# CHAPTER 6

# Determining the Reference Condition



## 6.1 INTRODUCTION AND DEFINITION

A reference condition is the comprehensive representation of data from several similar, minimally impacted, "natural" sites on a waterbody or from within a similar class of waterbodies, i.e., median values of TN, TP, chlorophyll *a*, or Secchi depth. However, in cases where severe degradation has occurred, surrogate values for reference site data may be required as described in this chapter. There are two basic approaches for their determination: (1) analysis of in situ estuarine and coastal data, and (2) analysis of watershed nutrient loading to estuaries and, through advective transport, nutrient loading to the coastal environment. These approaches reinforce each other, but one may be preferred or even required depending on comparative or site-specific data. Reference conditions are a primary element of nutrient criteria development, but should be used in conjunction with the other elements described in Chapter 1 and Chapter 7. Classification of estuaries and coastal waters should facilitate development of reference conditions but, as pointed out in Chapter 3, further research is essential to bring classification of these systems to the level of practical utility comparable to that of most freshwater systems. Models of estuarine susceptibility to nutrient overenrichment are at an early stage of development, and even less may be known about coastal ecosystems (Chapter 3).

## 6.2 SIGNIFICANCE OF REFERENCE CONDITIONS

The reference condition is made explicit through several environmental measures. This manual focuses on TN and TP as principal causative agents, but their relative roles depend on individual watershed/estuary and conditions. There are two response variables: chlorophyll *a*, a measure of algal biomass; water clarity, linked to algal biomass through chlorophyll *a*; and often a third, dissolved oxygen deficiency, particularly in estuaries. These explicit measures are indicators of nutrient enrichment but are linked conceptually to a continuum of biological resources and recreational opportunities (Figure 6-1). These linkages show considerable variability and apparent elasticity because ecological processes are not "hardwired" as are some physically engineered systems (e.g., cogs or pulleys that drive a machine). States and authorized Tribes are encouraged to employ additional response variables.

EPA assumes that ecosystems will support natural assemblages of aquatic life and high-quality recreational activities if a nutrient supply is achieved and maintained at a level to support the natural biological system. This can happen, of course, only if other environmental conditions are compatible.

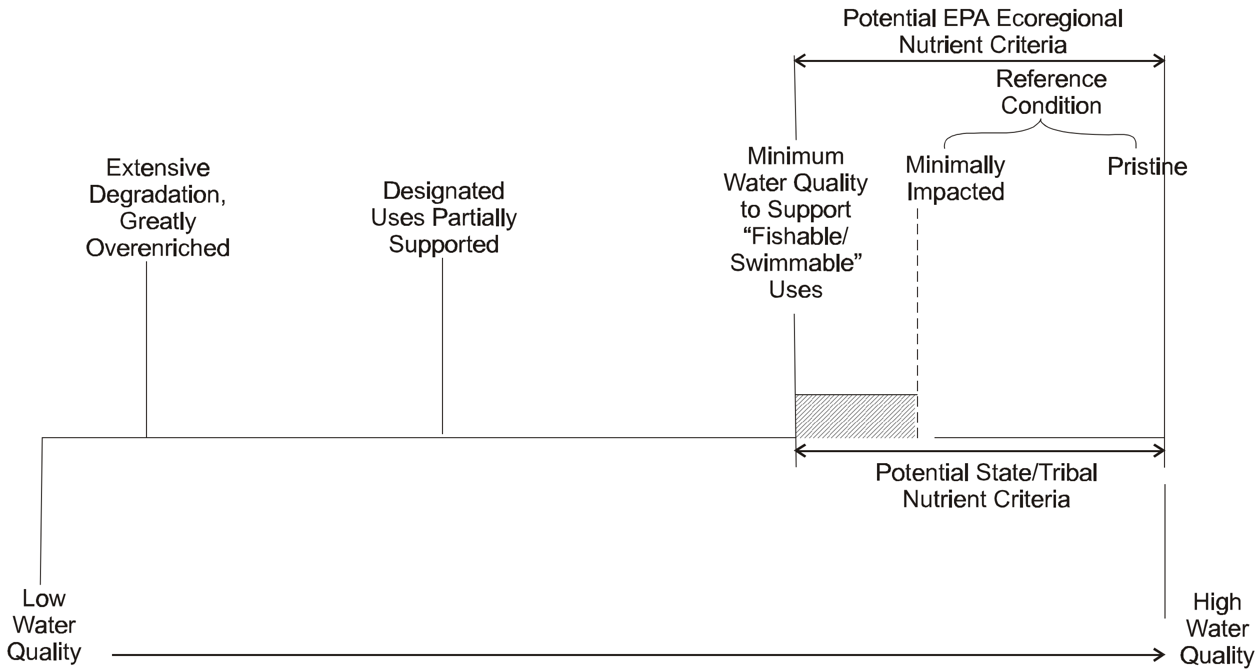


**Figure 6-1.** Environmental quality scale representing reference conditions and potential nutrient criteria relative to designated uses.

Conditions that support minimal or unimpaired aquatic resources are typically associated with very low human population densities and limited land use activities in watersheds that would otherwise be a source of increased human-mediated nutrient supplies to estuaries and coastal waters. This is a plausible association because once a watershed is moderately to heavily developed, it is practically impossible to control all nutrient inputs to the aquatic system. State and national preserves may have relatively high-quality environmental conditions, but even in these systems atmospheric nitrogen deposition likely has caused some nutrient enrichment. Ideal conditions may still exist in some estuaries and coastal waters, and they should be identified. However, where these ideal nutrient conditions no longer exist, especially in the 50% to 60% of moderately to heavily enriched estuaries (Bricker et al. 1999), the reference condition should be sought from comparative analyses of similar systems and/or the historical record, which provides an implied reference condition.

In this manual, a distinction is made for estuaries and coastal waters between "pristine" and minimally impacted waters. The precolonial period may have had water quality and habitat conditions, including nutrient loading, that were pristine. This would approximate the ideal of "restoration and protection of physical chemical and biological integrity" that is the ultimate goal of the Clean Water Act. But this ideal is largely hypothetical, because methods to estimate it invariably contain a relatively high degree of uncertainty. However, "fishable and swimmable" conditions are commonly used as an interim goal of the act and represent a goal of the Nutrient Program, exemplified by reference conditions associated with minimal human-mediated nutrient enrichment.

The term “fishable and swimmable” is not easily quantified in any waters because of their inherent natural variability. A lake example helps provide a perspective. When a lake shifts from an oligotrophic to a mesotrophic fishery because of nutrient overenrichment, at some point the change becomes demonstrable. Likewise, in an estuary when nutrient enrichment shifts phytoplankton production and algal species composition toward microbial dominance and away from oyster production, the change becomes demonstrable. What is needed are early warning indicators of the impending change. This is the role of nutrient criteria. Although it is clear that additional research is called for, there is sufficient symptomatic knowledge such as changes of species with enrichment to merit setting such indicator criteria.

Identifying a reference condition in degraded waters should start with an analysis of the best existing estuarine or marine waters within a watershed or coastal area, or as commonly stated, “the best of what’s left.” Because of the difficulties in identifying reference sites in some overenriched estuaries and nearshore coastal waters, it may be necessary to derive an “implied” reference condition by comparing the “best of what’s left” with “what used to be” as established by the historical record. In any case, it is still important to identify the best remaining sites in the waterbody of concern. Where the the “best” sites are known to be severely degraded, more emphasis must be placed on the historical record, but some knowledge of the continuum from past to present is necessary to establish protective criteria.

Nutrient enrichment-based impacts are a function of the concentrations and supply of nutrients as well as the ecological conditions and nutrient processes characteristic of the system. Nutrient enrichment effects may be exacerbated in estuaries where the dominant grazing populations (e.g., menhaden and oysters) have been lost through human causes, natural causes, or a combination of the two over the past century or the past several decades. For this reason, it is important to assess the factors that may have modified the “assimilative capacity” of coastal waterbodies. Reference conditions are not threshold values (a concentration less than some specified value). For example, in the lower Potomac River estuary, Chesapeake Bay, the average N load caused a larger phytoplankton bloom than either drought or flood conditions (Chapter 2). This response involved system hydrodynamics. The point is that reference conditions should be interpreted in an ecosystem context, especially when the system has experienced significant nutrient overenrichment and/or is subject to periodic natural disruption such as hurricanes, winter storms, or droughts.

Some argue that one of the earliest symptoms of impairment involves a nutrient stimulation of harmful algae relative to beneficial algae. Many types of algal blooms that become a nuisance or harmful clearly are a form of pollution. There is mounting evidence that many harmful algal blooms are associated with nutrient enrichment (NRC 2000). For example, substantial loss of seagrass habitat due to algal shading or bottom habitat due to hypoxia are associated with negative effects on living resources. Seagrasses also stabilize shorelines and provide cover from predators.

This manual emphasizes the importance of reference conditions to address nutrient problems in a timely manner. They serve as the best initial measure for identifying nutrient loads that could cause use impairments. Statistical and computer-based modeling can improve site-specific estimates of the load and response relationships.  Classification may assist in extrapolating nutrient effect relationships between systems in the same class, although classification of coastal waters probably has less predictability and utility than it does for lakes and streams.  As pointed out in Chapter 2, for coastal waters, the relationships between nutrient loading (e.g., TN and TP) and the response indicators of chlorophyll *a* and water clarity normalized to chlorophyll *a* can be less than straightforward.  However, an understanding of the reference condition will help prevent resource managers from being blindsided by complications associated with cause-effect relationships.

## 6.3  PAUCITY OF SIMILAR ESTUARINE AND COASTAL MARINE ECOSYSTEMS

Estuaries and coastal marine ecosystems tend to be relatively individualistic in their sensitivity and response to nutrient overenrichment.  Susceptibility to nutrient enrichment ranks as a premier research need (Hobbie 2000).  The lack of physically similar waterbodies may severely limit grouping (classifying) waterbodies as recommended for lakes, reservoirs, rivers, and streams where frequency distributions are used to derive reference conditions (e.g., upper 75th percentile of a priori nutrient-unimpaired waterbodies or lower 25th percentile of all waterbodies; EPA 2000a,b).  As mentioned in Chapter 1, an exception may be coastal embayments that form behind barrier islands.  If several relatively similar embayments can be identified within a given geographic area, then one or more may serve as benchmarks against which the others may be compared.

## 6.4  APPROACHES FOR ESTABLISHING REFERENCE CONDITIONS

Three primary estuarine approaches may provide considerable flexibility to meet the diversity of conditions encountered by resource managers.  A fourth approach focuses on nutrient loading from the watershed.  A fifth approach is described for coastal marine waters.  There are situations where light and estuarine flushing limit the expression of nutrient enrichment effects.  In such cases, downstream effects may nonetheless be a problem requiring attention.  Consequently, we have proposed a variety of criteria development approaches.  Reference conditions in any case should be defined with due consideration of salinity gradients and seasonal and interannual variability.  Table 6-1 summarizes the five approaches to establishing reference conditions in estuaries and coastal waters.

The alternatives for reference condition determination presented in the following text and table represent two general approaches to developing baseline nutrient quality measurements.  The reference conditions approach per se acknowledges that the system response to overenrichment can be extremely variable, as described earlier in this manual.  For that reason, measuring the nutrient characteristics of minimally impacted sites provides a reliable nutrient goal regardless of how those nutrients may or may not be assimilated.  This is the approach upon which the National Nutrient Criteria Program is predicated, and reference sites should always be sought when designing nutrient criteria protocols.

**Table 6-1. Summary of estuarine and coastal nutrient reference condition determinations**

| Degree of apparent estuarine degradation | Method recommended | Criterion measure |
|---|---|---|
| **A. In Situ Observations as the Basis for Estuarine Reference Condition** | | |
| 1. Recognized unique excellent condition | Median ambient concentration. Fig. 6-2. | Concentration of TP, TN, chlorophyll *a*, Secchi depth (m) |
| 2. Some degradation, but reference sites exist | Upper quartile. Fig. 6-2. | Same as above |
| 3. Significantly degraded, including all potential reference sites | Intercept value on a regression or distribution curve as illustrated in Fig. 6-3 and 6-4 or by use of a comparable comparative regression model. | Same as above |
| **B. Watershed-Based Approaches for Estuarine Reference Condition** | | |
| 4. Same as approach 3 above, but insufficient historical data | Ref. sites along each trib. and calculate delivery. Summation is reference condition. Fig 6-5. Model required to back-calculate load where all tribs. are degraded | Load of TP and TN; model is required to convert load to estuarine concentration |
| **C. Coastal Reference Condition** | | |
| 5. Applicable to all coastal reaches<br>- Estuarine plumes<br>- Coastal areas | Index site approach; models may help distinguish anthropogenic contribution See also Appendix H. | Concentrations |

However, many estuaries are so degraded and/or exhibit such short retention times that investigators cannot determine reference sites with any degree of confidence. In this instance, dose-response curves and similar approaches as described below may be more appropriately applied in determining historical reference conditions, i.e., conditions before degradation was first exhibited. Although these approaches may not provide the real-time affirmation of existing reference sites, their strength is the documentation of system decline coincident with the overenrichment. The investigator is expected to assess the characteristics of the given estuary and select the most responsive option for reference condition determination from those presented.

In all cases, historical information is important either as an alternative reference condition for heavily enriched systems or as one of the five elements of criteria development essential to providing a status and trend perspective important to data evaluation before criteria are established.

## In Situ Observations as the Basis for Estuarine Reference Condition

These approaches require nutrient and relevant hydrographic data within an estuary.

***Recognized Unique Excellent Condition***

Typically, this condition is based on an extensive spatial and temporal scientific database. If an existing excellent condition is agreed to by the RTAG and stakeholders, then the State, authorized Tribe, or appropriate government agency may establish reference conditions based on data that document the condition and address the remaining elements of criteria development. With limited data, in a very small number of cases it may be possible to document that the watershed is unimpacted (e.g., has very little human development, is distant from the influence of local population centers, adjacent land uses are relatively undisturbed, and is outside of major atmospheric deposition of nitrogen). It is necessary to document, or augment with additional data, to ensure the original hypothesis is confirmed. Segmenting the estuary by salinity zones, typically based on estuarine circulation, may be required to reflect nutrient conditions associated with salinity gradients. However, the geographic scale of the nutrient overenrichment problem suggests that this a priori approach likely will be limited to a relatively small number of estuaries and coastal waters (Chapters 1 and 2). The data can be summarized as either medians of the indicator endpoints or frequency distributions (Figure 6-2). Areas that meet or come very close to minimally impaired conditions include Plum Island Sound and Blue Hill Bay, ME, and lower Narragansett Bay, RI.

***Some Degradation Exists But Reference Sites Can Be Identified***

Two situations may be applicable for characterizing reference conditions where some degradation occurs.

*A. Some Minimally Impaired Sites Are Available*

Reference sites should be representative of the system (e.g., a branched estuarine system where one branch is unimpaired by nutrients and otherwise relatively similar ecological conditions prevail). Comparisons should be made among similar salinity zones. This example may apply only rarely because in atmospheric nitrogen deposition and land use practices likely will have so altered the landscape that truly undisturbed conditions are unavailable. In those cases where minimal biological resource uses are impaired by nutrient overenrichment, then reference conditions for nutrients should be deemed to occur. Clearly, point and nonpoint source discharges must be at a minimum. Land cover in the watershed should be very close to natural for the ecoregion or, if modified in the past, then recovery must be well along (e.g., forests should be near the anticipated climax condition for the region). The reader is referred to Chapter 4 of “Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance,” December 2000 (EPA-822-B-00-024), for additional information (U.S. EPA 2000b). Although the upper estuary likely does not qualify, reference-quality sites probably occur in lower Delaware Bay, especially under sustained periods of low Delaware River input. Under these conditions, because the measurement values likely will not exhibit a trend or show high variability, the data can be summarized in terms of median values or a frequency distribution.

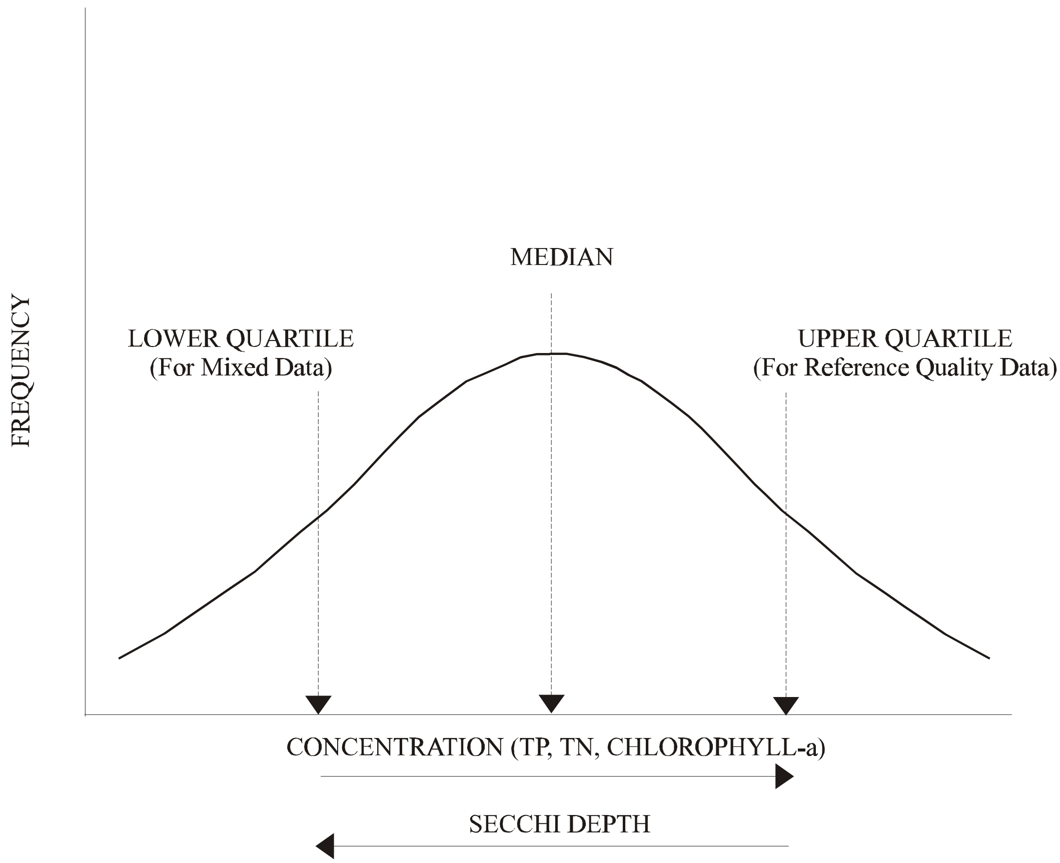


**Figure 6-2.** Hypothetical frequency distribution of nutrient-related variables showing quantities for reference or high-quality data and mixed data (all data incuded).

*B. Reference Condition Derived From A Priori Selection of a Subset of Reference Estuaries or Coastal Waters Within a Class of Systems*

This approach may apply to a series of coastal embayments located within a physically similar reach of coastline (e.g., some estuaries along the Maine coast and possibly New England salt ponds). Where freshwater inputs contribute to a strong salinity gradient, salinity zones may be compared. The goal is to establish frequency distributions for similar systems. If a population of 15 or more estuaries or embayments occurs within the class, then a frequency distribution may be applicable (see Chapter 6, Nutrient Criteria Technical Guidance Manual–Lakes and Reservoirs, April 2000, EPA-822-B00-001). A sample size of fewer than 15 systems will not likely have enough predictive power to justify application of this approach. However, if only a small number exists, then one or two embayments may serve qualitatively or possibly semiquantitatively as references for the remaining systems. Seasonality and similar freshwater inputs are important to ensure that physical processes are not masking potential nutrient effects. To date, it is unknown whether there are enough reference embayments to make a frequency distribution approach feasible. Other examples may be difficult to identify but tributaries to North Inlet, SC, may qualify.

***Significant Degradation Exists—Reference Sites Cannot Be Identified From Current Monitoring Data***

*Historical Analysis of Estuarine Data*

Because of nutrient overenrichment, it is highly likely that no minimally impacted estuarine waters are available for many coastal areas. Under these circumstances, the "best" of the existing waters are clearly degraded. An alternative is to establish reference conditions from the historical record. Three approaches are recommended: (1) analysis of historical ambient nutrient and hydrographic data; (2) analysis of sediment cores to reveal the historical record, including the paleoecological record; and (3) model hind-casting. The analysis of ambient data is likely available only for a small number of estuaries (e.g., Chesapeake Bay and some tributaries, San Francisco Bay, Narragansett Bay, Tampa Bay), because many estuaries were impaired before nutrient data were initially collected.

*Empirical In Situ Data Analysis*

The first approach depends on the availability of an adequate database. Such a database will need considerable scientific judgment even for systems with a relatively rich database. For example, the ambient nutrient-based historical record for the entire main-stem Chesapeake Bay becomes much less abundant during the 1970s and earlier (Harding and Perry 1997). In addition, the spatial coverage was much less widespread in earlier years. In many systems, early studies focused primarily on the deep channels because of the interest in hypoxia. Analysis of ambient trends in chlorophyll *a* may be complicated by the interaction with freshwater flow, as reported by Harding and Perry (1997) and Hagy et al. (2000). This co-linear effect may affect assessment of trends in water clarity and cause a nonlinear relationship between a limiting nutrient and hypoxia (Chapter 2). Hypoxia is the result of an extended temporal effect of nutrient loading (lag effect), so published empirical relationships usually are based on seasonal or annual nutrient loads (Chapter 2), not on short-term concentration data.

An important aspect of the historical approach is the selection of a period when nutrient loading caused minimal use impairments. Often the nutrient monitoring data are more continuous for past decades than is documentation of use impairments (e.g., visual pollution and reduction in fish productivity) due to nutrient overenrichment. The economics and technology that affect fishery statistics in estuaries and coastal waters are not easily translated into quantitative fish population abundance data. In some systems (e.g., Tampa Bay, Janicki and Wade 1996, Greening et al. 1997), seagrasses were monitored to demonstrate recovery but not necessarily prior to nutrient-based losses. The effects of increased nutrient loads may be confounded by increased suspended sediments. Sediments can cause light limitation and impair benthic habitats, with potential negative effects on living resources.

Historical ambient nutrient-related data will encompass seasonal and interannual variability. It is important that the key variables (TN, TP, chlorophyll *a*,[1] and water clarity—usually Secchi depth) be distributed in a representative spatial and temporal manner. Although the Secchi disc is inexpensive and has been widely used, it is recommended that future measurements of water clarity employ submersible

[1]It is recommended that future algal pigment analyses consider some high-performance liquid chromotography (HPLC) measurements that can also quantify algal groups.

PAR meters as a minimum and that submersible spectral radiometers will be used more frequently. Some precautions are relevant. For example, comparing nutrient-related variables in the turbidity maximum, if light limitation dominates algal net production, would seem to provide little insight into the nutrient problem. Another consideration is to ascertain where on the long-term hydrograph the reference period falls (e.g., a wet or dry decade). These past measurements can then be used as a basis for comparison to present condition (Figure 6-3). If a spring bloom is evident in the data, a judgment is required as to whether remineralization of the spring bloom helps fuel a summer algal bloom, and whether the spring bloom contributed directly to summer hypoxia or other use impairments. Therefore, it is recommended that two averaging periods, a spring and summer period, be used.

The magnitude and duration of historical algal blooms are expected to be much lower than those of current blooms in nutrient overenriched waterbodies under similar physical conditions. Some evidence indicates that the magnitude of algal blooms (e.g., coefficient of variation) may increase as systems become more enriched. At some point light limitation may limit variability. The historical data should be aggregated within a physical classification, such as salinity zones, similar to present data analysis. Several options exist for data summation. A point-in-time estimate may not capture the anticipated seasonal and interannual variability in the data. In some cases, data for one or more key variables may exist before an inflection, indicating worsening conditions. Such variables may include increase in concentrations or loads of TN or TP, increase in chlorophyll *a*, decrease in Secchi disk values, and increase in hypoxic volumes. If this more ideal case prevails, then seasonal medians (medians are less sensitive to outliers or extreme values in a distribution than are means) or medians of seasonal index periods (month of highest chlorophyll *a*) should be calculated. If available, the median of seasonal medians for one or more years is desirable and may be essential to capture interannual variability.

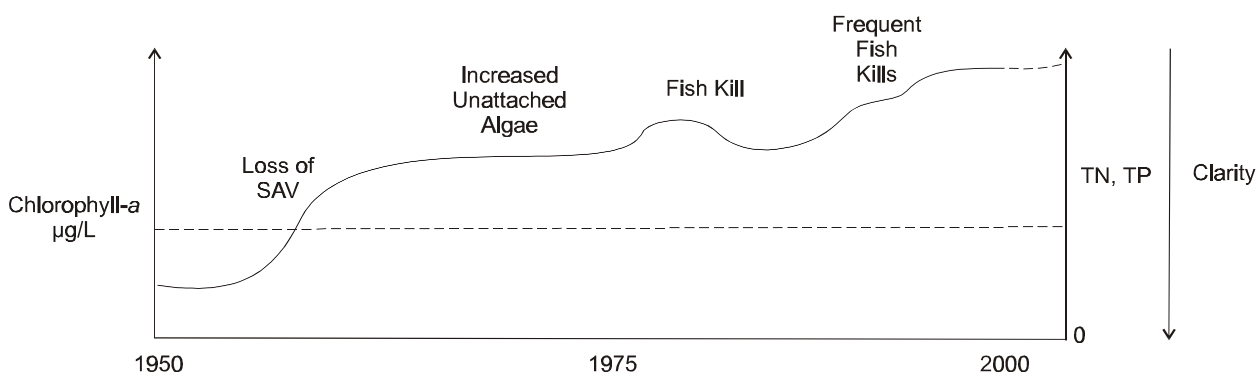


**Figure 6-3.** Hypothetical example of load/concentration response of estuarine biota to increased enrichment. Dashed line represents the selected reference condition level.

Years may need to be excluded from the reference period if the reference period includes increasing problem-related values (e.g., chlorophyll *a* and extinction coefficients). Nutrient and chlorophyll *a* concentrations and Secchi disk values often will show a gradient within a given salinity zone. In data-rich cases within similar salinity zones, one may express the values as a frequency distribution (e.g., Figure 6-4; see EPA 2000a, Chapter 6, EPA-822-B00-001, for more details). However, attention needs to be paid to potential confounding effects (co-linear) of freshwater input, even when comparing similar salinity zones, because vertical density stratification may be a dominant controlling influence and be dissimilar over time. When the above precautions are addressed and confounding factors are poorly understood, it may be appropriate to set the reference condition at the median between the historical median and the median for present data (Figure 6-4). This simple procedure reflects the magnitude of the departure from minimally impacted waters and is, in part, a function of the length of the historical database, addresses inherent variability, and is a realistic approximation of a reference condition over the time span.

***Sediment Core-Based Reconstruction***

Sediment core analysis is becoming widely used in assessment of historic biogeochemical and climatological conditions in lake and marine environments (Brush 1984, 1986; Cooper 1995). The approach is applicable in sediment depositional areas where bioturbation and other forms of sediment disturbance are minimal. Improved sediment dating techniques (e.g., lead-210, cesium-154, carbon-14) have contributed to the understanding of historical conditions when sediments were deposited. Certain

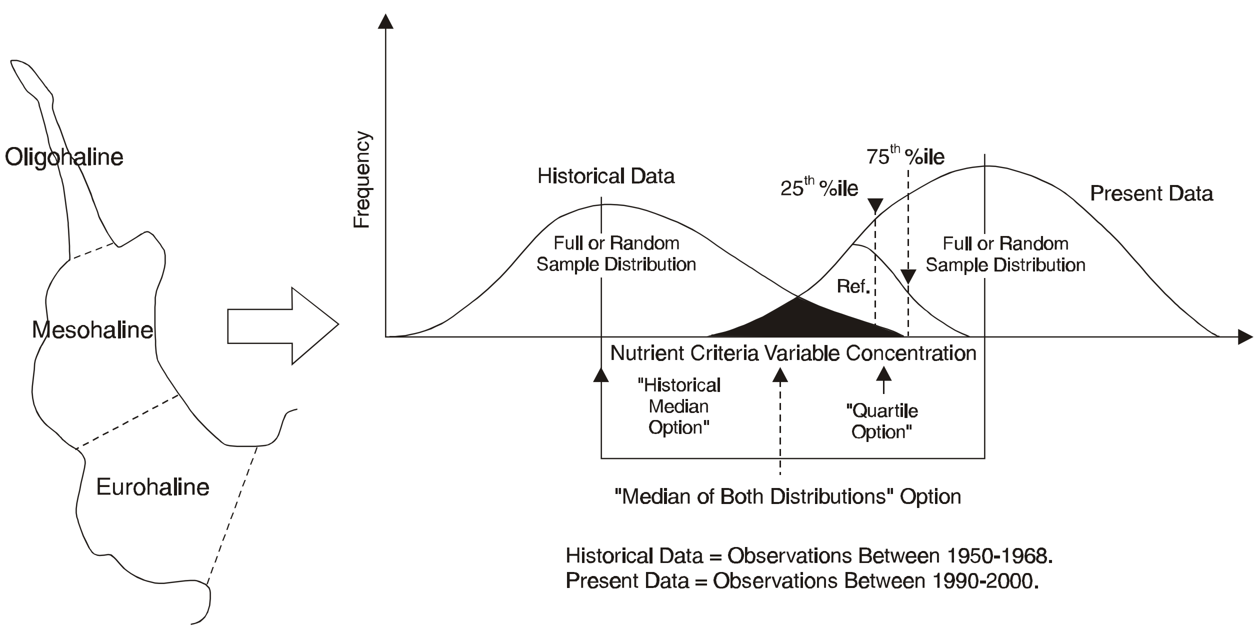


**Figure 6-4.** An illustration of the comparison of past and present nutrient data to establish a reference condition for intensively degraded estuaries. The option of selecting the distributions from both time periods is compared to an expected frequency distribution if the observations were available.

other chemicals (e.g., plasticizers) began to leave signatures when developed in the 1930s. Sediment cores may provide information about metals and organic chemicals with long half-lives. Many environmental indicators of past sediment conditions now are widely reported in the literature. These include pyrite formation related to anoxia, history of submerged aquatic vegetation, diatom composition related to nutrient enrichment, presence and composition of certain dinoflagellate species, distribution and abundance of indicator species of *Foraminifera*, hard body parts of molluscs and crustaceans, land use based on oak and ragweed pollen, total nitrogen and phosphorus profiles, and stable isotope analysis of carbon, nitrogen, and sulfur in organic materials. Hind-casting with sediment cores provides a means to infer reference conditions at a time when nutrient concentrations were much lower than present. In shallow estuaries where depositional areas are not present or questionable, sediment cores have limited applicability.

#### *Model Hind-Casting*

Hind-casting is a controversial approach because it is difficult to calibrate and verify a model when the data difficult to quantify, as with past nutrient and hydrographic conditions. Running a computer-based environmental process model backwards involves many uncertainties; however, where ambient data are inadequate, sediment cores are not applicable, and a model is available and in the hands of experienced scientists, then with expert guidance it seems reasonable to estimate reference conditions on a first-order basis. Use of geographic-based land use models coupled to estuarine hydrodynamic-algal growth models is one approach to hind-casting. Chapter 9 describes several models that may be useful.

#### *Watershed-Based Approaches for Estuarine Reference Condition*

An alternative to using in situ coastal marine data to establish reference conditions is to base estimates on watershed nutrient loading characteristics. One can, in some situations, use watershed loading estimates to define conditions in the watershed where nutrient loads would represent minimally impaired waters downstream in estuaries. This assumes that in an undisturbed estuary and its watershed, the nutrient load would historically represent the most natural condition. In some cases, the watershed above the confluence of major freshwater streams may contain a relatively low level of human development, but the nearshore estuarine area may contain considerable development (e.g., Elevenmile Creek, Perdido Bay, AL/FL, and development near lower Perdido Bay distributary systems; see Livingston 2001a). Some estuarine watersheds may still contain a tributary, or segment thereof, whose nutrient load represents a minimally impaired stream system because human development is minimal. The minimally impaired stream nutrient loading to head of tide may be used to estimate the nutrient load for the entire watershed if certain assumptions are met. Application of a watershed stream segment to estimate nutrient loading is based on seven assumptions, as described in Table 6-2, including atmospheric deposition of nitrogen as a constant.

### Areal Load Approach to Identification of Reference Condition

The nutrient load is measured for the minimally disturbed subtributary or segment. State and national preserves, when available, typically offer appropriate conditions (Clark et al. 2000, Fulmer and Cooke 1990). A decision is required as to whether the geology is approximately homogeneous across the watershed to extrapolate from the reference tributary to the entire suite of tributaries. If not, then a

**Table 6-2. Requisite assumptions for establishing watershed-based reference conditions**

| Assumptions | Description |
|---|---|
| **Estuarine systems are usually unique rather than being readily divided into similar classes of estuaries.** | There are some instances of coastal bays that can be classified together so that one or more of them may be designated as reference sites that collectively may comprise a reference condition against which other similar estuaries in a given area can be compared. However, most often each estuary must be addressed individually and the reference condition must be derived from data within that system. |
| **The tidal factor and large volume shifts make regional subdivision of each overenriched estuary difficult.** | In the instance of biological criteria development, it was possible to subdivide the estuary by salinity habitat regimes and thus reduce the portions of the estuary and its water column dynamics to a manageable level, especially for assessments of nonmobile benthic invertebrates. This is not viable with nutrient-related planktonic organisms and dissolved or suspended water column materials. |
| **We can estimate "pristine" or natural loads from estimations of concentration-flow relationships, and therefore loading estimations in unaltered subestuarine watersheds. That loading can be extended to an entire estuary for reference condition development.** | Loading estimations are an established practice in water resource management. The universal soil loss equation (USLE) is the best known example, and it has been extended to other unit loading estimations. This robust and rather straightforward concept estimates most of the nutrients that enter an estuary regardless of how effectively the system processes or assimilates nutrients. |
| **Most of the measurable load to an estuary is tributary based, and atmospheric deposition is a constant over the system.** | Admittedly, there is an atmospheric source of nitrogen to and from estuarine waters, but this is variable and, generally, is much less than runoff from streams and rivers. The effect is somewhat mitigated because the atmospheric deposition to the stream surfaces is incorporated in the loading estimation. Phosphorus and suspended material as well as algal responses to nutrients are most certainly more tributary related than atmospheric. Shoreline sheet runoff can be incorporated into the loading approach. |
| **Loading from coastal marine waters is usually negligible compared with anthropogenic watershed loads to the estuary** | While many estuarine ecologists are properly concerned with this aspect of estuarine dynamics, from the practical criteria development approach, a large portion of the marine load may be presumed to have originated in the previous outgoing estuarine tidal water. The remainder is to some extent a part of a natural process inherent to estuarine systems. This assumption may not prevail when estuaries enter deep, upwelling, oceanic waters. |
| **The predevelopment nutrient loading rates expressed as yield per watershed land area are similar within a single geographic region (e.g., province, ecoregion, or subecoregion). Local regional uniformity of geography is assumed.** | This is a reasonable expectation in the absence of extensive land development with attendant anthropogenic discharges and runoff. The geographic subdivisions of a natural landscape can be expected to be homogeneous by definition (i.e., similar soil type, topography, and vegetative cover). |
| **Because the National Nutrient Criteria Program assumes that groundwater influence is a separate loading factor to surface water eutrophication, groundwater-dominated estuaries should be treated separately for the development of nutrient criteria.** | The groundwater factor can be highly significant in some localities such as coastal Florida. This generalized approach does not address that factor, but Regional Technical Assistance Groups should be aware of the groundwater contribution and account for it in their estimations. |

second minimally disturbed subtributary should be sought to represent a different geology; this logic should be applied if additional subwatersheds differ substantially. Nutrient loads are then extrapolated in a simple proportional manner from the reference tributaries to the entire tributary system within the watershed or subunit and the aggregate load is calculated (Figure 6-5). This load represents the "reference load" reflecting in situ reference conditions for the four primary indicators (TN, TP, chlorophyll *a*, and water clarity).

Extrapolation from a reference tributary can be augmented by application of geographic-based nutrient erosion and transport models. This nutrient load would become the target load for the downstream estuary or coastal waterbody. Consideration should be given to the representative nature of the freshwater flow over the average hydrograph. It is desirable and may be necessary to obtain a measure of the average multidecadal freshwater flows at the head of tide. Nutrient loads based on a drought period would not accurately represent conditions in terms of nutrient-based ecological impairments. Extremely high flows are important, but they are likely to fall outside of resource managers' capabilities to solve a nutrient problem. Therefore, this approach has its limits. Large fluvial streams do not necessarily transport the most upstream load to the lowest fluvial portion of the stream tributary; in-stream ecosystem processes modulate the load. In summary, a sequence of steps is outlined in the following box to complete the areal load watershed approach for reference condition determination.

***Coastal Reference Conditions***

Following is an example of a nutrient loading assessment from a very large watershed, the Mississippi River system. In 1997, the EPA Gulf of Mexico Program, through a Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, asked the White House Office of Science and Technology Policy to conduct a scientific assessment of the causes and consequences of Gulf hypoxia through its Committee on Environment and Natural Resources (CENR). The National Oceanic and Atmospheric Administration (NOAA) was asked to lead the assessment. The assessment included various computer-based modeling approaches to characterize the nutrient delivery to coastal Louisiana and Texas.

Nutrient load reduction within the various watersheds to meet resource management objectives is an analogue of the reference condition approach (see NOAA website for details: www.nos.noaa.gov/products/pubs_hypox.html). Two conditions are considered: coastal estuarine plumes and shelf waters.

***Coastal Estuarine Plumes***

The foregoing example for the Mississippi River watershed is a large-scale effort to assess nutrient conditions associated with a large coastal nutrient plume. For large estuarine watersheds with the potential to cause nutrient overenrichment on the continental shelf, it is important to extend the reference concept beyond the local area. In many cases, the concerns will be large enough to warrant development of a hydrodynamic model with coupled nutrient-phytoplankton growth kinetics (Chapter 9). Smaller estuarine plumes along the coast may be addressed through a well-designed research and monitoring plan with expert input on design features. An initial EPA-sponsored sampling effort in the Mid-Atlantic is currently underway to provide range-finding data to assist in development of a more comprehensive

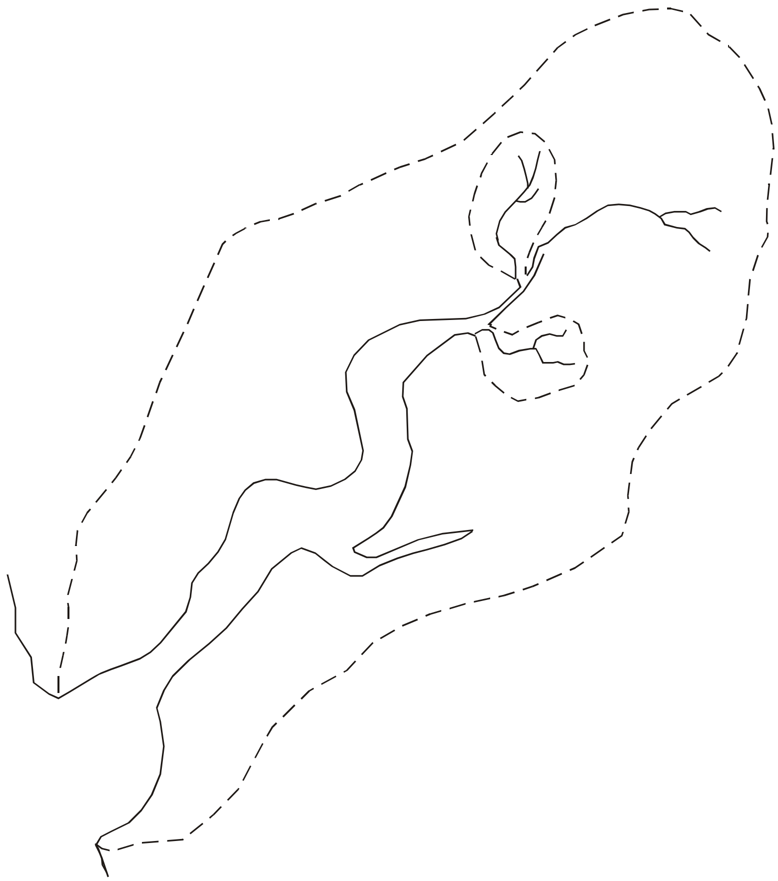

**Figure 6-5.** Areal load estimate approach to nutrient reference condition determination. The watershed is estimated to be approximately 368 square miles; the reference tributary streams representative of above head of tide systems in the watershed are approximately 20 square miles combined. The median load estimate at the mouths of the tributaries could therefore be multiplied by 18.4 to approximate a reference condition load for the river.

monitoring plan. The first step is to assess the shelf's mixing and dispersive capabilities to attenuate the negative effects of nutrient enrichment. Bloom development along physical discontinuities should be assessed. If dispersive mechanisms are large enough to attenuate phytoplankton blooms, then concerns are given a lower priority. In coastal estuarine plumes where the physical processes may not attenuate the nutrient enrichment effects to acceptable levels, then an appropriate level of research, monitoring, and modeling may be required to assess nutrient reduction from upstream nutrient sources as well as from seaward upwelling of nutrients and atmospheric deposition (Paerl and Whitall 1999, Vitousek et al. 1997, Howarth et al. 1996).

***Open Coastal Water***

The NRC (2000) publication (Chapter 6) recommends an index site approach for estuaries and coastal waters. The index site approach in particular has merit because the continental shelf is very extensive and too large for the Nation to conduct comprehensive studies of all sites potentially affected by nutrient enrichment. A priority-setting rationale should be based on a physical classification system that arrays coastal water masses relative to their susceptibility to nutrient enrichment, especially waters that are likely to respond similarly to nutrient enrichment. This would allow resource managers an opportunity to apply unique “dose-response” curves to a particular coastal water class. Because such a system likely is relatively crude, the best professional judgment of experts should augment physical classification systems. Because this approach has a significant research element, it would be appropriate to begin it in the competitive research forum with oversight provided by some mix of Federal, State, and university participation. Chapter 7 also discusses the roles of monitoring and modeling, which offer useful insights applicable to the coastal ocean. This manual recommends that the index site approach be given serious consideration, especially for coastal waters including estuarine plumes. The coastal ocean is large and oceanographically dynamic and complex. Thus, assessment of individual States’ contribution to nutrient overenrichment will in most cases require a Federal and States’ partnership. Even in large estuaries whose watersheds or tidal waters are shared by more than one State, a multi-State agreement is probably required (e.g., Chesapeake Bay Program and the New York and Connecticut TMDL Agreement).

The Coastal Research and Monitoring Strategy, an element of the Clean Water Action Plan, contains approaches that can help determine reference conditions. The strategy provides for a coordinated effort among Federal, State, and private agencies. Clearly, an approach that coordinates use of aerial surveillance tools (e.g., satellite-based water quality sensors), data buoys, and ship-based measurements (especially ships of opportunity such as the North Carolina Albemarle Sound ferryboat monitoring program; H. Paerl, personal communication) within an index site to underpin a cause-and-effect framework is highly desirable.

On a provisional basis, any additional monitoring might include a stratified random approach (e.g., EMAP), because this provides an opportunity to address known ecological structure and functional processes and unbiased trend monitoring. It is important to continue monitoring that involves identified relationships. A challenge will be to design a program that can distinguish the effects of natural coastal processes (e.g., nutrient upwelling) from anthropogenic influences (atmospheric nitrogen deposition, fluxes of nutrient from estuaries, and possible expansion of mariculture activities).

One such investigation is the design presently being tested by the National Nutrient Criteria Program in the Mid-Atlantic Bight. This near-coastal marine nutrient sampling protocol is intended to identify inshore (within the 3-mile limit) reference sites based on land use and physical coastal characteristics together with comparisons to offshore nutrient water quality. A stratified-random approach is used, and the compiled data from reference sites establish the reference condition for that portion of the coastal marine waters. Riverine and estuarine plumes or other discharges can then be evaluated relative to this minimally impacted condition. Sampling is recommended for spring and summer conditions with multidepth collections. The technique is being tested in a variety of State waters. A description of the design and preliminary results is presented in Appendix H.

**1. Identify major tributaries to the estuary.** Classify similar tributaries by physical size and freshwater delivery and compare similar geological features of the subwatersheds for classification.

Three nutrient loadings can be estimated:

A. *Existing (actual current load)*. Existing load is estimated from the known tributary loads as measured at the mouth above head of tide and extrapolated to similar land units in the watershed, plus any shoreside runoff and discharges that directly enter the estuary, plus direct atmospheric deposition. This is the present status of the waterbody.

B. *Best existing load*. Find the **best existing** tributary(ies) or **best subtributary**(ies) in the region and calculate the nutrient yield. Extrapolate this value to the rest of the watershed tributaries or subtributaries as appropriate.

C. *"Pristine" or unimpacted load*. Identify a regional reference streams in an undisturbed watershed having little or no development, such as State or national preserves, that can be used to estimate areal yield for the region approximating an entire unimpaired, undeveloped condition as though there were no significant cultural impairments.

**2. Find the tributary(ies) with the least impaired status and minimal disturbed lands contributing to nutrient loads.**
These are B and C-type conditions from above. Each of these tributaries is monitored enough to establish a nutrient load. Seasonal and interannual variability should be assessed. Cross-sectional sampling at the head of tide is required because of nutrient flux variability. The USGS has established protocols for this type of stream monitoring. Where available, dams on rivers, if located near the head of tide (e.g., Conwingo Dam on the lower Susquehanna River, MD), make very desirable locations to measure nutrient loads.

**3. Estimate the annual areal nutrient yield for TN and TP.**
Extrapolate from the unimpaired or minimally impaired watersheds above head of tide to all other similar tributaries in the watershed and apply the load estimate to direct runoff portions of the tributary. Do this for each monthly or seasonal increment throughout the year. Do the same for each major tributary.

**4. Extrapolate the nutrient yield to the entire watershed land area within the region.**
For example, generate total best existing nutrient loading. This will, in many cases, represent the best attainable loads.

**5. Repeat for other regions if the estuary watershed covers more than one major geological landform.**
This is necessary to comply with the assumption that regional homogeneity within the watershed covers only part of the entire estuarine watershed.

**6. Sum the nutrient yield for all tributaries within the estuarine watershed.**
Do not factor in atmospheric nitrogen loads, as they were incorporated into the tributary loads. The atmospheric nitrogen loads may need to be reduced to achieve an acceptable nutrient condition in the estuary. The summation of tributary loads becomes the estuarine reference condition. Computer modeling may be required, especially in larger watersheds, because in very long tributaries some nutrients, especially phosphorus, may become embedded in the stream bottom, and some nitrogen and phosphorus is potentially lost on the scale of years to decades in the floodplain. The chlorophyll *a* concentrations in the estuary will need to be modeled from the reference nutrient loads and some measure of central tendency of freshwater inflows to the estuary. When a larger estuarine system may dominate the lower tributary estuarine hydrodynamics (e.g., the mainstem of the Chesapeake Bay dominates the hydrodynamics in the lower Patuxent River estuary), then as a minimum, a box modeling approach may be required to account for the two-estuarine interactions of the freshwater inflow and lower estuarine interactions (Hagy et al. 2000).