A frequent criticism of conclusions drawn from a Monte Carlo simulation revolves around the choice of parameter distributions. As a result, sensitivity to the choice of parameter distributions is an important issue to consider; unfortunately, the effect of different distributional choices is difficult to assess. A second potential problem lies in the computer-intensive nature of the analysis. For large, complex models with disperse parameter distributions, Monte Carlo analysis may be computationally infeasible. Stratified sampling techniques (e.g., Latin hypercube sampling) may be used to reduce the effort required to obtain a representative approximation of the cumulative distribution frequency.

Several popular environmental fate and transport models are currently available with Monte Carlo analysis capability (such as QUAL2E). Others may be modified to perform such a function, with level of effort dependent on the clarity and structure of the original computer code. Hession et al., (1996) describe the application of the Monte Carlo analysis to the EUTROMOD model for a TMDL for Wister Lake, Oklahoma.

RECOMMENDED READING

(Note that the full list of references for this section is at the end of the document.)

- Chapra, S. 1997. *Surface Water-Quality Modeling*. The McGraw-Hill Companies, Inc.

- Thomann, R.V., and J.A. Mueller. 1987. *Principles of Surface Water Quality Modeling and Control.* Harper & Row, New York.

- USEPA. 1980. *Technical Guidance Manual for Performing Waste Load Allocations - Simplified Analytical Method for Determining NPDES Effluent Limitations for POTWs Discharging into Low-flow Streams.* U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Monitoring and Data Support Division, Washington, DC.

- USEPA. 1984a. *Technical Guidance Manual for Performing Waste Load Allocations.* Book II, *Streams and Rivers.* Chap.1, Biochemical oxygen demand/dissolved oxygen. EPA 440/4-84-020. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1984b. *Technical Guidance Manual for Performing Waste Load Allocations.* Book IV, *Lakes and impoundments.* Chap. 2, Nutrient/eutrophication impacts. EPA 440/4-84-019. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1984c. *Technical Guidance Manual for Performing Waste Load Allocations.* Book II, *Streams and Rivers.* Chap. 2, Nutrient/eutrophication impacts. EPA 440/4-84-021.

U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1985. *Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling*, EPA/600/3-85/040. U.S. Environmental Protection Agency, Washington, DC.

- USEPA. 1987. *Technical Guidance Manual for Performing Waste Load Allocations.* Book VI, *Design Conditions.* Chap.1, Stream design flow for steady state modeling. EPA 440/4-87-004. U.S. Environmental Protection Agency, Washington, DC.

- USEPA. 1997a. *Compendium of Tools for Watershed Assessment and TMDL Development.* EPA841-B-97-006. U.S. Environmental Protection Agency, Washington, DC.

- USEPA. 1997c. *Technical Guidance Manual for Performing Waste Load Allocations.* Book II, *Streams and Rivers.* Part 1, BOD/DO and nutrients/eutrophication. EPA823-B-97-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Allocations

Objective: Using total assimilative capacity developed in the linkage component, develop recommendations for the allocation of loads among the various point and nonpoint sources, while accounting for uncertainties in the analyses (i.e., MOS) and, in some cases, a reserve for future loadings.

Procedure: Determine the allocations based on a determination of the acceptable loading (loading capacity), the margin of safety, and the estimated loads from significant sources. The available load is then allocated among the various sources.

OVERVIEW

A TMDL consists of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for both nonpoint sources and natural background levels for a given waterbody. The sum of these components must result in the attainment of water quality standards for that waterbody. The TMDL also must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is denoted by the equation:

$$\text{TMDL} = \Sigma\ \text{WLAs} + \Sigma\ \text{LAs} + (\text{MOS})$$

To establish a TMDL, the administering agency must find an acceptable combination of allocations that adequately protects water quality standards. However, deciding how to divide the assimilative capacity of a given waterbody among sources can be a challenging task. Issues that affect the allocation process include:

- Economics
- Political considerations
- Feasibility
- Equitability
- Types of sources and management options
- Public involvement
- Implementation
- Limits of technology
- Variability in loads, effectiveness of BMPs

Although there is more than one approach to establishing TMDLs, typical steps in the allocation process are addressed in the following sections.

KEY QUESTIONS TO CONSIDER FOR ALLOCATIONS

1. What are the steps for completing the allocations?

The first step in establishing a TMDL is to specify the methods to use to incorporate an MOS. Section 303(d) of the CWA requires TMDLs to include "a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." Given that TMDLs address both point source allocations (WLAs) and nonpoint source allocations (LAs), this concept may be extended to cover uncertainty in BMP effectiveness in addition to effluent limitations.

There are two basic methods for incorporating the MOS (USEPA, 1991a; 1999):

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations or
- Explicitly specify a portion of the total TMDL as the MOS and use the remainder for allocations.

In many cases, the MOS is incorporated implicitly. In these cases, the conservative assumptions that account for the MOS should be identified. An explicit calculation, including evaluation of uncertainty in the linkage analysis, has the advantage of clarifying the assumptions that go into the MOS determination.

Key Questions to Consider for Allocations

1. What are the steps for completing the allocations?
2. How should candidate allocations be evaluated?
3. How can TMDLs be translated into controls?
4. How should issues of equitability and fairness be addressed?
5. How should stakeholders be involved?
6. What changes does the proposed rule speak to?

Example Allocation

Suppose the linkage analysis indicates that protection of uses in a lake requires a phosphorus TMDL equivalent to 250,000 kg/yr (685 kg/day) total P. Current P load to the lake is estimated to be 300,000 kg/yr. Of this total existing load, 200,000 kg/yr is derived from agricultural nonpoint sources (assuming reasonable worst-case contributions) and 100,000 from two point sources (wastewater treatment plants contributing 75,000 and 25,000 kg/yr respectively). Because the existing load exceeds the TMDL, further reductions are required. The state also has decided to apply an MOS of 10 percent on the TMDL to account for uncertainties in the analysis, equivalent to 25,000 kg/yr. An analysis of the effectiveness of supporting additional BMPs for agriculture suggests that a net P loading reduction of 33 percent can be obtained. Thus, the tentative LAs for the NPS are 200,000 x (1 - 0.33) = 134,000 kg/yr. The sum of the WLAs needed to meet the TMDL may then be calculated from

$$\Sigma \text{ WLAs} = \text{TMDL} - \Sigma \text{ LAs} - \text{MOS} =$$
$$250{,}000 - 134{,}000 - 25{,}000 = 91{,}000 \text{ kg/yr.}$$

The WLAs must then be adjusted to equal this sum.

The state has decided to impose reductions on point sources proportional to their current percentage contribution to the total point source loads. These percentage contributions are 75 percent and 25 percent for the two WWTPs, respectively. The revised WLAs can then be calculated as follows:

WWTP A: 75% x 91,000 = 68,250 kg/yr
WWTP B: 25% x 91,000 = 22,750 kg/yr

Permit conditions may then be written to ensure attainment of these WLAs as annual averages.

2. How should candidate allocations be evaluated?

TMDLs by definition are combinations of WLAs and LAs that allocate assimilative capacity to achieve water quality standards. The first step in the evaluation is to determine which segments and sources require allocation adjustment to achieve water quality standards. The actual adjustment to allocations likely will be based on the administering agencies' policies and procedures. For instance, should reductions be spread out across all sources or apply to only a few targeted sources? Each agency may have its own criteria for making these decisions (e.g., magnitude of impact, degree of management controls now in place, feasibility, probability of success, cost, etc.). The following subsections provide information on the types of factors that might need to be considered when making allocation decisions in cases where technology-based controls on point sources alone are not sufficient to meet water quality standards and thus a TMDL is required.

Assessing alternatives

Each allocation strategy under consideration will need to be tested using the linkage analysis (Section 6) to evaluate the potential effectiveness of the proposed alternative. The analysis might need to include consideration of the seasonal or annual variability in loadings, particularly where significant contributions are made by precipitation-driven nonpoint sources. As alternative allocation strategies are developed, it might be necessary to reassess the adequacy of the selection of targets and linkages.

Achieving a balance between WLAs and LAs

An appropriate balance should be struck between point source (PS) and nonpoint source (NPS) controls in establishing the formal TMDL components. Finding a balance between WLAs and LAs involves the evaluation of several factors. First, the manager needs to know how the loads causing the impairment are apportioned between PS and NPS. Is one source dominating the other? Imposition of controls should reflect the magnitude of the source, where possible. For instance, if a pollutant load from NPS was found to be 80 percent of the total loading to a problem area and a 40 percent overall reduction in loading was needed, necessary load reductions cannot be achieved through point source controls alone.

Managers also must consider the differences in terms of nutrient availability among the various sources. For example, an agricultural source might be a relatively large contributor of total phosphorus load, but if the phosphorus load remains largely in nonbioavailable form within the impaired waterbody segment, a reduction in loading is likely to have less of an impact. In general, it is advisable to develop the TMDL in terms of total phosphorus (because of the possibility of transformation from unavailable to available phosphorus), but in some cases allocations to individual sources might need to be prorated based on the refractory nature of their phosphorus contribution.

3. How can TMDLs be translated into controls?

Translate WLAs into NPDES permit requirements

The National Pollutant Discharge Elimination System (NPDES) permit is the mechanism for translating WLAs into enforceable requirements for point sources. The NPDES Program is established in section 402 of the Clean Water Act (CWA). Under the NPDES program, permits are required for the discharge of pollutants from most point source discharges into the waters of the United States (see 40 CFR Part122 for applicability). Although an NPDES permit authorizes a point source facility to discharge, it also subjects the permittee to legally enforceable requirements set forth in the permit. 40 CFR 122.44(d)(1)(vii)(B) requires effluent limits to be consistent with WLAs in an approved TMDL.

One way WLAs are translated into permits is through effluent limitations. Effluent limitations impose restrictions on the quantities, rates of discharge, and concentrations of specified pollutants in the point source discharge. Effluent limitations reflect either minimum federal or state technology-based guidelines or levels needed to protect water quality, whichever is more stringent. By definition, TMDLs involve WLAs more stringent than technology-based limits to protect water quality standards, and are therefore used to establish appropriate effluent limitations. Effluent limitations may be expressed either as numerical restrictions on pollutant discharges or as best management practices when numerical limitations are infeasible (40 CFR 122.44(k)). 40 CFR 122.45(d) requires numerical NPDES effluent limitations for continuous discharges to be expressed, unless impracticable, as average weekly and average monthly discharge limitations for publicly owned treatment works (POTWs) and as daily maximums and monthly averages for other dischargers.

Translate LAs into implementation plans

Unlike NPDES permits for point sources, there are no corresponding permit requirements for nonpoint sources. Instead, load allocations are addressed, where necessary, through implementation of BMPs. However, implementation of BMPs generally occurs through voluntary and incentive programs, such as government cost-sharing. Therefore, when establishing nonpoint source load allocations within a TMDL, the TMDL development documentation should show (1) there is reasonable assurance that nonpoint source controls will be implemented and maintained or (2) nonpoint source reductions are demonstrated through an effective monitoring program (USEPA, 1991a; 1999).

Although LAs may be used to target BMP implementation within a watershed, translation of LAs into specific BMP implementation programs can be a problem. One reason for this difficulty is that often many agencies are involved in BMP implementation, rather than a single oversight agency, as for NPDES permits. In addition to numerous landowner-operators, BMP implementation can typically include federal, state, and local involvement. Often, the objectives of the varying agencies are different, which makes coordination difficult.

Moreover, it is not always easy to predict the effectiveness of BMPs. TMDL strategies heavily dependent on loading reductions through LAs should include long-term watershed water quality monitoring programs to evaluate BMP effectiveness.

4. How should issues of equitability and fairness be addressed?

One issue that arises in distributing assimilative capacity is equitability among allocations. Chadderton et al. (1981) provide an examination of a variety of methods to establish WLAs among interacting discharges. Five methods were reviewed for a situation involving five interacting discharges of biochemical oxygen demand (BOD):

- Equal percentage removal or equal percentage treatment.
- Equal effluent concentration.
- Equal incremental cost above minimum treatment (normalized for volumetric flow rate).
- Effluent concentration inversely proportional to pollutant mass inflow rate.
- Modified optimization (i.e., least cost solution that includes the minimum treatment requirements of the technology-based controls).

A comparison of the methods was made based on cost, equity, efficient use of stream assimilative capacity, and sensitivity to stream quality data. The authors concluded that "equal percent[age] treatment" was preferable in the example studied because of the method's insensitivity to data errors and accepted use by several states. Although such a method could be used to strike a balance between various point sources or (in some cases) between similar nonpoint sources, it is unlikely to be feasible for balancing between point and nonpoint sources. The other methods cited by Chadderton et al. (1981), or combinations thereof, might be preferable under different circumstances.

5. How should stakeholders be involved?

Following federal regulations for water quality management planning (40 CFR Part 130), TMDLs should be available for public comment. For TMDL strategies to succeed, however, those parties likely to be affected by the TMDL (i.e., the stakeholders) should also participate in the TMDL development process. Effective communication is a key element of the public participation process. Stakeholders should be made aware of and engaged in the decisions regarding priority status of a waterbody, the modeling results or data analyses used to establish TMDLs for the waterbody, and the pollutant control strategies resulting from the TMDL (i.e., WLAs and LAs).

Methods for Communicating TMDLs to Stakeholders

- Issue public notices.
- Hold public meetings or hearings.
- Circulate basin or watershed plans for public review.
- Use educational and outreach programs to expand general knowledge of the TMDL process.

SUMMARY

The allocation step translates the TMDL into allowable loads, distributed among the various sources, and accounts for a margin of safety. Allocations are required for both point sources (WLAs) and nonpoint sources (LAs) and must include either an implicit or explicit margin of safety. Point source wasteload allocations are translated into NPDES permit requirements; nonpoint sources load allocations are translated into implementation plans. The TMDL implementation plan for point and nonpoint sources can be submitted with the TMDL, but it is not an element of the actual TMDL and is not approved or disapproved by EPA. Because the allocations will involve issues such as equity, economics, and political considerations, it is important that the administering agency involve stakeholders throughout development of the TMDL.

6. What changes does the propose rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the allocation step, an approvable TMDL will need to include the following information:

1. Wasteload allocations to each industrial and municipal point source permitted under §402 of the Clean Water Act discharging the pollutant for which the TMDL is being established ; wasteload allocations for storm water, combined sewer overflows, abandoned mines, combined animal

feeding operations, or any other discharges subject to a general permit may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated to attain or maintain water quality standards may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that wasteload allocations when implemented, will attain and maintain water quality standards;

2. Load allocations to nonpoint sources of a pollutant, including atmospheric deposition or natural background sources. If possible, a separate load allocation must be allocated to each source of natural background or atmospheric deposition; load allocations may be allocated to categories of sources, subcategories of sources or individual sources. Pollutant loads that do not need to be allocated may be included within a category of sources, subcategory of sources or considered as part of the background load. supporting technical analyses must demonstrate that load allocations, when implemented, will attain and maintain water quality standards;

3. A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant;

4. Consideration of seasonal variation and high and low flow conditions such that water quality standards for the allocated pollutant will be met during all design environmental conditions;

5. An allowance for future growth which accounts for reasonably foreseeable increases in pollutant loads; and

6. An implementation plan, which may be developed for one or a group of TMDLs.

Minimum Elements of an Approvable Implementation Plan

Whether an implementation plan is for one TMDL or a group of TMDLs, it must include at a minimum the following eight elements:

- *Implementation actions/management measures:* a description of the implementation actions and/or management measures required to implement the allocations contained in the TMDL, along with a description of the effectiveness of these actions and/or measures in achieving the required pollutant loads or reductions.

- *Time line:* a description of when activities necessary to implement the TMDL will occur. It must include a schedule for revising NPDES permits to be consistent with the TMDL. The schedule must also include when best management practices and/or controls will be implemented for source categories, subcategories and individual sources. Interim milestones to judge progress are also required.

- *Reasonable assurances:* reasonable assurance that the implementation activities will occur. Reasonable assurance means a high degree of confidence that wasteload allocations and /or load allocations in TMDLs will be implemented by Federal, State or local authorities and /or voluntary action. For point sources, reasonable assurance means that NPDES permits (including coverage under applicable general NPDES permits) will be consistent with any applicable wasteload allocation contained in the TMDL. For nonpoint sources, reasonable assurance means that nonpoint source controls are specific to the pollutant of concern, implemented according to an expeditious schedule and supported by reliable delivery mechanisms and adequate funding.

- *Legal or regulatory controls:* a description of the legal authorities under which implementation will occur (as defined in 40 CFR 130.2(p)). These authorities include, for example, NPDES, Section 401 certification, Federal Land Policy and Management programs, legal requirements associated with financial assistance agreements under the Farm Bills enacted by Congress and a broad variety of enforceable State, Territorial, and authorized Tribal laws to control nonpoint source pollution.

- *Time required to attain water quality standards:* an estimate of the time required to attain water quality. The estimates of the time required to attain and maintain water quality standards must be specific to the source category, subcategory or individual source and tied to the pollutant for which the TMDL is being established. It must also be consistent with the geographic scale of the TMDL, including the implementation actions.

- *Monitoring plan:* a monitoring or modeling plan designed to determine the effectiveness of the implementation actions and to help determine whether allocations are met. The monitoring or modeling plan must be designed to describe whether allocations are sufficient to attain water quality standards and how it will be determined whether implementation actions, including interim milestones, are occurring as planned. The monitoring approach must also contain an approach for assessing the effectiveness of best management practices and control actions for nonpoint sources.

- *Milestones for attaining water quality standards:* a description of milestones that will be used to measure progress in attaining water quality standards. The milestones must reflect the pollutant for which the TMDL is being established and be consistent with the geographic scale of the TMDL, including the implementation actions. The monitoring plan must contain incremental, measurable milestones consistent with the specific implementation action and the time frames for implementing those actions.

- *TMDL revision procedures:* a description of when TMDLs must be revised. EPA expects that the monitoring plan would describe when failure to meet specific milestones for implementing actions or interim milestones for attaining water quality standards will trigger a revision of the TMDL.

Recommendations for Allocations

- The method of incorporating the Margin of Safety (i.e., implicitly or explicitly) should be identified.
- Allocations should reflect the relative size and magnitude of sources, where possible, and represent an appropriate and feasible balance between WLAs and LAs.
- Allocations should be accompanied by adequate documentation to provide reasonable assurance that water quality standards will be attained.
- Affected stakeholders should help to develop allocations.

RECOMMENDED READING

(Note that the full list of references for this section is at the end of the document.)

- Chadderton, R.A., A.C. Miller, and A.J. McDonnell. 1981. Analysis of waste load allocation procedures. *Water Resources Bulletin* 17(5):760-766.

- Thomann, R.V., and J.A. Mueller. 1987. *Principles of surface water quality modeling and control.* Harper & Row, New York, NY.

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- USEPA. 1995c. *Watershed protection: A project focus*. EPA 841-R-95-003. U.S. Environmental Protection Agency, Office of Water, Washington, DC

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Follow-up Monitoring and Evaluation

Objective: Define the monitoring and evaluation plan to validate the Total Maximum Daily Load (TMDL), assess the adequacy of control actions to implement the TMDL, and provide a basis for reviewing and revising TMDL elements or control actions in the future.

Procedure: Identify the key questions that a monitoring plan needs to address, and evaluate monitoring options and implement the monitoring program. Describe the specific monitoring plan, including timing and location of monitoring activities, parties responsible for monitoring, and quality assurance and quality control procedures. Describe the schedule for reviewing monitoring results and considering the need for TMDL or action plan revisions, and discuss the adaptive management approach to take. The monitoring component of a TMDL results in a description of monitoring and adaptive management plan objectives, methods, schedules, and responsible parties.

OVERVIEW

TMDL submittals should include a monitoring plan to determine whether the TMDL has attained water quality standards and to support any revisions to the TMDL that might be required. Follow-up monitoring is recommended for all TMDLs, given the uncertainties inherent in TMDL development (USEPA 1991a; 1997b; 1999). The rigor of the monitoring plan should depend on the confidence in the TMDL analysis: a more rigorous monitoring plan should be included for TMDLs with more uncertainty and where the environmental and economic consequences of the decisions are most significant. This section discusses key factors to consider in developing the monitoring plan and suggests additional sources of guidance on monitoring plan development.

Models often can prove useful in evaluating the results of monitoring. Because weather and other watershed process drivers usually are not identical before and after implementation, it is difficult to compare monitoring data results. The monitoring must consider that situation. If models are calibrated to conditions before and after implementation, they then can be run for the post-implementation period assuming implementation practices are not applied. This approach can facilitate the evaluation of the relative effectiveness of different implementation approaches and the adequacy of different TMDL components.

KEY QUESTIONS TO CONSIDER FOR FOLLOW-UP MONITORING AND EVALUATION

1. What key factors influence monitoring plan design?

Key factors to consider in developing the TMDL monitoring plan include the following:

Need to evaluate specific TMDL elements

TMDL problem identification, indicators, numeric targets, pollutant estimates, and allocations may need to be reevaluated to determine if they are accurate and effective. The monitoring plan should define specific questions to be answered about these elements through the collection of monitoring information. Potential questions include the following:

- Are the selected indicators capable of detecting designated use impacts of concern and responses to control actions?
- Have baseline or background conditions been adequately characterized?
- Are the numeric targets set at levels that reasonably represent the appropriate desired conditions for designated uses of concern?
- Have all important pollutant sources been identified?
- Have pollutant sources been accurately estimated?

Key Questions to Consider for Follow-up Monitoring and Evaluation

1. What key factors influence monitoring plan design?
2. What is in an appropriate monitoring plan?
3. What is an appropriate adaptive management plan, including review and revision schedule?
4. What constitutes an adequate monitoring plan?
5. What changes does the proposed rule speak to?

- Has the linkage between pollutant sources and impacts to the waterbody been accurately characterized?
- Have other watershed processes (e.g., hydrology) that affect nutrient production or that impact designated uses been accurately described?
- Where reference sites were used to help determine TMDL targets and load reduction needs, were reference site conditions accurately described?
- Were models or methods used for the TMDL accurately calibrated, validated, verified?

Not all questions will be appropriate for all TMDL monitoring plans because the degree of uncertainty for different TMDL elements will vary case-by-case.

Need to evaluate implementation actions

It is often important to determine whether actions identified in the implementation plan actually were carried out (implementation monitoring) and whether these actions were effective in attaining TMDL allocations (effectiveness monitoring). Specific questions to answer concerning implementation actions should be part of the monitoring plan.

Stakeholder goals for monitoring efforts

Watershed stakeholders often participate in follow-up monitoring and stakeholder interests should be considered in devising monitoring plans.

Existing monitoring activities, resources, and capabilities

Analysts should identify existing and planned monitoring activities to coordinate TMDL monitoring needs with other planned efforts, particularly for a long-term monitoring program, large study areas, or if the water quality agency's monitoring resources are limited. Staff capabilities and training should also be considered, to ensure that monitoring plans are feasible.

Practical constraints to monitoring

Monitoring options are often limited by practical constraints (e.g., problems with access to monitoring sites and concerns about indirect impacts of monitoring on habitat). Other factors influencing the design of monitoring plans and different types of monitoring that are of interest for TMDLs are discussed in detail in MacDonald et al. (1991).

Types of monitoring

Several types of monitoring may be considered in developing the monitoring plan (modified from MacDonald et al., 1991).

- *Baseline monitoring.* Baseline monitoring describes existing conditions and provides a basis for future comparisons. This type of monitoring is not always necessary for the monitoring plan. Usually, some baseline data already exist and were considered during TMDL development.

- *Implementation monitoring.* This type of monitoring would ensure that identified management actions (such as specific BMPs or resource restoration or enhancement projects) are undertaken. This information also would be analyzed as a factor that influences the conclusions from the trend monitoring.

- *Project or effectiveness monitoring.* Specific projects undertaken in the context of the TMDL or separate from the TMDL but potentially affecting water quality conditions for the watershed area under consideration should be monitored both to determine their immediate effects and the effects on the water quality downstream of the project.

- *Trend monitoring.* This type of monitoring assesses the effectiveness of management actions and the changes in conditions over time relative to the baseline and identified target values. Trend monitoring is the primary type of follow-up monitoring, assuming the other elements of the TMDL are appropriately developed. It would address the changing conditions in the waterbody that result from TMDL-specific activities and other land management activities over time. This is the most critical component of the monitoring program, because it also serves to document progress toward achieving the desired water quality conditions.

- *Validation monitoring.* This type of monitoring is used to re-evaluate the selection of indicators, numeric targets, and source analysis methods.

2. What is in an appropriate monitoring plan?

The first step in developing an appropriate monitoring and adaptive management plan is to clarify the goals of the monitoring program. It may be possible to accomplish several of these monitoring goals simultaneously. For example, the primary need in most TMDLs will be to document progress toward achieving the numeric targets. During this process, the additional information collected may lead to a better understanding of the processes, suggesting a revision to the pollutant source analysis that would better pinpoint the nutrient problem and lead to faster attainment of water quality improvements; or, maybe a particular restoration or enhancement project did not produce the desired effects and it should be changed.

The relationships between the monitoring plan and the TMDL's numeric targets, source analysis, linkages, and allocations, and the implementation plan, should be addressed. Specific questions to be answered should be articulated as monitoring hypotheses, and the plan should explain how the monitoring program will answer those questions. Any assumptions should be explained. The monitoring plan's approach to both episodic events and continuous effects should be explained, and the likely effects of episodic events should be discussed. The design can be delineated by source type, by geographic area, or by ownership parcel.

The monitoring methods to be used should be described and the rationale for selecting these methods provided. Monitoring locations and frequencies should be defined, and the parties responsible for conducting the monitoring should be listed (if known).

An appropriate Quality Assurance Project Plan should be developed, detailing the sampling methods, selection of sites, and analysis methods consistent with accepted quality assurance and quality control practices. The monitoring plan should be peer reviewed, if possible. (For more information see USEPA, 1994a, 1994b.)

3. What is an appropriate adaptive management plan, including review and revision schedule?

The plan should contain a section that addresses the adaptive management component. This section should discuss when and how the TMDL will be reviewed. If possible, the plan should describe criteria to guide TMDL review and revision. For example, the plan could identify expected levels of progress toward meeting TMDL numeric targets at the initial review, stated as interim numeric targets or interim load reduction expectations. The plan also could identify "red flag" thresholds for key indicators that would signal fundamental dangers to designated uses and perhaps trigger a more in-depth review of the TMDL and implementation plan's components.

The adaptive management component need not schedule every TMDL review ever needed; it should be adequate to indicate an estimated frequency of review and specify a date for the initial review. Reliably forecasting how often TMDL reviews will be needed would be difficult, especially where problems are likely to take several years (or more) to solve.

4. What constitutes an adequate monitoring plan?

The monitoring and adaptive management plan is a required component of TMDLs developed under the phased approach. The plan should incorporate each component discussed above, with adequate rationale for the selected monitoring and adaptive management approach. If it is infeasible to develop the monitoring plan in detail at the time of TMDL adoption, it may be adequate to identify the basic monitoring goals, review the time frame, and identify responsible parties while committing to develop the full monitoring plan in the near future. The plan should clearly indicate the monitoring goals and hypotheses, parameters to monitor, the locations and frequency of monitoring, the monitoring methods to use, schedule for review and potential revision, and the parties responsible for implementing the plan.

5. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the monitoring step, an approvable TMDL will need to include a monitoring plan as part of the implementation plan. The monitoring plan needs to determine the effectiveness of control actions and/or management measures being implemented and whether the TMDL is working, as well as a procedure that will be followed if components of a

TMDL must be refined. The plan should clearly indicate the monitoring goals and hypotheses, the parameters to be monitored, the locations and frequency of monitoring, the monitoring methods to be used, the schedule for review and potential revision, and the parties responsible for implementing the plan. It must contain incremental, measurable targets consistent with the specific implementation action and the time frames for implementing those actions. This information is needed to adequately assess whether the specified actions are sufficient to attain water quality standards.

The following are key factors to consider when developing a TMDL monitoring plan:

- *Need to evaluate specific TMDL components*. TMDL problem identification, indicators, numeric targets, source estimates, and allocations might need reevaluation to determine whether they are accurate and effective. The monitoring plan should define specific questions to be answered about these components through the collection of monitoring information

- *Need to evaluate implementation actions*. It is often important to determine whether actions identified in the implementation plan were actually carried out (implementation monitoring) and whether these actions were effective in attaining TMDL allocations (effectiveness monitoring). Specific questions to be answered concerning implementation actions should be articulated as part of the monitoring plan.

- *Stakeholder goals for monitoring efforts*. Watershed stakeholders often participate in follow-up monitoring and their interests should be considered in devising monitoring plans.

- *Existing monitoring activities, resources, and capabilities*. Analysts should identify existing and planned monitoring activities to address TMDL monitoring needs in concert with these efforts, particularly where a long-term monitoring program is envisioned, the study area is large, or water quality agency monitoring resources are limited. Staff capabilities and training should also be considered to ensure that monitoring plans are feasible.

- *Practical constraints to monitoring*. Monitoring options can be limited by practical constraints (e.g., problems with access to monitoring sites and concerns about indirect impacts of monitoring on habitat).

Characteristics of Effective Monitoring Plans

- Quantifiable in approach. Results must be discernible over time, to compare them to previous or reference conditions.
- Appropriate in scale and application and relevant to designated uses and the TMDL methods.
- Adequately precise, reproducible by independent investigators, and consistent with scientific understanding of the problems and solutions.
- Able to distinguish among many different factors or sources (e.g., pasture washoff, cropland erosion, urban runoff, septic systems).
- Versatile. Generally looks at the problem from many different perspectives.
- Understandable to the public and supported by stakeholders.
- Feasible and cost-effective.
- Anticipates potential future conditions and climatic influences.
- Minimally disruptive to the designated uses during data collection.
- Conducive to reaching and sustaining conditions that support the designated uses.

RECOMMENDATIONS FOR FOLLOW-UP MONITORING AND EVALUATION

- Clearly identify the goals of the monitoring program.
- Define specific questions to answer about the evaluation of individual TMDL elements.
- If possible, coordinate with other existing or planned monitoring activities.
- Determine which type(s) of monitoring (e.g., implementation, trend) is (are) appropriate for accomplishing the desired goals.
- Develop an appropriate quality assurance plan; follow-up monitoring should be designed to yield defensible data that can support future analysis.

RECOMMENDED READING

(Note that the full list of references for this section is at the end of the document.)

- MacDonald, L., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska*. EPA 910/9-91-001. U.S. Environmental Protection Agency, Region 10, Nonpoint Source Section, Seattle, WA.

- USEPA. 1990. *Monitoring lake and reservoir restoration*. EPA 440/4-90-007. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

- USEPA. 1992c. *Monitoring guidance for the national estuary program*. EPA 842 B-92-004. U.S. Environmental Protection Agency, Washington, DC.

- USEPA. 1996c. *Nonpoint source monitoring and evaluation guide*. November 1996. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Considerations for Monitoring Algal Biomass and Nutrients in Streams and Rivers

The following information on monitoring considerations for streams and rivers was prepared for use in one of the guidance documents being drafted as part of EPA's *National Strategy for the Development of Regional Nutrient Criteria* (USEPA, 1998a). Guidance for monitoring nutrients and algae in lakes and reservoirs is available from *Monitoring Lake and Reservoir Restoration* (USEPA, 1990), and other sources.

Attached algal biomass can vary greatly in time and space within the same stream. Thus, the number of replicates required to reduce the standard error of mean biomass to a reasonable percentage can be too large to be practical. To reduce variability, the focus should be on algal sampling in the part of the stream where algae is most likely to conflict with designated uses. For rivers with unwadable depths, sampling must be confined to the wadable portions. For streams and rivers shallow enough to be wadable during the growing season, it may be possible to sample randomly across the entire width of the stream if the resulting sample variability is acceptable. If variability is too large, the focus should be on an indicator zone with a delimited range of water velocity, depth, and substrate size.

In general, it is recommended to collect 20 replicate samples and to analyze at least 10 of them to determine the variability in the data. (The second 10 then may be analyzed, should the standard error for the first 10 be too large.) For a few years, it is advisable to analyze all samples collected until the number of samples required to detect changes and trends of the desired magnitude has been determined.

Once criteria for algal biomass have been established, certain sampling considerations must be addressed to obtain meaningful samples.

How can algal criteria be applied to samples that come from only certain depths of the stream? British Columbia has developed the following algal biomass criteria for small wadable streams (Nordin, 1985): 50 mg/l of chlorophyll *a* to protect aesthetics and 100 mg/l to protect against undesirable changes in the stream community. Nordin, the principal author of these criteria, agreed that it was reasonable to apply the aesthetic criteria to the wadable portion of larger rivers. The level necessary to protect aquatic life is likely to be system-specific and is best evaluated by determining how algal biomass affects dissolved oxygen, pH, and aquatic communities.

How large an area should be characterized when assessing whether a reach exceeds a quantitative criterion? To ensure that a reasonably representative portion of a reach is sampled, replicate samples should be distributed over a reach of at least 100 m. Before selecting a point for sampling, a researcher should walk a few hundred meters upstream and downstream to ensure that the preferred sampling point is not atypical of the reach being characterized. Low altitude aerial photos taken on a sunny day in mid-to-late growing season are very useful to determine the longitudinal extent of conditions similar to those at the sampling site. Floating the stream by boat can serve a similar purpose.

For how long must algal biomass exceed criteria to be considered unacceptable? Attached algal biomass does not change as rapidly as water column parameters. Hence, one sample a month (from June to September) is probably adequate to assess algal biomass. If only two samplings can be afforded, the period likely to contain the highest biomass levels should be bracketed. However, such a sampling scheme may be unacceptable if both sample values exceed aesthetic criteria. If algal biomass is high enough to cause excessive dissolved oxygen or pH fluctuations that violate water quality standards or that release toxins at unacceptable levels, then the time frames for those water quality violations should be used to judge the acceptability of algal biomass levels. As an example, some states might regard the exceedance of algal biomass criteria once in 10 years (i.e., only during the 10-year low-flow) as acceptable, but more frequent exceedances may be deemed unacceptable.

Monitoring for nutrients attempts to determine the seasonal pattern in nutrient levels and how they related to algal biomass levels. The following offers some ideas for when and where to most efficiently sample nutrients.

When should samples be taken? Annual total nutrient loading is unlikely to be a good predictor of river algal biomass because growth may be poor during the periods of highest loading (from scour and turbidity). River algal growth is likely to relate to nutrient levels during the season of greatest algal growth. Nutrient sampling should be conducted monthly to bimonthly during the season of greatest nutrient loading and during the season of greatest algal growth. Comparison of nutrient levels between the seasons of greatest and least algal growth helps to determine how much of the loading algae take up. Hence, some nutrient sampling also should occur during the season of lowest algal biomass levels (at least three samplings spread over the period). Many nutrient monitoring programs are based on quarterly sampling. However, year-to-year variations in the window of high flows, the period of high nutrient uptake and algal growth, and the period of algal sloughing at the end of the growing season make detecting long-term trends from quarterly samples very difficult.

Where to sample: Nutrient levels may vary greatly throughout a river system, necessitating numerous sampling sites. To quantify sources and loads, monitoring stations for nutrients in rivers should be located upstream and downstream of major sources of nutrients or of diluting waters (e.g., discharges, development, tributaries, areas of major groundwater inputs).

Source: Watson, 1997.

Assembling the TMDL

Objective: Clearly identify the components of a TMDL submittal to support adequate public participation and to facilitate TMDL review and approval.

Procedure: Compile all pertinent information used to develop the TMDL and prepare the final submittal. The final submittal should document all of the major assumptions and analyses.

OVERVIEW

It is important to clearly identify the "pieces" of the TMDL submittal and to show how they fit together to provide a coherent planning tool that can lead to attaining water quality standards for nutrient-related water quality impairments. Where TMDLs derive from other analyses or reports, it is helpful to develop a separate document or chapter that ties together the TMDL components and shows where background information can be found.

RECOMMENDATIONS FOR CONTENT OF SUBMITTALS

Section 303(d) of the CWA and EPA's implementing regulations specify that a TMDL consists of the sum of WLAs for future and existing point sources and LAs for future and existing nonpoint sources and natural background, considering seasonal variation and a margin of safety. These loads are established at levels necessary to implement applicable water quality standards with seasonal and interannual variation and a margin of safety. Experience indicates, however, that information in addition to the statutory and regulatory requirements is useful to support adequate public participation and to facilitate EPA review and approval. As partners in the TMDL development process, it is in the best interest of the state and EPA to work together to determine how much supporting information the TMDL submittal needs.

Recommended Minimum Submittal Information

The following outlines suggestions for TMDL submittals:

1. Submittal Letter
   - Each TMDL submitted to EPA should be accompanied by a submittal letter stating that the submittal is a draft or final TMDL submitted under §303(d) of the CWA for EPA review and approval.

2. Problem Statement
   - Waterbody name and location.
   - A map is especially useful if information displayed indicates the area covered by the TMDL (e.g., watershed boundary or upper and lower bounds on the receiving stream segment) and the location of sources.
   - Waterbody §303(d) list status (including pollutant covered by the TMDL and priority ranking).
   - Watershed description (e.g., predominant land cover or land use, geology and hydrology).

3. Applicable Water Quality Standards and Water Quality Numeric Targets
   - Description of applicable water quality standards, including designated use(s) affected by the pollutant of concern, numeric or narrative standard, and the antidegradation policy.
   - If the TMDL is based on a target other than a numeric water quality standard, describe the process used to derive the target.

4. Pollutant Assessment
   - Source inventory with location of
     - Background
     - Point sources
     - Nonpoint sources
   - Supporting documentation for the analysis of pollutants loads from each source.

5. Linkage Analysis
   - Rationale for the analytical method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources.
   - Supporting documentation for the analysis (e.g., basis for assumptions, strengths and weaknesses in the analytical process, results from water quality modeling).

6. TMDL and Allocations
   - Total Maximum Daily Load (TMDL)[1]
     - The TMDL is expressed as the sum of the WLAs, the LAs, and the MOS (if an explicit MOS is included).
     - If the TMDL is expressed in terms other than mass per time, explain the selection of the other appropriate measure.
   - Wasteload Allocations (WLAs)[2]
     - Loads allocated to existing and future point sources.
     - An explanation of any WLAs based on the assumption that loads from a nonpoint source will be reduced.
     - If no point sources are present, list the WLA as zero.
   - Load Allocations (LAs)[2]
     - Loads allocated to existing and future nonpoint sources.
     - Loads allocated to natural background (where possible to separate from nonpoint sources).
     - If there are no nonpoint sources or natural background, list the LA should as zero.
   - Seasonal Variation[1]
     - Description of the method chosen to consider seasonal and interannual variation.
   - Margin of Safety[1]
     - An implicit MOS is considered through conservative assumptions in the analysis. To justify this type of MOS, an explanation of the conservative assumptions used is needed.
     - An explicit MOS is incorporated by setting aside a portion of the TMDL as the MOS.
   - Critical Conditions[2]
     - Critical conditions associated with flow, loading, designated use impacts, and other water quality factors.

7. Follow-Up Monitoring Plan
   - Recommended component for TMDLs.

8. Public Participation[2]
   - Description of public participation process used.
   - Summary of significant comments received and the responses to those comments.

9. Implementation Plan
   - Implementation plans are needed before TMDL approval if they are necessary to provide reasonable assurance that the load allocations contained in the TMDL will be achieved.

Supplementary TMDL Submittal Information

In addition to the information described above, TMDL submittals can be improved by preparing supplemental information, including a TMDL summary memorandum, a TMDL executive summary, a TMDL technical report, and an administrative record. The effort required to develop these documents should be minimal because they are largely a repackaging of information contained in the TMDL submittal. For example, the TMDL executive summary would be prepared for the TMDL technical report but would also be ideal for press releases or distribution to the public.

The *TMDL summary memorandum* provides an overview of all the essential regulatory elements of a TMDL submittal. This overview can facilitate regulatory and legal review. The summary memo should include the following information:

- Waterbody (name, size) and location
- Pollutant of concern
- Primary pollutant source(s)
- Applicable water quality standards
- Major data and information sources
- TMDL establishment
- WLA, LA, MOS, critical condition, seasonality, background concentrations
- Implementation
- Reasonable assurance

[1]Required by statute.

[2]Required by regulation.

- Follow-up monitoring
- Public participation

The *TMDL executive summary* provides an overview of the TMDL, the conclusions and implications, the analyses, and the background. This document is useful for public information, news releases, and public hearing announcements.

The *TMDL technical report* provides a compilation of the information sources, technical analyses, assumptions, and conclusions. This document provides a summary of the technical basis and rationale used in deriving the TMDL. A sample report outline might include the following sections:

1. Executive Summary
2. Introduction
3. TMDL Indicators and Numeric Targets
4. Water Quality Assessment
5. Source Assessment
6. Linking the Sources to the Indicators and Targets
7. Allocation
8. Implementation
9. Monitoring
10. References

The *administrative record* provides the technical backup, sources of information, calculations, and analyses used in deriving the TMDL. A typical administrative record might include the following:

- Spreadsheets
- Modeling software, input and output files
- References
- Reports
- Paper calculations
- Maps (working copies)

Public Participation

Public participation is a requirement of the TMDL process and is vital to a TMDL's success. The August 23, 1999, proposed regulation states that the public must be allowed at least 30 days to review and comment on a TMDL prior to its submission to EPA for review and approval. In addition, with its TMDL submittal, a state, territory, or authorized tribe must provide EPA with a summary of all public comments received regarding the TMDL and the State's, Territory's, or authorized Tribe's response to those comments, indicating how the comments were considered in the final decision.

EPA believes, however, that stakeholders can contribute much more than their comments on a specific TMDL during the public review process. Given the opportunity, stakeholders can contribute credible, useful data and information about an impaired or threatened water body. They may also be able to raise funds for monitoring or to implement a specific control action and/or management measure.

More importantly, stakeholders can offer insights about their community that may ensure the success of one TMDL allocation strategy over an alternative, as well as the success of follow-up monitoring and evaluation activities. Stakeholders possess knowledge about a community's priorities, how decisions are made locally, and how different residents of a watershed interact with one another. A thorough understanding of the social, political, and economic issues of a watershed is as critical to successful TMDL development as an understanding of the technical issues. States, territories, and authorized tribes can create a sense of ownership among watershed residents and "discover" innovative TMDL strategies through a properly managed public participation process.

Each state, territory and authorized tribe is required to establish and maintain a continuing planning process (CPP) as described in section 303(e) of the Clean Water Act. A CPP contains, among other items, a description of the process that the state, territory or authorized tribe uses to identify waters needing water quality based controls, a priority ranking of these waters, the process for developing TMDLs, and a description of the process used to receive public review of each TMDL. EPA encourages states, territories, and authorized tribes to use their CPP as the basis for establishing a process for public participation, involvement, and in many cases leadership, in TMDL establishment. On a watershed level, the continuing planning process allows programs to combine or leverage resources for public outreach and involvement, monitoring and assessment, development of management strategies, and implementation.

RECOMMENDED READING

(Note that the full list of references for this section is at the end of the document.)

- USEPA. 1991a. *Guidance for water quality-based decisions: The TMDL process.* EPA 440/4-91-001. U.S. Environmental Protection Agency, Assessment and Watershed Protection Division, Washington, DC.

- USEPA 1999. *Draft guidance for water quality-based decisions: The TMDL process (second edition)*. EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC.

APPENDIX: Case Studies

Laguna de Santa Rosa, California, TMDL
Chatfield Basin, Colorado, TMDL

TMDL Summary: Laguna de Santa Rosa, California

Waterbody Type:	Stream
Pollutant:	Nutrients
Designated Uses:	Various
Size of Waterbody:	Approximately 12 miles
Size of Watershed:	255 square miles
Water Quality Standards:	0.025 mg-N/L un-ionized ammonia 7.0 mg/L minimum dissolved oxygen concentration
Indicators:	Same as above
Analytical Approach:	Load-response relationship

Introduction

The TMDL developed for the Laguna de Santa Rosa illustrates the steps that can be taken to address a waterbody impaired by elevated total nitrogen and ammonia and by low dissolved oxygen levels. The plan is consistent with a phased-approach TMDL: estimates are made of needed reductions of pollutant loads, load-reduction controls are implemented, and water quality is monitored for plan effectiveness. Flexibility is built into the plan so that load reduction targets and control actions can be reviewed if monitoring indicates continuing water quality problems.

TMDL Submittal Elements

Loading Capacity:	Varies by season
Load Allocation:	Varies by season
Wasteload Allocation:	Varies by season
Seasonal Variation:	Varies by season
Margin of Safety:	Implicit through conservative assumptions

Problem Identification

A cover memo should describe the waterbody as it is identified on the state's section 303(d) list, the pollutant of concern, and the priority ranking of the waterbody. The TMDL submittal must include a description of the point, nonpoint, and natural background sources of the pollutant of concern, including the magnitude and location of the sources. The TMDL submittal should also contain a description of any important assumptions, such as (1) the assumed distribution of land use in the watershed; (2) population characteristics, wildlife resources, other relevant characteristics affecting pollutant characterization and allocation, as applicable; (3) present and future growth trends, if this factor was taken into consideration in preparing the TMDL; (4) explanation and analytical basis for expressing the TMDL through *surrogate measures*, if applicable.

Laguna de Santa Rosa is a tributary of the Russian River and is located near the city of Santa Rosa, California. The Laguna is home to salmonid and trout species and is a resource for recreational fisheries. However, the Laguna de Santa Rosa was listed on California's section 303(d) list of impaired waterbodies in 1992, 1994, and 1996. It was listed because of seasonal high ammonia and low dissolved oxygen levels caused by excessive nutrient loadings. High levels of un-ionized ammonium exceeded EPA's existing criterion of 0.025 mg-N/L (USEPA, 1986). (Levels of un-ionized ammonia above 0.025 mg-N/L are considered toxic to fish.) Low levels of dissolved oxygen in the Laguna were also detected, violating the North Coast Region's Basin Plan objective of 7.0 mg/L for minimum dissolved oxygen.

Description of the Applicable Water Quality Standards and Numeric Water Quality Target

The TMDL submittal must include a description of the applicable state water quality standard, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the antidegradation policy. This information is necessary for EPA to review the load and wasteload allocation required by the regulation. A numeric water quality target for the TMDL (a quantitative value used to measure whether the applicable water quality standard is attained) must be identified. If the TMDL is based on a target other than a numeric water quality criterion, the submittal must include a description of the process used to derive the target.

EPA's numeric criterion of 0.025 mg-N/L for un-ionized ammonia was used as the target value for the total ammonia indicator. Ammonia exists in water in either the ionic state or the un-ionized state. The percentage of measured total ammonia present in the toxic un-ionized state is a function of pH and temperature. As pH and temperature rise so does the relative percentage of total ammonia in the un-ionized state. The TMDL analysis assumes a conservative temperature of 24 °C and a pH of 8 in establishing the total ammonia target. These temperature and pH levels are worst-case conditions for ammonia toxicity and are rarely observed during the year in the Laguna; the target value for the indicator therefore implicitly accounts for a margin of safety.

Source Assessment

High algal productivity is common in the Laguna. Algal growth depends on an adequate supply of two nutrients, nitrogen and phosphorus. Historically high nitrogen concentrations in the Laguna's water column and the prevalence of many typical pollutant sources led investigators to suspect a nutrient loading problem in the watershed (Morris, 1995). Algal Growth Potential Studies conducted characterized the algal growth in the Laguna's water as being limited by nitrogen (Roth and Smith, 1992, 1993, 1994).

Two section 205(j) studies were conducted to determine the sources of nitrogen in the watershed. North Coast Regional Water Quality Control Board (NCRWQCB) staff conducted the first study in 1989-91, and it concluded that urban runoff, animal waste runoff, and wastewater from the city of Santa Rosa's Subregional Wastewater Reclamation Plant are sources of nitrogen, including ammonia. A subsequent 205(j) study conducted by the city of Santa Rosa in 1991-93 estimates the waste loads of nitrogen and organic matter from each loading sector in the watershed, including loads from septic systems, open space, agricultural operations, urban runoff, and wastewater from the Subregional Plant. Total loads of nitrogen and ammonia for the various loading sectors are estimated for each season and further disaggregated spatially by four distinct watershed areas. For example, the watershed area between Trenton-Heraldsburg Road and Guerneville Road has total estimated wintertime loads of 772,576 pounds total nitrogen. Twenty-four percent of the load is attributed to urban runoff, 32 percent to wastewater sources, 10 percent to non-irrigated agricultural sources, 25 percent to dairy farm sources, 2 percent to dairy pond overflows, 4 percent to septic loadings, and the remaining 3 percent to open space runoff.

NCRWQCB staff reduced the septic loading estimates from the 1991-93 205(j) study by 58 percent, citing overly conservative assumptions used by the city (e.g., the city's assumptions included an excessive estimate of wastewater flow per capita). Septic waste load estimates used in the TMDL may still be too high because the TMDL assessment assumes, probably incorrectly, that all wastewater discharged through septic systems reaches the Laguna, even those systems at the edge of the watershed (Strauss, 1995). The strategy outlined by NCRWQCB staff commits to a more intensive study of septic system discharges and transport to the Laguna to better characterize septic loading.

Loading Capacity — Linking Water Quality and Pollutant Sources

As described in EPA guidance, a TMDL describes the loading capacity of a waterbody for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a waterbody can receive without violating water quality standards (40 CFR 130.2(f)). The TMDL submittal must describe the rationale for the analytical method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many circumstances, a *critical condition* must be described and related to physical conditions in the waterbody (40 CFR 130.7(c)(1)). Supporting documentation for the analysis must also be included, including the basis for assumptions, strengths and weaknesses in the analytical process, and results from water quality modeling, so that EPA can properly review the elements of the TMDL required by the statute and regulations.

High ammonia levels in the Laguna are the result of inputs of nitrogen in various forms. The NCRWQCB focused on controlling the supply of nitrogen to the Laguna as a means of controlling ammonia. The un-ionized ammonia goal was converted into numeric concentration-based targets for total nitrogen and total ammonia using the conservative temperature and pH assumptions for partitioning un-ionized ammonia discussed above.

At night, in the absence of light, algae use oxygen in a respiration reaction. As algae levels increase, so does the corresponding respiration oxygen demand. When respiration demands exceed oxygen transfer rates across the water surface, low levels of dissolved oxygen can result. Since nitrogen is the limiting nutrient for algal growth in the basin, NCRWQCB focused on controlling the supply of nitrogen to the Laguna as a means of controlling the growth of algae and thus increasing the levels of dissolved oxygen in the river. Direct actions to increase the levels of dissolved oxygen in the Laguna are infeasible due to both technical challenges and the complex interaction of factors that affect oxygen supply and demand. Because of insufficient information relating nutrient levels to dissolved oxygen and algae levels directly, NCRWQCB used the un-ionized ammonia goal to derive loading reductions in nitrogen. NCRWQCB staff expect that reductions in total nitrogen will result in reductions in total ammonia, total phosphate, and organic matter. Reductions in these parameters are expected to reduce algal growth, which is in turn expected to increase levels of dissolved oxygen in the water. NCRWQCB staff have continued to monitor dissolved oxygen levels in the Laguna and will modify nitrogen loading reduction goals if minimum goals are not attained in the first phase of the TMDL.

The numeric concentration-based targets for total nitrogen and total ammonia were combined with seasonal flow information at each attainment point in the watershed to derive total permissible loading targets for each area by season.

Allocations

EPA regulations require that a TMDL include wasteload allocations (WLAs), which identify the portion of the loading capacity allocated to existing and future point sources (40 CFR 130.2(g)). If no point sources are present or the TMDL recommends a zero WLA for point sources, the WLA must be listed as zero. The TMDL may recommend a zero WLA if the state determines, after considering all pollutant sources, that allocating only to nonpoint sources will still result in attainment of the applicable water quality standard. In preparing the WLA, it is not necessary that every individual point source have a portion of the allocation of pollutant loading capacity. It is necessary, however, to allocate the loading capacity among individual point sources as necessary to meet the water quality standard. The TMDL submittal should also discuss whether a WLA is based on an assumption that loads from a nonpoint source or sources will be reduced. In such cases, the state needs to demonstrate reasonable assurance that the nonpoint source reductions will occur within a reasonable time.

EPA regulations also require that a TMDL include load allocations (LAs), which identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background (40 CFR 130.2(h)). Load allocations may range from reasonably accurate estimates to gross allotments (40 CFR 130.2(g)). Where it is possible to separate natural background from nonpoint sources, separate LAs should be made and described. If there are neither nonpoint sources nor natural background or the TMDL recommends a zero LA, an explanation must be provided. The TMDL may recommend a zero LA if the state determines, after considering all pollutant sources, that allocating only to point sources will still result in attainment of the applicable water quality standard.

The statute and regulations require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between effluent limitations and water quality (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)). EPA guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS must be described. If the MOS is explicit, the loading set aside for the MOS must be identified.

The statute and regulations require that a TMDL be established with seasonal variations. The state must describe the method chosen for including seasonal variations in the TMDL (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)).

Several allocation scenarios were developed for the Laguna TMDL, each satisfying total permissible seasonal loading targets for each of the four areas. A period of public review allowed for stakeholder input, resulting in selection of an appropriate scenario that allocated responsibilities for nutrient loading reduction equitably and allowed for phased implementation. Criteria used for allocating load reductions were to

- Meet water quality goals.
- Best represent the Laguna flow and pollutant loading dynamics.
- Provide a reasonable time frame for stakeholders to make load reduction adjustments.
- Provide reasonable and achievable load reductions.

Targeted load reductions were implemented through allocations among

- Nonpoint source nutrient discharge reduction projects.
- Urban stormwater load reductions.
- Municipal wastewater plant upgrades in Santa Rosa.
- Septic system upgrades.

NCRWQCB staff divided the Laguna watershed into four areas and established attainment points at the downstream end of each reach. They developed seasonal loads for each of the four areas. Seasonal loads were developed because variation in seasonal flow patterns is an important factor in determining nutrient concentrations in the Laguna. NCRWQCB staff relied on flow information gathered in May 1991 to December 1993 in making load allocations; two of the three years were dry years and are probably representative of the longer-term flow record (Strauss, 1995).

Table 1 summarizes the existing and targeted reduction loads for one attainment point during the summer season. Implementation of the TMDL should result in attainment of narrative and numeric surface water quality standards in the Laguna during most times of the year (Morris, 1995, cited in Smith, 1995). Although the planned load reduction activities will not be fully effective in meeting the summertime nitrogen reduction target goals, this is partly due to the overly high summer septic system load estimates. Actual loading from the septic systems is suspected to be much lower than originally estimated (Morris, 1995). Further studies to more accurately characterize the septic loading parameters are under way.

Table 1. Summer allocations for total nitrogen (pounds/season) for Trenton-Heraldsburg Road attainment point. Annual loads are composed of seasonal (winter, spring, summer, fall) loads distributed among four separate attainment points.

Pollutant Source	Estimated Existing Load	Allocation
Urban	647	0
Wastewater	0	0
Nonirrigated	987	987
Dairy Agriculture	584	0
Dairy Pond	13,727	0
Septic	33,170	33,170
Open Space	390	390
Total	49,505	34,547

Monitoring Plan

EPA's 1991 document Guidance for Water Quality-Based Decisions: The TMDL Process (EPA 440/4-91-001) calls for a monitoring plan when a TMDL is developed under the phased approach. The guidance provides that a TMDL developed under the phased approach also needs to provide assurances that nonpoint source control measures will achieve expected load reductions. The phased approach is appropriate when a TMDL involves both point and nonpoint sources and the point source WLA is based on an LA for which nonpoint source controls need to be implemented. Therefore, EPA's guidance provides that a TMDL developed under the phased approach should include a monitoring plan that describes the additional data to be collected to determine if the load reductions required by the TMDL lead to attainment of water quality standards.

NCRWQCB has developed a plan to monitor water quality at each of the four attainment points throughout each season. NCRWQCB collects water quality samples biweekly and during storm events. In addition, continuous remote monitoring is conducted for dissolved oxygen, pH, conductance, and temperature at monthly intervals. The monitoring evaluates Laguna water quality and informs the future direction of the TMDL plan.

Statistical methods are used to evaluate water quality compliance with the USEPA criterion for un-ionized ammonia and the Basin Plan minimum objective for dissolved oxygen. The minimum dissolved oxygen objective is considered obtained if median and 90th percentile values of dissolved oxygen concentrations are maintained above 7.0 mg/L, as determined with cumulative frequency distributions. A staged method was used to evaluate un-ionized ammonia goals, specifying the percentage of measurements that must meet the EPA criterion per the following schedule:

1. Sixty percent of the measurements must be below the EPA criterion by July 1996.
2. Seventy percent must be below the EPA criterion by July 1998.
3. Eighty percent must be below the EPA criterion by July 2000.

The water quality data are evaluated using cumulative distribution plots and t-tests of the mean of seasonal measurements compared to the USEPA criterion for un-ionized ammonia. Thus far the monitoring has indicated that the TMDL's interim goals have been attained (Otis, 1999).

Implementation Plans

On August 8, 1997, EPA's Bob Perciasepe issued a memorandum, "New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs)," which directs EPA regions to work in partnership with states to achieve nonpoint source load allocations established for 303(d)-listed waters impaired solely or primarily by nonpoint sources. To this end, the memorandum asks that regions assist states in developing implementation plans that include reasonable assurances that the nonpoint source load allocations established in TMDLs for waters impaired solely or primarily by nonpoint sources will in fact be achieved; a public participation process; and recognition of other relevant watershed management processes. Although implementation plans are not approved by EPA, they help establish the basis for EPA's approval of TMDLs.

The *Waste Reduction Strategy for the Laguna de Santa Rosa* includes a description of the actions that will take place to implement the TMDL. These include

- Grant program aimed at reducing waste inputs from confined animal operations.
- Stormwater runoff program.
- NPDES permit program.
- Voluntary actions organized by the Laguna Watershed Coordinated Resource Management and Planning Task Force.

Reasonable Assurances

EPA guidance calls for reasonable assurances when TMDLs are developed for waters impaired by both point and nonpoint sources or for waters impaired solely by nonpoint sources. In a water impaired by both point and nonpoint sources, where a point source is given a less stringent wasteload allocation based on an assumption that nonpoint source load reductions will occur, reasonable assurance must be provided for the TMDL to be approvable. This information is necessary for EPA to review the load and wasteload allocations required by the regulation.

In a water impaired by solely by nonpoint sources, reasonable assurances are not required for a TMDL to be approvable. For such nonpoint source-only waters, states are encouraged to provide reasonable assurances regarding achievement of load allocations in the implementation plans described in section 7, above. As described in the August 8, 1997, Perciasepe memorandum, such reasonable assurances should be included in state implementation plans and "may be non-regulatory, regulatory, or incentive-based, consistent with applicable laws and programs."

References

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TMDL Summary: Chatfield Basin, Colorado

Waterbody Type:	Reservoir
Pollutant:	Phosphorus
Designated Uses:	Recreation, Aquatic Life, Water Supply, Agriculture
Size of Waterbody:	1,450 acres
Size of Watershed:	3,000 square miles
Water Quality Standards:	Narrative
Indicators:	17 μg/L chlorophyll *a*
	27 μg/L total phosphorus from July to September
Analytical Approach:	Jones-Bachman Model; Canfield-Bachman Model

Introduction

Chatfield Reservoir is a U.S. Army Corps of Engineers facility located on the South Platte River just southwest of Denver, Colorado. The reservoir was completed in 1976 for purposes of flood protection for the metropolitan Denver area following the disastrous South Platte flood of 1965. Since that time, Chatfield Reservoir, which is now the primary attraction of a state park, has become increasingly popular as a recreational facility and concern over possible decreases in water quality due to upstream nutrient loadings has arisen.

The upstream watershed, called here the "Chatfield Basin" and shown in Figure 1, encompasses a total area of approximately 3,000 square miles and covers portions of six counties. It includes the headwaters of the South Platte River and extends westward to the continental divide and south nearly to Colorado Springs. The South Platte River portion of the basin is largely undeveloped and includes portions of the Pike National Forest and the Mount Evans Wilderness area. Some small urban areas and agricultural uses are also present. The eastern portion of the Chatfield Basin comprises the Plum Creek watershed, approximately 300 square miles in area.

TMDL Submittal Elements

Loading Capacity:	59,000 lbs/yr total phosphorus
Load Allocation:	20,000 lbs/yr reduction from NPS
Wasteload Allocation:	128,000 lbs/yr reduction from PS
Seasonal Variation:	Loads are specified on an annual basis
Margin of Safety:	Implicit through conservative assumptions

Problem Identification

The TMDL submittal must include a description of the point, nonpoint, and natural background sources of the pollutant of concern, including the magnitude and location of the sources. The TMDL submittal should also contain a description of any important assumptions, such as (1) the assumed distribution of land use in the watershed; (2) population characteristics, wildlife resources, other relevant characteristics affecting pollutant characterization and allocation, as applicable; (3) present and future growth trends, if this factor was taken into consideration in preparing the TMDL; (4) explanation and analytical basis for expressing the TMDL through *surrogate measures*, if applicable.

A Clean Lakes Study for Chatfield Reservoir performed in 1984 (DRCOG, 1984) stated: "The existing water quality of the reservoir is adequate for its designated purposes [recreation, aquatic life, water supply, and agriculture] and only minor concerns have occurred regarding water quality" and "The purpose of the Chatfield Reservoir Clean Lakes Study . . . is different from the purpose of most clean lake studies in that it attempted to prevent an adverse situation from occurring instead of studying how to resolve an existing one." This proactive, as opposed to reactive, management attitude is still applicable today. Since 1984, the growing-season average chlorophyll *a* goal (discussed below) for the reservoir has never been exceeded. Nonetheless, the continued presence of significant levels of phosphorus in the reservoir and the concomitant possibility of nuisance algal blooms have resulted in a growing awareness of the need for proactive management. Indeed, Douglas County, which composes

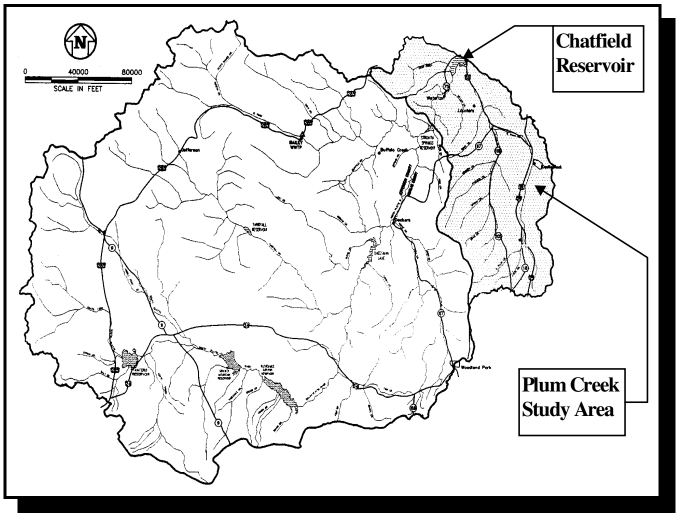

Figure 1. Chatfield Basin and Plum Creek Study Area

a portion of the watershed, is one of the most rapidly developing areas in the nation. Given the rapid urbanization in the watershed and the desire to preserve the historically good quality of water in the reservoir, the Chatfield Basin Authority ("the Authority," an intergovernmental water quality management agency) has embarked on a long-term TMDL program. Elements of that program include the following:

- *Water quality standard.* Establish a growing season average (July–September) in-reservoir total phosphorus standard protective of good historical water quality.

- *TMDL.* Phosphorus has been assumed to be the nutrient of primary concern, and the estimated 1995 total annual raw load (i.e., no existing upstream removal) to the reservoir from the entire basin under 1-in-10-year high-runoff conditions is approximately 207,000 pounds. Determine the Total Maximum Annual Load (TMAL) that will just meet this standard; that is, determine how much of the 207,000-pound load must be removed.

- *WLA/LA.* Determine an appropriate distribution of the TMAL between and among point sources and nonpoint sources.

This management program has been under way for nearly a decade, and the Authority's approaches to these objectives are discussed in this paper.

Description of the Applicable Water Quality Standards and Numeric Water Quality Target

The TMDL submittal must include a description of the applicable state water quality standard, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the antidegradation policy. This information is necessary for EPA to review the load and wasteload allocation required by the regulation. A numeric water quality target for the TMDL (a quantitative value used to measure whether the applicable water quality standard is attained) must be identified. If the TMDL is based on a target other than a numeric water quality criterion, the submittal must include a description of the process used to derive the target.

The water quality variable of concern in Chatfield Reservoir is chlorophyll *a*. The Authority, through the Denver Regional Council of Governments (DRCOG), has determined that maintaining growing-season average chlorophyll *a* concentrations of 17 μg/L is an appropriate management target (DRCOG, 1984). Because chlorophyll *a* itself is not input to a waterbody from point and nonpoint sources, the regulatory and management focus is on total phosphorus, which has been assumed to be the algal-limiting nutrient (or can be forced to be such through sufficient control). Thus, to set an in-reservoir, numerical, regulatory standard on total phosphorus such that the chlorophyll *a* goal is achieved, a quantitative relationship between total phosphorus and chlorophyll *a* was investigated.

The model DRCOG selected was the Jones-Bachman model (Jones and Bachman, 1976) which, when calibrated to Chatfield Reservoir, relates the two variables as

$$CHL = 0.1413*TP^{1.46} \quad (1)$$

where CHL is the chlorophyll *a* concentration (μg/L) and total phosphorus is the total phosphorus concentration (μg/L). The parameters of equation (1) were estimated from a single, paired chlorophyll *a*/total phosphorus sample, the only data available at the time of the study (1982). By specifying 17 μg/L for chlorophyll *a* in equation (1), the regulatory total phosphorus standard was determined by solving the equation for total phosphorus, resulting in a growing season average, in-reservoir concentration of 27 μg/L. (It should be noted that more recent data have shown that model (1) significantly overpredicts observed chlorophyll *a* concentrations, given observed total phosphorus concentrations. Thus, the current 27 μg/L standard is regarded as conservative. Future in-reservoir modeling activities are planned to develop a better relationship between the two variables and a more appropriate standard.)

Source Assessment

The current target value for nutrient management activities in the basin is the 27 μg/L total phosphorus standard in the reservoir. Sources of total phosphorus loads to the reservoir include point sources, nonpoint sources, and baseload (dry weather) inflows from both the South Platte and Plum Creek subbasins. Although the Plum Creek subbasin is the much smaller of the two, it contributes the great majority of the total phosphorus load due to its relatively higher state of development. In addition, there are several reservoirs upstream of Chatfield Reservoir in the South Platte subbasin and these reservoirs effectively serve as nutrient removal mechanisms so that little additional phosphorus removal is practicable in the South Platte subbasin. For these reasons, those point and nonpoint sources of total phosphorus amenable to further management control as part of the TMDL process are essentially limited to the Plum Creek subbasin.

Loading Capacity — Linking Water Quality and Pollutant Sources

As described in EPA guidance, a TMDL describes the loading capacity of a waterbody for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a waterbody can receive without violating water quality standards (40 CFR 130.2(f)). The TMDL submittal must describe the rationale for the analytical method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many circumstances, a *critical condition* must be described and related to physical conditions in the waterbody (40 CFR 130.7(c)(1)). Supporting documentation for the analysis must also be included, including the basis for assumptions, strengths and weaknesses in the analytical process, and results from water quality modeling, so that EPA can properly review the elements of the TMDL required by the statute and regulations.

The Jones-Bachman model (equation (1)) relates in-reservoir total phosphorus concentrations to chlorophyll *a* concentrations on a growing season average basis. For phosphorus management purposes, it is also necessary to relate total phosphorus concentrations to annual total phosphorus *loadings* to the reservoir. The model selected for this purpose (DRCOG, 1982) was the Canfield-Bachman model (Canfield and Bachman, 1981) which, when parameterized to the 1982 data pair and using a 1-in-10-year reservoir inflow, is expressed as

$$TP = L/(0.82 * L^{.589} + 59.4) \quad (2)$$

where TP is the in-reservoir total phosphorus concentration (μg/L) and L is the annual areal phosphorus loading (mg/m^2/yr). The first term in the denominator of (2) is a settling term. The second term reflects the flushing effect of annual inflow. Solving equation (2) for the total phosphorus standard (27 μg/L) results in an allowable annual areal load of 4,900 mg/m^2/yr, or an annual load of 59,000 pounds. Thus, 59,000 pounds is the estimated TMAL not to be exceeded in 90 percent of years.

Allocations

EPA regulations require that a TMDL include wasteload allocations (WLAs), which identify the portion of the loading capacity allocated to existing and future point sources (40 CFR 130.2(g)). If no point sources are present or the TMDL recommends a zero WLA for point sources, the WLA must be listed as zero. The TMDL may recommend a zero WLA if the state determines, after considering all pollutant sources, that allocating only to nonpoint sources will still result in attainment of the applicable water quality standard. In preparing the WLA, it is not necessary that every individual point source have a portion of the allocation of pollutant loading capacity. It is necessary, however, to allocate the loading capacity among individual point sources as necessary to meet the water quality standard. The TMDL submittal should also discuss whether a WLA is based on an assumption that loads from a nonpoint source or sources will be reduced. In such cases, the state needs to demonstrate reasonable assurance that the nonpoint source reductions will occur within a reasonable time.

EPA regulations also require that a TMDL include load allocations (LAs), which identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background (40 CFR 130.2(h)). Load allocations may range from reasonably accurate estimates to gross allotments (40 CFR 130.2(g)). Where it is possible to separate natural background from nonpoint sources, separate LAs should be made and described. If there are neither nonpoint sources nor natural background or the TMDL recommends a zero LA, an explanation must be provided. The TMDL may recommend a zero LA if the state determines, after considering all pollutant sources, that allocating only to point sources will still result in attainment of the applicable water quality standard.

The statute and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between effluent limitations and water quality (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)). EPA guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS must be described. If the MOS is explicit, the loading set aside for the MOS must be identified.

The statute and regulations require that a TMDL be established with seasonal variations. The state must describe the method chosen for including seasonal variations in the TMDL (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)).

Current annual loads (raw) in the Chatfield Basin have been estimated at approximately 207,000 pounds and the TMAL is estimated at 59,000 pounds, both under 1-in-10 annual inflow conditions. The annual load that must be reduced from point and nonpoint sources is then the difference, or approximately 148,000 pounds. Thus, the point source/nonpoint source load allocation issue for the Plum Creek subbasin is: How should the 59,000 pound TMAL be allocated among point sources (there are six) and between point and nonpoint sources so that total treatment costs are minimized? This section addresses that issue using an optimization approach. Because of the present uncertainty surrounding the TMAL, the optimal (minimum cost) removals for point sources and nonpoint sources are expressed as *functions* rather than as single values. (In the future, under possibly different TMAL conditions, these functions can be used for point source/nonpoint source load allocations.)

Treatment Costs

Twenty-year present worth treatment cost functions were developed for both point sources and nonpoint sources. Point source costs included only the additional costs (capital and operating) to remove phosphorus by chemical means and were based on data from USEPA (1987) and Murphy and Associates (1983). Nonpoint source treatment costs assumed that stormwater detention basins were the preferred best management practice (BMP) type and were based on data provided by Schueler (1987).

Optimal Point Source WLA

An optimization analysis was first performed to develop the minimum cost wasteload allocation function for point sources *only*. This optimization determined, for any given total annual load removed by point sources, the least cost means of attaining this removal among the six point source dischargers. The marginal cost principle was the basis of the optimization such that a given annual load removed was allocated among the dischargers in accordance with their marginal treatment costs. The result of this analysis was a function yielding minimum present worth point source treatment cost as a function of total annual phosphorus load removed among the dischargers (Figure 2).

Optimal Nonpoint Source LA

Similarly, a function relating minimum treatment costs for nonpoint sources *only* as a function of total annual nonpoint source load removed was developed. Given that some 40 discrete (noncontiguous) urbanized areas exist within the Plum Creek Study Area, this optimization problem was essentially whether to build 40 individual detention basins, one regional detention

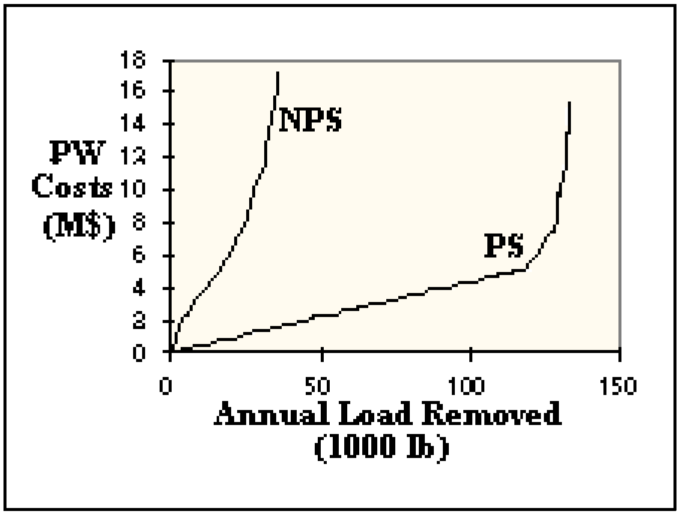

Figure 2. PS and NPS Minimum Cost Functions

basin, or some number in between. This optimization problem was originally formulated as a mixed-integer linear program, but proved prohibitively time-consuming to solve. Instead, a more conventional approach was taken wherein a limited number of alternatives were individually costed and the minimum selected. A single, regional detention basin was determined to be the optimal configuration.

Under the assumption that nonpoint source controls should be protective of the reservoir during 90 percent of years, a time series of runoff events representing the 1-in-10-year hydrology was developed. Phosphorus loads were also developed for these events, and the design time series was then routed through the regional detention basin for each of a variety of alternative basin volumes. For each alternative basin volume, the routed time series of runoff and phosphorus loads resulted in a total annual load removed by the detention basin. The result of the analysis thus yielded minimum nonpoint source treatment costs as a function of total annual load removed among nonpoint sources only (Figure 2).

Perhaps surprisingly, the optimal nonpoint source (NPS) cost function in Figure 2 reveals much higher costs for NPS phosphorus control than point source (PS) controls. This cost difference is attributable to at least the following factors: (1) the use of *structural* BMPs, (2) the choice of capturing runoff from the 1-in-10 runoff year instead of a more typical year, and (3) the relative ineffectiveness of detention basin phosphorus removal (assumed at 45 percent). It is not known to what extent these relative cost differences might also apply in other watersheds.

Optimal PS/NPS LA

The optimal point source and nonpoint source load allocation functions are shown together in Figure 2. Each represents the minimum cost of removing load from that source only. The question is then: What is the function representing optimal allocation *between* point sources and nonpoint sources?

The optimal point source/nonpoint source load allocation function was developed by solving a series of nonlinear programming models. The decision variables were: X_1 = annual load removed by point sources and X_2 = annual load removed by nonpoint sources (during 90th percentile year). The objective function was MIN [Cost(X_1) + Cost(X_2)] where Cost(X_1) is the minimum present worth cost function for point sources, discussed previously, and Cost(X_2) is the minimum present worth cost function for nonpoint sources, also discussed previously. Constraints on the optimization model were that X_1 plus X_2 equal the total annual load removed and, further, that X_1 and X_2 must be less than or equal to technological upper limits.

The nonlinear programming model was solved for a variety of total annual loads removed. The resulting minimum cost point source/nonpoint source load allocation function is shown in Figure 3 and the resulting allocation between point sources and nonpoint sources in Figure 4. Interestingly, but perhaps not surprisingly given the high nonpoint source costs, point sources are used exclusively to remove phosphorus up to an annual removal of approximately 128,000 pounds. Beyond this, it becomes economical to begin removing some of the additional load by using detention basins. Thus, of the currently estimated 148,000 pound annual load to be removed, the first 128,000 pounds would most economically be achieved by the point sources with the remaining 20,000 pounds to be removed by a regional detention basin. The 128,000 pound point source WLA corresponds to a uniform effluent concentration among all six dischargers of approximately 0.5 mg/L. (Given the study assumptions and uncertainties, this concentration is not considered to be significantly different from the 1.0 mg/L effluent

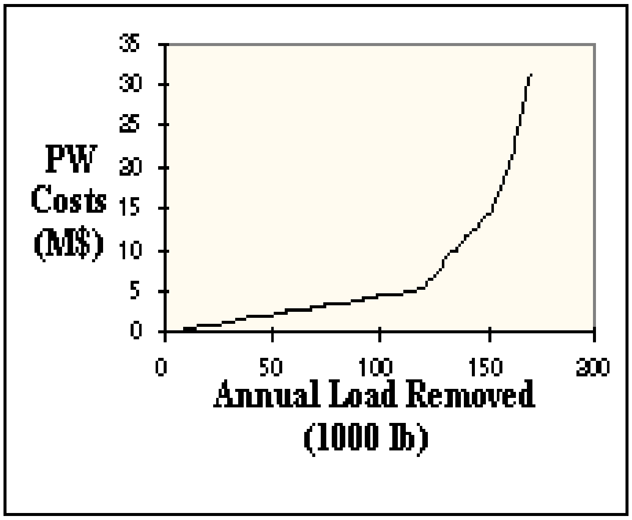

Figure 3. Minimum Cost Function

concentration that had already been established by the Colorado Water Quality Control Commission.)

Monitoring Plan for TMDLs Developed Under the Phased Approach

EPA's 1991 document *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 440/4-91-001), calls for a monitoring plan when a TMDL is developed under the phased approach. The guidance provides that a TMDL developed under the phased approach also needs to provide assurances that nonpoint source control measures will achieve expected load reductions. The phased approach is appropriate when a TMDL involves both point and nonpoint sources and the point source WLA is based on an LA for which nonpoint source controls need to be implemented. Therefore, EPA's guidance provides that a TMDL developed under the phased approach should include a monitoring plan that describes the additional data to be collected to determine if the load reductions required by the TMDL lead to attainment of water quality standards.

Monitoring efforts are continuing both in-reservoir and in the watershed. Specific monitoring objectives include trend analysis (total phosphorus and chlorophyll *a*), BMP effectiveness, standard compliance, and data collection to support future modeling.

Implementation Plans

On August 8, 1997, EPA's Bob Perciasepe issued a memorandum, "New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs)," which directs EPA regions to work in partnership with states to achieve nonpoint source load allocations established for 303(d)-listed waters impaired solely or primarily by nonpoint sources. To this end, the memorandum asks that regions assist states in developing implementation plans that include reasonable assurances that the nonpoint source load allocations established in TMDLs for waters impaired solely or primarily by nonpoint sources will in fact be achieved; a public participation process; and recognition of other relevant watershed management processes. Although implementation plans are not approved by EPA, they help establish the basis for EPA's approval of TMDLs.

Water quality in Chatfield Reservoir has been relatively good historically, and the management program for Chatfield Reservoir and the Plum Creek Basin is fortunate to find itself in a proactive position. Future TMDL-related activities intend to maintain this good quality, despite increasing urban pressures in the watershed. These future activities include the following:

- *Refinement of the TMAL estimate and margin of safety*. The 59,000-pound TMAL currently recognized is believed to be too conservative and, if true, functions as an implicit margin of safety. Future in-reservoir nutrient/chlorophyll *a* modeling

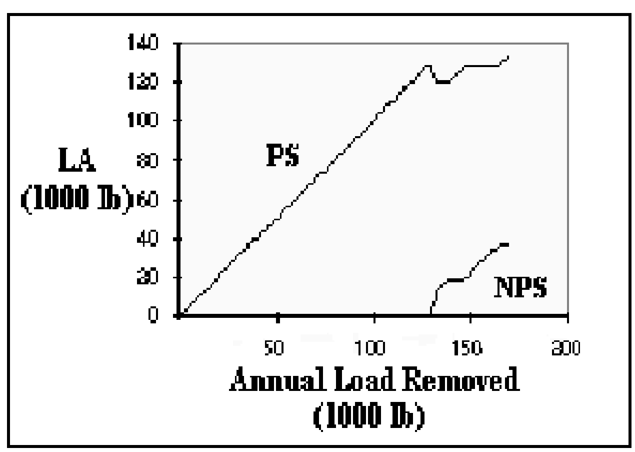

Figure 4. Optimum Load Allocation Schedule.

is planned to refine the TMAL estimate and the corresponding total phosphorus standard. It is anticipated that this modeling effort will include an uncertainty analysis that will result in an explicit margin of safety. The improved TMAL estimate will also permit a more precise determination of the cost-effective point source/nonpoint source load allocation, based on the schedule shown in Figure 4.

- *BMP implementation*. Despite the current uncertainty in the TMAL and concomitant uncertainty in the cost-effective point source/nonpoint source load allocation, the Authority is moving forward with implementation of BMPs in the watershed. Two structural BMPs, a Lemna system (in which duckweed is used to remove nutrients) and a constructed wetland, have been brought on-line in recent years. In addition, existing erosion and sediment control ordinances are being given more enforcement attention.

Reasonable Assurances

EPA guidance calls for reasonable assurances when TMDLs are developed for waters impaired by both point and nonpoint sources or for waters impaired solely by nonpoint sources. In a water impaired by both point and nonpoint sources, where a point source is given a less stringent wasteload allocation based on an assumption that nonpoint source load reductions will occur, reasonable assurance must be provided for the TMDL to be approvable. This information is necessary for EPA to review the load and wasteload allocations required by the regulation.

In a water impaired solely by nonpoint sources, reasonable assurances are not required for a TMDL to be approvable. For such nonpoint source-only waters, states are encouraged to provide reasonable assurances regarding achievement of load allocations in the implementation plans described above. As described in the August 8, 1997, Perciasepe memorandum, such reasonable assurances should be included in state implementation plans and "may be non-regulatory, regulatory, or incentive-based, consistent with applicable laws and programs."

Comment on Optimal PS/NPS Load Allocation Methodology

The USEPA funded the development of the optimal load allocation methodology highlighted in this case study. This funding was provided in an effort not only to assist water quality management in the Chatfield Basin, but also to assess the potential for use of optimization technology in TMDL activities for other watersheds. The Chatfield Basin application demonstrates that there is indeed an economical balance between point source and nonpoint source responsibilities in meeting a TMDL, and significant savings are possible when this balance is known. (The current 1.0 mg/L point source effluent limit in the Chatfield Basin resulted from an appeal, based on cost-effectiveness arguments, by the Authority to the Colorado Water Quality Control Commission to relax a previously required, very stringent effluent limit of 0.2 mg/L. If the 0.2 mg/L limit had remained a requirement of the load allocation, the resulting point source load removal would be 134,000 pounds, leaving 14,000 pounds to be removed from the nonpoint sources to achieve the TMAL. This load allocation would cost approximately 37 percent more than the optimal load allocation based on 0.5 mg/L effluent limits.)

In addition to the potential load allocation cost savings offered by an optimization approach, a broader conclusion might have emerged from this pilot study. There seems to be a prevailing belief in the watershed management community that removal of nonpoint source pollutants constitutes essentially a panacea for water quality problems because nonpoint source removal is regarded as generally less expensive than point source controls. However, the results of this study suggest that *structural* nonpoint source control is not nearly as cost-effective as might have been previously believed: a relatively high level of point source phosphorus removal is economically efficient before structural nonpoint source controls are appropriate. Thus, perhaps the real value of this study lies not so much in guiding phosphorus allocation between point sources and nonpoint sources controlled by *structural* BMPs, but rather in quantifying the economic costs of *failing to prevent* nonpoint source pollution in the first place. If source controls, such as erosion control or agricultural BMPs, are not in place and effective at preventing nonpoint source pollution, structural controls such as the detention basins used in this study become necessary. As demonstrated here, this after-the-fact treatment is very expensive.

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KEY TO ACRONYMS

AGNPS	Agricultural Nonpoint Source Pollution Model
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BLM	Bureau of Land Management
BMP	best management practice
BOD	Biochemical Oxygen Demand
CFR	Code of Federal Regulations
CREAMS	Chemical, Runoff, and Erosion from Agricultural Management Systems
CWA	Clean Water Act
DR3M	Multi-Event Urban Runoff Quality Model
DO	Dissolved Oxygen
EMAP	Environmental Monitoring and Assessment Program
FEMAT	Federal Ecosystem Management Team
FHWA	Federal Highway Administration
GIS	Geographic Information System
GWLF	Generalized Watershed Loading Functions
HSPF	Hydrologic Simulation Program-Fortran
LA	load allocation (for nonpoint sources in TMDLs)
MOS	margin of safety, a required TMDL element
NALMS	North American Lake Management Society
NAWQA	National Water Quality Assessment project led by USGS
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NRCS	Natural Resource Conservation Service
NTU	nephelometric turbidity units
PL-566	Public Law 566, which established the USDA Small Watersheds program
QA/QC	Quality Assurance/Quality Control
RBP	rapid bioassessment protocol
RUSLE	revised universal soil loss equation
SCS	Soil Conservation Service
SRP	Soluble Reactive Phosphorus
SD	Secchi Disc
SWAT	Soil Water Assessment Tool
SWMM	Storm Water Management Model
SWRRBWQ	Simulator for Water Resources in Rural Basins- Water Quality
TMDL	total maximum daily load
TP	Total Phosphorus
TSI	Trophic Status Index
TSS	total suspended solids
USDA	United States Department of Agriculture
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
USLE	universal soil loss equation
WLA	waste load allocation (for point sources in TMDLs)
WQS	water quality standards
WWTP	wastewater treatment plant

GLOSSARY

Acute toxicity. A chemical stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed within 96 hours or less is considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.

Adsorption-desorption. Adsorption is the process by which nutrients such as inorganic phosphorus adhere to particles via a loose chemical bond with the surface of clay particles. Desorption is the process by which inorganic nutrients are released from the surface of particles back into solution. Adsorption differs from absorption in that absorption is the assimilation or incorporation of a gas, liquid, or dissolved substance into another substance.

Advanced secondary treatment. Biological or chemical treatment processes added to a secondary treatment plant, including conventional activated sludge to increase the removal of solids and biochemical oxygen demand (BOD). Typical removal rates for advanced secondary plants are on the order of 90 percent removal of solids and BOD.

Advanced waste treatment (AWT). Wastewater treatment process that includes combinations of physical and chemical operation units designed to remove nutrients, toxic substances, or other pollutants. Advanced, or tertiary, treatment processes treat effluent from secondary treatment facilities using processes such as nutrient removal (nitrification, denitrification), filtration, or carbon adsorption. Tertiary treatment plants typically achieve about 95 percent removal of solids and BOD in addition to removal of nutrients or other materials.

Advection. Bulk transport of the mass of discrete chemical or biological constituents by fluid flow within a receiving water. Advection describes the mass transport due to the velocity, or flow, of the waterbody.

Aerobic. Environmental conditions characterized by the presence of dissolved oxygen; used to describe biological or chemical processes that occur in the presence of oxygen.

Algae. Any organisms of a group of chiefly aquatic microscopic nonvascular plants; most algae have chlorophyll as the primary pigment for carbon fixation. As primary producers, algae serve as the base of the aquatic food web, providing food for zooplankton and fish resources. An overabundance of algae in natural waters is known as eutrophication.

Algal bloom. Rapidly occurring growth and accumulation of algae within a body of water. It usually results from excessive nutrient loading and/or a sluggish circulation regime with a long residence time. Persistent and frequent blooms can result in low-oxygen conditions.

Algal growth. Algal growth is related to temperature, available light, and the available abundance of inorganic nutrients (N, P, Si). Algal species groups (e.g., diatoms, greens, etc.) are typically characterized by different maximum growth rates.

Algal respiration. Process of endogenous respiration of algae in which organic carbon biomass is oxidized to carbon dioxide.

Algal settling. Process in which phytoplankton cells (algae) are lost from the water column by physical sedimentation of the cell particles. Algal biomass lost from the water column is then incorporated as sediment organic matter and undergoes bacterial and biochemical reactions, releasing nutrients and consuming dissolved oxygen.

Allocations. That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Ammonia. Inorganic form of nitrogen; product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic nitrogen.

Ammonia toxicity. Under specific conditions of temperature and pH, the un-ionized component of ammonia can be toxic to aquatic life. The un-ionized component of ammonia increases with pH and temperature.

Anaerobic. Environmental condition characterized by zero oxygen levels. Describes biological and chemical processes that occur in the absence of oxygen.

Anoxic. Aquatic environmental conditions containing zero or little dissolved oxygen. See also **Anaerobic**.

Anthropogenic. Pertains to the [environmental] influence of human activities.

Antidegradation Policies. Policies that are part of each state's water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.

Aquatic classification system. Assigns a classification to a waterbody reflecting the water quality and the biological health (integrity). The classification is determined through use of biological indices (see **IBI**). Examples of classifications include oligosaprobic (cleanest water quality) and polysaprobic (highly polluted water).

Aquatic ecosystem. Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.

Assimilative capacity. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.

Attached algae. Photosynthetic organisms that remain in a stationary location by attachment to hard rocky substrate. Attached algae, usually present in shallow hard-bottom aquatic environments, can significantly influence nutrient uptake and diurnal oxygen variability.

Autotroph. An organism that derives cell carbon from carbon dioxide. The conversion of carbon dioxide to organic cell tissue is a reductive process that requires a net input of energy. The energy needed for cell synthesis is provided by either light or chemical oxidation.

Background levels. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

Bacteria. Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.

Bacterial decomposition. Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources). A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.

Benthic ammonia flux. The process by which decay of organic matter within the sediments of a natural water results in the release of ammonia nitrogen from the interstitial water of sediments to the overlying water column. Benthic release, or regeneration, of ammonia is an essential component of the nitrogen cycle.

Benthic organisms. Organisms living in, or on, bottom substrates in aquatic ecosystems.

Benthic photosynthesis. Synthesis of cellular carbon by algae attached to the bottom of a natural water system. Benthic photosynthesis typically is limited to shallow waters in which light is available at the bottom.

Best practicable control technologies (BPT). Effluent limitations that are based on the average performance of the best existing plants in an industry.

Best management practices (BMPs). Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bioaccumulation. The process by which a compound is taken up by an aquatic organism, both from water and through food.

Bioassessment. Biological assessment; the evaluation of an ecosystem using integrated assessments of habitat and biological communities in comparison to empirically defined reference conditions.

Bioavailability. A measure of the physicochemical access that a toxicant has to the biological processes of an organism. The less the bioavailability of a toxicant, the less its toxic effect on an organism.

Biochemical oxygen demand (BOD). The amount of oxygen per unit volume of water required to bacterially or chemically oxidize (stabilize) the oxidizable matter in water. Biochemical oxygen demand measurements are usually conducted over specific time intervals (5, 10, 20, 30 days). The term BOD generally refers to a standard 5-day BOD test. BOD = CBOD + NBOD.

Biological criteria. Also known as biocriteria, biological criteria are narrative expressions or numeric values of the biological characteristics of aquatic communities based on appropriate reference conditions. Biological criteria serve as an index of aquatic community health.

Biomass. The amount, or weight, of a species, or group of biological organisms, within a specific volume or area of an ecosystem.

Boundary conditions. Values or functions representing the state of a system at its boundary limits.

Calcareous. Pertaining to or containing calcium carbonate.

Calibration. The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Carbonaceous Biological Oxygen Demand (CBOD). Refers to the oxygen demand associated with the oxidation of organic carbon.

Carlson trophic status index (TSI). Index based on the correlations between the clarity or transparency expressed by the Secchi disc depth, algal concentrations expressed by chlorophyll *a*, and the spring, or average annual, total phosphorus concentrations. Identifies waterbodies as oligotrophic, mesotrophic, eutrophic, or hypertrophic.

Cation exchange capacity. The sum total of exchangeable cations that a soil can adsorb. Expressed in centimoles per kilogram of soil (or of other adsorbing material such as clay.)

Channel. A natural stream that conveys water; a ditch or channel excavated for the flow of water.

Chloride. An atom of chlorine in solution; an ion bearing a single negative charge.

Chlorophyll. A group of green photosynthetic pigments that occur primarily in the chloroplast of plant cells. The amount of chlorophyll *a*, a specific pigment, is frequently used as a measure of algal biomass in natural waters.

Chronic toxicity. Toxicity impact that lingers or continues for a relatively long period of time, often one-tenth of an organism's life span or longer. Chronic effects could include mortality, reduced growth, or reduced reproduction.

Cladophora. Filamentous green algae often associated with conditions of nutrient enrichment in both lakes and streams. *Cladophora* can be a particular problem where dense mats might physically interfere with water supply and recreational uses.

Clean Lakes Projects. The principal federal program dealing with the restoration of degraded lakes.

Clean Water Act (CWA). The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.

Coastal Zone. Lands and waters adjacent to the coast that exert an influence on the uses of the sea and its ecology, or whose uses and ecology are affected by the sea.

Combined sewer overflows (CSOs). Discharge of a mixture of storm-water and domestic waste when the flow capacity of a sewer system is exceeded during rainstorms. CSOs discharged to receiving water can result in contamination problems that may prevent the attainment of water quality standards.

Combined sewer system (CSS). Sewer system that receives both domestic wastewater and storm water and conducts the mixture to a treatment facility.

Completely mixed condition. A condition in which no measurable difference in the concentration of a pollutant exists across a transect of the waterbody (e.g., the concentration does not vary by 5 percent).

Concentration. Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).

Concentration-based limit. A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).

Conservative substance. A substance that does not undergo any chemical or biological transformation or degradation in a given ecosystem.

Contamination. The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.

Continuous discharge. A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.

Conventional pollutants. As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.

Cost-share program. A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs are paid by the producer (s).

Cross-sectional area. Wet area of a waterbody normal to the longitudinal component of the flow.

Critical condition. The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.

Decay. The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.

Decomposition. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also **Respiration**.

Denitrification. The process of decomposition of nitrites and nitrates (by bacteria) that results in the eventual release of nitrogen gas into the atmosphere.

Design stream flow. The stream flow used to conduct steady-state wasteload allocation modeling.

Designated uses. Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.

Deterministic model. A model that does not include built-in variability: same input will always result in the same output.

Detritus. Any loose material produced directly from disintegration processes. Organic detritus consists of material resulting from the decomposition of dead organic remains.

Diagenesis. Production of sediment fluxes as a result of the flux of particulate organic carbon in the sediment and its decomposition. The diagenesis reaction can be thought of as producing oxygen equivalents released by various reduced species.

Diatoms. Single-celled or colonial algae with siliceous cell walls; important component of phytoplankton.

Diel. Involving a 24-hour period.

Dilution. The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.

Dimictic. Describes lakes and reservoirs that freeze over and normally go through two stratification and mixing cycles within a year.

Direct runoff. Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.

Discharge. Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.

Discharge Monitoring Report (DMR). Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.

Discharge permits (under NPDES). A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.

Dispersion. The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.

Dissolved oxygen (DO). The amount of oxygen dissolved in water. This term also refers to a measure of the amount of oxygen available for biochemical activity in a waterbody, an indicator of the quality of that water.

Dissolved oxygen sag. Longitudinal variation of dissolved oxygen representing the oxygen depletion and recovery following a waste load discharge into a receiving water.

Diurnal. Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours.

Domestic wastewater. Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.

Drainage basin. A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

Dynamic model. A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.

Dynamic simulation. Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.

Ecoregion. A physical region defined by its ecology, which includes meteorological factors, elevation, plant and animal species composition, landscape position, and soils.

Ecosystem. An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.

Effluent. Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.

Effluent guidelines. The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.

Effluent limitation. Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.

Effluent plume. Delineates the extent of contamination in a given medium as a result of a distribution of effluent discharges (or spills). Usually shows the concentration gradient within the delineated areas or plume of flow of contaminants.

Empirical model. Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.

Endpoint. An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

Enhancement. In the context of restoration ecology, any improvement of a structural or functional attribute.

Environmental Monitoring and Assessment Program (EMAP). A USEPA program to monitor and assess the ecological health of major ecosystems, including surface waters, forests, near-coastal waters, wetlands, agricultural lands, arid lands, and the Great Lakes, in an integrated, systematic manner. Although EMAP has been curtailed somewhat during recent years, the program is designed to operate at regional and national scales, for decades, and to evaluate the extent and condition of entire ecological resources by using a common sampling framework to sample approximately 12,500 locations in the conterminous United States.

Epiphyte. A plant that grows above the ground, supported nonparasitically by another plant or object, and deriving its nutrients and water from rain, the air, dust, etc.

Estuary. Brackish-water area influenced by the tides where the mouth of a river meets the sea.

Estuarine number. A nondimensional parameter accounting for decay, tidal dispersion, and advection velocity; used for classification of tidal rivers and estuarine systems.

Eutrophication. The natural aging process during which a lake, estuary, or bay evolves into a bog or marsh and eventually disappears. During the later stages of eutrophication the waterbody is choked by abundant plant life as the result of increased amounts of nutritive compounds such as nitrogen and phosphorus. Human activities can accelerate the process of nutrient enrichment in waterbodies, resulting in accelerated biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass.

Eutrophication model. A mathematical formulation that describes the advection, dispersion, and biological, chemical, and geochemical reactions that influence the growth and accumulation of algae in aquatic ecosystems. Models of eutrophication typically include one or more species groups of algae; inorganic and organic nutrients (N, P); organic carbon; and dissolved oxygen.

Existing use. Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).

Fate of pollutants. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.

Feedlot. A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.

First-order kinetics. The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.

Flocculation. The process by which suspended colloidal or very fine particles are assembled into larger masses or floccules that eventually settle out of suspension.

Fluvial geomorphology. The effect of rainfall and runoff on the form and pattern of riverbeds and river channels.

Flux. Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.

Forcing functions. External empirical formulation used to provide input describing a number of processes. Typical forcing functions include parameters such as temperature, point and tributary sources, solar radiation, and waste loads and flow.

Geochemical. Referring to chemical reactions involving earth materials such as soil, rocks, and water.

Geomorphology. The study of the evolution and configuration of landforms.

Gradient. The rate of change of the value of one quantity with respect to another; for example, the rate of decrease of temperature with depth in a lake.

Ground water. The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.

Half-saturation constant. Nutrient concentration at which the growth rate of the population of a species or group of species is half the maximum rate. Half-saturation constants define the nutrient uptake characteristics of different phytoplankton species. Low half-saturation constants indicate the ability of the algal group to thrive under nutrient-depleted conditions.

Heterotroph. An organism that uses organic carbon for the formation of cell tissue, e.g., is unable to synthesize organic compounds from inorganic substrates for food and must consume organisms or their products. Bacteria are examples of heterotrophs; photosythesizing organisms are not.

Hydrodynamic model. Mathematical formulation used in describing fluid flow of circulation, transport, and deposition processes in receiving water.

Hydrograph. A graph showing variation of stage (depth) or discharge in a stream over a period of time.

Hydrologic cycle. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.

Hydrology. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Hydrolysis. A chemical reaction that occurs between a substance and water, resulting in the cleaving of a molecular bond and the formation of new bonds with components of the water molecule; a reaction of water with a salt to create an acid or a base.

Hyetograph. Graph of rainfall rate versus time during a storm event.

Hypolimnetic oxygen depletion rate. Describes changing dissolved oxygen concentrations with respect to time in the hypolimnion (lowest stratum) of lakes and reservoirs. Dissolved oxygen concentrations in the hypolimnion are especially significant because of their effect on fish.

Hyporheic. The volume of saturated sediment beneath and beside streams and rivers where ground water and surface water mix.

Index of Biotic Integrity (IBI). An index that uses measurements of the distribution and abundance or absence of several fish species types in each waterbody for comparison. A portion of a waterbody is compared to a similar, unimpacted waterbody in the same ecoregion.

Indicator. A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.

Indicator organism. An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.

Indirect discharge. A nondomestic discharge introducing pollutants to a publicly owned treatment works.

Infiltration capacity. The capacity of a soil to allow water to infiltrate into or through it during a storm.

Initial mixing zone. The region immediately downstream of an outfall where effluent dilution processes occur. Because of the combined effects of the effluent buoyancy, ambient stratification, and current, the prediction of initial dilution can be complex.

In situ. In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.

Irrigation. Applying water or wastewater to land areas to supply the water and nutrient needs of plants.

Irrigation return flow. Surface and subsurface water that leaves a field after the application of irrigation water.

Kinetic processes. Description of the rates and modes of changes in the transformation or degradation of a substance in an ecosystem.

Land application. Discharge of wastewater onto the ground for treatment or reuse. See also **Irrigation**.

Leachate. Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.

Leachate collection system. A system that gathers leachate and pumps it to the surface for treatment.

Light saturation. The optimal light level for algae and macrophyte growth and photosynthesis.

Loading, Load, Loading rate. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.

Load allocation (LA). The portion of a receiving water's loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished. (40 CFR 130.2(g))

Loading capacity (LC). The greatest amount of loading a water can receive without violating water quality standards.

Low-flow (7Q10). The 7-day average low flow occurring once in 10 years; this probability-based statistic is used in determining stream design flow conditions and for evaluating the water quality impact of effluent discharge limits.

Macrophyton. The larger aquatic plants of all types. They are sometimes attached to the waterbody bottom (benthic), sometimes free-floating, sometimes totally submersed, and sometimes partially emergent. Complex types usually have true roots, stems, and leaves; the macroalgae are simpler but may have stem- and leaf-like structures.

Margin of safety (MOS). A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).

Mass balance. An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.

Mass loading. The quantity of a pollutant transported to a waterbody.

Mass wasting. Downslope transport of soil and rocks due to gravitational stress.

Mathematical model. A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.

Maximum depth. The greatest depth of a waterbody.

Mean depth. Volume of a waterbody divided by its surface area.

Meiofauna. Microorganisms that can be caught in sieves with holes of a certain size.

Mineralization. The transformation of organic matter into a mineral or an inorganic compound.

Mitigation. Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those which restore, enhance, create, or replace damaged ecosystems.

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

Monomictic. Describes lakes and reservoirs that are relatively deep, do not freeze over during the winter months, and undergo a single stratification and mixing cycle during the year. These lakes and reservoirs usually become destratified during the mixing cycle, most often in the fall of the year.

Monte Carlo simulation. A stochastic modeling technique that involves the random selection of sets of input data for use in repetitive model runs. Probability distributions of receiving water quality concentrations are generated as the output of a Monte Carlo simulation.

Narrative criteria. Nonquantitative guidelines that describe the desired water quality goals.

National Pollutant Discharge Elimination System (NPDES). The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.

N/P ratio. The ratio of nitrogen to phosphorus in an aquatic system. The ratio is used as an indicator of the nutrient limiting conditions for algal growth; also used as an indicator for the analysis of trophic levels of receiving waters.

Natural waters. Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

Nitrate (NO_3) and Nitrite (NO_2). Oxidized nitrogen species. Nitrate is the form of nitrogen preferred by aquatic plants.

Nitrification. The oxidation of ammonium salts to nitrites (via *Nitrosomonas* bacteria) and the further oxidation of nitrite to nitrate (via *Nitrobacter* bacteria).

Nitrifier organisms. Bacterial organisms that mediate the biochemical oxidative processes of nitrification.

Nitrogen. A nutrient assimilated by plants which promotes growth. The most bioavailable forms of nitrogen are nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3).

Nitrogenous biochemical oxygen demand (NBOD). The oxygen demand associated with the oxidation of ammonia.

Nonpoint source. Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Numeric targets. A measurable value determined for the pollutant of concern which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.

Numerical model. Model that approximates a solution of governing partial differential equations which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. A primary element necessary for the growth of living organisms. Carbon dioxide, nitrogen, and phosphorus, for example, are required nutrients for phytoplankton growth.

Nutrient limitation. A deficit of a nutrient (e.g., nitrogen and phosphorus) required by microorganisms to metabolize organic substrates.

One-dimensional (1-D) model. A mathematical model defined along one spatial coordinate of a natural water system. Typically, 1-D models are used to describe the longitudinal variation of water quality constituents along the downstream direction of a stream or river. In writing the model, it is assumed that the cross-channel (lateral) and vertical variability is relatively homogenous and can, therefore, be averaged over those spatial coordinates.

Organic matter. The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.

Organic nitrogen. Nitrogen in a form that is bound to an organic compound.

Organic phosphorous. Phosphorus in a form that is bound to an organic compound.

Orthophosphate. Phosphorus in a form that is most readily available to plants. It consists of the species $H_2PO_4^{2-}$, HPO_4^{2-}, and PO_4^{3-}. (Also known as soluble reactive phosphorus (SRP).)

Outfall. The point where water flows from a conduit, stream, or drain.

Oxidation. The chemical union of oxygen with metals or organic compounds accompanied by a removal of hydrogen or another atom. It is an important factor for soil formation and permits the release of energy from cellular fuels.

Oxygen demand. Measure of the dissolved oxygen used by a system (microorganisms) in the oxidation of organic matter. (See also **Biochemical oxygen demand**.)

Oxygen depletion. A deficit of dissolved oxygen in a water system due to oxidation of organic matter.

Oxygen saturation. The natural or artificial reaeration or oxygenation of a water system (water sample) to bring the level of dissolved oxygen to maximum capacity. Oxygen saturation is greatly influenced by temperature, elevation, and other water characteristics.

Partitioning coefficient. A constant symbolizing the ratio of the concentration of a solute in the upper of the two liquid phases in equilibrium to its concentration in the lower phase. Chemicals in solution are partitioned into dissolved and particulate adsorbed phases based on their corresponding sediment-to-water partitioning coefficient.

Peak runoff. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.

Periphyton. Microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, pilings, and other structures.

Permit. An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Permit Compliance System (PCS). Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.

Phased approach. Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.

Phosphorus. A nutrient assimilated by plants which promotes growth. The most bioavailable form of phosphorus is soluble reactive phosphorus (SRP), also known as orthophosphate.

Photosynthesis. The biochemical synthesis of carbohydrate-based organic compounds from water and carbon dioxide using light energy in the presence of chlorophyll. Photosynthesis occurs in all plants, including aquatic organisms such as algae and macrophytes. Photosynthesis also occurs in primitive bacteria such as blue-green algae.

Phytoplankton. A group of generally unicellular microscopic plants characterized by passive drifting within the water column. See **Algae**.

Plankton. Group of generally microscopic plants and animals passively floating, drifting, or swimming weakly. Plankton include the phytoplankton (plants) and zooplankton (animals).

Point source. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollutant. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).

Pollution. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Pool. Portion of a stream with reduced current velocity, often with deeper water than surrounding areas and with a smooth surface.

Postaudit. A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.

Pretreatment. The treatment of wastewater to remove or reduce contaminants prior to discharge into another treatment system or a receiving water.

Primary productivity. A measure of the rate at which new organic matter is formed and accumulated through photosynthesis and chemosynthesis activity of producer organisms (chiefly, green plants). The rate of primary production is estimated by measuring the amount of oxygen released (oxygen method) or the amount of carbon assimilated by the plant (carbon method).

Primary treatment. A basic wastewater treatment method that uses settling, skimming, and (usually) chlorination to remove solids, floating materials, and pathogens from wastewater. Primary treatment typically removes about 35 percent of biochemical oxygen demand (BOD) and less than half of the metals and toxic organic substances.

Privately owned treatment works. Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.

Public comment period. The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a *Federal Register* notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).

Publicly owned treatment works (POTW). Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.

Raw sewage. Untreated municipal sewage.

Reaction rate coefficient. Coefficient describing the rate of transformation of a substance in an environmental medium characterized by a set of physical, chemical, and biological conditions such as temperature and dissolved oxygen level.

Reaeration. The net flux of oxygen occurring from the atmosphere to a body of water with a free surface.

Receiving waters. Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

Reserve capacity. Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.

Residence time. Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.

Respiration. Biochemical process by means of which cellular fuels are oxidized with the aid of oxygen to permit the release of the energy required to sustain life; during respiration, oxygen is consumed and carbon dioxide is released.

Restoration. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.

Riffle. A rocky shoal or sand bar located just below the surface of the water.

Riparian areas. Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.

Riparian vegetation. Hydrophytic vegetation growing in the immediate vicinity of a lake or river closely enough so that its annual evapotranspiration constitutes a factor in the lake or river regime.

Riparian zone. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.

Roughness coefficient. A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.

Rotating biological contactor (RBC). A wastewater treatment process consisting of a series of closely spaced rotating circular disks of polystyrene or polyvinyl chloride. Attached biological growth is promoted on the surface of the disks. The rotation of the disks allows contact with the wastewater and the atmosphere to enhance oxygenation.

Runoff. That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Scoping modeling. A method of approximation that involves simple, steady-state analytical solutions for a rough analysis of the problem.

Scour. To abrade and wear away. Used to describe the weathering away of a terrace or diversion channel or streambed. The clearing and digging action of flowing water, especially the downward erosion by stream water in sweeping away mud and silt on the outside of a meander or during flood events.

Secchi depth. A measure of light penetration into a waterbody that is a function of the absorption and scattering of light in water. Secchi depth is operationally defined as the depth at which a white disc is indistinguishable from the surrounding water or the black and white quadrants of a black and white disc are indistinguishable from one another when the disc is lowered into the water.

Secondary treatment. The second step in most publicly owned waste treatment systems, in which bacteria consume the organic parts of the waste. It is accomplished by bringing together waste, bacteria, and oxygen in trickling filters or in the activated sludge process. This treatment removes floating and settleable solids and about 90 percent of the oxygen-demanding substances and suspended solids. Disinfection is the final stage of secondary treatment. (See **Primary treatment, Tertiary treatment**.)

Sediment oxygen demand (SOD). The solids discharged to a receiving water are partly organics, and upon settling to the bottom, they decompose anaerobically as well as aerobically, depending on conditions. The oxygen consumed in aerobic decomposition represents another dissolved oxygen sink for the waterbody.

Septic system. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a system of tile lines or a pit for disposal of the liquid effluent (sludge) that remains after decomposition of the solids by bacteria in the tank; must be pumped out periodically.

Sewage fungus. Proliferations of bacteria and/or fungi that may form feathery, cotton-wool-like growths in streams and rivers that have high concentrations of dissolved organic compounds.

Sewer. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.

Simulation. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Sinuosity. The degree to which a river or stream bends.

Slope. The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).

Soluble reactive phosphorus. Form of phosphorus that is most readily available to plants. It consists of the species $H_2PO_4^{2-}$, HPO_4^{2-}, and PO_4^{3-}. (Also known as orthophosphate.)

Sorption. The adherence of ions or molecules in a gas or liquid to the surface of a solid particle with which they are in contact.

Spatial segmentation. A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.

Stabilization pond. A large earthen basin used for the treatment of wastewater by natural processes involving the use of both algae and bacteria.

Steady-state model. Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.

Stoichiometric ratio. Mass-balance-based ratio for nutrients, organic carbon, and algae (e.g., nitrogen-to-carbon ratio).

STORET. U.S. Environmental Protection Agency national water quality database for STORage and RETrieval (STORET). Mainframe water quality database that includes physical, chemical, and biological data measured in waterbodies throughout the United States.

Storm runoff. Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.

Stratification (of waterbody). Formation of water layers each with specific physical, chemical, and biological characteristics. As the density of water decreases due to surface heating, a stable situation develops with lighter water overlaying heavier and denser water.

Streamflow. Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term “streamflow” is more general than “runoff” since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Stream restoration. Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.

Stressor. Any physical, chemical, or biological entity that can induce an adverse response.

Substrate. Bottom sediment material in a natural water system.

Surface area. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.

Surface runoff. Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

Surface water. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

Suspended solids or load. Organic and inorganic particles (sediment) suspended in and carried by a fluid (water). The suspension is governed by the upward components of turbulence, currents, or colloidal suspension. Suspended sediment usually consists of particles smaller than 0.1 mm, although size may vary according to current hydrological conditions. Particles between 0.1 mm and 1 mm may move as suspended or be deposited (bedload).

Technology-based standards. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.

Temperature coefficient. Rate of increase in an activity or process over a 10 degree Celsius increase in temperature. Also referred to as the Q_{10}.

Tertiary treatment. Advanced cleaning of wastewater that goes beyond the secondary or biological stage, removing nutrients such as phosphorus, nitrogen, and most biochemical oxygen demand (BOD) and suspended solids.

Thalweg. Deepest part of a stream channel.

Three-dimensional (3-D) model. Mathematical model defined along three spatial coordinates where the water quality constituents are considered to vary over all three spatial coordinates of length, width, and depth.

Topography. The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.

Total Kjeldahl nitrogen (TKN). The total of organic and ammonia nitrogen in a sample, determined by the Kjeldahl method.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Total nitrogen (TN). The total amount of nitrogen in a sample, including organic nitrogen, nitrate (NO_3), nitrite (NO_2), and ammonia (NH_4).

Total phosphorus (TP). The total amount of phosphorus in a sample, including both organic and inorganic forms. In most lakes, the organic forms of phosphorus make up a large majority of the total phosphorus.

Toxic substances. Those substances, such as pesticides, plastics, heavy metals, detergent, solvent, or any other natural or man-made materials, that are poisonous, carcinogenic, or otherwise directly harmful to human health and the environment.

Transit time. In nutrient cycles, the average time that a substance remains in a particular form; the ratio of biomass to productivity.

Transport of pollutants (in water). Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.

Tributary. A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

Trophic state. A classification of the condition of a waterbody pertaining to the availability of nutrients. Trophic states include oligotrophy (nutrient-poor), mesotrophy (intermediate nutrient availability), eutrophy (nutrient-rich), and hypertrophy (excessive nutrient availability).

Turbidity. A measure of opacity of a substance; the degree to which light is scattered or absorbed by a fluid.

Turbulent flow. A flow characterized by agitated and irregular, random-velocity fluctuations.

Turbulence. A type of flow in which any particle may move in any direction with respect to any other particle and not in a smooth or fixed path. Turbulent water is agitated by cross currents and eddies. Turbulent velocity is that velocity above which turbulent flow will always exist and below which the flow may be either turbulent or laminar.

Two-dimensional (2-D) model. A mathematical model defined along two spatial coordinates where the water quality constituents are considered averaged over the third remaining spatial coordinate. Examples of 2-D models include descriptions of the variability of water quality properties along (a) the length and width of a river that incorporates vertical averaging of depth, or (b) the length and depth of a river that incorporates lateral averaging across the width of the waterbody.

Uncertainty factors. Factors used in the adjustment of toxicity data to account for unknown variations. Where toxicity is measured on only one test species, other species may exhibit more sensitivity to that effluent. An uncertainty factor would adjust measured toxicity upward and downward to cover the sensitivity range of other, potentially more or less sensitive species.

Unstratified. Indicates a vertically uniform or well-mixed condition in a waterbody. See also **Stratified**.

Use Attainability Analysis (UAA). A structured scientific assessment of the factors affecting the attainment of the use, which may include physical, chemical, and economic factors as described in the Code of Federal Regulations section 131.10(g). (40 CFR 131.3)

Validation (of a model). Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.

Verification (of a model). Testing the accuracy and predictive capabilities of the calibrated model on a data set independent of the data set used for calibration.

Volatilization. Process by which chemical compounds are vaporized (evaporated) at given temperature and pressure conditions by gas transfer reactions. Volatile compounds have a tendency to partition into the gas phase.

Wasteload allocation (WLA). The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Wastewater. Usually refers to effluent from a sewage treatment plant. See also **Domestic wastewater**.

Wastewater treatment. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.

Water quality. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

Water quality-based effluent limitations (WQBEL). Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.

Water quality-based permit. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).

Water quality criteria. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water quality-limited segments. Those water segments which do not or are not expected to meet applicable water quality standards even after the application of technology-based effluent limitations required by sections 301(b) and 306 of the Clean Water Act (40 CFR 130.29(j)). Technology-based controls include, but are not limited to, best practicable control technology currently available (BPT) and secondary treatment.

Water quality standard. Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Watershed-based trading. Watershed-based trading is an efficient, market-driven approach that encourages innovation in meeting water quality goals, but remains committed to enforcement and compliance responsibilities under the Clean Water Act. It involves trading arrangements among point source dischargers, nonpoint sources, and indirect dischargers in which the "buyers" purchase pollutant reductions at a lower cost than what they would spend to achieve the reductions themselves. Sellers provide pollutant reductions and may receive compensation. The total pollution reduction, however, must be the same or greater than what would be achieved if no trade occurred.

Watershed protection approach (WPA). The U.S. EPA's comprehensive approach to managing water resource areas, such as river basins, watersheds, and aquifers. WPA has four major features—targeting priority problems, stakeholder involvement, integrated solutions, and measuring success.

Watershed-scale approach. A consideration of the entire watershed, including the land mass that drains into the aquatic ecosystem.

Watershed. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Wetlands. An area that is saturated by surface water or ground water with vegetation adapted for life under those soil conditions, as in swamps, bogs, fens, marshes, and estuaries.

Zero-order kinetics. Describes a reaction with a constant rate of pollutant depletion per unit time.

Zooplankton. Very small animals (protozoans, crustaceans, fish embryos, insect larvae) that live in a waterbody and are moved passively by water currents and wave action.