CHAPTER 1

Introduction and Objectives

Man has had a long and intimate association with the sea. It has borne his commerce and brought food to his nets; its tides and storms have shaped the coast where his great cities have grown; the broad estuaries have provided safe harbors for his ships; and the rhythm of its tides has taught him the mathematics and science with which he now reaches for the stars (U.S. Department of the Interior 1969).

1.1 BACKGROUND

Nutrient overenrichment is a major cause of water pollution in the United States. The link between eutrophication—the overenrichment of surface waters with plant nutrients—and public health risks has long been presumed. However, human health concerns such as (1) *Escherichia coli* and the spread of disease in sewage-enriched waters; (2) trihalomethanes in chlorine-treated eutrophic reservoirs; (3) the incidence of nutrient-stimulated hazardous algal blooms in eutrophic estuarine surface waters with suspected attendant human illnesses, including recent *Pfiesteria* investigations; and (4) the relationship of phytoplankton blooms in nutrient-enriched coastal waters of Bangladesh to cholera outbreaks (Scientific American, December 1998) all suggest that overenrichment pollution is not only an aesthetic, aquatic community problem, but also a public health problem.

The purpose of this document is to provide scientifically defensible technical guidance to assist States, authorized Tribes, and other governmental entities in developing numeric nutrient criteria for estuaries and coastal waters under the authority of the Clean Water Act (CWA), Section 304a. The objective is to reduce the anthropogenic component of nutrient overenrichment to levels that restore beneficial uses (i.e., described as designated uses by the CWA), or to prevent nutrient pollution in the first place. The primary users of this manual are State/Tribal and Federal agency water quality management specialists and related interest groups. The manual is intended to facilitate an understanding of cause-and-effect relationships in these complex systems and serve as a guide for nutrient criteria development, a resource of technical information, a summary of the scientific literature, and a brief technical account of the ecological structure and function of estuaries and coastal waters to facilitate an understanding of these complex systems.

To combat the nutrient enrichment problem and other water quality problems, EPA published the Clean Water Action Plan, a presidential initiative, in February 1998. Building on this initiative, EPA developed a report entitled National Strategy for the Development of Regional Nutrient Criteria (U.S. EPA 1998a). Criteria form the scientific basis, or yardstick, for ensuring that a desired result will occur because of a particular form of environmental stress, in this case nutrient overenrichment. The strategic report outlines a framework for development of waterbody type-specific technical guidance with emphasis on the reference condition approach that can be used to assess nutrient status and develop region-specific numeric nutrient criteria. This technical guidance builds on that strategy and provides guidance for nutrient criteria development for estuaries and coastal waters. Because estuaries and coastal waters lie at the interface of the land and include various ecoregions and their rivers, this manual departs somewhat from the freshwater manuals (e.g., Lakes and Reservoirs, EPA-822-B00-001, and Rivers and Streams, EPA-822-B-00-002; also available on the EPA web site: www.epa.gov/ost/standards/nutrient.html in PDF format) and considers both land-based ecoregions and coastal ocean provinces as the geographic framework. The freshwater nutrient guidance manuals used the ecoregion and subecoregion as the predominant geographic operational units.

Because of differing geographic and climatic conditions among the East, Gulf, and West Coasts, uniform national criteria for estuarine and coastal waters are not appropriate; they should be developed at the State, regional, or individual waterbody levels. Figures 1-1a,b illustrate the pertinent ecoregions (including geologic province) of the continental United States associated with coastal and estuarine waters. In some cases, multiple criteria may be required for large systems with extended physical gradients. This manual therefore does not provide guidance on how to set nationwide criteria, but provides State water resource quality managers with guidance on how to set nutrient criteria themselves relative to EPA regional criteria. This approach is in contrast to toxic chemical criteria, which tend toward single national numbers with appropriate modifiers (e.g., water hardness for metals). It explores some approaches to classification of estuaries and coastal shelf systems. The ability to develop useful classification schemes is still in a highly developmental stage and needs considerable improvement. The manual describes a minimum set of variables that are recommended for criteria development and describes methods for developing appropriate values for these criteria. It also provides information on sampling, monitoring, data processing, modeling, and approaches to implementation and management responses.

1.2 DEFINITION OF ESTUARIES AND COASTAL SYSTEMS

It is important to have a clear view of the ecosystems that are the focus of this manual. The term “estuary” has been defined in several ways. For example, a classical definition of estuaries focuses on selected physical features—e.g., “semi-enclosed coastal waterbodies which have a free connection to the open sea and within which sea water is measurably diluted with freshwater derived from the land” (Pritchard 1967) (see Kjerfve 1989 for expanded definition). This definition is limited because it does not capture the diversity of shallow coastal ecosystems today often lumped under the rubric of estuary. For example, one might include tidal rivers, embayments, lagoons, coastal river plumes, and river-dominated coastal indentations that many consider the archetype of estuary. To accommodate the full range of diversity, the classical definition should be expanded to include the role of tides in mixing, sporadic freshwater input (e.g., Laguna Madre, TX), coastal mixing near large rivers (e.g., Mississippi and Columbia Rivers), and tropical and semitropical estuaries where evaporation may influence circulation. Also, reef-building organisms (e.g., oysters and coral reefs) and wetlands (e.g., coastal marshes) influence ecological structure and function in important ways, so that biology has a role in the definition.

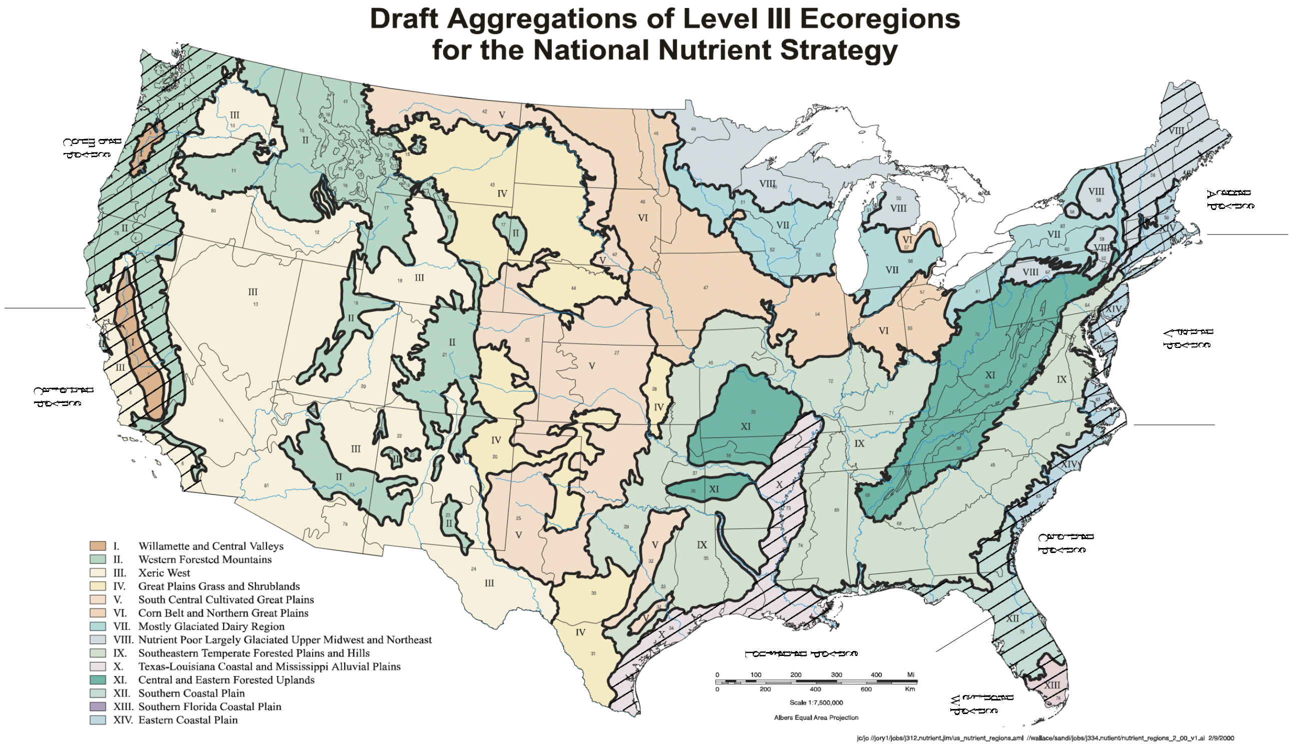

Figure 1-1a. Draft aggregation of Level III ecoregions for the National Nutrient Strategy illustrating those areas most related to coastal and estuarine criteria development.

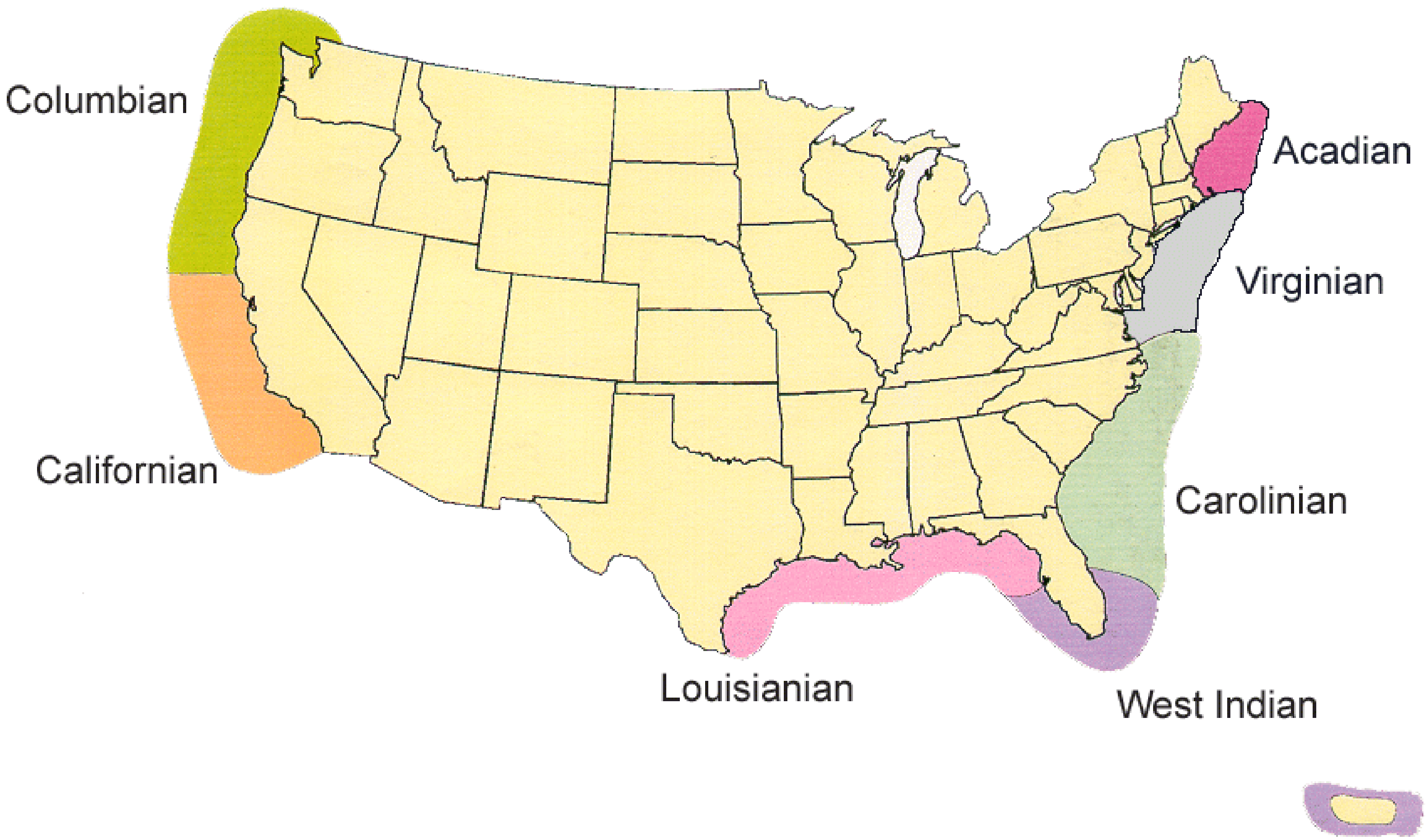

Figure 1-1b. Coastal provinces.

As will be shown, water depth plays a role in the relative importance of sediment-water column fluxes of materials, including nutrients. These features paint a picture of high ecosystem diversity, where prediction of susceptibility to nutrient overenrichment is still a scientific challenge and often requires a great deal of site-specific information. It is because of this diverse response that reference conditions are a part of nutrient criteria development.

Coastal waters are defined in this manual as those marine systems that lie between the mean highwater mark of the coastal baseline and the shelf break, or approximately 20 nautical miles offshore when the continental shelf is extensive. This area will hereafter be referred to as coastal or near-coastal waters. Most States have legal jurisdiction out to the 3-nautical-mile limit. However, coastal oceanic processes beyond this limit may influence nutrient loading and system susceptibility within the 3-mile zone.

1.3 NATURE OF THE NUTRIENT OVERENRICHMENT PROBLEM IN ESTUARINE AND COASTAL MARINE WATERS

Scope and Magnitude of the Problem

Nutrient overenrichment problems are perhaps the oldest water quality problems created by humankind (Vollenweider 1992) and have antecedents that extend into biblical history. The basic cause of nutrient problems in estuaries and nearshore coastal waters is the enrichment of freshwater with nitrogen (N) and phosphorus (P) on its way to the sea and by direct inputs within tidal systems. Eutrophication, an aspect of nutrient overenrichment, is portrayed in Figure 1-2. In recent decades, atmospheric deposition of N has been an important contributing factor in some coastal ecosystems (Vitousek et al. 1997, Paerl and Whitall 1999).

In U.S. coastal waters, nutrient overenrichment is a common thread that ties together a diverse suite of coastal problems such as red tides, fish kills, some marine mammal deaths, outbreaks of shellfish poisonings, loss of seagrass and bottom shellfish habitats, coral reef destruction, and hypoxia and anoxia now experienced as the Gulf of Mexico's "dead zone" (NRC 2000, Rabalais et al. 1991). Additionally, recent evidence suggests that nutrient enrichment can exacerbate human health effects (Colwell 1996). These symptoms of nutrient overenrichment often are preceded by primary symptoms (e.g., an increase in the rate of organic matter supply, changes in algal dominance, and loss of water clarity) followed by one or more secondary symptoms listed above (Figure 1-3). Nixon (1995) defined eutrophication as an increase in the rate of supply of organic matter to a waterbody. In this manual, nutrient overenrichment is defined as the anthropogenic addition of nutrients, in addition to any natural processes, causing adverse effects or impairments to beneficial uses of a waterbody. The scientific literature still uses overenrichment and eutrophication as synonyms. The terms have different meanings, however, because eutrophication is a natural process in freshwater lakes and presumably in coastal marine waters. An argument can be made that nutrient stress on coral reefs can cause a loss of symbiotic algae (i.e., dinoflagellates), resulting in loss of organic matter and death of the coral colony, a condition not consistent with eutrophication in the strict sense.

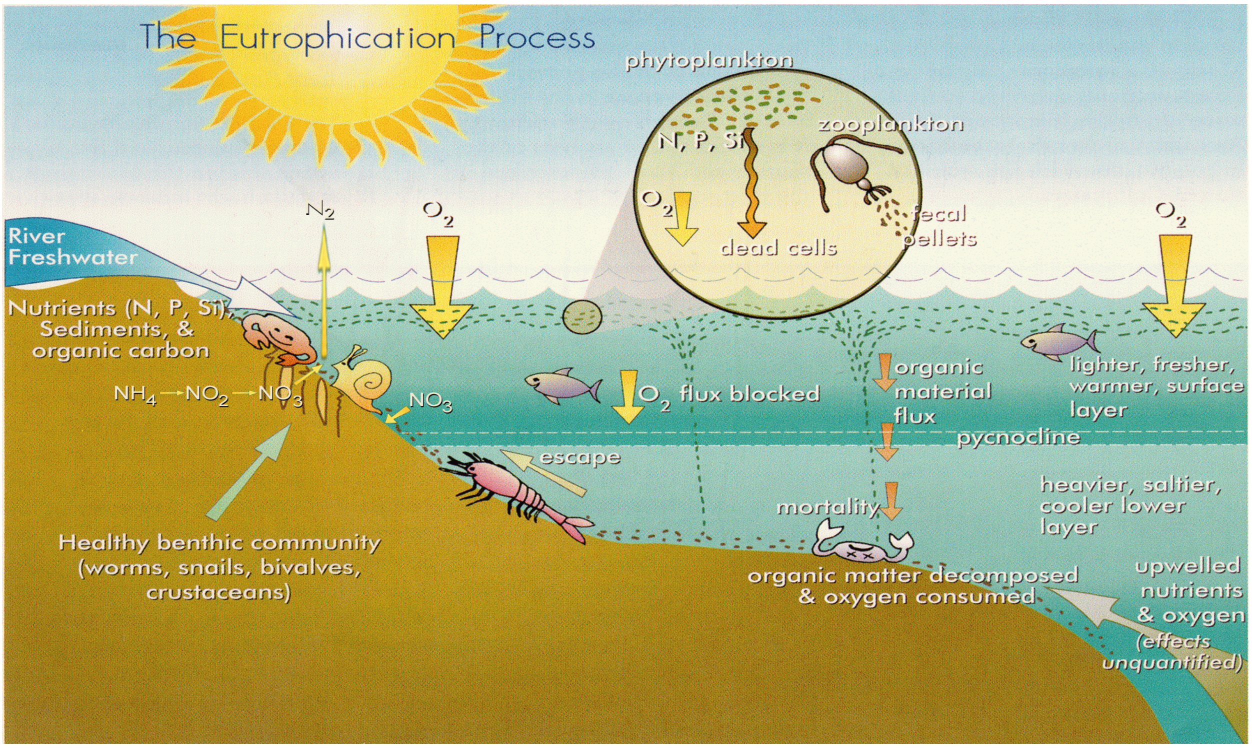

Figure 1-2. The eutrophication process. Eutrophication occurs when organic matter increases in an ecosystem. Eutrophication can lead to hypoxia when decaying organic matter on the seafloor depletes oxygen, and the replenishment of the oxygen is blocked by stratification. The flux of organic matter to the bottom is fueled by nutrients carried by riverflow or, possibly, from upwelling that stimulates growth of phytoplankton algae. This flux consists of dead algal cells together with fecal pellets from grazing zooplankton. Sediment coupled nitrification-denitrification is shown as well as NO_3 transport into sediments when it can be identified. Source: modified from CENR 2000.

Despite several decades of progress in reducing nutrient pollution from waste treatment facilities, nutrient runoff from farms and metropolitan areas, often far inland, has gone unabated or actually increased (The Pew Oceans Commission: www.pewoceans.org; Marine Pollution in the United States: Significant Accomplishments, Future Challenges, 2001; Mitsch et al. 2001). Interestingly, early marine scientists considered nutrients as a resource, not a problem (Brandt 1901), and reflected on ways to fertilize coastal seas to increase biological production. In fact, in the 1890s Brandt concluded that N was the primary limiting nutrient in marine waters and that nitrification and denitrification were important processes in the N cycle.

Nutrient overenrichment of estuaries and nearshore coastal waters from human-based causes is now recognized as a national problem on the basis of CWA 305b reports from coastal States that list waters whose use or uses are impaired; these figures vary from 25% to 50% of the waters surveyed. The National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Eutrophication Assessment (Bricker et al. 1999) indicated that about 60% of the estuaries out of 138 surveyed exhibited moderate to serious overenrichment conditions. Nutrient overenrichment of coastal seas now has international implications (NRC 2000) and is especially well documented for coastal systems of Europe

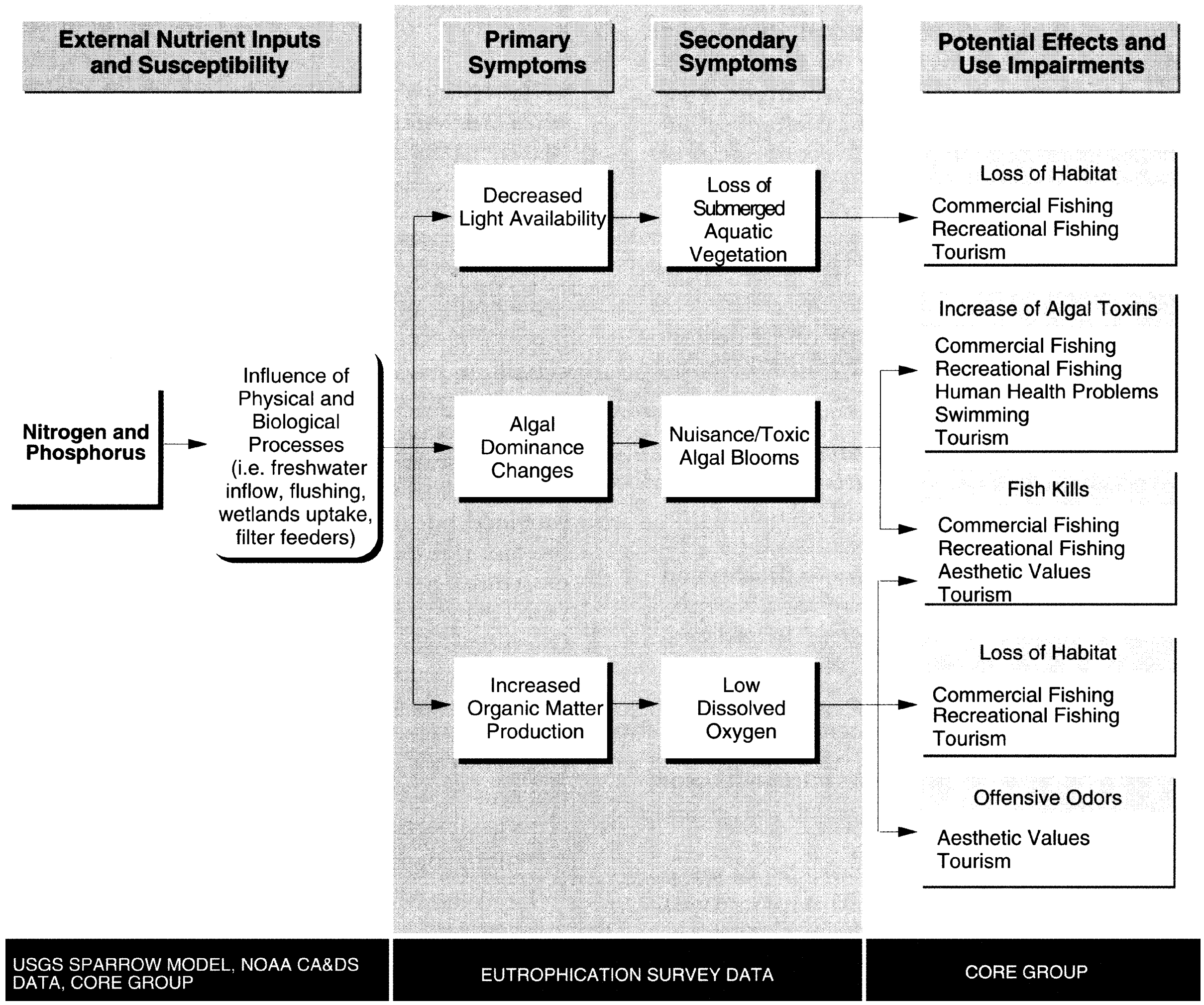

Figure 1-3. Expanded nutrient enrichment model. Source: Bricker et al. 1999.

(Justic 1987, Jansson and Dahlberg 1999, Gerlach 1990, cited in Patsch and Radach 1997, Radach 1992), Australia (McComb and Humphries 1992), and Japan (Okaichi 1997). The problem is likely underreported for developing nations. Currently, the European Union has initiated an effort to develop nutrient criteria for surrounding fresh and marine waters (personal communication, U. Claussen, German Environmental Protection Agency).

In summary, these examples demonstrate that both N and P may limit phytoplankton biomass production depending on season, location along the salinity gradient, and other factors. Nutrient overenrichment problems have been present from early history, especially in estuaries downstream of cities, and the nutrient criteria development approach that follows is a new element in EPA's effort to address these longstanding problems.

1.4 THE NUTRIENT CRITERIA DEVELOPMENT PROCESS

Preliminary Steps

It is impossible to recommend a single national criterion applicable to all estuaries. Natural enrichment varies throughout the geographic and geological regions of the country, and these subdivisions must be considered in the development of appropriate nutrient criteria. For example, "drowned river estuaries" may exhibit a range of inherent or ambient natural enrichment conditions from less than 1.3 µM TP in the thin soils of the Northeast to 2.6 µM TP in the delta regions of the South and Gulf of Mexico.

Although lakes and reservoirs and streams and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management, except for barrier island estuaries and mangrove bays in a given area this is not feasible for estuaries. A major distinction between this manual and the one prepared for lakes and reservoirs is that estuarine and coastal marine waters tend to be far more unique, and development of individual waterbody criteria rather than for classes of waterbodies (such as glacial temperate lakes) is a greater likelihood. Also, estuaries will likely require classification by residence time or subdivision by salinity or density gradients.

Consequently, it will be necessary in many cases to determine the natural ambient background nutrient condition for each estuary or coastal area so that the eutrophication caused by human development and abuse can be addressed. Human-caused eutrophication is the focus of this manual, but the development of nutrient criteria, frequently on a waterbody-specific basis, will require another major distinction for coastal marine criteria development. In the absence of comparable reference waterbodies, the historical record of inherent and cultural enrichment may be particularly significant to developing reference conditions of a particular estuary or coastal reach. The historical perspective is always important to criteria development, but in this instance it may also be essential to reference condition determination.

An outline of the recommended process for coastal and estuarine criteria development is as follows: (1) Investigation of historical information to reveal the nutrient quality in the past and to deduce the ambient, natural nutrient levels associated with a period of lesser cultural eutrophication, (2) determination of present-day or historical reference conditions for the waterbody segment based on the least affected sites remaining, such as areas of minimally developed shoreline, of least intrusive use, fed by those tributaries of least developed watersheds, (3) use of loading and hydrologic models to best understand the density and flow gradients, including tides, affecting the nutrient concentrations, (4) the best interpretation of this information by the regional specialists and Regional Technical Assistance Group (RTAG) responsible for developing the criteria, and (5) consideration of the consequences of any proposed criteria on the coastal marine waters that ultimately receive these nutrients to ensure that the developed criteria provide for the attainment and maintenance of these coastal uses. This concept, as illustrated in Figure 1-4, is the basis for the National Nutrient Criteria Program and is explained throughout this text.

In deriving the reference condition (Figure 1-5), the extreme values of hypereutrophy on one hand and pristine or presettlement conditions on the other can be estimated from monitoring, historical records,

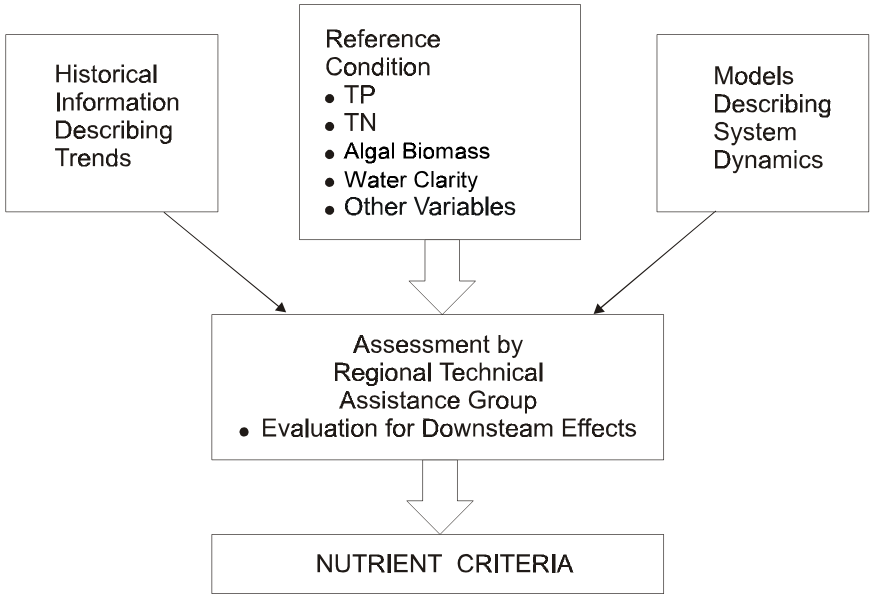

Figure 1-4. Elements of nutrient criteria development and their relationships in the process.

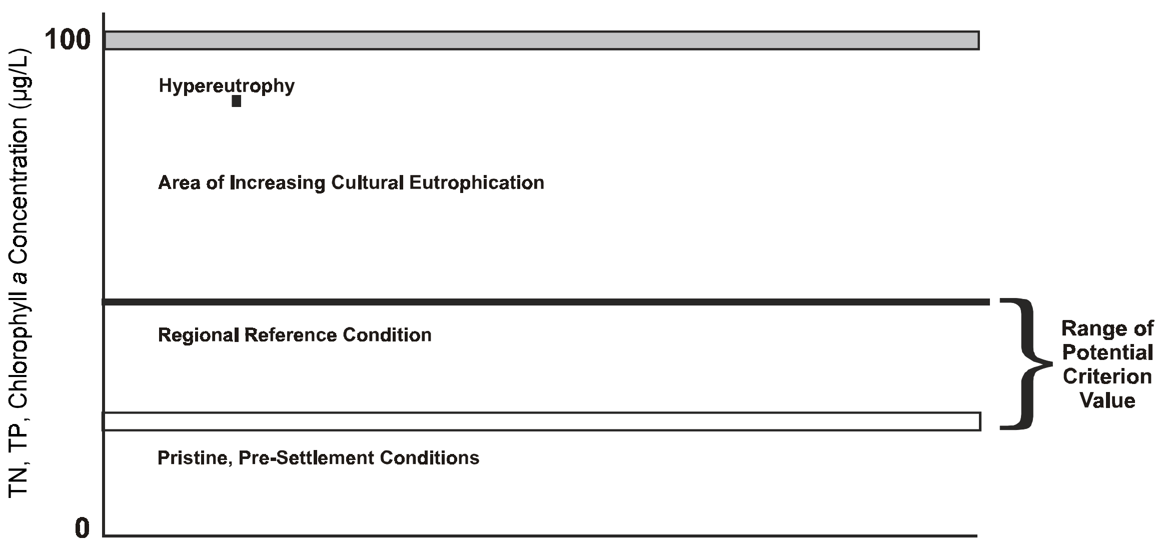

Figure 1-5. Derivation of the reference condition and the National Nutrient Criteria Program using TP, TN, and chlorophyll *a* as example variables. Clarity or Secchi depth would be on a reversed scale. Protectivity nutrient criteria should be between pristine conditions and present reference conditions, i.e., the most "natural" attainable.

and paleoecological determinations. The reference condition and the derived criteria are scientifically based estimates expected to be a present-day approximation of the natural state of the waters approaching but not likely duplicating pristine conditions. They include a conscious decision to use areas of least human impact as indicators of low cultural eutrophication. A measure of practical judgment is also necessary where scientific methods and data are not adequate.

The use of minimally impacted reference sites has been adapted from biological criteria development and is endorsed by EPA's Science Advisory Board (U.S. EPA 1992). Minimal impacts provide a baseline that should protect beneficial uses of the Nation's waters. The term "minimally impacted" implies a high percentage of conditions in reference locations and a low percentage of conditions in all locations (i.e., some enrichment is allowed, but not enough to cause adverse local effects or adverse coastal receiving water effects). The upper end of the data distribution range from reference sites represents the threshold of a reference condition, whereas lower percentiles represent high-quality conditions that may not or cannot be achieved. The upper 25th percentile represents an appropriate margin of safety to add to the minimum threshold, excludes the effect of spurious outliers, and serves as a sufficiently protective value. Where sufficient data are available, comparison and statistical analysis of causal and response variables can help determine effect thresholds and further refine reference conditions (see Figure 6-2).

Establishing the reference condition is but one element of the criteria development process. Reference condition values are appropriately modified on the basis of examination of the historical record (most important), modeling, expert judgment, and consideration of downstream effects.

Strategy for Reducing Human-Based Eutrophication

Six key elements are associated with the strategy for reducing human-based eutrophication (U.S. EPA 1998):

- EPA believes that nutrient criteria need to be established on an individual estuarine or coastal water system basis and must be appropriate to each waterbody type. They should not consist of a single set of national numbers or values because there is simply too much natural variation from one part of the country to another. Similarly, the expression of nutrient enrichment and its measurement vary from one waterbody type to another. For example, streams do not respond to phosphorus and nitrogen in the same way that lakes, estuaries or coastal waters.

- Consequently, EPA has prepared guidance for these criteria on a waterbody-type and region-specific basis. With detailed manuals available for data gathering, criteria development, and management response, the goal is for States and Tribes to develop criteria to help them deal with nutrient overenrichment of their waters and protect designated uses.

- To help achieve this goal, the Agency has initiated a system of EPA regional technical and financial support operations, each led by a Regional Nutrient Coordinator—a specialist responsible for providing the help and guidance necessary for States or Tribes in his or her region to develop and adopt criteria. These coordinators are guided and assisted in their duties by a team of inter-Agency and intra-Agency specialists from EPA headquarters. This team provides both technical and financial support to the RTAGs created by these coordinators so the job can be completed and communication maintained between the policymaking in headquarters and the actual environmental management in the regions.

- EPA will develop basic ecoregional coastal ocean province nutrient criteria for waterbody types. The Regional Teams and States/Tribes can use these values to develop criteria protective of designated uses; the Agency also may use these values if it elects to promulgate criteria for a State or Tribe. These criteria, once adopted by States and authorized Tribes into water quality standards, will have value in two contexts: (1) as decisionmaking benchmarks for management planning and assessment and (2) as the basis of National Pollution Discharge Elimination System (NPDES) permit limits and Total Maximum Daily Load (TMDL) target values. The Standards and Health Protection Division of the EPA Office of Water will be developing implementation guidance for these latter applications.

- EPA plans to provide sufficient information for States and Tribes to begin adopting nutrient standards by 2003.

- States/Tribes are expected to monitor and evaluate the effectiveness of nutrient management programs implemented on the basis of the nutrient criteria. EPA intends the criteria guidance to reflect the "natural," minimally impaired condition of a given estuary or coastal water or the class of these systems, respectively. Once water quality standards are established for nutrients on the basis of these criteria, the relative success or failure of any management effort, either protection or remediation, can be evaluated.

Thus, the six elements of the National Nutrient Criteria Program describe a process that encompasses taking measurements of the collective water resources of an area, establishing nutrient criteria for evaluating the discrete waters within that region, assessing individual waterbodies against these criteria and associated standards, designing and implementing the appropriate management, and, finally, evaluating its relative success.

Nutrient Criteria Development Process

The activities that compose the nutrient criteria development process are listed below in the order generally followed, and the subsequent chapters of this document follow this sequence. Figure 1-6 presents a schematic illustration of the process with parallel, corresponding chapter headings.

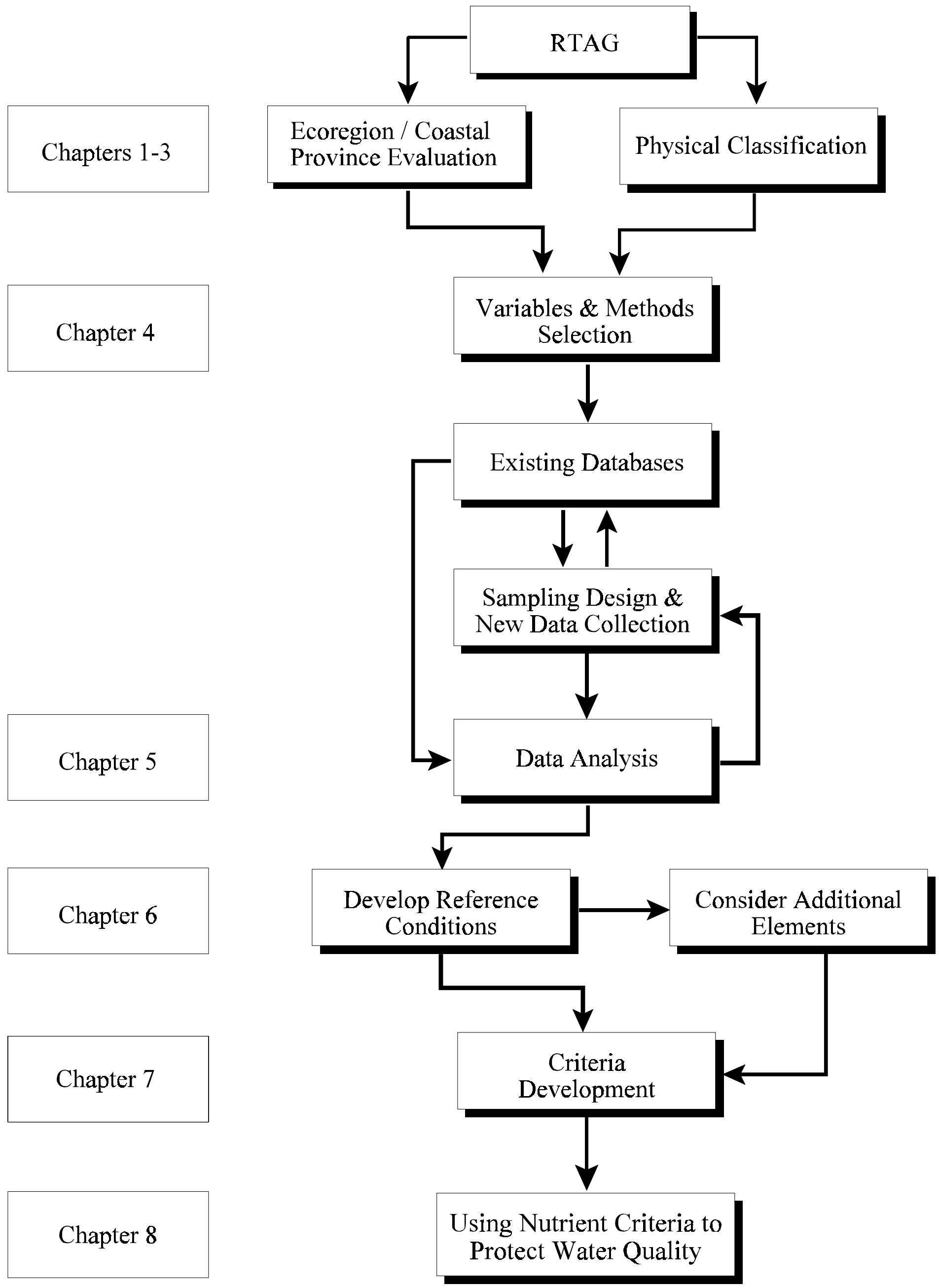

Figure 1-6. Flowchart of the nutrient criteria development process.

■ ***Preliminary Steps for Criteria Development (Chapter 1)***

Establishment of Regional Technical Assistance Groups

The Regional Nutrient Coordinator in each EPA multistate region should obtain the involvement of key specialists (e.g., estuarine and marine ecologists, water resource managers, oceanographers, stream and wetland ecologists, water chemists, and agricultural and land-use specialists) with respect to the waterbodies of concern. These experts should be recruited from other Federal and State agencies.

Experts from academia and industry may serve as technical advisors on an as need basis but not official voting members of the RTAG.

Particular Federal agencies of interest are the U.S. Geological Survey (USGS); Natural Resources Conservation Service (NRCS); National Oceanic and Atmospheric Administration (NOAA); National Marine Fisheries Service (NMFS) and National Ocean Survey (NOS); U.S. Department of the Interior; National Park Service (NPS); National Seashores; the U.S. Fish and Wildlife Service (USFWS); U.S. Army Corps of Engineers (USACE); and, in certain areas of the country the Bureau of Land Management (BLM) or special government agencies such as river basin commissions and inter-State commissions. Similarly, for information and education activities, the National Sea Grant Program and for agriculture, the USDA Cooperative Extension Service are valuable resources.

State agencies with responsibilities relevant to this effort are variously named, but are commonly referred to as Department of Natural Resources, Department of Water Resources, Department of the Environment, Department of Environmental Management, Fisheries and Wildlife Management, State Department of Agriculture, State Department of Forestry, or other land-use management agencies. Most state land-grant universities have faculty talent important to natural resource and nutrient management, and almost all colleges and universities have applied science faculty with research interests and talents appropriate to this initiative.

In selecting participants for the group, diverse expertise is an obvious prerequisite, but willingness to cooperate in the group effort, integrity, and a lack of a strong alternative interest are also important factors to consider in selecting these essential people who must make collective and sometimes difficult determinations.

The experts chosen will constitute the RTAG, which will be responsible for developing more refined nutrient criteria guidance for their respective estuaries and coastal waters. The RTAG should be large enough to have the necessary breadth of experience, but small enough to effectively debate and resolve serious scientific and management issues. A membership of about 30 approaches an unwieldy size, although that number may initially be necessary to maintain an effective working group of half that size. EPA expects that States and authorized Tribes will use the information developed by the RTAGs when adopting nutrient criteria into their water quality standards. The RTAG is intended to be composed of scientists and resource managers from Federal agencies and their State counterparts. The RTAG should not delegate its responsibility with the private sector. The perspectives of private citizens, academicians, and special interest groups are important, and these and other members of the public may attend RTAG meetings and offer opinions when invited, but the final deliberations and decisions are the responsibility of the Federal and State members of the RTAG—the States when adopting nutrient criteria into their water quality standards, and the EPA when determining whether to approve or disapprove such criteria. They must also be able to meet and debate the issues without undue outside influence.

As a matter of policy, however, EPA encourages the RTAGs to regularly provide access and reports to the public. The meetings should generally be open to the public and the schedule of those meetings published in the local newspapers. At a minimum, RTAGs are encouraged to hold regular "stakeholders" meetings so that environmental, industrial, and other interests may participate via a separate public forum associated with responding to the group's efforts. It is important that citizens and public groups be involved, and any significant determinations of the RTAG should include a public session at which a current account of activities and determinations is presented and comments acknowledged and considered. In addition, where specific land uses or practices are addressed, those property owners, farmers, fishermen, or other involved parties should be consulted in the deliberation and decisionmaking process.

It is reasonable to expect the RTAG to meet monthly, or at least quarterly, with working assignments and assessments conducted between these meetings. To coordinate activities among the 10 RTAGS, and with the National Nutrients Team, regular conference calls are recommended. At these sessions, new developments in the Program, technical innovations and experiences, budgets, and policy evolutions will be conveyed and discussed. In the same context, an annual meeting of all Regional Nutrient Coordinators, State representatives, and involved Federal agencies should be held each spring in or near Washington, DC. At this meeting, major technical reports are presented by specialists and issues significant to the Program are discussed.

The composition and coordination discussed above are intended to establish the shortest possible line of communication between the State, region, and national Program staff members to promote a rapid but reasoned response to changing issues and techniques affecting nutrient management of our waters. This format is also designed to be responsive to the water resource user community without becoming a part of user conflicts.

Delineation of Nutrient Ecoregions/Coastal Province Appropriate to the Development of Criteria
The initial step in this process has been taken through the creation of a national nutrient ecoregion map consisting of 14 North American subdivisions of the coterminous United States (Figure 1-1). These are aggregations of Level III ecoregions revised by Omernik (2000). Alaska, Hawaii, and the U.S. Territories will be subdivided into nutrient ecoregions later, with the advice and assistance of those States and their governments.

The initial responsibility of each RTAG will be to evaluate the present ecoregional map with respect to variability on the basis of detailed observations and data available from the States and Tribes in that EPA region. This preliminary assessment will further depend on the additional nutrient water quality data obtained by those States. The databases, especially with respect to selected reference sites, may be used to refine the initial boundaries of the map in each EPA region.

EPA recognizes that the coastal margins of these ecoregions will be of the greatest concern to the States developing estuarine and coastal marine criteria, but in some instances watersheds will extend a considerable distance inland. In any case, the consistent application of the ecoregion concept facilitates both upstream and inland coordination by the RTAGs and States and integrates the coastal efforts with rivers, lakes, and streams.

- ***Scientific Basis (Chapter 2)***

Chapter 2 emphasizes the role of physical processes interacting with biological processes in modulating the expression of nutrient enrichment effects and the potential of inaccurately assessing cause and effects in developing management plans.

- ***Physical Classification (Chapter 3)***

The next step in evaluating the data is to devise a classification scheme for rationally subdividing the population of estuarine and coastal marine waters in the State or Tribal territory. Because identification of overenrichment is the objective of nutrient criteria development, trophic classification per se should be avoided, as should any classification based on levels of human development. Physical characteristics independent of most human-caused enrichment sources are far more appropriate.

However, as stated above, many estuarine and some coastal marine areas will probably require individual attention and development of reference conditions that are site-specific or at least specific to waterbody segments. Within these contiguous segments, the reference stations should have similar residence time, salinity, general water chemistry characteristics, depth, and grain size or bottom type.

Once the waters have been subdivided and classified, it is important to select the key indicator variables of concern and determine how much information is available on the enrichment status of these stations.

- ***Selection of Indicator Variables (Chapter 4)***

Chapters 4 through 7 describe the variables for which EPA anticipates developing 304 (a) criteria for nutrients in estuaries and coastal waters and how they should be sampled, preserved, and analyzed. Although a wide variety of indicator variables may be possible, this technical manual describes development of numerical criteria for total phosphorus (TP) and total nitrogen (TN) as primary nutrient causal variables of eutrophication, and measures of algal biomass (e.g., chlorophyll *a* for phytoplankton and ash-free dry weight for macroalgae) and a measure of water clarity (e.g., Secchi depth or electronic photometers) as primary variables of eutrophic response. In those systems that have hypoxia or anoxia problems, dissolved oxygen also should be added as a primary response variable. States or Tribes may elect to include other indicators as well, but the four primary variables and dissolved oxygen as indicated are recommended as the essential indicators. Other variables are loss of seagrass/submerged aquatic vegetation (SAV), benthic macroinfauna, iron, and silica as well as other indicators of primary and secondary productivity.

State and Federal agency records are the basis for an initial data search. In many States, water quality information resides in more than one agency. For example, Maryland has a Department of Natural Resources and a Department of the Environment, both of which retain water quality records. To compound the data search problem further, States may also have pertinent data sets in their Department of Fisheries and Department of Public Health. It is wise to initiate the search for information with calls and questionnaires to colleagues in the State or Tribal agencies likely to be involved so an appropriate list of contacts and data sets can be compiled. In doing so, regional Federal agencies should not be overlooked either. These include the agencies described above in the selection of RTAG members.

■ ***Nutrient Data Collection and Assessment (Chapter 5)***

EPA has initiated the data collection and assessment process by screening the existing STORET and ODES databases for information on lakes, reservoirs, streams, estuaries and coastal waters with respect to the four initial parameters, and dissolved oxygen where appropriate (see reference to Chapter 4 above). These primary variables were originally selected for robustness and conservativeness of estimation; however, the preliminary screening of the STORET data revealed that these measurements are also relatively abundant in the database.

Although this is an entirely appropriate starting point for nutrient criteria development, States and Tribes are not required to confine their investigations and data selection to only these variables. States and Tribes are encouraged to select additional measures that contribute to the best assessment of the enrichment of their regional waters and protect designated uses. In particular, it is advisable to use both *causal indicators* and *response indicators* as mentioned above.

Combining nutrient and biological system response information will yield the most definitive and comprehensive criteria. To use only causal or only response variables in the criteria puts the State or Tribe in jeopardy of not protecting the designated uses. For example, a highly enriched estuarine system with a rapid flushing rate may appear to be in attainment when only the biota and dissolved oxygen are measured, but the load of nutrients being delivered downstream in its coastal discharge plume is degrading the receiving waters. Using a balanced combination of both causal and response variables in the criteria, together with careful attention to tidal and seasonal variability, should mitigate against false-positive or false-negative results.

Chapters 4 and 5 both discuss proper sampling, preservation, and analysis of samples. Seasonality, spatial distribution of sample sites, composite versus discrete sampling, and fixed station versus stratified random sampling are also explored.

Establishing an Appropriate Database

Review of Historical Information. Historical information, including sediment core analysis, is important to establish a perspective on the condition of a given waterbody. Has its condition changed radically in recent years? Is the system stable over time? What is the variability? Has there been a trend up or down in trophic condition? Only an assessment of the historical record can provide these answers. Without this information, the manager risks setting reference conditions and subsequent criteria on the basis of present condition alone, which may in fact be a degraded state. Valid historical information places the current information in its proper perspective and is particularly important to coastal and estuarine nutrient criteria development because of the difficulty in establishing classes and the scarcity of reference waterbodies.

Data Screening. The first step in assessing historical or current data is to review the material to determine its suitability to support nutrient criteria development. Anecdotal information and observations are valuable, but the sources must be carefully considered. Fishermen's accounts, local sport-fishing news stories, and observational logs of scientific field crews are all legitimate sources of information, but they are subject to different levels of scrutiny before a trend is determined. The same applies to databases. Nutrient information gathered for identifying failing wastewater treatment plants cannot be assessed in the same light as similar data collected to determine overall water quality or trophic state. The analytical procedures used, type of sampling design and equipment, and sample preservation are other variables that must also be considered in any data review and compilation. Once this screening is done, the compiled data may be sorted according to station location, physical characteristics, relative depth, time, and date, and then analyzed for the establishment of reference conditions.

■ ***Establishing Reference Conditions (Chapter 6)***
Candidate reference locations can be determined from compiled data with the help of regional experts familiar with the waters of the area. Classification will be an important first step and should be based on physical characteristics of the waterbodies, including morphology, geological origin, and hydrologic factors such as residence time, flow characteristics, tidal processes, and freshwater-saltwater interchanges. An estuary may then be subclassified into lower, medium, and upper salinity regimes. Specialists can also help to select the least culturally impacted sites or stations within each area.

Three candidate approaches are recommended for development of tidal estuarine reference conditions. Two more approaches use loading information within the fluvial watershed. A sixth approach is described for coastal waters. Where several replicate systems occur, each classified as near-pristine based on recent data (e.g., past 10 years), then one can apply a frequency distribution approach, and this manual recommends that the upper 75th percentile be used as a starting point. If some minor nutrient enrichment is present, then all the data would be considered and, in this case, the lower 25th percentile is suggested. In the case of significant nutrient-based environmental degradation, where reference sites cannot be identified from current monitoring data, then hind-casting with ambient data is recommended. There are three approaches: (1) empirical in situ data analysis, (2) sediment core or paleoecological analysis, and (3) model hind-casting. Interpretation of this approach is potentially sensitive to confounding by physical factors (e.g., freshwater inflows). The watershed approach is load-based. Here, one attempts to locate a relatively nutrient-unenriched tributary, or stream segment, that is approximately representative of the watershed, and extrapolate the nutrient load for the entire watershed. This can be done empirically or, preferably, with models. The coastal approach focuses on changes in the nutrient regime of estuarine plumes and waters some distance from such plumes. An index approach is described that accounts for variability and facilitates identification of natural enrichment (e.g., upwelling). Long-term monitoring is required to distinguish anthropogenic effects from natural variability.

■ ***Criteria Development (Chapter 7)***

Nutrient Criteria Components

The move from data review and data gathering to criteria development involves a sequence of five interrelated elements:

- Examination of the historical record or paleoecological evidence for evidence of a trend.

- Determination of a reference condition using one of several alternative approaches. Remember that the reference condition, however derived, is only part of the criteria development process.

- Use of empirical modeling or surrogate data sets in some instances where insufficient information exists. This may be the case especially in estuaries with insufficient hydrological data, or significantly developed or modified watersheds.

- Objective and comprehensive interpretation of all of this information by a panel of specialists selected for this purpose (i.e., the RTAG). These experts should have established regional reputations and expertise in a variety of complementary fields such as oceanography, estuarine ecology, nutrient chemistry, and water resource and fisheries management.

- Finally, the criterion developed for each variable should reflect the optimal nutrient condition for the waterbody in the absence of cultural impacts and protect the designated use of that waterbody. Second, it must be reviewed to ensure that the proposed level does not entail adverse nutrient loadings to downstream waterbodies. In designating uses for a waterbody and developing criteria to protect those uses, the State or Tribe must consider the water quality standards of downstream waters (40 CFR 131.10 (b)). This concern extends all the way to coastal waters, but in practice the immediate downstream receiving waters are the area of greatest attention for the resource manager. The criteria must provide for the attainment and maintenance of standards in downstream waters. A criterion for that estuary or subclass of estuary will not protect downstream water quality standards, it should be revised accordingly.

Once the initial criteria (either Regional or State/Tribal) have been selected, they can be verified and calibrated by testing the sampling and analytical methods and criteria values against waterbodies of known conditions. This ensures that the system operates as expected. This calibration can be accomplished either by field trials or by use of an existing database of assured quality. This process may lead to refinements of either the techniques or the criteria.

Criteria are developed for more than one parameter. For example, all reference sites of a given class may be determined to manifest characteristics of a particular level for TP concentration, TN concentration, algal biomass,and water clarity. These four measures, and dissolved oxygen as appropriate, become the basis for criteria appropriate to optimal nutrient quality and the protection of designated uses. The policy for criteria attainment will be developed by the State or Tribe in consultation with EPA.

When the estuarine or coastal marine segment in question reveals high TN and TP concentrations, but not the expected high algal biomass and low water clarity, further investigation is indicated before deciding whether criteria have been met. Flushing rates, inorganic turbidity, water color, or toxins may be additional factors influencing the condition of the estuary.

Assessing Attainment With Criteria
An action level then is established for the nutrient criteria that have been selected for each indicator variable. The list includes two causal variables (TN and TP) and three primary response variables (e.g., when dissolved oxygen problems occur this will add an additional variable to the response variables. Failure to meet either of the causal criteria should be sufficient to prompt action. However, if the causal criteria are met, but some combination of response criteria are not met, there should be some form of decision making protocol to resolve the question of whether the waters in question meet the nutrient criteria. There are two approaches to this:

- Establish a decisionmaking rule equating all of the criteria such as the frequency and duration of exceedences and the critical combination of response variables requisite for action

- Establish an index that accomplishes the same result by inserting the data into an equation that relates the multiple variables in a nondimensional comprehensive score

■ ***Management Response (Chapter 8)***
There are a variety of possible management responses to the overenrichment problem identified by nutrient criteria. Chapter 8 describes some regulatory and nonregulatory processes that involve the application of nutrient criteria. It also presents a 10-step process that allows the resource manager to use these approaches to improve water resource condition. The emphasis is on developing a scientifically responsible, practical, and cost-effective management plan.

The chapter also describes three basic categories that encompass all management activities: education, funding, and regulation. It closes with the admonition to always carefully evaluate the success of the management project, report results, and continue monitoring the status of the water resource.

■ ***Model Applications (Chapter 9)***
A variety of empirical and theoretical models are described and discussed, and two specific illustrations of the application of models to estuarine nutrient management are presented.

■ ***Appendices***
A number of appendices supplement the primary text.

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

In any event, a responsible nutrient management plan should meet three conditions. First, the plan and its component elements must be *scientifically defensible*; otherwise it might lead to well-intentioned management actions that are unnecessary or harmful. This is like the admonition to physicians, "above all do no harm." Second, effective nutrient management must strive to be *economically feasible*. The public and local interests are more likely to support approaches that provide meaningful benefit compared with their cost. Finally, these approaches should be *practical and acceptable to the communities involved*. The approaches should address appropriate social and political issues, such as conflicts that might exist between public agencies and landowners, agricultural or other resource users, or between commercial fishermen and recreationists and environmental or industrial groups. Any management plan may fail if these three general elements are not sufficiently addressed, and it is almost certain to fail if they are all ignored.